Volume 6

WPI-AIMR NEWS

July 31, 2009

World Premier International Research Center
Advanced Institute for Materials Research

Tohoku University

Produced by the WPI-AIMR Communication Office

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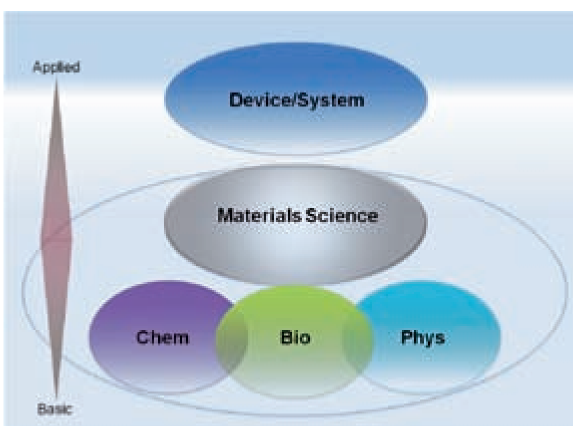
Modification of the Structure and Clarification of Vision of WPI-AIMR

Yoshinori Yamamoto
Director, WPI-AIMR, Tohoku University

The MEXT committee for WPI Program advised us to improve the following points in the FY2008 follow-up report;
http://www.jsps.go.jp/english/e-toplevel/data/08_followup/Followup_e.pdf (English)
http://www.jsps.go.jp/j-toplevel/data/08_followup/Followup_j.pdf (Japanese): Among many points, I think the following three points are major ones which should be responded seriously and pertinently at our earliest convenience. (1) There is an inherent conflict of interest in the execution of the project, because Dr. Inoue serves both as University President and the PI of the WPI project. (2) The program committee expresses concern also regarding the leadership of center director: Center director should make strong commitment and take strong steps to ensure a strong interdisciplinary culture: The center director should exhibit more leadership to make the AIMR visible. (3) Leadership needs to develop energetic strategy for publicizing the AIMR, and for developing other mechanisms to establish AIMR as global leader. This includes energetic recruiting of PIs and international visitors, hosting of workshops, and developing relationships abroad.

Along the lines pointed out by the program committee, I have changed (or I am changing) the structure of WPI-AIMR as mentioned below. (1) Professor Inoue steps down from PI, and he assists us from a broader point of view as a WPI research advisor.

(2) I have made the vision and future direction of our WPI-AIMR much clearer; please look at the Figure.



Research of materials science is essentially based on integration of very basic disciplines, such as physics, chemistry, and bio-science, and materials research is much closer to the exit (device/system) than the basic sciences. The materials science is primarily based on physics (hard materials) in Tohoku University and applications of those hard materials have been very strong, making Tohoku University one of the world leaders for many years. The Institute of Materials Research (IMR) which was a major research backbone of AIMR at the time when it was inaugurated in October, 2007. However, I think that the importance of bio-materials in materials research (soft materials) is increasing dramatically and research of bio-materials in our country is rather behind compared to US and EU. I want to strengthen the materials research based on Bio and Chem basic disciplines in our WPI-AIMR. I expect that we will be able to establish a world-top materials research center through the fusion research of BioChemPhys-materials, since Phys-materials research of Tohoku University is already very strong. Accordingly, I intend to hire younger bright foreign PIs in the field of Bio-materials who can stay at Sendai for several months per year and can perform research together with PDs, students, AP, or other PIs. At the time when WPI-AIMR started, I asked many established and senior professors to join AIMR as foreign PIs, and fortunately we could arrange such well-established people as PIs. However, they are very busy in their home institutes and therefore most of them came to Sendai only for attending the AIMR-workshop, exchanging ideas, or discussing research results briefly, and they did not have laboratories here at WPI-AIMR to run research. I want to change this style to practical PI system.

To make fusion research more realistic in AIMR, I want to ask all the researchers and PIs the following issue. If you are a specialist of Phys-Materials and heavily involved in this specialty, please start to incorporate PhysChem- and/or PhysBio-Materials in your research theme. This is also applicable to a specialist of Chem-Materials; please incorporate ChemPhys- and/or ChemBio-Materials. In this way, I believe we can pursue the fusion research of Materials Science based on BioChemPhys. Not only this top-down approach for fusion research, but also the bottom-up approach which has been proceeding actively in our AIMR is encouraged.

(3) To make AIMR more visible globally, I want to invite practical foreign young (or senior) PIs, as mentioned above. I am now searching actively such candidates to make the practical PI system feasible. If you have any good candidates, please let me know. We have now only one AIMR-satellite at Cambridge University, but I am intending to

set one or two additional AIMR-satellites in US and/or in EU, to strengthen the role of satellites, and to make satellites practical. In order to publicize the research activity of AIMR, *"AIMResearch"* by Nature/Macmillan publisher will appear in web from July, which highlights top research accomplishments done by our researchers. A printed version will appear in autumn. I am also planning many other enterprises for publicizing the AIMR, which will be mentioned in near future.

By the changes and modifications mentioned above, I believe that our AIMR must become a better shape and the major problems pointed out by the program committee will be solved. Finally, I appreciate very much your continuous cooperation and help to WPI-AIMR.

Interview

Interview with Professor Alain Reza YAVARI, Principal Investigator, WPI-AIMR

"Analyzing the Metastable state in terms of Length and Time scales"

Prof. Komatsu (K): This interview is for non professionals, and it would be interesting to know your family and boyhood. Secondly, your motivation to science, and thirdly your exciting findings you met in amorphous materials. I would appreciate to hear your personal history why you get into this field.

Prof. Yavari (Y): Yes, thank you. If we start at a young age, I guess I come from a family with several children. In particular I have several sisters. My sisters are very good in arts and music. I always found that I could not make nice drawings like they used to make or I could not learn quickly to play music like they could. On the other hand, I was better than them in physics, chemistry and math and so on. So, I had no choice but to go for my stronger points as a survival in the family. In school, especially in middle school, a lot depends on the teachers, and one can become very attached to the subject just because the teacher teaches it so well. In high school, I had a very good chemistry teacher and a very bad physics teacher.

So, I decided to study chemistry. When I went to MIT, I initially started chemistry, mainly organic chemistry. Of course, we had many professors who were very good. I had the opportunity to have some good physics professors. Then I did not know what to do, physics or chemistry? And in the end, when I went to Stanford University for a Masters Degree, I decided on materials science, which is something between physics and chemistry and includes a little bit of both. Materials science is a very horizontal field of research. You have to have some vertical capacity of knowledge in the sense that you have to be able to have some in-depth understanding of certain important theoretical and experimental issues, questions and research. But in the end, materials science is a multidisciplinary field.

I suppose from my background, in the end, choosing materials science at Stanford was probably a good choice for me.

And of course, I was supposed to do my Ph.D. at Stanford. I had a scholarship to do my Ph.D. as a research assistant with Professor G. M. Pound, who was a well known professor in nucleation theory. Unfortunately, just at the time when I was finishing my Master program, Professor Pound already had the Parkinson condition. His condition deteriorated very strongly. He called me to his office and said, "Yavari, I am sorry I cannot keep you as a Ph.D. student." I said, "why?" he said, "Because of Parkinsonism, but do not worry, I have contacted David Turnbull at Harvard and you can go to Harvard." So, I ended up going to Harvard for Ph.D.

This is how now I have a materials science background. After my Master program at Stanford, we had to choose some Ph.D. topic. Professor Turnbull was in the division of Applied Physics. This was interesting for me because at that time we had Nobel Prize winners as physics professors in the Harvard Ph.D. courses. You had options to go one way or the other. But I did not feel that I was really the type of person to go into theoretical physics and particle physics because I like it when I am close to the physical world of senses. When you go to particle physics, then you kind of lose that. Physics becomes purely mathematical.

K: That is right.

Y: You write tensors and determinants. You look for eigenvalues and you look for particles that should be there but nobody has seen. You are building machines but you do not operate them yourself. Your technicians and engineers operate them. It is quite different. I thought applied physics for me was quite good. That is how I ended up doing applied physics.

Professor Turnbull, member of the US Academy of Sciences, was active in several different fields of research (He obtained the Japan Prize in 1986 and I was in Japan in Kyoto and part of his Welcome Committee and we went together to Tokyo for him to receive the prize from the Emperor of Japan who was then the Crown Prince). I was one of his students working more on problems of anomalous diffusion or fast diffusion, such as diffusion of copper in silicon, which at the time was important for mastering the conditions for obtaining very high purity silicon for electronic industries.

Professor Turnbull had a strong contribution in the field of steady state nucleation theory with Professor Cohen and so on. But he was also an experimentalist and I learned most of my experimental approach from him.

Now, we come to research, if you have Ph.D. courses and Ph.D. qualifications, you have to choose a subject for subsequent research. If you choose to continue research after your Ph.D. that does not necessarily mean that you are going to continue on the subject of your Ph.D. work. In fact, many people say that is not such a good idea, because it is better to develop diversity by doing a Post-Doc, for example, one or two Post-Doc years in different areas. I did the same. You are a prominent scientist yourself and you know that allocating resources whether it is human resources or material resources to a subject; in other words choosing a research project, is perhaps choosing the right or wrong way. It is probably half of the success already because if you choose subjects that do not bring out the best potentials of yourself and your environment, you are in the wrong business.

K: That is right.

Y: We should let somebody else do that and optimize for ourselves. Then the question comes for careers of people, how successful have they been and where have they gotten. In some ways, it depends on how accurately they made that judgment at every step. We all know when people make the right decisions and particularly, we all get excited by the recent discoveries of others. All of a sudden, scanning tunneling microscope was discovered, high-Tc superconductors were discovered, glassy alloys and bulk metallic glasses were discovered, giant magnetoresistance was discovered and so on... When we are in areas not so far from this, we all feel like wanting to contribute. But then if we try to do all of them, we will not be good in any of them. Especially if we have a small group and it depends on how you do research also. In the United States, the university structure is generally that there is a research group and there is one professor, one or two assistant professors who are five or ten-year track and a few Post-Docs and then two or three Ph.D. students per professor. That is basically a research group plus a technician and a secretary.

Roughly speaking, you are working with around 10 to 15 people. It is not like a big national lab like Los Alamos or some other national labs here in France. Each group is basically independent in the sense that they have to apply for their own funding and fix their own research priorities. In our laboratory, we have worked usually small groups with between five and ten Master, and Ph.D. students or Post-Docs. And funding is mostly 50/50; 50% from public bodies which are in Europe and France both and 50% from private sectors. Of course, I have now worked for a long time with my Japanese colleagues and my Japanese colleagues' contribution to my research has been huge. I wish that I will also have contributed to the research of my Japanese collaborators.

But I follow your suggestion that somehow we want to have continuity between our adolescent education and our research, in other words a little bit of the human side of ourselves. I had the opportunity to have very smart people, several Nobel Prize winners as my professors. That has two immediate consequences. One is that it makes me very humble. I realize if you work with people who are stronger and bigger than you, then you have a better idea of where you stand. If you just work with people who are weaker than you or your students, you maybe have some kind of misevaluation of yourself. It is nice to have people who are stronger than you and who are kind enough to share their vision with you.

In that sense, I have a very reasonable assessment of my own capabilities. Nevertheless, as most of us who are university professors, we were among the best students in our classes in high school and university; otherwise, we would not have stayed in this business. It is like my sisters who are better artists and better musicians. I had no choice. Probably we are still in this business because we were doing quite well in class. We felt confident that we could work in this area. If I evaluate my own capabilities at that level, one of the things that happened to me was that I would get bored very quickly when the intellectual stimulus was not there. Like if you sit by your grandmother or your grandfather, they speak very slowly, you do not mind because it is grandmother and grandfather. But if you sit in a job and people speak so slowly or if you have a discussion and it comes so slow, you get very quickly bored.

K: Yes.

Y: So, in this sense there is something about this in research and repetitiveness and meticulousness and so on. It is all necessary but it is a little bit boring. When I got into materials science, I realized that materials science probably did not exist 50 years ago because if you go 100 years back, physics was part of philosophy. It is something that for me at least in practice is associated with what happened after the 2nd World War, with the discovery of dislocations and electron microscopes and this kind of thing; otherwise, it would be impossible.

In materials science, when I started looking at books at the library at Harvard, we had a privilege that we had the keys to the library. For example we could go there at night and go to the shelves. It is a little bit like that at the IMR also. I like to go there late at night. The advantage of going at that time was that you were not only working. You were just reading. You take something that has nothing to do with your subject. This is when I realized that there is a huge amount of literature for example on steel. Steels were as old as the Damascus saber and even older. Because I was always getting bored quickly and a little bit in a hurry, when I saw the so-called non equilibrium processing, I thought this is for me because in equilibrium thermodynamics, nothing happens. When you are at absolute equilibrium thermodynamics, nothing happens. The further you go from equilibrium, the more you can freeze things. Nothing happens when you lower the temperature. You put everything in liquid nitrogen and liquid helium, and nothing happens. You can keep that state, that metastable state, but that is a metastable state. So, when it is heated up, it changes.

A lot of action happens in a very short time at certain temperatures, a little bit like when you cook or when there is a volcano irruption. This was exciting for me. One of the things I noticed when I was following my courses as a student was that I read that actually a lot of these experiments were done in Japan. If you take pure copper and you irradiate it with heavy ions or neutrons, you create a lot of interstitials and vacancies. If you do this at room temperature, you will most likely not see anything as most of them disappear faster than you can detect them. But if you do this when the copper is cold, then all these things stay in there. And then as you let your cold material come up in temperature followed by resistivity measurements or by DSC calorimetric measurements, first you see interstitials forming interstitial dipoles then you see formation of vacancy dipoles that go faster than single vacancies. Then all these just start combining and making stacking faults and other larger defects up to room temperature and above so there are many steps of the recovery that you will not see if you are not coming from a cold metastable regime.

So, it was this fascination for the potentials of the metastable state that related me to my friend, President Akihisa Inoue of Tohoku University, who had more or less the same kind of vision. He wanted to look at metastable equilibrium and metastable materials. When we go there, we must realize that the time scale is of course very important but also length scale is very important. That is the next issue. An atom knows its neighboring atoms and for making short range order, it takes less than a nanosecond, almost impossible to stop this except if you deform at low temperature. If you deform at low temperature, you can make an ordered intermetallic crystal become a disordered solid solution.

But then you also have a few atoms further away with medium range order. Medium range order is like coherent domains in ordered materials. So everything starts with length scales. For example, about 16, 17 years ago we published in Physical Review Letters showing that if you take two immiscible elements like iron and copper and you subdivide the mixture to a scale of nanometer, the interfacial energy for small radii becomes such a big component of the total energy that the system prefers dissolution and the making of a metastable solid solution.

At this length scale, the ratio of energy per volume and energy per interface determines a lot of things and this is fascinating in terms of mechanical properties like in the Hall-Petch effect in the nanocrystalline hard materials. It determines as well giant magnetoresistance phenomena in films and granular materials. It determines the color. It determines catalytic properties, almost everything now depends on it and this is why nano materials are so important as pointed out by Professor H. Gleiter (who previously received the Acta Materialia Gold Medal that was now awarded to Professor A. Inoue as well). In the case of metallic glasses, it has now been discovered that in addition to short range order, due to chemical affinity, there is a lot of medium range order in these materials. What is interesting is that this medium range order is of the order of a couple of nanometers. It has the same size as the scale of the critical size of crystal nuclei as I pointed out in a commentary in the journal Nature. It is also just a few times more than the thickness of a shear band which is the thickness of the localization of deformation and heterogeneous deformation in glassy metals.

All of these things are length scales and we are talking about them as if they were the most natural thing in the world. But when I was a student, it was not easy to look at 1 nm, 2 nm with microscopes, x-ray microscopy or other means. We are beneficiaries of nanotechnologies. Nanotechnologies allow us to think this way. Nanotechnology has allowed us to investigate these things.

Now I am going towards retirement in less than 10 years. The cutting edge of materials science is focused on the impact of length scale on the nature, stability and properties of materials – on the one hand, and on the other hand on the accession of nanotechnologies to the same length scale. This is a great opportunity for engineers and inventors to come and see the scientists and go together to see which predictions are correct and what else they can offer. In some ways, I regret not being 20 years younger because I think in that case I could have gone a little bit further. Anyway, we still have many problems to solve. We are working very hard with President Inoue and Professor Greer at Cambridge, who was my colleague at Harvard, on an interesting problem regarding mechanisms of shear localization as a function of length scale. Concerning properties versus thickness of metallic glass, we have very good results that we have not yet published. We just want to make sure of a few more issues, then we hope to have some new important results to publish.

K: I see. As I am not in the amorphous field, so when you say "shear," that means a slip between the crystal units. But in the case of amorphous, no units.

Y: Yes.

K: What does shear really mean?

Y: Yes, at high temperatures near the glass transition Tg, metallic glasses deform homogenously by creep. Deformation is homogenous. In other words, all the atoms participate in the deformation process. At low temperatures in thick samples, this deformation is referred to as heterogeneous. Yield strength is very high with 2% of elastic strength. As we approach this yield strength, we always have some kind of defect in the material. And as you know, for mechanical properties, any defect becomes a stress concentrator.

In that local region, yield strength is reached before the other regions. So as that region starts to deform, we have this phenomenon called "shear softening" in metallic glasses. Shear softening is due to the fact that on the one hand, you destroy some chemical order by deformation and on the other hand, you generate free volume, which is a form of dilatation. This makes the local viscosity go down, which means that the yield strength of the material that has already been deformed becomes lower and lower. For this reason, if the material wants to deform further, it will deform in the same place that it already deformed. It localizes shear to that region which is called a shear band.

K: It is somewhat similar to rheological phenomena in the ordinary material. Depending on the time of the pressing, the deformation is different. Or if you press it very quickly, the deformation mechanism and the strength will be different.

Y: Yes, what we are exploring now is that as you reduce the dimensions of the metallic glass to a micron scale, another homogenous deformation regime appears. Now, this is not very well known but has recently been demonstrated experimentally by Pr C. Volkert (current President of the Materials Research Society MRS). This is another issue that may have very good implications for use of metallic glass chips in composites.

K: I see, and then related phenomenon is that if you do Brinell Hardness testing, perhaps you have some pile up formed by many slips.

Y: Yes.

K: This is also again the cleavage phenomena?

Y: Yes, this is a set of shear bands. In fact, in two weeks in connection with our WPI project, we are going to use an x-ray microscope at a synchrotron in Grenoble. In other words, a very high brilliance beam, but which has a cross section of only one micron to look at the bottom of the indentations.

K: Very interesting.

Y: And determine the atomic structure of the deformed material just underneath the indent, and compare it to the non-deformed material and compare it again to itself after we anneal the material to above the glass transition temperature to remove any trace of deformation.

K: I see, very interesting. So, there are several phenomena which still are waiting for analysis.

Y: Yes, right now we are very busy and the young people are very busy.

K: I see, so eventually the aim of the research is to lead to applications.

Y: Yes.

K: What sort of application do you have in your mind?

Y: We have projects that are in collaboration with about 14 European laboratories – I mean on the subject of metallic glasses. And the applications that people look at are very diverse. One thing is sure, we are not going to build bridges with bulk metallic glasses because they are too expensive and they are too small. So, in one way or another, application of metallic glasses will not be in massive pieces. It would be in the centimeter range down to microscopic.

The fact is that macroscopic properties of metallic glasses are very different from their microscopic properties. Regarding macroscopic properties of metallic glasses, they can be solicited to up to about half of their yield strength on a regular basis for fatigue, resistance and so on. This essentially puts a limit of about 2 GPa in terms of solicitation for the best, hardest metallic glasses. At any place where you look for mechanical solicitation that requires 2 GPa, you can put in metallic glass. It is always better than steels because steels start to deform permanently at 0.2% strain whereas metallic glasses can go to up to 2% strain reversibly.

There are places to put them. The question is the price. For example, as you know, they put them now in sports equipments for enhanced rebound, Professor W. L. Johnson and Professor Inoue have contributed to introducing them into golf clubs, tennis rackets and telephone casings. Also, in Japan, Professor Inoue collaborates with Professor Saotome who makes very small gears and these are going to micro-motors where metallic glass gears are extremely high performing and extremely solicited for surgery. All these applications exist and these are still all in the range of bulk metallic glass. But if you go to the micron scale, then you have another regime where metallic glasses can be used as a second phase both hard and ductile. Here they help maintain elasticity up to much higher levels of stress. They can be almost ideal second phases in certain composites.

I think the first property is the elasticity: the spring properties, the resilience, the energy storage, mechanical energy storage. The second part is the approaching of an ideal material, a combination of hard and ductile material. As you know, ductility and hardness are often mutually exclusive. You can go to the hardest materials like diamonds, some ceramics and so on. They are very hard but they have no ductility. You can go to pure copper, it is very ductile but it cannot keep its own shape.

It is possible that microscopic metallic glasses are the miracle material that has both extreme hardness and extreme ductility. That should be explored.

K: Possibility to be applied. How about the nano particles?

Y: Yes, nano particles are part of that range. If you go submicron, the nano particle is the same. The metallic glass nano particle is for me, probably an ideal material for mechanical properties.

K: Very interesting.

Y: Good?

K: O.K. and I would like to know your principles in research you have in mind or your motto or even some philosophy if you have some philosophy in research.

Y: I think maybe if I am still in good health when I am retired, I would like to think more about the way we think. Because I think the human mind is incredible. Actually not just the mind, the human being is an incredibly advanced device. I do not know if you like to cook at home, I like to cook because I raised children. After you do high temperature cooking, sometimes the pans have burned food attached to them. You must remove that and so you rub and rub it. When you look and it is almost clean and you go by hand to touch and see if it is really clean, you can almost always feel some things with your hand that you cannot see with your eyes.

K: That is right.

Y: That shows how sensitive your fingers are. You will notice this with your fingers. I am not saying it is as sensitive as STM but it is actually not very, very far from it. I mean you can feel a micron particle with your finger. The same with the mind, you will notice that many times just by looking at somebody, you can tell if they are comfortable or if they are uncomfortable or something. Your brain just analyses things all the time without your ordering it to do so. Your hand just feels things all the time without your asking it to do so. So, the question is if they do this naturally, what more can they do if you ask them? This is all subconscious, internal mechanisms. The question of doing research is to direct that, to channel your mind's power, channel your efforts.

This is a very interesting subject for me. I would like to know what do we do exactly when we sit down and think about a problem. What is the process? How do we focus? Some people think that if you are very careful with your body, your mind becomes stronger. Eastern cultures, Buddhist and Chinese cultures pretend that there is too much parasitic sounds and social events to allow the mind to really concentrate on a certain higher level of thinking and meditation.

These are all things that are very difficult to explore in our Western style kind of lifestyle. I think young people think a lot about these things when they are 18 or 20 years old. Before they have a job and responsibility, they can dream. I hope that someday I can again think about the way the mind works and maybe going back and forth between a Western style daily responsibility and more abstract philosophical way of looking at things is good.

K: O.K., very interesting. In that sense, it seems to me that the Western world likes symmetry but Asian people like asymmetry. For instance, ikebana (traditional Japanese flower arrangement), the shape is always asymmetry. We like slight asymmetry. If it is rigid symmetry we think it is very simple, nothing more. That is Asian attitude towards anything. So, we do not like the clear-cut device. We like mysterious things, unique device, something remains. That sort of thinking is Asian attitude towards this.

Y: Yes. I think that asymmetry or the Asian attitude is something that allows for more freedom and more natural character.

K: That is right. Nearly symmetry and not exact symmetry. This is debated much but deviation is important.

Y: Complete opposite to that is the Gardens of Versailles in Paris where the bushes and the trees are cut in the shapes of cubes. It is the complete domination of man over nature.

K: We cannot stand it.

Y: Right. Different standards.

K: Yes, instinctively.

Y: Yes, different standards.

K: We feel like happy to watch the asymmetry of cloud in the sky always changing. This is very important. If things are fixed at symmetry, it is dead.

Y: Yes.

K: So, disorder in a way, not total disorder but slight disorder is important.

Y: I think it is in the windows of time. The brain can actually go very, very fast, or it can go slow. And depending on an idea within a slow conversation, there can be a very fast thought process that actually influences that conversation. You can imagine two military people going to war, going to kill people, going to defend their country sitting in the train and talking about war, guns, fighting. And at the same time between two conversations, between two phrases, in a split second, they can think about their families, their wives, their children, their childhood. It does not even take 5 seconds. It just goes so fast that they can still come back and answer to the question that was asked of them by the other military guy. In the same way while I am having this very nice conversation with you, I had the very quick thought process about the fact that you must go to the mountain now, otherwise it will get dark. In less than one hour, it will get dark.

K: Thank you very much.

Y: I recommend unless there is something really important to continue.

K: It is a very nice talk. I appreciate it very much. Thank you very much indeed.

Interviewer: Prof. H. Komatsu

in the seminar room, Institute National Polytechnique de Grenoble, November 3, 2008

Honorary Degree Ceremony for Prof. V. Narayanamurti on May 22, 2009

President Inoue's Introduction of Professor Venky Narayanamurti

I am greatly honored to welcome my long-time friend, Dean Venky Narayanamurti of Harvard University.

Please allow me to address to him as "Dean Venky," as all his friends call him. One of the reasons for this title is that he has been a "Dean (学部長, 研究科長) for almost 20 years. After 5 years of Vice Presidency at Sandia National laboratories, he took over the Deanship of College of Engineering at UC Santa Barbara in 1992 and quickly established it as one of the best Engineering Colleges in the USA. In 1997 Dean Venky was invited to Harvard University to run the Division of Engineering and Applied Sciences as the Dean. In 2007, he established the School of Engineering and Applied Sciences as the founding Dean, realizing a 100 year dream of the engineering community at Harvard. This school is the first at Harvard since the Kennedy School over last 40 years. So he is rightly called Dean Venky by everyone.

Dean Venky was born in Bangalore, India, on September 9, 1939 and graduated from the University of Delhi with a Bachelor of Science and a Master of Science in Physics at the age of 18 and 20, respectively. He received his Ph. D. in Physics from Cornell University in 1965. In his Ph.D. thesis, Dean Venky was the first to observe the rotational and tunneling states of defects in solids, which is now known to be the dominant factor in determining the properties of amorphous materials and glasses.

In 1968, Dean Venky joined Bell Laboratories, where he carried out research in many areas of solid state physics and electronics successfully and thus, became Head of the Semiconductor Electronics Research Department in 1976. He then went on to become Director of the Solid State Electronics Research laboratory, one of the highest research positions at Bell labs, in 1981 at 41.

In 1987, he moved to Sandia National Laboratories as Vice President of Research to oversee a staff of 1100. During his tenure at Sandia, he started many new activities, including massively-parallel computing and robotics. Additionally, he instituted a new "Center for Compound Semiconductor Technology" and "Speciality Metals Consortium" with 10 US industries and projection x-ray lithography.

At UC Santa Barbara from 1992 to 1997 as Dean of College of Engineering, along with launching it as one of the best in the USA, Dean Venky established and renewed an NSF-funded "Materials Research laboratory," "Optoelectronics Technology Center,"

and “Supercomputing Center.”

I better note that Dean Venky has excelled not only as an administrator, but also in research and that he was elected to membership in the National Academy of Engineering (USAE) in 1992 at the age of 53. He has been elected to fellow of IEEE, American Physical Society, Royal Swedish Academy of Engineering Sciences, in addition to many others.

In addition to his premier work using different forms of elementary excitations-phonons, electrons and photons-to probe to probe solid state materials, especially semiconductors involving tunneling phenomena, he has helped science and technology in Japan greatly by advising and tutoring young Japanese researchers and by serving on policy making committees in Japan. I am particularly thankful to Dean Venky for his service of over 10 years since I became Director of IMR and he is now on the Foreign Advisory Board of WPI-AIMR.

Based on Dean Venky’s premier academic achievements and contributions to Tohoku University, I am happy to present you, Dean Venky, an Honorary Doctoral Degree of Tohoku University.

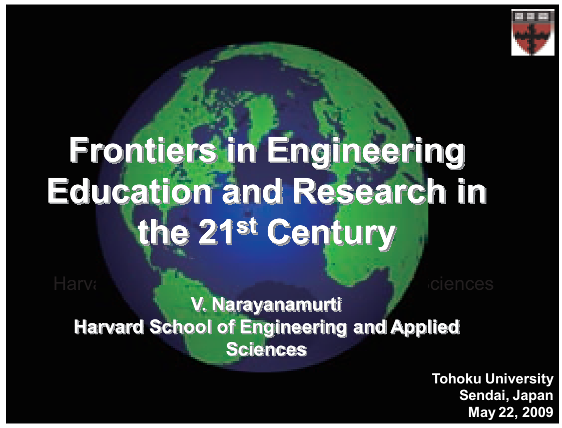
Prof. Venkatesh Narayanamurti

(Transcript)

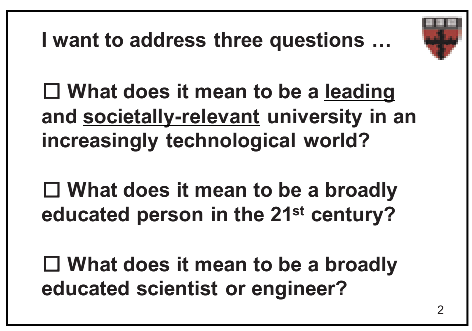
Prof. Venkatesh Narayanamurti: Good afternoon President Inoue, Prof. Sakurai, distinguished members of the faculty and researchers. I am deeply honored to be here today and I am very touched by all this gracious hospitality, and above all that I am now really a citizen of this university. I thought that was the right time to wear the university tie.

Prof. Sakurai: Yes.

Prof. Narayanamurti: So, I am really honored and very touched about what you said for my introduction. Thank you very, very much. As you will hear, I have changed the title a little bit as "Frontiers in Engineering Education and Research in the 21st Century." When I use the word engineering, I think of engineering very broadly; it is applied science. In fact there is very little difference between applied science and engineering. That is the basic message of this talk. So, engineering is a short word for applied science and all of the features that go with it.



So, I would like to discuss about the frontiers. Later this afternoon you will be at the opening of the WPI Integration Laboratory and I think one of the real things of science is it is always global and international, where we do not have any boundaries. But I think that what has happened with communications technology today, with information technology, pace of change has accelerated greatly. Professor Inoue became president of Tohoku University and, I think, articulated a tremendous vision of international relationship for Tohoku University. We will come back to that later this afternoon. But I thought it might be good to see what we have been doing at Harvard in this area and why Harvard created the engineering school, because I came from the Bell Labs where in fact there was no difference between science and engineering.

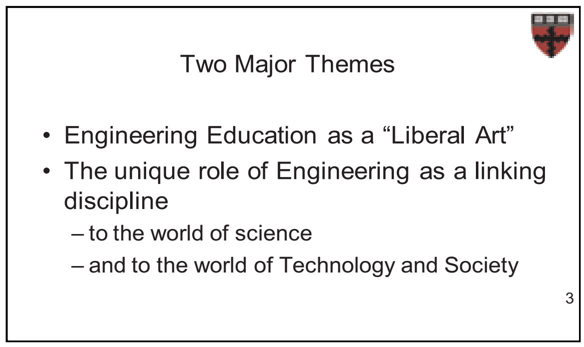


So, what I want to address today are three questions. This relates to, I think, even Prof.

Inoue’s vision for Tohoku University. What does it mean to be a leading and societally-relevant university in an increasingly technological world? What does it mean to be a broadly educated person in the 21st century? And what does it mean to be a broadly educated scientist or engineer?

Harvard prided itself with the old British tradition of liberal art education, and I actually convinced President Lawrence Summers (27th President of Harvard, 2001-2006) that liberal art education is a good concept that needs to evolve with the times and needs to move into the 21st century and that is one reason we created the School of Engineering (School of Engineering and Applied Science).

So, that is the basic message where in fact you think of research and technology as greatly impacting society and vice versa. We need to understand those complex relationships and train both non-scientists and scientists for this modern world.

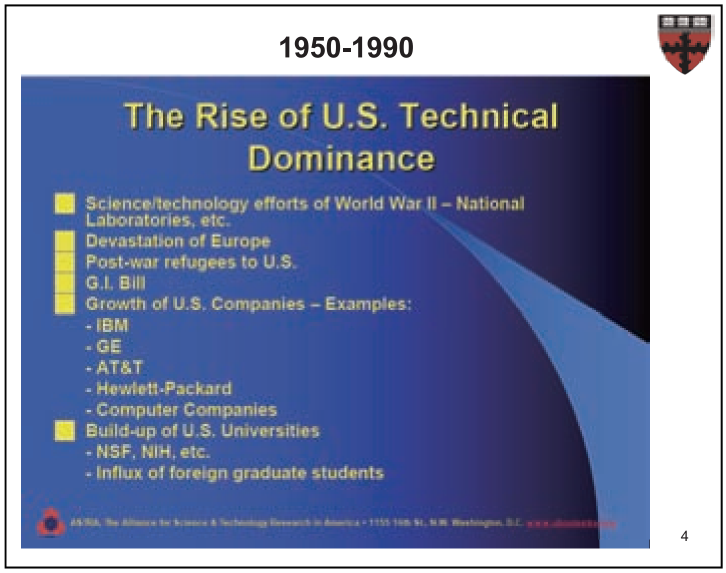


So, that is all of the essence of my talk. There are two major themes. Think of engineering education as a liberal art. What does liberal arts education actually mean? And then the unique role of engineering as a linking discipline to the world of science and to the world of technology and society.

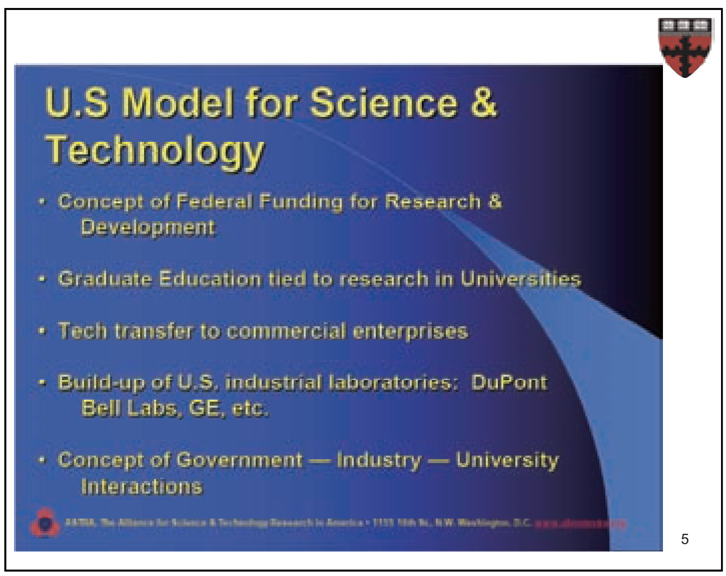
You see too often, we have thought of engineering as simply rooted in physics and mathematics, and that is partly true. But engineering itself as a discipline, as a linking discipline, has much to contribute. I was telling people at lunch today, if you look at biology, biology is much more similar to engineering than actually physics or mathematics. Physics is basically a reductionist science. A lot of engineering is integrated science, and biology is in fact very much an integrated science. I think we have learned that biological networks are similar to networks for engineering and vice versa. In fact, we have at Harvard a new institute for biologically inspired engineering.

Engineering as a discipline, I believe, achieved a totally new status as a natural evolution from the 18th century, 19th century, 20th century and 21st century. After all, the internet and communications technology are almost as revolutionary as the printing press to read and write. Times have changed.

So, let us go back a little bit in the history of the role of science and technology. I would say that in the United States, the big changes happened after World War II. Science and technologies were very important in World War II, as many of the advances came from applied physics such as microwave radar. There was, of course, the G.I. Bill. There are big integrated U.S. companies like IBM, General Electric, AT&T, with huge research laboratories. Simultaneously the build-up of United States research universities occurred. The National Science Foundation (NSF) was created in 1950, so it is now 60 years old. Until then there was not much funding. For example, Cornell's physics department where I studied was funded like the humanities department now. It was only in the last 60 years that things changed.

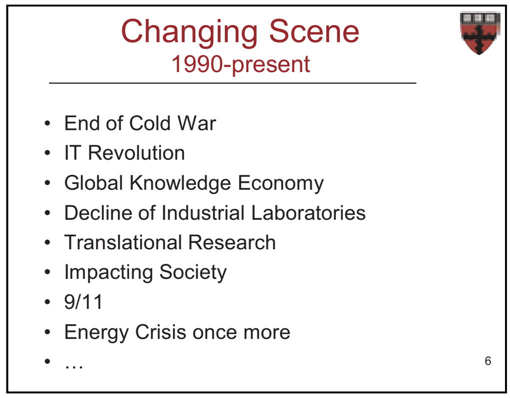


So, in fact the United States model for science and technology was a concept of federal funding for research and development. Graduate education grew enormously in this period due to federal funding. I always thought as an undergraduate, the system which was very much based on the British system in India which was very good, but the United States system at the graduate level really excelled in that open way and the way research was done between the graduate students and the professors.



So, I think there is a very special model there which could be discussed: technology transfer to commercial enterprises, build-up of US industrial laboratories and concept of government-industry-university interactions. All of these evolved over the last 40 or 50 years.

What has happened in the last 10 or 20 years? The Cold War ended in 1989 and there was a big change which happened, because much of physics and engineering, especially in the United States, was defense-related. “Defense Research” was very important; that is why the government established the National Science Foundation modeled after agencies like the Office of Naval Research (ONR).



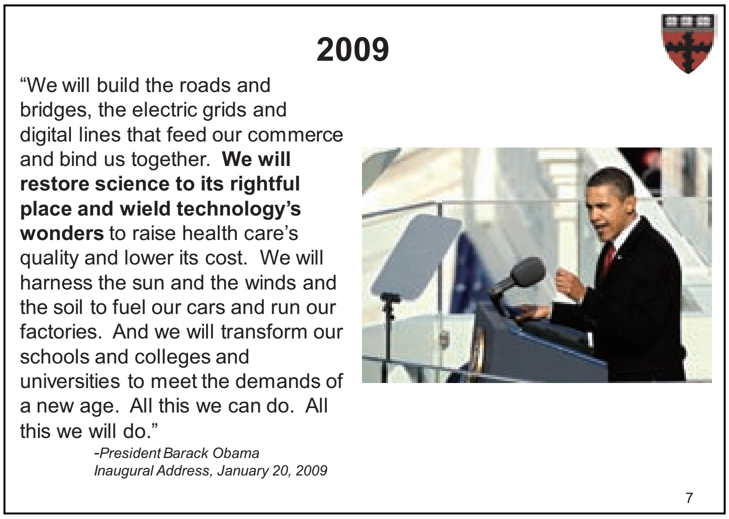
The IT revolution had really come. The worldwide web had completely changed how we do business. We became a global knowledge economy. A country of my birth, namely India, suddenly came from poverty and now if we are talking about it, we think of India as an economic superpower. It happened so fast that one cannot even imagine, you know, that something different could happen.

Then the tremendous decline, the global competition and changes of the rules of the game for the large monolithic caused a decline of the industrial laboratories. IBM almost went bankrupt; luckily it came back alive, but the idea of an industrial research lab was in the decline. AT&T was broken up and Bell Laboratories ended up in demise over the last few years. The translational research showing… you see, when you were dominated by defense funding, your expensive research could be very easily justified and cost was no object, but when you go to the modern world, the role of translational research and impact on society became increasingly more important, as we think of problems like sustainability and the environment, etc.

In the United States, when 9/11 occurred, there was a big change for us. Big change; it was like a new kind of Cold War, a different kind of Cold War, and then of course there is the energy crisis once more……, we can go on. So, we must prepare our students and our universities for the future, which might not be the same as the past.

So, if you come to 2009—and once, I am again really proud to be an American citizen with President Obama when he gave his address to the nation at his inauguration as President;

"We will build the roads and bridges, the electric grids and digital lines that feed our commerce and bind us together. We will restore science to its rightful place and wield technology's wonders to raise healthcare's quality and lower its cost. We will harness the sun and the winds and soil to fuel our cars and run our factories, and we will transform our schools and colleges and universities to meet the demands of a new age. All this we can do. All this we will do."

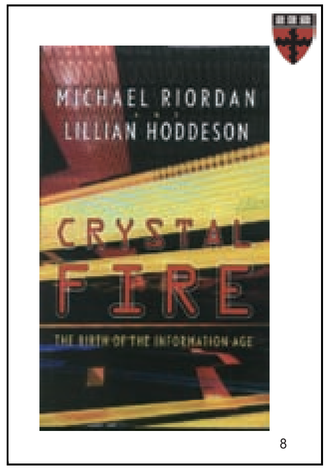


It was very heartwarming for me to listen to this kind of Inaugural Address and to another address, that the United States president gave to the U.S. Academy of Science a couple of weeks ago. US President coming to Academy of Science, this is good for us. The last time it happened was when President Kennedy was in charge, some 40 years ago, and I came as a graduate student then and the United States had a golden age with the Sputnik event and NASA mission to the moon after Sputnik.

So, our hope is that once more we will have another golden age for science and engineering in the United States, a very important time. Obviously the United States with its special status will be intimately connected with many of the global powers, with the G8 nations of which Japan is a part as well as Germany and Europe, and now increasingly the G20, which includes countries such as Brazil, Russia, India and China.

So, I want to go back a little bit in history. For me, many universities are great; I was very fortunate to work with great places like the University of California, arguably the best public university in the world and Harvard University, arguably the best private university, at least in America. But for me Bell Labs was a special mecca. Bell Labs was absolutely number one in my life. One has to ask the question why. I will come back to it. So, a history of Bell Labs. When the 50th anniversary of the transistor occurred, which was in 1997, historians, Michael Riordan of Stanford University and Lillian Hoddeson of the University of Illinois, wrote a book "*Crystal Fire, the Birth of the Information Age*." It was really the story of Bell Labs in one form.

For all the graduate students in this room, especially material science, I urge you to read this book because it tells you how materials science should be done. It really brings the experimentalists and the theorists together. It brings the physicists, the chemists and the electrical engineers together, and there is no boundary between electrical engineering and science. They are together mixed in this melting pot, managed in a very special way. That was also true for many of the other industrial laboratories, of course.



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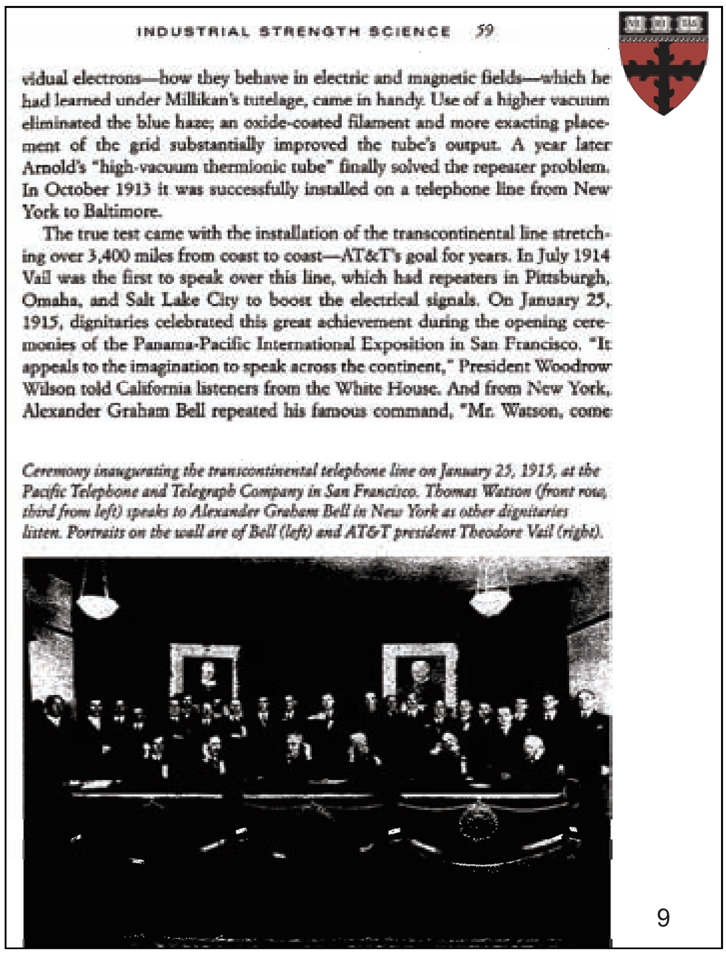
So, we have come to this a little more. Why did Bell Labs do this? As all of you can remember in your history, Tohoku University has a great history; it had its 100th anniversary 2 years ago. The history of Bell Labs is in many ways the history of industrial research in science. It owes its origins to Alexander Graham Bell who founded it was actually a visionary. Back in 1876 when he discovered the telephone, he tried to convert speech into electric signals, and in those days to convert sound into electricity was unheard of. He actually even thought of fiber-optic communication. It turned out they wanted to build a system to communicate between San Francisco and New York and you know the signals would go weak with distance, so you have to have repeaters and amplifiers.

According to Riordan and Hoddeson:

"The true test came with the installation of the transcontinental line stretching from coast to coast, AT&T's goal for years. In



INDUSTRIAL STRENGTH SCIENCE 59

vidual electrons—how they behave in electric and magnetic fields—which he had learned under Millikan's tutelage, came in handy. Use of a higher vacuum eliminated the blue haze; an oxide-coated filament and more exacting placement of the grid substantially improved the tube's output. A year later Arnold's "high-vacuum thermionic tube" finally solved the repeater problem. In October 1913 it was successfully installed on a telephone line from New York to Baltimore.

The true test came with the installation of the transcontinental line stretching over 3,400 miles from coast to coast—AT&T's goal for years. In July 1914 Vail was the first to speak over this line, which had repeaters in Pittsburgh, Omaha, and Salt Lake City to boost the electrical signals. On January 25, 1915, dignitaries celebrated this great achievement during the opening ceremonies of the Panama-Pacific International Exposition in San Francisco. "It appeals to the imagination to speak across the continent," President Woodrow Wilson told California listeners from the White House. And from New York, Alexander Graham Bell repeated his famous command, "Mr. Watson, come

Ceremony inaugurating the transcontinental telephone line on January 25, 1915, at the Pacific Telephone and Telegraph Company in San Francisco. Thomas Watson (front row, third from left) speaks to Alexander Graham Bell in New York as other dignitaries listen. Portraits on the wall are of Bell (left) and AT&T president Theodore Vail (right).

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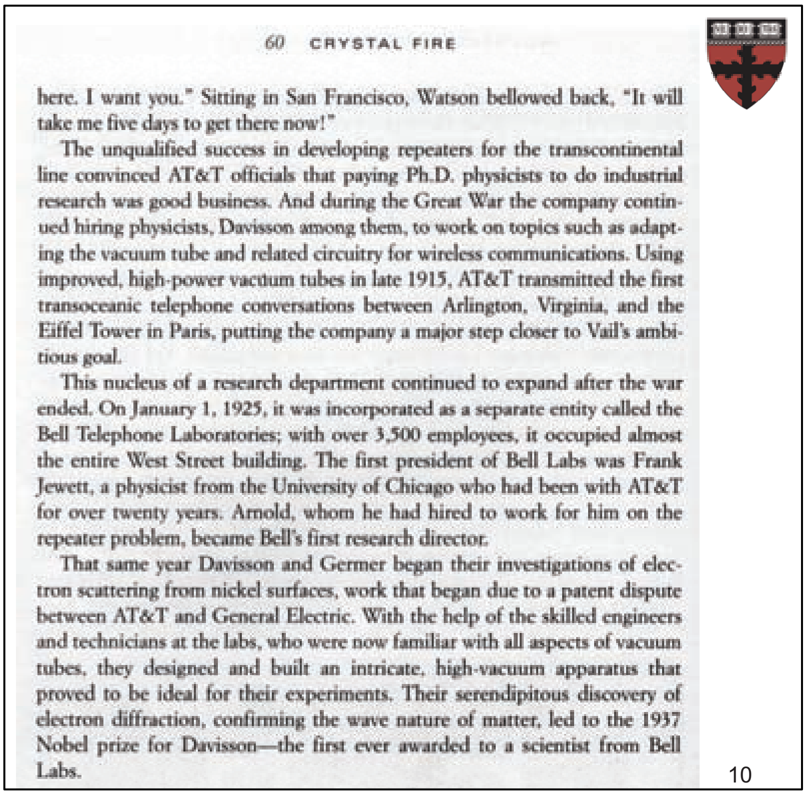

60 CRYSTAL FIRE

here. I want you." Sitting in San Francisco, Watson bellowed back, "It will take me five days to get there now!"

The unqualified success in developing repeaters for the transcontinental line convinced AT&T officials that paying Ph.D. physicists to do industrial research was good business. And during the Great War the company continued hiring physicists, Davisson among them, to work on topics such as adapting the vacuum tube and related circuitry for wireless communications. Using improved, high-power vacuum tubes in late 1915, AT&T transmitted the first transoceanic telephone conversations between Arlington, Virginia, and the Eiffel Tower in Paris, putting the company a major step closer to Vail's ambitious goal.

This nucleus of a research department continued to expand after the war ended. On January 1, 1925, it was incorporated as a separate entity called the Bell Telephone Laboratories; with over 3,500 employees, it occupied almost the entire West Street building. The first president of Bell Labs was Frank Jewett, a physicist from the University of Chicago who had been with AT&T for over twenty years. Arnold, whom he had hired to work for him on the repeater problem, became Bell's first research director.

That same year Davisson and Germer began their investigations of electron scattering from nickel surfaces, work that began due to a patent dispute between AT&T and General Electric. With the help of the skilled engineers and technicians at the labs, who were now familiar with all aspects of vacuum tubes, they designed and built an intricate, high-vacuum apparatus that proved to be ideal for their experiments. Their serendipitous discovery of electron diffraction, confirming the wave nature of matter, led to the 1937 Nobel prize for Davisson—the first ever awarded to a scientist from Bell Labs.

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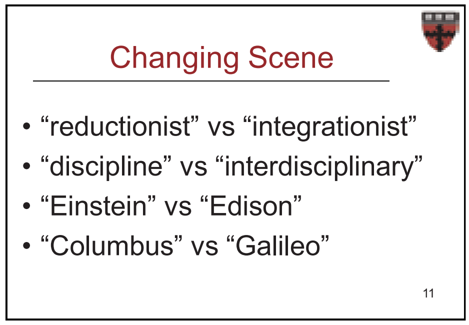
July 1914, Vail was the first to speak over this line which had repeaters in Pittsburgh, Omaha, and Salt Lake City. On 25 January 1915, dignitaries celebrated this great achievement during the opening ceremonies of the Panama-Pacific. It appeals to the imagination to speak across the continent, President Woodrow Wilson told California listeners from the White House. From New York, Alexander Graham Bell repeated his famous command. "Mr. Watson, come here, I want you." Sitting in San Francisco, Watson bellowed back, and it is the same Watson of "IBM," bellowed back, "It will take me five days to get there now.""

And of course 50 years later, when I got my Ph.D. from Cornell you can of course telephone across the ocean, and the day when my mother died about five years ago, the telephone worked instantly and effortlessly. It completely changed human life. The reason it changed human life is because in fact science and engineering came together in new ways. The AT&T realized unqualified success in developing repeaters for the transcontinental line. It was clear that the Ph.D. physicists who did industrial research were also good business, and in the Great War the company continued hiring physicists, Davisson (1937 Physics Nobel Laureate, the first ever awarded to a scientist in industrial Labs) among them, to work on topics such as adapting the vacuum tube and related circuitry for communication. Using improved, high power vacuum tubes in late 1915, AT&T transmitted the first transoceanic telephone in Arlington, Virginia, and the Eiffel Tower in Paris, putting the company on a major step to Vail's ambitious plan to unite the world. If you think of human beings, communication, we are able to communicate in special ways. It is a fundamental human calling.

So, these were men of vision who said this is very good thing to do, to build amplifiers and hire physicists, and that tradition was set in motion which kept going because in fact it showed value to the customers as well.



So that is the origin of the place. So, what has happened today… you can really think of the changing scene. Reductionist science is about looking at something deeper and deeper. I come from nano-science; it is in fact that kind of science. Or integrationist, which is really a strength of engineering because in fact you want to think of everything holistically as a system. Prof. Inoue, the great presidents of the university have to think of it holistically as a university.

There is always that dichotomy between what is disciplinary and what is interdisciplinary. Discipline is usually something where the knowledge is well understood. Interdisciplinary necessarily is the intersection of those disciplines where in fact new knowledge is to be made.

We can always argue about what is important. I convinced President Summers that the world was not only about Einstein but also Edison. When somebody invents the light bulb and the telephone, then which is more important? Is it Einstein or is it Edison? Both are equally important and these people can change the world. Harvard needs the future explorer, the inventor, the discoverer, not just the theorist. In fact, when I read Prof. Inoue’s charter for the university, he thought about practical research and it is actually a good way of describing it, and that is very important to keep that in mind—that the theorists are not better than the experimentalists and vice versa. So it is “not actually about Einstein versus Edison, it is both Einstein and Edison or Edison and Einstein.”

In another way, we can do science in many ways. You come to the Bell Labs Materials Research Laboratory and the most important thing which happened there was you always were developing new instruments. There might be electron microscopes, it might be a scanning probe microscope because the new tools of discovery come from applied physics, from engineering and related disciplines. In fact, Galileo became famous not just because he said “the Earth is not the center of the universe.” He invented the first telescope in 1609 (2009 is the 400th anniversary World Astronomy year) and he looked at the stars and he discovered, by this telescope, the moons of Jupiter. So, when you develop new tools, you end up with new science. In fact, progress is always when the great instruments are developed. That is why applied physics is so important, it is why Bell Labs succeeded and why the materials people are so important.

Columbus had a different kind of approach. “We build the biggest ship and then we will sail the oceans and we will discover India,” he thought, but he actually discovered America. And so the point is that you can do science in different ways and you will never know what you will discover. You might discover the moons of Jupiter or you might discover America. That is what you do if you are an explorer. So, you should never forget that. This is why we created an engineering school in Harvard. I have to commend Lawrence Summers. I can tell you that he could be decisive and visionary.

So, I thought it would be good to examine the list of Nobel Prizes in Physics over the last 15 or 20 years. I chaired the National Research Council panel on the future of condensed matter physics about 10 years ago. This year I was the reviewer for the panel. The number of Nobel Prizes which came from solid state physics or condensed matter physics is huge and you have to ask if the string theorists and the high energy

TABLE O.1 Nobel Prizes Awarded for Research Related to Condensed-matter and Materials Physics since 1986

Year	Field	Citation	Laureates
1986	Physics	For design of the first electron microscope (Ruska) and the scanning-tunneling Microscope (Binning and Rohrer)	Ernst Ruska, Gerd Binning, and Heinrich Rohrer
1987	Physics	For discovery of superconductivity in ceramic materials	Johannes Georg Bednorz and Karl A. Müller
1991	Physics	For discovery of methods for studying order phenomena in complex forms of matter, particularly liquid crystals and polymers	Pierre-Gilles de Gennes
1994	Physics	For development of neutron-scattering techniques for studies of condensed matter	Clifford G. Shull and Bertram N. Brockhouse
1996	Chemistry	For the discovery of fullerenes	Harold Kroto, Robert Curl Jr., and Richard E. Smalley
1996	Physics	For the discovery of superfluidity in helium-3	David M. Lee, Douglas D. Osheroff, and Robert C. Richardson
1997	Physics	For development of methods to cool and trap atoms with laser light	Steven Chu, Claude Cohen-Tannoudji, and William D. Phillips
1998	Chemistry	For development of the destiny-functional theory (Kohn) and computational methods in quantum chemistry (People)	Walter Kohn and John A. Pople
1998	Physics	For discovery of a new form of quantum fluid with fractionally charged excitations	Robert B. Laughlin, Horst L. Störmer, and Daniel C. Tsui
2000	Physics	For bandgap engineering, Si Ic’s	Zh. I. Alferov, H. Kroemer and J. Kilby
2000	Chemistry	For conducting Polymers	A. Heeger, A. McDiarmid, Hideki Shirakawa
2003	Physics	Superconductivity (superfluidity)	Abrikosov, Ginzburg and Legett

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physicists tell you that is not physics, you have then to ask where Nobel prizes are coming from.

If you look at this list, it includes Walter Kohn who won the prize in Chemistry with John Pople. Walter Kohn was solid state physicist and discovered pseudo potentials, but he got the Nobel Prize in chemistry because the physicists did not quite regard him the right way. Very important, also to remember that the Nobel Prize in 2003 went to Herbert Kroemer at Santa Barbara, professor of electrical engineering not physics. Most of my colleagues in Santa Barbara did not know who Herbert Kroemer was, but I had told the UCSB Chancellor Henry Yang in 1992 that Herbert Kroemer had a good chance to win the Nobel Prize.

In 2003 when he got Nobel Prize, I was in Harvard and many of Santa Barbara professors called me: “Venky, you should be here.” One of them was really unhappy, he says “You left us and went to Harvard; UCSB 2, Harvard 0” he said because Allen Heeger was Professor of Materials and Herbert Kroemer Professor of Electrical Engineering, at UCSB.

Nobel Prizes are coming from materials science to electrical engineering, not from our physics departments—not from the Harvard physics department but from Bell Laboratories, to IBM, etc and then it was no longer a fluke. It is the environment which creates it. So if somebody separates basic research and applied research, tell them that is not the right way, that it is one unite system.

So, you look at all of these examples. It turns out that this is not a fluke, that there has to be something about the culture of those institutions and the way they ran, which produced it.

I thought I would list this for you since you want to see the

Some new inorganic materials of the past fifteen years

Advance	Driver	Nature of Advance
New compounds/materials		
High temperature superconductors	Science	Revolutionary
Organic superconductors	Science	Revolutionary
Rare earth optical amplifierl	Technology	Evolutionary
High field magnets	Technology	Evolutionary
Organic electronic materials	Technology	Evolutionary
Magnetoptical recording materials	Technology	Evolutionary
Bulk Amorphus metals	Technology	Evolutionary
	Technology	Evolutionary
New Structure of known materials		
Quasicrystals		
Buckyballs and related structures	Science	Revolutionary
Nanoclusters	Science	Revolutionary
Metallic hydrogen	Science	Evolutionary
Bose-Einstein condensates	Science	Evolutionary
Giant magnoresistance materials	Science	Evolutionary
Porous silicon	Technology	Revolutionary
Diamond films	Technology	Evolutionary
Quantum dots	Technology	Evolutionary
Foams/gels	Technology	Evolutionary
	Technology	Evolutionary
New properties of known materials		
Gallium nitride	Technology	Revolutionary
Sillicon germanium	Technology	Evolutionary

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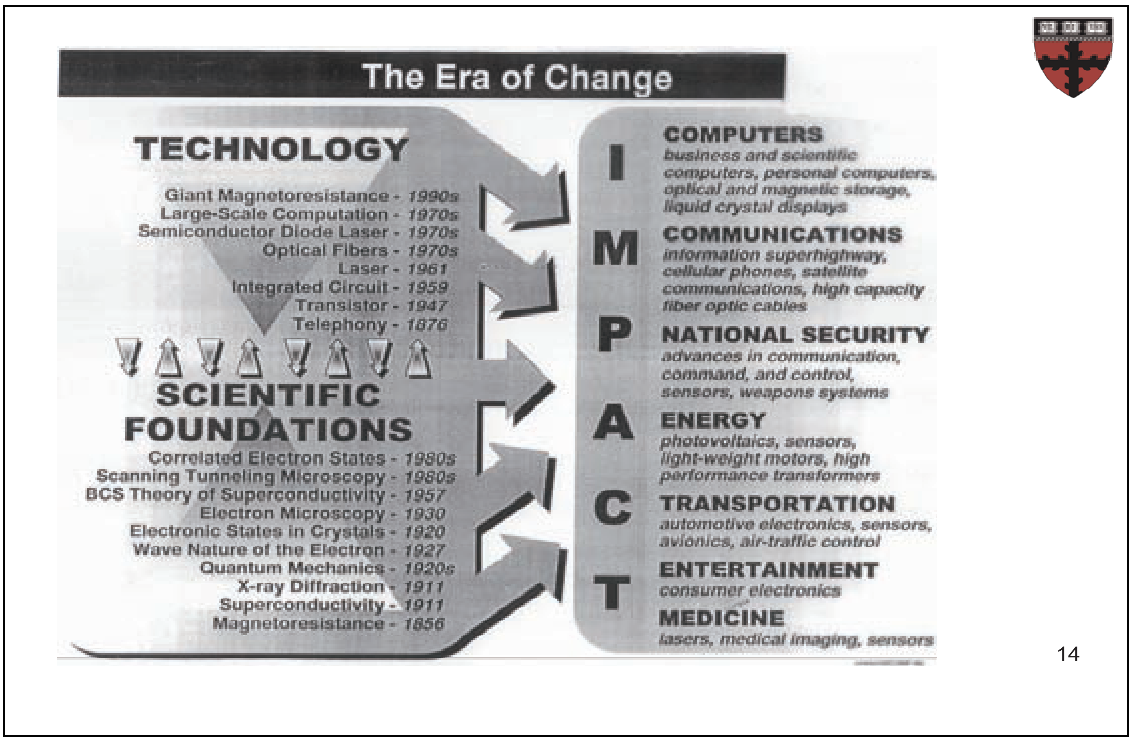
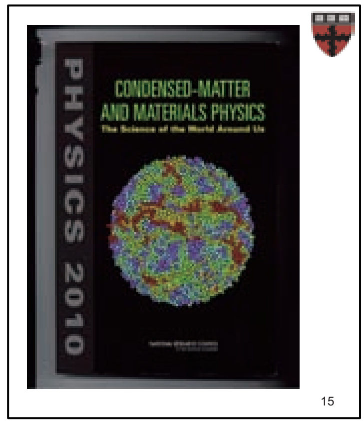
frontiers. So, it is a list of new inorganic materials for the past 15 years, many of them came from industrial laboratories, some right here in this place. We have got here the world leaders in metallic glasses. We have got some wonderful work going on in oxides in many places. An enormous number of things happened. This happened at IBM, something happened here, at universities, etc., an enormous number of materials. Gallium nitride is a wonderful example of a new semiconductor… which is so messy and so dirty, completely different from silicon and germanium, but very important. Actually done at the industrial laboratory the Nichia Labs in Japan, and Shuji Nakamura was the pioneer who defied all the conventional logic. Sometimes you have to be unconventional and defy the conventional.

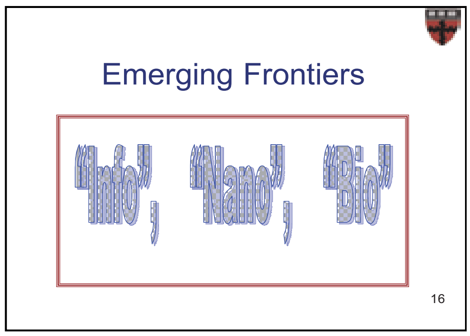


So, the era of change which happened was in fact this integral relationship between the scientific foundations and technology. The arrow is both ways, sometimes it is this way, sometimes it is that way. MBE (molecular beam epitaxy) is one of the best examples, it started with basic surface physics and then it became very applications oriented and with improved materials new basic phenomena such as fractional quantum Hall Effect (FQHE) were discovered and the cycle goes on. It is a very delicate ecosystem. You will see many wonderful things from telephone to giant magnetoresistance, semiconductor diode laser, etc and computers, communication, national security, energy, transportation, entertainment, medicine, and very broad aspects of society.

So, if somebody tells you that you do not want to know what the issues of society are, then you will not be really doing great science. I find it exciting that there is the really important energy problem and you are solving that problem. That is what it used to be in the telephone company. We were simply not making the next repeater but we knew this technology will be important 20 years down the road. We need to be connected and know how we relate to society and the technology at large. So, that is sort of the message from this.

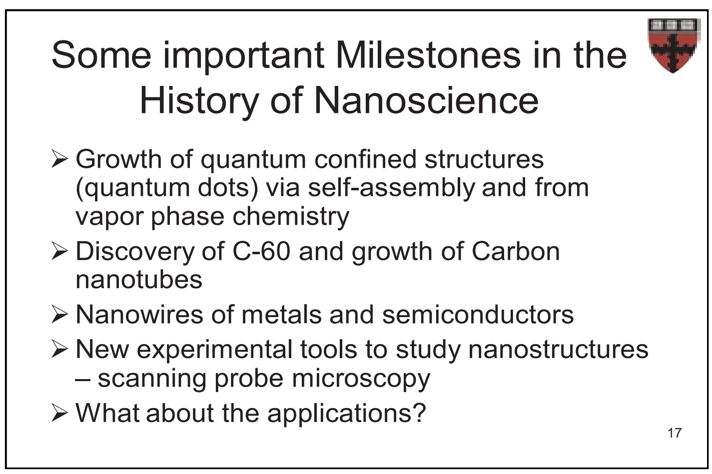


About six months ago, Professor Millie Dresselhaus (MIT) chaired the next National Academy Condensed Matter and Materials Physics Study, the science of the world around us, “Physics 2010.” For all National Research Council studies, there has to be one final reviewer, who has to certify that this work is done well and that the external reviewer comments have been satisfied. This year it happens to be me. So I know the detail of the study.



So the emerging frontiers as we said, of course, are information, nano, and biotechnology.

Some history of nano science since Prof. Sakurai wanted me to say something about it; growth of quantum confined structures, quantum dots, self-assembly and vapor phase chemistry. Discovery of carbon-60 and growth of carbon nano tubes, much of some very nice work happened in Japan. Nano tubes, nano wires of metals and semiconductors, new experimental tools to study nanostructures, scanning probe microscopy, lots and lots of exciting things have happened.



If you take what the top five are in physics, now they sometimes are worried "Too much emphasis on numbers." Sometimes in science, one has to look at the quality in different ways but it is good to have at least a feeling and a yardstick. We all have an h-number. If you have an h-number of 100, you have 100 hundred papers with more than 100 citations; with an h-number of 10, you have 10 papers with more than 10 citations. So, it depends on the feedback, and you have to be very careful about this.

TOP FIVE IN PHYSICS

Are you working on the hottest topic in your field? Many scientists may think so, but it has been a tough assertion to prove — until now, that is. A German physicist has devised a way of answering the 'Hot or not?' question for his discipline. If it stands up to scrutiny, it could be used to rate topics across the sciences. In physics, the results show that hotness — measured by a parameter known as *m* — correlates well with the promise of future wealth... and that promise is greatest in nanotechnology.

12.85 Carbon nanotubes

Super-strong materials and blisteringly fast electronic circuits: the potential applications of these tiny carbon tubes, discovered in 1991, are so enticing that everyone is pouring money into the field.

8.75 Nanowires

Less well studied than nanotubes, but the possible uses are similar. Nanowires could eventually prove more useful than nanotubes, because their chemistry is easier to tailor and they can be used to create nano-sized lasers.

7.84 Quantum dots

Another nanotechnology with a huge range of potential applications. These tiny specks of semiconductor material, measuring as little as a few nanometres across, have already been used to create dyes for cell biologists and new kinds of laser. Physicists hope they might one day form the basis of a quantum computer.

7.78 Fullerenes

These spheres of carbon atoms are attracting significant research interest. But the latest ranking rewards newness, so the topic may have slipped down the list because it predates nanotubes by around six years. The discovery of fullerenes earned a Nobel prize and spawned studies of numerous potential uses, such as drug delivery agents.

6.82 Giant magnetoresistance

Not a new topic, but still hot because of its economic importance. Modern hard disk drives were made possible by the discovery of giant magnetoresistant materials, which show marked falls in electrical resistance — more than around 5% — when a magnetic field is applied. Researchers are now aiming to make hard disks even more powerful.

How the topics were ranked

The ranking is an extension of a recently proposed system for rating the research output of individual scientists. The *h* index uses the highest number of papers a scientist has published that have each received at least that number of citations: for example, a researcher with an *h* of 50 has written 50 papers that have each had at least 50 citations (see *Nature* **436**, 900; 2005). The index has attracted interest from bibliometricians, but was first described only last year and has yet to be studied in depth.

Michael Banks, a PhD student at the Max Planck Institute for Solid State Research in Stuttgart, Germany, totted up the *h* index for physics topics, rather than people, and then calculated the parameter *m* by dividing by the number of years over which the papers involved had been published (www.arxiv.org/abs/physics/0604216).

Jim Giles

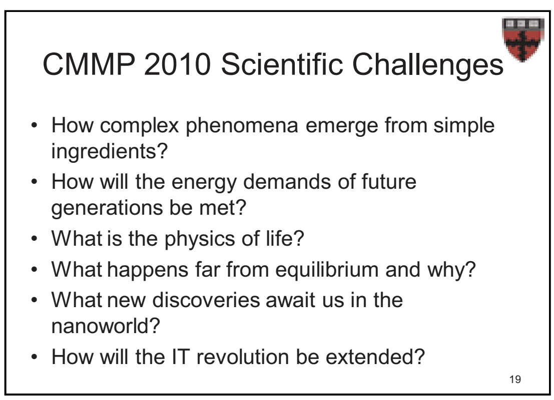
Do you agree with the winners? Tell us what you think on our news blog

blogs.nature.com/news/blog/2006/05/top_five_in_physics.html

Nature, Vol. 441, May 18, 2006, p. 265 18

In Nature, 3 years ago, they published a new kind of analysis on publication by field topics in physics they have their own number system. They came up with the top five things in physics (There are no particle physics); carbon nano tubes, nano wires, quantum dots, fullerenes, giant magnetoresistance. That is where all the papers are being published and cited. That is what interests them. This is two or three years ago but I do not think these have changed very much.

So, the scientific challenges of 2010, are how complex phenomena emerge from simple ingredients? How will the energy demands of future generations be met? What is the physics of life? What happens far from equilibrium and why? What new discoveries await us in the nano world if we just go down the hall and see



some of the work being done here either on our site or where you see the work done in magnetic semiconductors… who knows, there may be some new discoveries like that and how will the IT revolution be extended? I think predictions are very hard to make. When Watson started IBM, he thought the world had use for only five computers. There are many, many such mistakes. In 1900 the Head of the US Patent office was reported to have said that everything that had to be invented had been done and the US should close the office. So, we should take all the predictions with a grain of salt because something new and unexpected will happen and this is the only thing we can be certain of.

So, some of the Nobel Prizes had many contributions from industrial laboratories… Look at them.

TABLE 9.1 Some Nobel Prize–Winning Contributions from Industrial Laboratories

Activity	Corporate Sponsor	Name of Researcher(s) and Date of Prize
Surface chemistry	GE Laboratories	Langmuir, 1932
Electron diffraction	Bell Laboratories	Davisson and Thomson, 1937
Transistor	Bell Laboratories	Bardeen, Brattain, and Shockley, 1956
Maser-laser	Bell Laboratories/Columbia University	Townes, Basov, and Prokhorov, 1964
Quantum tunnel junctions	IBM T.J. Watson Laboratories/ GE Laboratories	Esaki and Giaever, 1973
Theory of disordered materials	Bell Laboratories	Anderson, Mott, and van Vleck, 1977
Cosmic microwave background radiation	Bell Laboratories	Penzias and Wilson, 1978
Scanning tunneling microscopy	IBM Zurich Research Laboratory	Binnig and Rohrer, 1986
High-temperature superconductivity	IBM Zurich Research Laboratory	Bednorz and Mueller, 1987
Quantum Hall effect	Bell Laboratories	Laughlin, Stormer, and Tsui, 1998
Integrated circuit	Texas Instruments	Kilby, 2000

SOURCE: See http://nobelprize.org.

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They came from General Electric, from Bell Labs, from IBM Zurich, Texas Instruments, and this is not even a complete listing. This is from the field of condensed matter. So one has to ask the question, how will universities and nations create that kind of environment where advances can be done? Is the WPI the answer? Some other method?

My own view is one should try different experiments and I want to write a lot on that subject which needs to be clear. Very important, how you create that environment where this kind of work flourishes even though now Bell Labs is dead and IBM is dead and General Electric is dead, etc.

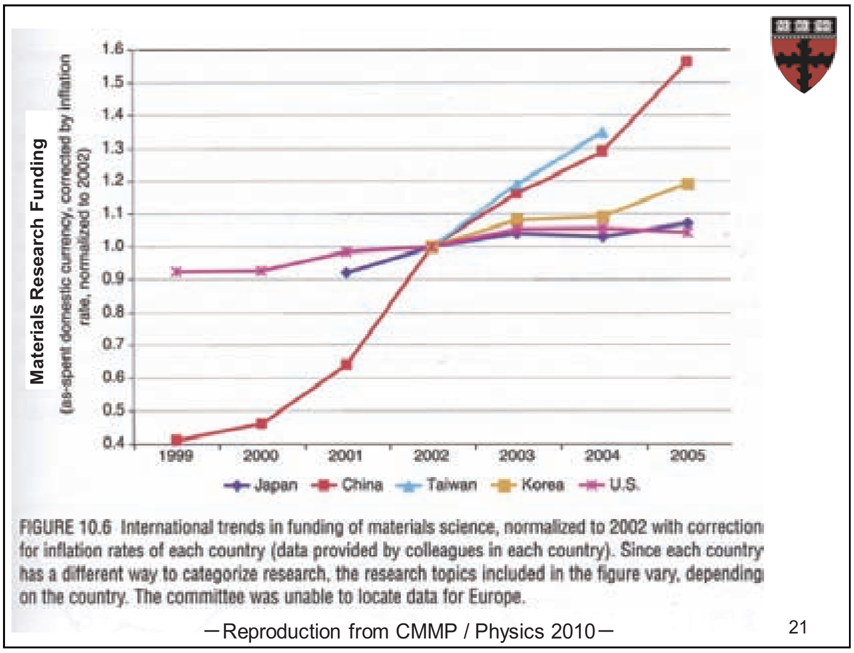


FIGURE 10.6 International trends in funding of materials science, normalized to 2002 with correction for inflation rates of each country (data provided by colleagues in each country). Since each country has a different way to categorize research, the research topics included in the figure vary, depending on the country. The committee was unable to locate data for Europe.

—Reproduction from CMMP / Physics 2010—

Look at the changes in materials research. Again from materials research funding, Japan, China. China! You can see how it is growing like leaps and bounds… and Taiwan, Korea. United States has remained flat. We see that in engineering, you see that much of the action is in the Far East; previously it was only Japan there but not any more. South Korea, Taiwan, China or all, and you know this. India is even missing, but India is coming up fast.

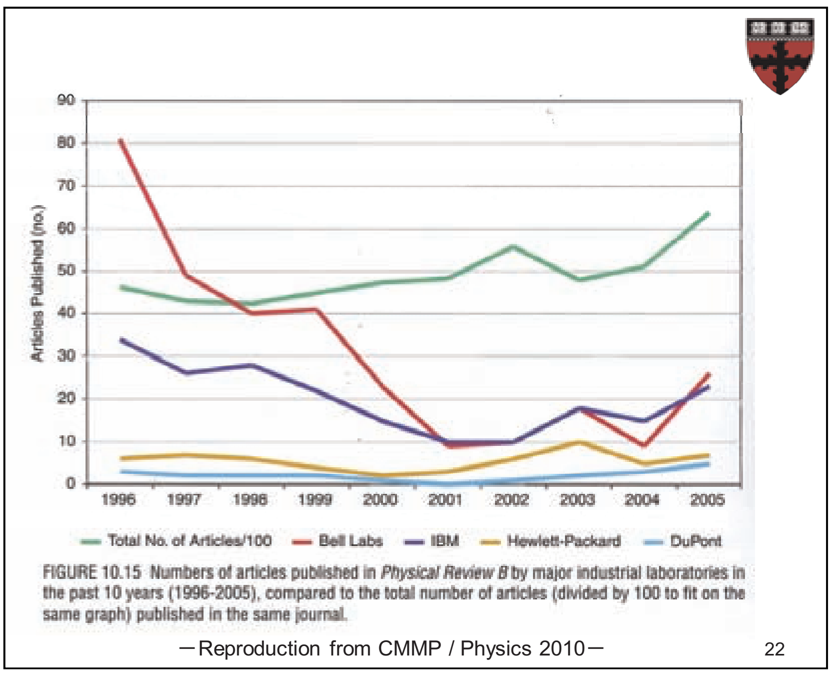
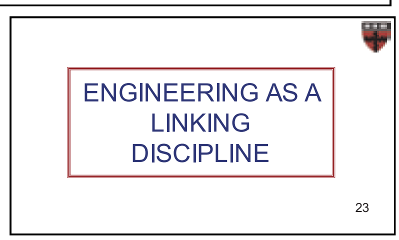


FIGURE 10.15 Numbers of articles published in *Physical Review B* by major industrial laboratories in the past 10 years (1996-2005), compared to the total number of articles (divided by 100 to fit on the same graph) published in the same journal.

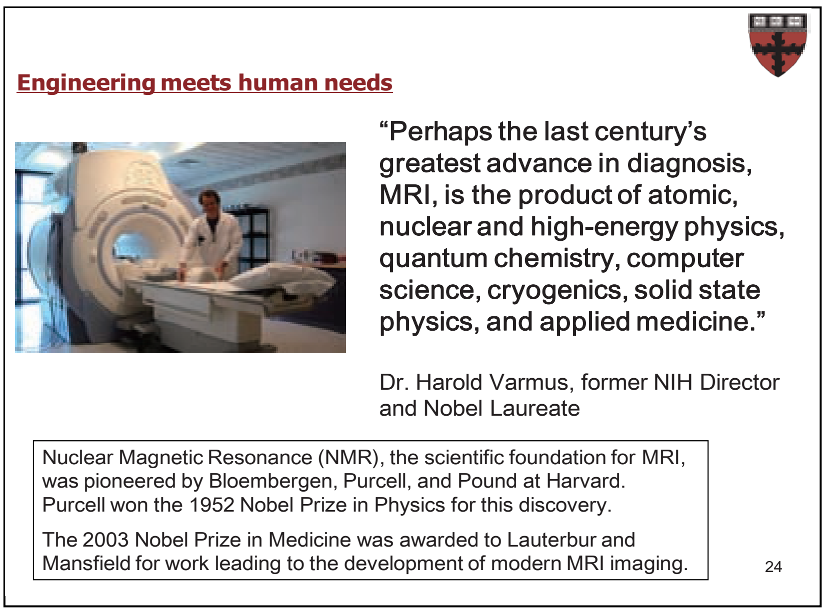
—Reproduction from CMMP / Physics 2010—

If you look at articles and publications in PRL and PRB, you will find that the industrial laboratories, Bell Labs and IBM, which published so many in the past, went down to zero almost, and it really tells you that there is something wrong. While the total number of articles is going up, the industrial labs are finished, it is huge change.



Now I want to say a little bit about engineering and what it is in education, and then we have some policy. So, this is the example which I always use, which I used at the Harvard Board of Overseers as to why Harvard should do engineering and why engineering should be a thing to do.

Actually, last week, I was at Harvard at a very big symposium on “Two Cultures.” I do not know how many of you know C. P. Snow. He was the English scientist and philosopher and writer who was a student of Rutherford and Bragg and then wrote novels and then became a high government official. In 1959 he gave a famous lecture in Cambridge University which is titled “Two Cultures,” meaning the humanities on one side, the sciences on the other side and it was engineering at the bottom. He was very concerned about this. He said you have to break this divide between the humanists and the scientists, and take advantage. That is another important reason Britain and Oxford have actually fallen behind today, because the great powers depend on technology. The United States may suffer the same fate and who knows who the next one will be, is it China or is it some other country? We do not know.



I showed this to Larry Summers because it said, “Perhaps the last century’s greatest advance in diagnosis, the MRI, is the product of many disciplines” The nuclear magnetic resonance which led to MRI was pioneered by Nicholas Bloembergen. He was a graduate student at Harvard for Edward Purcell, and in fact the Harvard physics department did not want to appoint Bloembergen to its faculty because he was too applied. Purcell won the Nobel Prize in 1952. And the Dean of the Engineering and Applied Physics was Van Vleck, the famous Nobel Prize-winning physicist in 1977. He said “I will hire Bloembergen in applied physics” because applied physics was in the Division of Engineering then. Bloembergen, of course, was also inventor of the laser and also nonlinear optics and won the Nobel Prize in physics in his own right in 1981 and became a University Professor at Harvard from the Division of Engineering and Applied Sciences (DEAS).

But what is more important was you could not go from NMR to the MRI in a straight forward way. You will have to do wonderful amounts of electrical engineering and applied physics. In fact the two people, Lauterbur and Mansfield, would apply to the development and realize to actually do the imaging of the brain, you have to look at the gradient of the magnetic field of the nuclei that allowed you to image the brain and that won them the Nobel Prize in Medicine in 2003.

So, if anybody tells you physics did it, well physics was important, but engineering was equally important for the things that really changed our lives. Nobody could have predicted that you would go from what might be useful for chemistry and solid state physics to something like putting the human being into MRI. This is not a simple linear path. It requires enormous amount of thinking, that is why they got Nobel Prize. Such work will be done at engineering schools, at Santa Barbara, or applied physics departments. So practical research is really a key.

Engineering meets human needs. Takes aim at cancer. The tinkerers and engineers,

Engineering meets human needs

NEWS

Nanotechnology Takes Aim at Cancer

The science of extremely small materials is poised to revolutionize cancer diagnostics, imaging, and treatment and could finally usher in the long-awaited era of personalized medicine

If there is a case to be made for personalized medicine, cancer is it. Every year, nearly 1.4 million Americans are diagnosed with the disease; another 600,000 die from it. Yet, although cancer is often portrayed as a monolithic illness, it is anything but. There are more than 200 types of cancers, each with many variants. Some are aggressive, some docile; some are easily treated, others are almost always fatal. Diagnosing, treating, and tracking the progress of therapy for each type of cancer has long been a dream among oncologists, and one that has grown closer thanks to parallel revolutions in genomics, proteomics, and cell biology. Now a new revolution in nanotechnology is pushing personalized cancer treatment closer than ever before.

Nanotechnology's ability to

These promises have already set off a burgeoning effort to marry nanotechnology with oncology. Most notably, in 2004, NCI launched a $144 million cancer nanotechnology initiative. As the foundation of this effort, last month NCI announced $26.3 million for the first year of funding for seven centers of cancer nanotechnology excellence designed to foster interdisciplinary work among chemists, materials scientists, and biologists. Europe and Japan are also invest-

"The science in this area is exploding. The cancer community really gets this now."
—Gregory Downing, NCI

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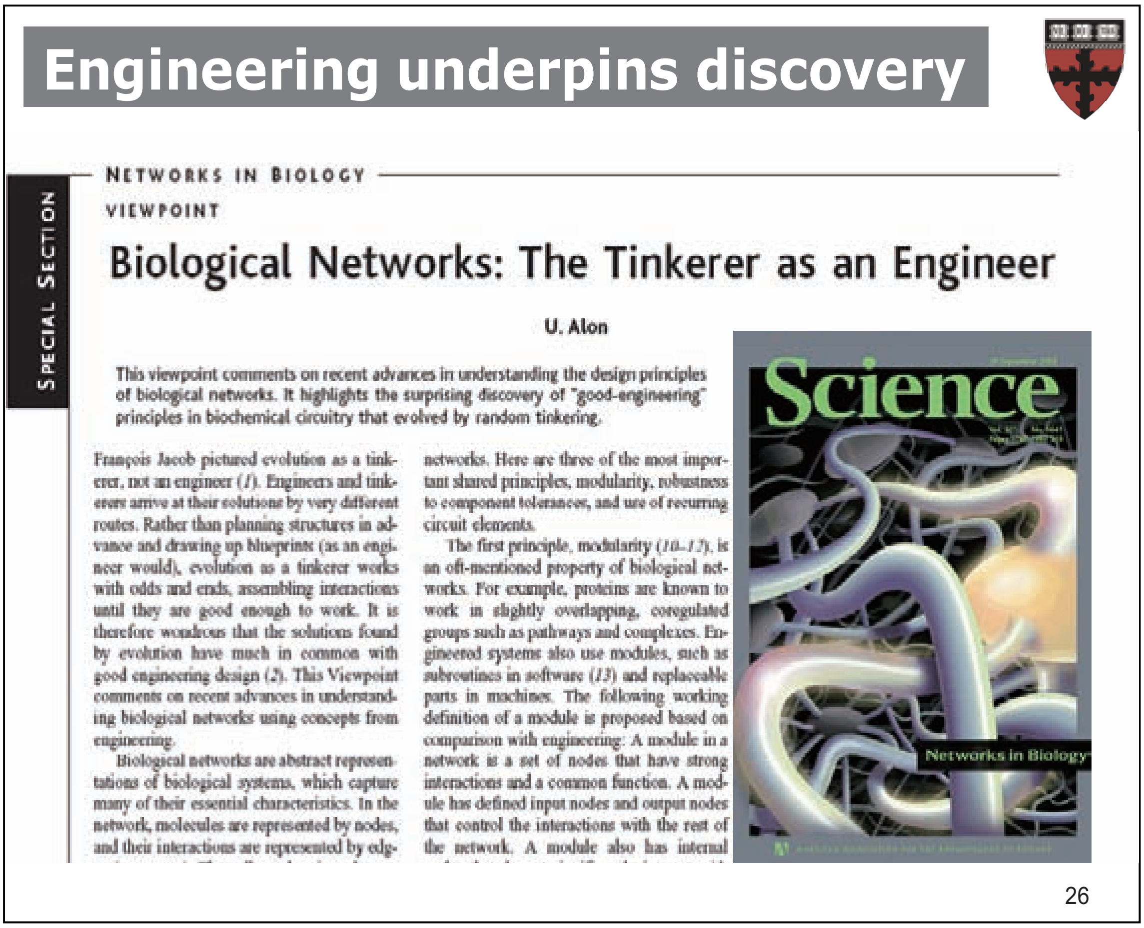


NETWORKS IN BIOLOGY

VIEWPOINT

SPECIAL SECTION

Biological Networks: The Tinkerer as an Engineer

U. Alon

This viewpoint comments on recent advances in understanding the design principles of biological networks. It highlights the surprising discovery of "good-engineering" principles in biochemical circuitry that evolved by random tinkering.

François Jacob pictured evolution as a tinkerer, not an engineer (1). Engineers and tinkerers arrive at their solutions by very different routes. Rather than planning structures in advance and drawing up blueprints (as an engineer would), evolution as a tinkerer works with odds and ends, assembling interactions until they are good enough to work. It is therefore wondrous that the solutions found by evolution have much in common with good engineering design (2). This Viewpoint comments on recent advances in understanding biological networks using concepts from engineering.

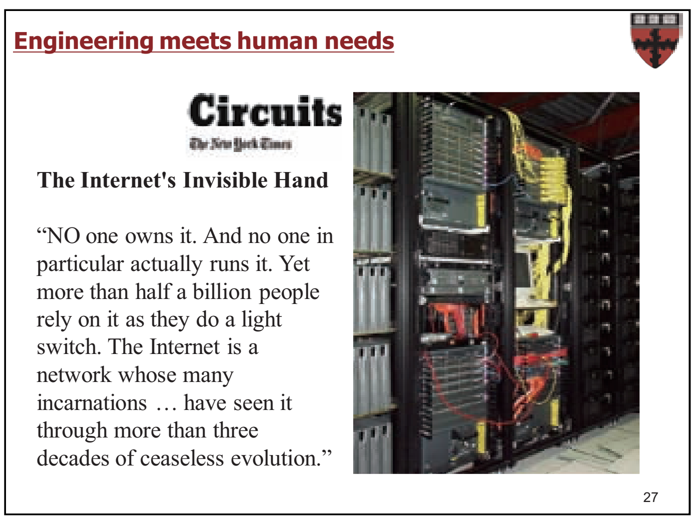
Biological networks are abstract representations of biological systems, which capture many of their essential characteristics. In the network, molecules are represented by nodes, and their interactions are represented by edg-

networks. Here are three of the most important shared principles, modularity, robustness to component tolerances, and use of recurring circuit elements.

The first principle, modularity (10–12), is an oft-mentioned property of biological networks. For example, proteins are known to work in slightly overlapping, coregulated groups such as pathways and complexes. Engineered systems also use modules, such as subroutines in software (13) and replaceable parts in machines. The following working definition of a module is proposed based on comparison with engineering: A module in a network is a set of nodes that have strong interactions and a common function. A module has defined input nodes and output nodes that control the interactions with the rest of the network. A module also has internal

this viewpoint commenced on recent advancement to understand the design control, biological efforts, it highlights the supply of good engineering principle evolved by random tinkering. This is coming in science. Therefore, if somebody says "applied science and engineering" is beneath, that is where the action is. It is a message that I want to keep on drilling, that it is helping laboratories function.

Another example where engineering meets human needs is the case of the Internet's invisible hand. No one owns it. No one in particular runs it. Yet more than half a billion people rely on it. The Internet network has evolved over more than three decades of seamless evolution.



Today, we are trying to change all of medical care (using Internet technology) and that is how we hope to transform the world. This is the cover of New York Times, Feb. 1, 2009. You are relating to the world. I am really fond of my Blackberry and I tell you it has saved me. I do not like to answer the phone and disturb people in meetings, but if there is an emergency it just vibrates; I can look at it and I can respond quietly. Twice it has saved me with family emergencies in a good way without disturbing anybody. Communication is very important and getting here was not easy. Japan of course has been a leader in it, but in United States this was very different.

President Bush did barely use email, but Obama took it to another level, he had to fight with the Secret Service agents to keep his Blackberry with him. He cares about technology. He cares about science. He cares about communication. He used the Internet to bring communities of people together and to vote for him. He completely transformed it and won the nomination over Hillary Clinton because he used modern technology and understood the consequences of Internet on society. It is really quite something. In Washington, D.C., a new symbol of insider status is "email with the chief."

Engineering meets human needs

THE FIRST 100 DAYS

In D.C., a new symbol of true insider status: e-mail with the chief

By Peter Baker
NEW YORK TIMES

WASHINGTON — Anthony Lake served as one of Barack Obama's principal counselors on foreign affairs during the campaign and exchanged e-mail messages with him regularly. But now that Obama is president, Lake no longer has his e-mail address.

"No," he said when asked whether he had it. "Did. Don't."

Neither does Nancy Pelosi, the speaker of the House, nor Steny H. Hoyer, the majority leader, but they do not use e-mail much anyway. Mitch McConnell, the Senate Republican leader, is a BlackBerry fiend, but he does not have Obama's address. Nor do many members of the Cabinet, including Defense Secretary Robert M. Gates. Vice President Joe Biden has it, along with his own new super-secret BlackBerry and e-mail address. So do Obama's chief of staff, his top advisers, and some of his oldest friends from Chicago.

'This is the 21st-century version of . . . special access.'
JOEL P. JOHNSON,
a former top Bill Clinton adviser

lists and Camp David visitor logs for clues to who was in and who was out. Now there is Obama's e-mail, the first time a commander in chief has used it while in office. "This is the 21st-century version of the same special access that certain people are always granted to the president," said Joel P. Johnson, a senior White House adviser under Clinton. "In FDR's White House, it was Harry Hopkins and Harold Ickes. There will be a similar select few in this White House."

Those select few who have Obama's e-mail address, according to people informed about the matter, include Rahm Emanuel, the White House chief of staff; David Axelrod and Valerie Jarrett, both senior advisers; and Robert Gibbs, the press secretary. But Cabinet members like the interior secretary, Ken Salazar, said they did not have it. Secretary of State Hillary Rodham Clinton is a frequent BlackBerry user, but a spokesman said he did not know whether she had the president's address.

The exclusivity is not just a matter of safeguarding the president's time or even protecting him from spam. Security personnel worry that the more available his address, the more vulnerable it may be to hacking pranksters or, worse, to cyber-attackers from, say, Russia or China.

Imagine a president's e-mail put on display for the whole world to see — or perhaps just for

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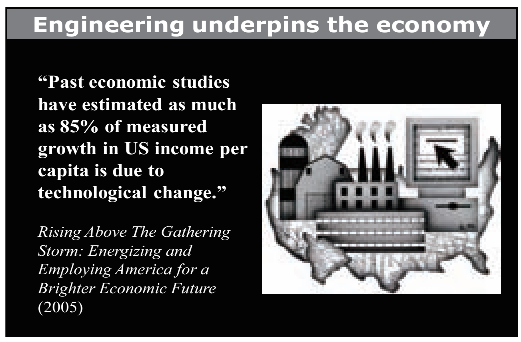
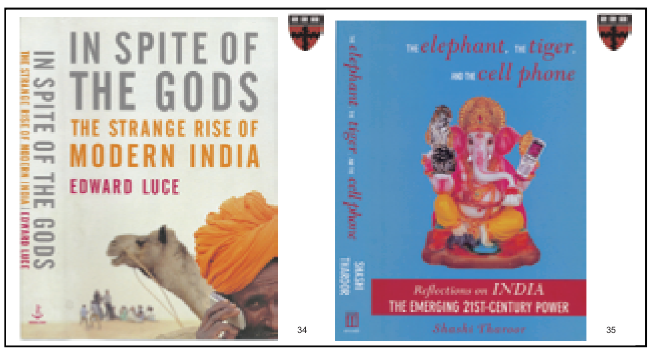
So, at Harvard, the fact that computing is important is taking root. You know the first PhD program in computer science was started at Harvard in 1950. Then the Harvard president, Derek Bok, he said "Well, that is too applied; Harvard does not do it." It was the biggest mistake, of course. Today, my associate dean for Computer Science has now become the Dean of the Faculty of Arts and Sciences, the most important in Harvard. Things have changed here even in the Harvard because in fact computer science changed the view of engineers. That is what Bell Labs and IBM did; computing and communication changed the view of applied science. In the old days, mechanics, they thought of greasy automobiles… you have a car, it is a very wonderful thing. But President Obama changed the image because when the president carries that and computers that way, it has got the knowledge, the communication.

Take advantage, you know it but now United States is coming closer towards Japan's work. You were ahead of us. I do not know about your prime minister. But it is nice to see our president having a Blackberry and wanting to communicate with the people and not be hung up in Washington, D.C. I will advise VIPs to always go into the lab and be where the scientists do their work and where the people are. That is another message.

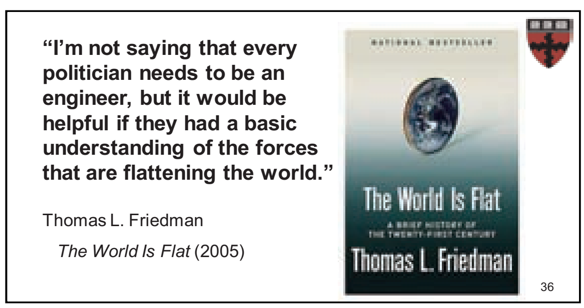
So entire corporations are going to change. Toyota, Honda, all of them are going to look different 20 years down the road. It is truly about community, a collaboration on a scale never seen before, the tools that make it possible, the worldwide web. Businesses are awash in a sea of data.



Engineering underpins the economy. Past studies show that as much as 85% of the growth in the United States is due to technological change. "In spite of the god and the strange rise of modern India; you have both," it is a wonderful story with the camel and the cell phone. You will have Lord Ganesha, my favorite Lord. He makes you cross the oceans. I carry Ganesha so I can fly to Japan, and not have an accident, and Ganesha carries a cell phone, reflection of India in the emerging 21st century power.



As Thomas Friedman has written, "I am not saying like every politician needs to be an engineer, but we have to have a basic understanding of the forces that are affecting the world. In fact when I visited India as a delegate of the United



States and visited then Indian president Dr. Abdul Kalam, at the Indian White House, he gave me a PowerPoint presentation of carbon nano tubes, etc. I could never have imagined President Bush doing this. With Obama, maybe there is a chance. This is kind of nice to realize that, this is very important because technology is changing very fast and bringing people closer together.

So, that is why, President Inoue, you have to build a real global university. Globality is coming. We have to learn… I had a compliment when I visited NIMS yesterday as well as here, but you seek so many more foreign researchers come here. You will not see the benefits immediately; but long term, it is a good thing to do, because the world will be coming together and we must change global services.

At Harvard… it is a huge circle. We must renew ourselves, otherwise Harvard would die also, because I think the forces which the Internet has released are like the printing press 400 years ago. If you just see that, it is a tremendous impact. So globality means we will be competing sometimes and we can collaborate sometimes with everyone from everywhere for everything. So, we must completely change the education of our students. I decided that I would step down as dean; 10 years was plenty, because Harvard students must understand the consequences of technology. If they go to Washington, D.C. now, Obama went to Harvard, Summers went to Harvard, so many of the ministers went to Harvard… if they do not have an appreciation for this, we will have a big problem. It is very important that we train them accordingly because it is about the brighter students coming to Harvard.

People talk about the IIT’s in India; it is not because their education is that great, it is because they have the crème of the crème, the best students of India. Same thing goes with Harvard. Same thing goes for you, if you lead in education.

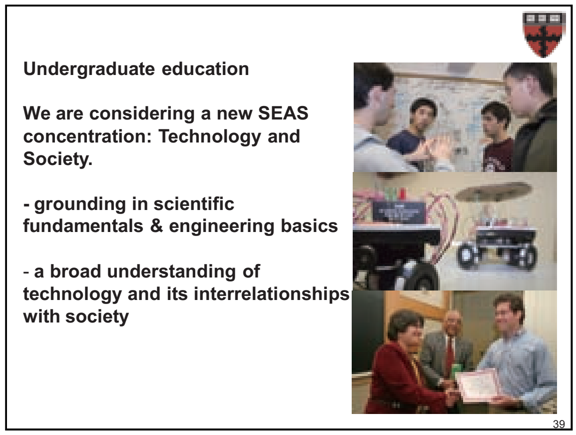
I am happy to develop, and I am very happy to tell you that. I sent this new outline of a course in Technology and Society for approval of the faculty and this faculty of Arts and Sciences is a highly deliberative and complex faculty from classics and Sanskrit professors to real engineers. I finally got their approval by email on a Blackberry, “Venky, we are so happy in doing it, everyone helps to achieve this.” At the beginning, I did not believe this possible, but Harvard too is changing. I thought I would have great difficulty getting approval for this because I alone cannot just do this.

I need the faculty's approval. In fact, what I really want to teach everybody is the essence of what we are as human beings. It is about learning, communicating and above all curiosity for a scientist. You all understand these keywords. My wife is an English major, I am getting a bit more curious and that is very important, that Obama may not know everything but he is curious and asks the right people how it works. Or can balance the risk when there is a… to think that a nuclear terrorism is the same as gasoline bombs in the World Trade Center. You can understand the differences, but a president has to decide: are we going to have a nuclear arsenal or people will be protected against biological terrorism?

You had better have some ways to think through and analyze it, because all society's problems, whether you take biology and stem cells, or drugs, you take the flu epidemic, you take nuclear terror. You had better understand the consequences of technology. Like I say, we want our engineers to understand not only how things work, but how the world works, and we want this humanist and social scientist who understands how science works, both sides. So we must continue to fight at the engineer faculty. You are not a real engineer unless you know so much mathematics and so much physics but we turn them all off. Because too early, we make it too difficult. We never show them why they should be interested to do it and of course, eventually you must learn enough mathematics and physics. But it is a question of when.

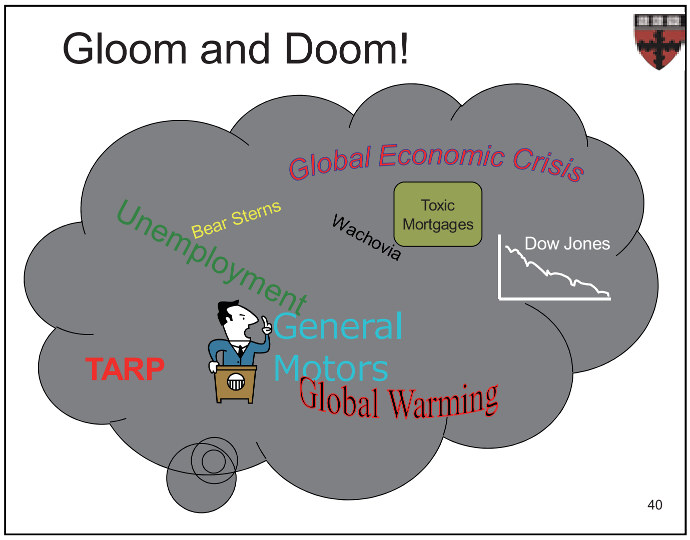
This is where I was taught 50 years ago. Now we have a new way to learn. I am finally willing to make changes. Harvard must lead the change because times are different and you must not lose so many of the students from engineering to the social sciences. We want to be able to explain what we do. It is much easier to explain physics which I know something about, with the equations than by thought. Doing it with thought is a lot more harder. I am trying to do it, but I want to write a text book on it. It is very important that we make science not such a difficult thing. It is not cheapening science. It is actually advancing science. So that is the message.

In fact there is a book by a Professor Richard Muller of Berkeley that is entitled "*Physics for future presidents*." I encourage you to read it and I am using that as a text. Somebody actually has worried about it. It is a wonderful thing, the way he explains physics without equations.



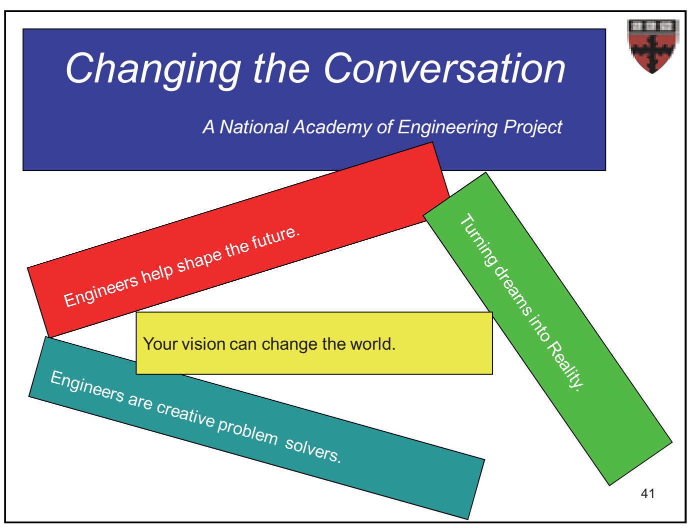
So that is your broader education, technology and its broader relationships with society.

Right from the beginning, nuclear power for example, would have gone much further if we had worried about the societal consequences. So, now there is so much prejudice where a lot of those nuclear reactors are in the United States. We need nuclear reactors for energy but we cannot get approvals because of the past.



So the gloom and doom: global economic crisis, about global warming, General Motors is going down, toxic mortgages, in fact you have TARP; there is a toxic asset relief program. And NAE, of which I am a fairly active member, has a new study changing the conversation.

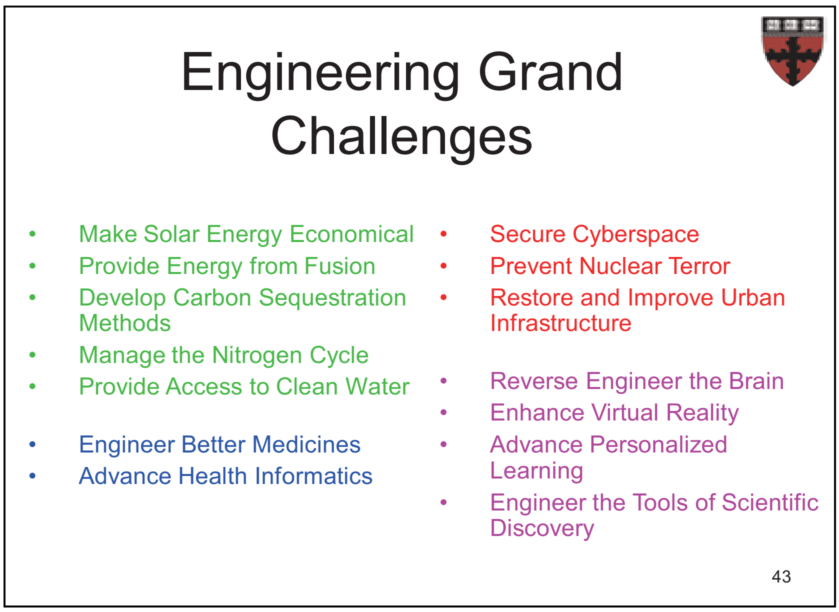
Dr. Charles Vest, my friend and President of NAE, has spoken eloquently on the subject and I am grateful to him for providing me the NAE related material.



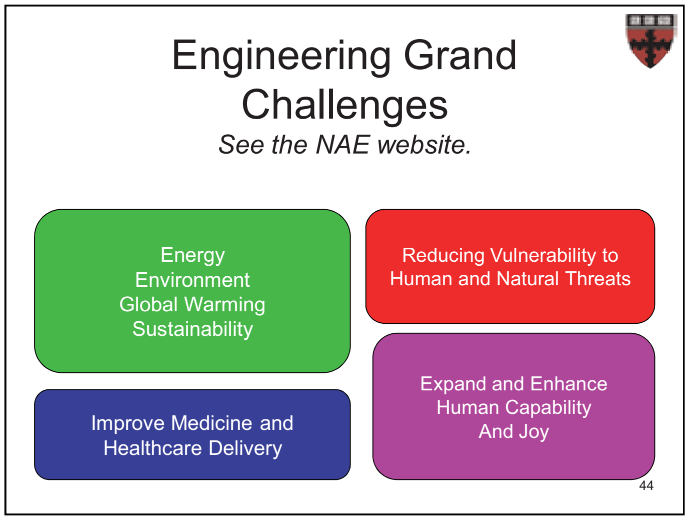
It's about engineering. Engineers help shape the future, turning dreams into reality. The vision can change the world. Engineers are creative problem solvers.

In fact, Bill Wulf, the last President of NAE often said that “science is about what is and engineering is about what will be.” It is more of the future. That is what Bell Labs. was about. I am actually a physicist. The grand challenges which NAE has come up with. I started with the physics challenges and went with the engineering challenges. Engineering grand challenges, they call it stirring our souls. It is a Panel which was headed by William Perry (former Defense Secretary) and 10 other leading NAE members. In fact, there is an open website, everybody can see it.

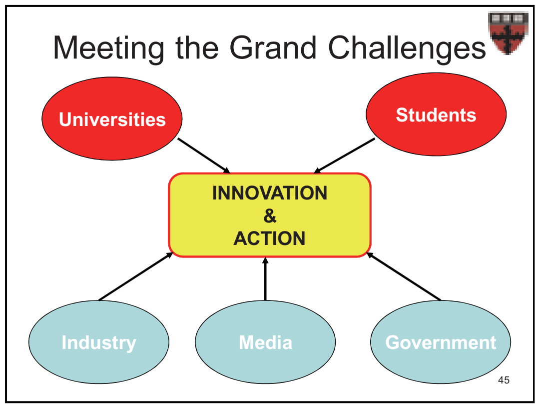
The challenges include providing energy for the future. Developing carbon sequestration methods and managing the nitrogen cycle, providing access to clean water. That was the most important thing; you take clean water in many parts of the world, but you cannot give drugs in Africa because they cannot drink the medicines with the water they have. It is such a simple and basic problem that needs to be fixed. Engineer better medicines, advance healthcare, secure cyber space; in fact cyber terrorism is a far greater problem than nuclear terrorism. It is not easy to make a big bomb and take it around the world. You need a missile. But you can easily sit in your office somewhere and destroy the Internet. Prevent nuclear terror, restore and improve urban infrastructure, reverse-engineer the brain, now bringing closer to science, enhance virtual reality, advance personalized learning, engineer tools of scientific discovery. That is my favorite because I am closest to that. We are building new microscopes and that made it to the list because that is a way of seeing things.



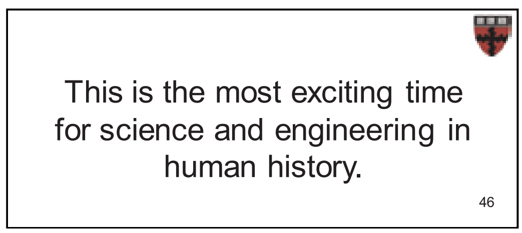
So, the Engineering Grand Challenges, see the NAE website, energy environment, global warming; it is all about society. Improve medicine and healthcare delivery. Reducing vulnerability to human and natural threats; expand and enhance human capability and especially the joy of living. What we should do, hopefully, if I can remain in touch with my wife and my children this way, that is joyous and that is a good thing which technology can do.

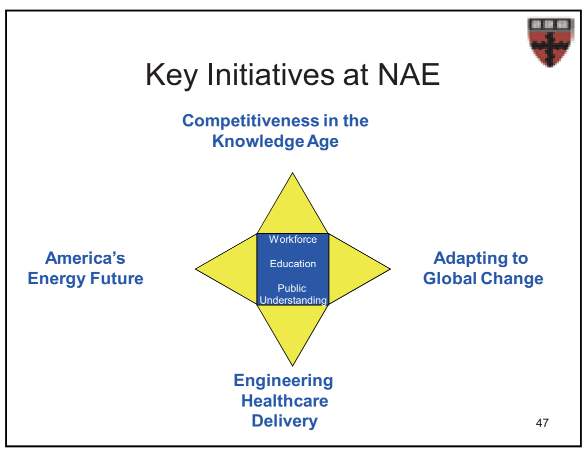


It is our institutions that must lead the grand challenges. There will be universities; students, industry, media and government with innovation and action. It will have to involve all of those features.

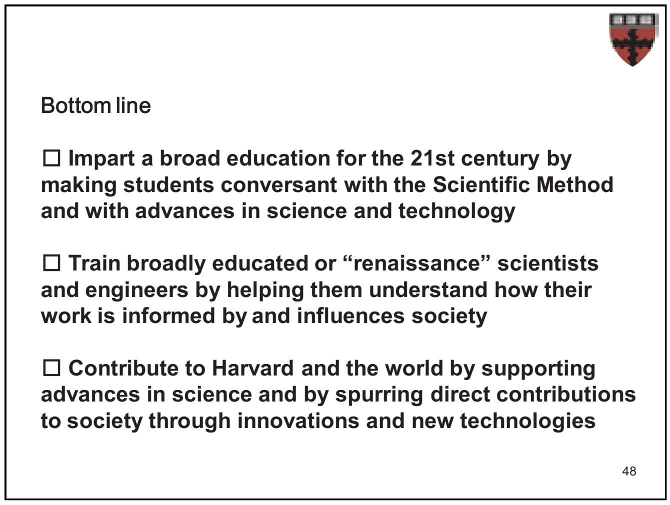


This is the most exciting time for science and engineering in human history. I am very encouraged by what is happening in the United States. Maybe we will have another golden era like under Kennedy and Sputnik, and maybe it is the energy challenge; this time we are taking it seriously. Japan was suffered for energy for over 40 years because you did not have the resources, so you took earlier action than us. We can learn from you. But we have a key. So, this is the technology age, engineering the energy future, engineering healthcare, adapting to global change.





Bottom line, we must impart in our students this excitement. In fact, President Inoue, you are correct in your plan for the university. I would love to talk to you some more about the liberal arts education in the future. It must include science and applied science; train students broadly as I mentioned by helping them understand how their work is informed by and influences society; contribute to the world by supporting advances in sciences and by spurring direct contributions to society through research.



So, this is the ultimate vision and implication for research; and enhance integrative, interdisciplinary research, WPI, I think, is an example of that, with a particular focus on linking and translating basic research to applications; develop innovative teaching with improved content and delivery, especially experiential learning.

I want to teach this class. Take for example GPS systems, all the kids know GPS and then they are going to find and do little treasure hunting with the GPS system. So, they will not be afraid and you are going to explain to them the simple way why you need these four signals and a little bit of relativity to understand GPS. Teach physics by taking the mechanical forces in the most experimental way but that is the way all professors taught in the past. We wanted the most exciting lasers, the GPS systems. Then they can learn the forces and the mechanics. It is a different way to approach the problem and you are not cheapening it, you are attracting people. I am fascinated about it. I want to actually influence all of Harvard. This is what the new education is about. So, I am very happy that science now fits the new times.

Science Times

D1

TUESDAY, JANUARY 27, 2009

The New York Times

ESSAY

Elevating Science, Elevating Democracy

By DENNIS OVERBYE

All right, I was weeping too.

To be honest, the restoration of science was the least of it, but when Barack Obama proclaimed during his Inaugural Address that he would "restore science to its rightful place," you could feel a dark cloud lifting like a sigh from the shoulders of the scientific community in this country.

When the new president went on vowing to harness the sun, the wind and the soil, and to "wield technology's wonders," I felt the glow of a spring sunrise washing my cheeks, and I could almost imagine I heard the music of swords being hammered into plowshares.

Wow. My first reaction was to worry that scientists were now in the awkward position of being expected to save the world. As they say, be careful what you wish for.

My second reaction was to wonder what the "rightful place" of science in our society really is.

The answer, I would argue, is On a Pedestal — but not for the reasons you might think.

Forget about penicillin, digital com-

In the pursuit of science, of truth, learning the values that sustain a free society.

puters and even the Big Bang, passing fads all of them.

The knock on science from its cultural and religious critics is that it is arrogant and materialistic. It tells us wondrous things about nature and how to manipulate it, but not what we should do with this knowledge and power. The Big Bang doesn't tell us how to live, or whether God loves us, or whether there is any God at all. It provides scant counsel on same-sex marriage or eating meat. It is silent on the desirability of mutual assured destruction as a strategy for deterring nuclear war.

Einstein seemed to echo this thought when he said, "I have never obtained any ethical values from my scientific work." Science teaches facts, not values, the story goes.

Worse, not only does it not provide any values of its own, say its detractors, it also undermines the ones we already have, devaluing anything it can't measure, reducing sunsets to wavelengths and romance to jiggly hormones. It destroys myths and robs the universe of its magic and mystery.

So the story goes.

But this is balderdash. Science is not

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Elevating science is elevating democracy, according to a very nice editorial in the NY Times, Jan. 27, 2009, on the Obama speech. You should never limit the progress of science. You see how this is happening now in our country frankly.

Science Times

D1

TUESDAY, JANUARY 27, 2009

The New York Times

THE NEW YORK TIMES, TUESDAY, JANUARY 27, 2009

Elevating Science and Elevating Democracy

From First Science Page

"But once you can't talk about one subject, the origin of the universe, for example, sooner or later other subjects are going to be off limits; like global warming, birth control and abortion, or evolution…"

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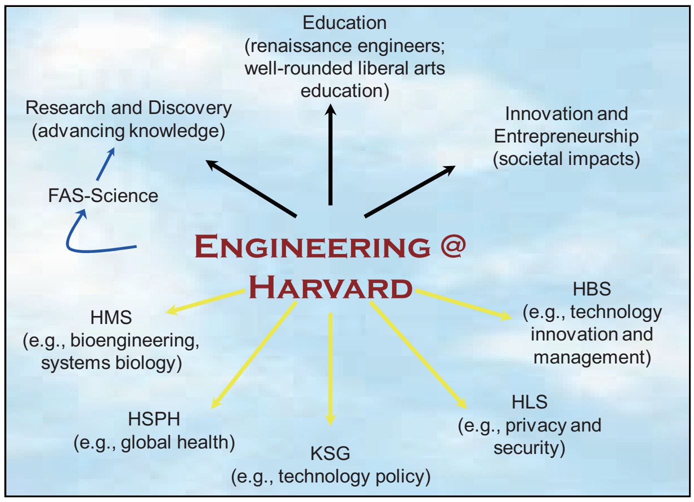
We had arguments about abortion. Well, I know how life is! And you will hear that Darwin was not important to be taught in these schools, and that is backward. Science has to be open. Once you cut the voice of the university, for example, sooner or later other stuff is going to be off-limits. That is what was happening in the Soviet Union. Now, you are heading that way, that global warming, birth control and evolution. Science must be open; actually science and democracy are intimately related. It is a responsibility we have too as scientists to make sure that this is done in a correct way.



So, engineering at Harvard is going to be a "connector." It is going to connect with all of the professional schools. I was experimenting in my sabbatical by spending time with the business school. I am a nano scientist, and what am I doing with these places? But it is a good experience. Learning things in the business school, the Kennedy School is in some ways much better than in the faculty of arts and science or engineering. They have developed a case study method and they teach the students very well. Engineering with the case study method is a very good way because it takes some of the most challenging problems in energy, makes a case of it and have the students debated. That is how you make designs. So, in fact, you can adapt. Not everything that the business school does is bad; there are things you can learn from those other places including in our teaching. That is what I was doing in my sabbatical. In fact this will connect biology and engineering.

Also, you cannot do great science without great engineering and that is an important message. That is what Bell Labs was about and IBM was about. Thank you.

Prof. Sakurai: Thank you very much. I am really overwhelmed by the completeness of understanding covering the basic science, technology and Harvard policies and the global future visions you presented today. We have few minutes for questions and discussions.

Prof. Matsuo: Prof. Venky, it was a very exciting talk that we are in a very exciting time for science and technology. I think universities are still behind a little bit about promoting science and technology understanding, especially to non-technology students, and I am wondering how the United States universities like Harvard educate non-technology students on technology and science?

Prof. Narayanamurti: I think this is a very challenging question, and for too long to those first who came from science… and I think it is a problem not just for the non-scientist but even for those in science, because we turn off so many of them; say they want to come to engineering, but they all leave and go on and become social scientist and economist because we turned them off.

I am trying to change this personally, that is why I designed this program. I hope one day before I retire there will be 500 students coming to my class because they will find this exciting. I actually believe you, young people, you must challenge them with what the great societal problems are and teach them accordingly. So you motivate them first. Second, we too often frighten people with the mathematics and the physics. I mean, there is a book by Richard Muller which I just found and I have invited him, the symposium I am organizing for the National Science Foundation in Hawaii, with all the leading deans and presidents; Chancellor Yang, USCB, Dean Plummer of Stanford, because I want the big places to actually agree with me so they would transform that education.

So, we get the very best professors, to start exploring. Not everybody can communicate. So I want to go to the freshman class to teach by myself. I think I can reach them and be one of the very best professors to be doing that. So, how to completely transform teaching science is big. We were having enrollment in computer science decreasing, because you will not be regarded as a computer scientist unless you could do the hardest programming. Even the engineers did not want to go to the computer science class because the computer science faculty had made it so difficult. Unless you are truly award-winning, you will be turned off in the class. It is not the way you teach computer science. If you are truly an award-winner, then you do not need any lectures at all.

So, I got a simple vehicle to make computing exciting. We got a lecturer who actually believed in it, and the enrollment went from 100 to 500. The computer scientists are better too because some of them, who want to becomes serious computer scientists, then began to really understand the detail. So, the mindset which we have, a kind of a macho mindset, has to be changed. It is not cheapening it. It is making it interesting. I firmly believe that. There are so many global challenges. Young people who want to be social entrepreneurs, and you can do good for Africa or the poor world, young people like to do it. You want the excitement with that.

So, I want to teach them. I got a book that says *What I wish I knew when I was 20*, and we want to teach them to explore and actually be creative, so that they actually blossom to their full extent. I think we have gotten students we will be able to teach and engineering has special problems because there are so many requirements of math and physics. It should happen later. So I am leading a big fight to change the traditional policies because in four years, you cannot do all of that. You want to first teach them the broader aspects of society.

Prof. Matsuo: I understand you personally go to the undergrads to talk to them? Are you reaching both into the system of the school?

Prof. Narayanamurti: Yes, the courses are now approved, and I am going to teach it as a regular course. I am very serious, I want to set the rule and I am getting the leading people in the United States to come, because I think it is important that education must change. I firmly believe that. I do not know much about the Japanese system but the United States system I know, I have been there 46 years. I know the Indian system needs to change, especially the way we teach physics. We turn too many people off. So, which subject is that? And it is exciting. So, we will do that sentiment and we must use and ensure the excitement to us.

Prof. Challapalli: You said engineering and science should be related to society, but what does this offer exploration and research, where there is no direct connection for an industrial requirement, immediately at least?

Prof. Narayanamurti: You always go to your environment. I would say the most important thing you want to do for engineering is invent curiosity, right? Alexander Graham Bell in fact transformed society but he wanted to see how speech will convert to electricity. So it is a way of thinking. So what I am saying is you really want to be confident, you want to change the world but you see the full scope. You want to be an entrepreneur. You want to explore.

So, if I did not convey that part properly, my apologies. That is essential; you want to build because that is a basic human need and automatically it relates. So people are mistaken as if you are going to force it, they will have to force telephone but he knew building new high-speed communication system is a good thing to do because that whole environment still does not serve the context. All the great scientists, well, you take Watson, who discovered DNA, they always had a goal in mind. Having some goals is not a bad thing.

If it is not Einstein, you just leave Einstein alone. That is not what we are talking about. But you have a lot of great people, the environment that you are losing and the way you think. Maybe I should not use the word “society” but really, it is in a certain context which has to be understood. It is too often misunderstood, that we just have lots of pure philosophy and research. People do not have a clue what to do. There are whole bunches of other things we should do, how you hire excellent people, how you support them. All of those have to be part of it. So, hiring the best faculty at Tohoku University is almost the most important job that will then be the contribution.

Prof. Sakurai: You mentioned the decline in industrial research laboratories. What is the reason? Do we have some better future to change this trend?

Prof. Narayanamurti: So, I think the reason the decline happened was partly because we started thinking in very short term. When I said about problems of society, I still think it will be very long term which is aiming at the future. So there are time-scales, which I need always to emphasize. It is a very long time-scale. So the way United States companies were being treated, the stock market, the quarterly profits, it won’t work. Research has to be funded based on the long term, and really only the big companies like IBM and AT&T could afford it but even they suffered terribly with the global competitions.

So, you have written at many articles. You are creating like WPI here, interdisciplinary centers, etc, but I still think it is not enough. There are pieces of management; management is not the right word. It is how you nurture and encourage that kind, it is missing. Ultimately there has to be a leader who understands; a good dean, a good president, a good director of a laboratory who understands how scientists’ and engineers' work and brings them and keeps the environment to make it work.

So government funding is very valuable, but until you build the rest of that system—that is what I will write the book on—they will not succeed. My hope is that now that Steven Chu is secretary of Energy, Larry Summers is adviser to Obama and John Holdren too, maybe I could convince a few of them, but I am worried because the government will say you have to follow so many rules, you have to fill in so many forms. That is not the way to encourage. So, we need to have areas of roughly the correct size, where the boundaries of basic and applied research are blurred, there is a leader who understands how all of this works and gives them the stability and the support to do the work, free of bureaucratic interference.

So, I was very close and very attracted and that is some of the design and then the stock market crashed. I told Larry Summers we should do that at Harvard. We should be rich enough university. Let us build few mini Bell Labs, which is very important. I think somehow that needs to be created. We must try different experiments. There is no perfect formula for this, but that needs to happen. That is what I want to write about because I think under Obama there may be a chance: or hopefully some big donor will come in. It may be Bill Gates. It might be Steve Balmer, my friend; anything we want to support you, I would go. Because I think the government became a different profit firm, at least in the United States, very, very inclusive. When they first started the national laboratories, it was the Atomic Energy Commission, NASA, AMES Lab., and AT&T ran the Sandia National Labs for not money. Now Sandia Labs are run by a profit contractor. They are in it to make money. So, I think I explained when I said you want industrial connections as the long-term connection, so you know what the most exciting challenges are 10-20 years down the road.

So, I hope Japan applies those. Other countries will start because that is what will be required. Very steady funding. Big funding is not as important but steady funding.

Prof. Sakurai: Everybody knows Einstein. Everybody knows Edison, but I have never thought of combining them together, Einstein and Edison. So, let's thank Dean Venky for his great talk.

Prof. Narayanamurti: Thank you.

News Update

President Inoue's Congratulatory Remarks at the Open House Ceremony

Thank you, Professor Yamamoto, Head of WPI, and Professor Nakajima, Head of IMR, for organizing this Integration Laboratory Open House ceremony.

Ladies and Gentlemen, distinguished guests, starting with Dr. Kuroki, WPI project President, Mr. Okaya, Head of this Program at Department of Education, and Professor Narayanamurti, WPI-AIMR Advisory Board member, and all the members of WPI-AIMR and IMR of Tohoku University!

As President of Tohoku University, I am happy to present congratulatory remarks at the inauguration ceremony of the new Integration Laboratory, consisting of some 9,000 square meters.

Being noted globally with its excellence in materials science over several decades, all of us at Tohoku University have worked and will continue to work diligently and intelligently, to further excel in fundamental and applied research, based on the founding principles conceived and initiated by Dr. Koutaro Honda, founding Director of IMR and the president of the University.

Considering the difficult time we are facing both economically and socially, not just in Japan, but all over the world, it is indeed remarkable that we celebrate this day, the inauguration of our research laboratory. Planned almost 3 years ago, this laboratory has just been completed in time for the start of the third year of the WPI-AIMR 10 year project. We are grateful that we welcome this joyous day which was made possible by the generosity of tax payers.

I am happy to tell you that, in addition to this Integration laboratory, new construction of the "Integrated Education and Research Building" comprising of 9,000 square meters, has been approved. Funded by this year's government supplementary budget, construction is now underway.

I must congratulate and thank all the University members on these developments, since your daily efforts and premier achievements have made it possible. Thanks are also warranted to the Central Government, in addition to MEXT and JSPS.

Mr. Okaya and Dr. Kuroki, thank you so much for all your support in the past and we would greatly appreciate your continued support in the future.

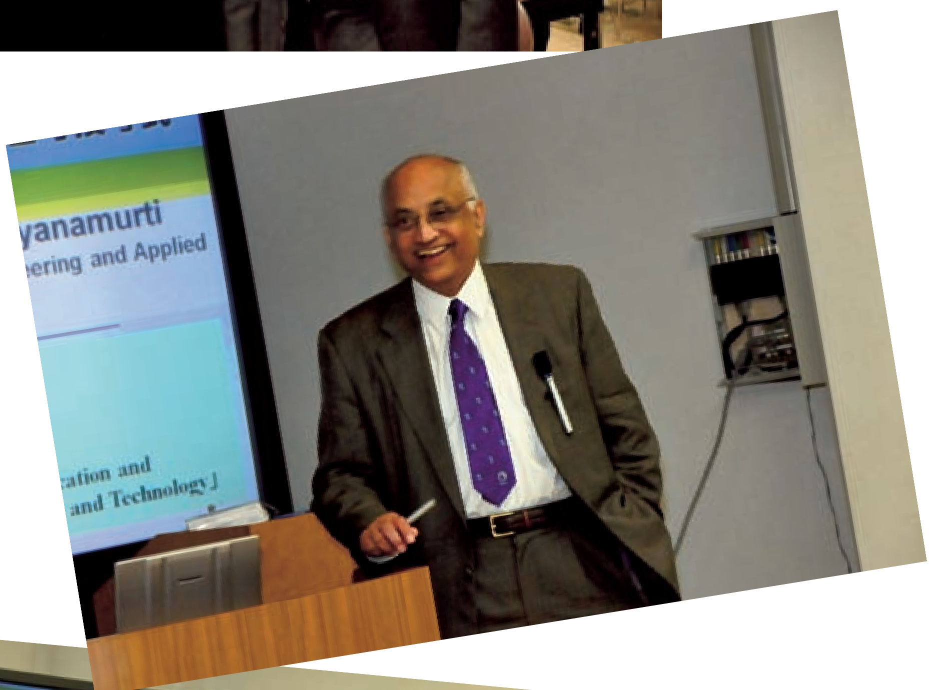
When I assumed the presidency of the University in 2007 on the university's centennial anniversary, I proposed a challenging "University Action Plan," noted as "Inoue Plan 2007." Simply stated, this plan challenges us to become a world premier university in the near future, perhaps within 10 to 20 years, by re-birthing and creating a new higher education infrastructure, for the purpose of promoting strategic, visionary education and research for the next 100 years. Professor Narayanamurti's speech earlier this afternoon was indeed very valuable for our future strategy. Thank you very much, Dean Venky!

Needless to say, WPI-AIMR and IMR will assume the leading role in promoting and executing this Inoue Plan. Let's work together to achieve this goal.

"YES, WE CAN and YES, WE WILL DO IT!!

Finally, may I express my sincere gratitude to everyone who was involved in establishing this Laboratory, the high officials at MEXT and JSPS, private sectors, and the supporting staff at the University.

Thank you all for your participation in this happy event!!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Program Director Dr. Kuroki's Congratulatory Remarks

Prof. Toshio Kuroki, Program Director of WPI,
Deputy Director, Research Center for Science Systems, JSPS

Good afternoon, ladies and gentlemen, distinguished guests. I am very happy to be here. I would like to deliver my congratulatory remarks on this occasion of the inauguration of the integration laboratory of WPI.

You know well, the WPI project was initiated in the fiscal year 2007, just two years ago. This project is the very ambitious and long-standing project of the government trying to support the institutes which are aiming to become internationally visible research institutes that make a new area of science in Japan by great leap over existing disciplines and creating paradigm shifts or even breakthroughs of existing science.

Another important thing is: the WPI institutes want to be internationally open institutes because, I think, the science of Japan is very highly evaluated or reputed around the world. For example, the last year, four Japanese received the Nobel Prize in physics and chemistry. But if you ask about Japanese institutes and Japanese universities, maybe people of the world think they are exclusively made with Japanese people and Japanese scientists, which means that our institutes are keeping very high standards of science, but are still staying in the country of Japan and do not open the doors to the world. All the institutes have to be internationally open, globally visible institutes. This is very important, to improve further, to go to advance further in this 21^{st} Century. So, one of the most important aims of WPI program is to establish a globally visible, really international institute. Of course, excellence of science is fundamental.

Tohoku University is well-known for physics and materials science, as you everyone here knows very well. For the past five year's citations, I think Tohoku University ranked in the third position in materials science field, followed by the National Institute of Materials Science (NIMS) in Tsukuba. The top two institutes are the Chinese Academy of Sciences and the Max Planck institutes. They are a complex of several, more than 10 institutes. But, if you think of individual universities and institutes, actually Tohoku University is the best institute in terms of citations for many years.

This is a very long-standing history from Kotaro Honda who established the Institute for Materials Sciences (IMR: KINKEN in Japanese) in 1916. I think we are very proud of this KINKEN because I was a graduate of Tohoku University many years ago, but not in hard science, very soft science. I am in medical science. So, we know that not only at Tohoku University, all the scientists and materials scientists are very proud of Tohoku University because of its contributions to this field.

WPI is a really new step for Tohoku University as well as for materials science in Japan. I understand that this is a very important step because it is an inaugural step to become an even more prominent institute, a world-wide recognized prominent universities. I would like to congratulate on having this integration laboratory under one roof. May not be all PIs, but the most PIs are coming, getting together and communicating with each other face-to-face and doing new research and making new materials science, fusion. I really expect that in the next few years you will do great fusion research. This is really our expectation and also the expectation of the Japanese people because we are facing economic crisis. To overcome such economic crisis, it is very important to have new fusion science and technology.

Thank you very much, and I appreciate your attention.

Professor A. Inoue's "Acta Materialia Gold Medal"

The winner of the 2010 Acta Materialia Gold Medal Award is Professor Akihisa Inoue, President of Tohoku University at Sendai in Japan. Dr. Inoue will receive his Gold Medal Award during the NANO 2010 International Conference in September 2010 in Roma.

He received his B.S. degree from Himeji Institute of Technology, and his M.S. degree from Tohoku University, both in Materials Science and Engineering. His Ph.D. in Materials Science and Engineering is from Institute for Materials Research (IMR), Tohoku University in 1975. Dr. Inoue had been a research staff of IMR, initially as a research associate, then associate professor and professor until his appointment to President of Tohoku University in 2006. He was the Director of the Institute between 2000 and 2006, and also Vice President of Tohoku University between 2005 and 2006. As "University Professor" and Principal Investigator of World Premier International Research Center Initiative, Advanced Institute for Materials Research (WPI-AIMR) of Tohoku University since 2007, he continues research with his members in both institutes of IMR and WPI-AIMR, in addition to the presidential work of Tohoku University.

Dr. Inoue is a member of the Japan Academy (2006), Foreign Member of the U.S.A. National Academy of Engineering (2008), Honorary Doctor of the Royal Institute of Technology in Stockholm (2004), Honorary Member of the Indian Institute of Metals (2006), and Honorary Member of the Indian Materials Research Society (2001).

Throughout his professional career, Dr. Inoue has been an enthusiastic researcher, educator and administrator. He has begun his research on rapidly solidified amorphous alloys early in his career under Professor T. Masumoto, another Acta Materialia Gold Medal winner in 1998, followed by contributions in nanocrystalline alloys with improved mechanical and soft magnetic properties and manufacturability for their engineering applications. His research interests also include studies of scientifically interesting and technologically relevant structural, chemical, electronic, and magnetic properties of glassy metallic materials, in bulk or sheet form produced by slow cooling methods. In particular, he pioneered a novel material science and engineering field of bulk metallic glasses (BMGs) through systematic development based on the finding of an empirical component rule. This finding has enabled the discovery of several hundreds of multi-component BMGs, the development of various bulk glassy alloys with functional properties and viscous flow deformability and the realization of their applications.

Among his honors/awards are the Japan Academy Prize ("in recognition of his outstanding scholarly contribution to the pioneering development of BMGs," Japan Academy, 2002), the Kelly Lecture ("in recognition of his outstanding contribution to the exploration of BMGs and Nanocrystalline Alloys," University of Cambridge, 2003), the Japan Prime Minister Award ("in recognition of his outstanding Industry-University-Government Cooperation Achievement of BMGs," the Ministry of Cabinet Office, 2006), and the James C. McGroddy Prize for New Materials ("in recognition of the development of slow cooling methods for the fabrication of BMGs with remarkable mechanical properties and the characterization and applications of these materials," American Physical Society, 2009). Among his other recognitions are the Citation Laureate Award (Institute for Scientific Information (ISI), 2000), Dr. Morris Traverse Lecture (Indian Institute of Science, Bangalore, 2008), 17 Best Paper Awards (Acta Metallurgica et Materiallia Inc., Japan Institute of Metals, Japan Society of Mechanical Engineering, Japan Institute of Metal Forming, Japan Institute of Plasma Applied Science, High Temperature Society of Japan), and 12 Engineering Development Awards (Japan Institute of Metals).

President Inoue was a Visiting Scientist at AT&T Bell Laboratories, Murray Hill, NJ (1982-1983, 1984, 1986), a Visiting Researcher at the Swedish Institute for Metals, Stockholm (1985), a Visiting Scientist at the Royal Institute of Technology, Stockholm (1988), a Visiting Professor at the Institute for Forshung Werkstoff, Dresden (1995), and an Honorary Professor at 6 universities (Dalian University of Technology, Tianjin University, Beijing University of Science Technology, Ningbo Institute of Material Technology and Engineering, Harbin Institute of Technology, and Beihang University) in China for the past 9 years. He served as Science Advisor at the Ministry of Education, Culture, Sports and Science in Japan (2001-2004), and Councilor, Trustee or Vice President of many academic associations (TMS, Japan Institute of Metals, Japan MRS, High Temperature Society of Japan, and Japan Powder and Powder Metallurgy Institute) for the past 13 years. He organized or co-organized the 8th International Conference on Rapidly Quenched and Metastable Materials (1993), the 5th International Conference on Nanostructured Materials (2000), the 11th International Symposium on Metastable, Mechanically Alloyed and Nanocrystalline Materials (2004) and the 5th International Conference on BMGs (2006) in Japan, and the MRS Fall Meeting Symposiums on BMGs (1998, 2000, 2002) in Boston. He conducted 7 national research projects associated with BMGs and Nanocrystalline Alloys supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, Japan Science and Technology Association, and New Energy Development

Organization for the last 14 years, and served as the project leaders in multiple projects. He has also been a Member of Scientific and Technological Investigation Council, MEXT of Japan (2005-present), and Vice President of the Japan Association of National Universities (2007-present).

Dr. Inoue has authored and co-authored over 2000 publications, including books, reviews, and introductory articles for general information. He has been recognized by ISI (Institute for Scientific Information) as first in worldwide-ranking of highly cited authors publishing scientific papers in materials science and engineering journals for the last 11 years (1998-2008). He also holds over 200 patents.

The Acta Materialia Gold Medal is awarded annually by the Board of Governors of Acta Materialia, Inc. with partial financial support from Elsevier, Ltd. Nominees are solicited each year from the Cooperating Societies and Sponsoring Societies of Acta Materialia, Inc., based on demonstrated ability and leadership in materials research. The candidates are placed on a ballot for the selection committee (a panel of international judges who serve for three-year terms). A preferential ballot is then conducted among the judges, and the candidate with the most points is awarded the Gold Medal. The Award consists of the gold medal, an inscribed certificate, and a check for a sum of money that constitutes the Board’s contribution to the award winner.

Professor T. Miyazaki's "9th JSAP Outstanding Achievement Award"

"The Japan Society of Applied Physics (JSAP) Outstanding Achievement Award" is an annual award given by JSAP to recognize and encourage outstanding discovery, invention, theoretical or experimental contributions to its scientific field or industry. "9th JSAP Outstanding Achievement Award" was awarded to Prof. Miyazaki from WPI-AIMR in Tohoku University for his "Pioneering research on room temperature tunnel magneto-resistive devises."

Prof. Miyazaki had first discovered tunnel magnetoresistance (TMR) of 18% at room temperature in 1994. On discovering this large TMR effect, a lot of companies and research institutes researched and developed the tunnel magneto-resistive devices extensively to date, which have been applied to commercial magneto-resistive read-head in high-storae density hard disk drive and solid state nonvolatile memory (MRAM). In addition, research on tunnel magneto-resistive device is chief subject in new spintronics field, to date.

The ceremony was hold in annual JSAP conference at Tsukuba University, Tsukuba on 30th March 2009.

Professor Y. Yamamoto's "RSC Centenary Prize 2009"

Professor Y. Yamamoto, WPI-AIMR Director, is one of the recipients of the 2009 Centenary Prize of Royal Society of Chemistry (RSC) of UK. The Centenary Prizes was created to promote the interchange of chemistry and are awarded to outstanding chemists from overseas to give lectures in the British Isles. Prof. Yamamoto has been awarded for his innovative contributions to methodology in organic synthesis.

RSC | Advancing the Chemical Sciences

Policy

Centenary Prize 2009 Winner

Yoshinori Yamamoto
Tohoku University, Japan

Awarded for his innovative contributions to methodology in organic synthesis.

About the winner

Yoshinori Yamamoto received his MS and PhD degrees from Osaka University. In 1970 he was appointed as an Instructor at Osaka University, after which he went to Professor H. C. Brown's research group at Purdue University as a Postdoctoral Associate (1970-1972). In 1977 he was appointed as an Associate Professor at Kyoto University. In 1986 he moved to Tohoku University to take up his present position, Professor of Chemistry.

He was awarded the Chemical Society of Japan Award for Young Chemists (1976), the Chemical Society of Japan Award (1996), the Humboldt Research Award (2002), Purple Ribbon Medal from The Cabinet (2006), and A. C. Cope Scholar Award from ACS (2007).

He is the Regional Editor of Tetrahedron Letters, and he was the President of the International Society of Heterocyclic Chemistry (2000-2001). He was the project leader of the 21 Century COE Program of MEXT "Giant Molecules and Complex Systems, Chemistry Group of Tohoku University" (2002-2006). Further, he was a vice-president of Tohoku University (2006-2007) and a vice-president of the Chemical Society of Japan (2006-2007).

From 2007, he is the director of WPI-Advanced Institute for Materials Research in Tohoku University.

He has a wide range of research interests in synthetic organic and organometallic chemistry. His recent work focused on the use of transition-metal complexes and (sigma and/or pi electrophilic) Lewis acids as catalytic reagents in organic synthesis and synthesis of complex natural products, such as Brevetoxin B and Gambierol.

Related Links

Yamamoto Group Webpage
Yoshinori Yamamoto's Research Group at Tohoku University, Japan

External links will open in a new browser window

(http://www.rsc.org/ScienceAndTechnology/Awards/CentenaryPrizes/2009winner3.asp / 2009 winner of the RSC Centenary Prize - Yoshinori Yamamoto)

For more information:
http://www.rsc.org/ScienceAndTechnology/Awards/2009prizes.asp

AIM Research

Masashi Kawasaki

WPI-AIMR is launching a new Scientific Communication Project, named "AIM Research", to enhance awareness of WPI-AIMR, its activities and achievements in global scientific community and to raise further the international standing of WPI-AIMR and its stuff. An original WPI-AIMR research highlight website is established at
http://research.wpi-aimr.tohoku.ac.jp/
as can be seen in the captured image in the next page.

Here a few scientific achievements are highlighted monthly with science communication products (both in English and Japanese languages) that summarize the results by 200-500 words description and a picture. The contents will be made by professional writers based on the input of the researchers. This activity will make them accessible to a general audience outside the specialized field. Also uploaded will be "Spotlight" including interview to the WPI-AIMR executives and voices from young researchers and "News" for announcing important achievements, forthcoming events, and recruiting. Every 10-15 scientific products, the contents will be issued as a hard copy magazine (only in English) that will be distributed world-wide. WPI-AIMR expects this activity will be an aid for recruitment of talented scientists from overseas and in Japan and a promotion of international collaborative research.

Editorial board members consist of four Principal Investigators, Mingwei Chen (Bulk Metallic Glass), Masashi Kawasaki (Nano Physics), Masatsugu Shimomura (Nano & Bio Chemistry) and Terunobu Miyazaki (Devices and Systems) and two directors, Toshio Sakurai (Administrative Director) and Yoshinori Yamamoto (Center Director).

The editorial board seeks for the inputs from WPI-AIM members. Well deserved high-level papers and achievements are most welcome. Any comment to improve the web site is always welcome.

AiM Research

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The Advanced Institute for Materials Research (AIMR) at Tohoku University in Japan is a World Premier International (WPI) Research Center for interdisciplinary and internationally focused research at the cutting edge of materials science. AIM*Research* is a new online and print publication that highlights the best of research from the WPI-AIMR, and casts a spotlight on the scientists and laboratories behind one of the world's leading institutes for the development of new and innovative functional materials.

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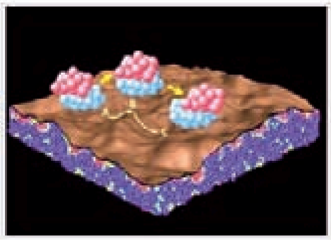
feature highlight Jun 29, 2009

In the zone

Published in *Proceedings of the National Academy of Sciences*

Nanoscopic shear zones have been identified as responsible for plastic flow in bulk metallic glass



Metal alloys with a glassy atomic structure, known as bulk metallic glasses (BMGs), are much stronger than normal metals and have great promise for a variety of applications. Unfortunately, they are also less ductile, making them more susceptible to fracture. To try to understand why, Mingwei Chen and colleagues from the Advanced Institute for Materials Research (AIMR) at Tohoku University have conducted the first experimental characterization of shear transformation zones that arise when a BMG is subject to plastic deformation.

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spotlight

forthcoming spotlight:
Roundtable Discussion

June 2009 — AIM*Research* hosts a roundtable discussion of the Director and Group Leaders of the WPI-AIMR to deliberate on the challenges of increasing the global presence of the WPI-AIMR and creating Japan-originated disciplines in materials science. *Full coverage will be available in late July.*

spotlight

research highlights

Titanium coming out on top
Jun 29, 2009
High-resolution electron microscopy settles the problem of the atomic structure at the surface of titania, an important catalyst material

Poacher turned gamekeeper: From insulator to superconductor
Jun 29, 2009
An insulating material has been converted into a superconductor using only an electrical field — without the need for chemical doping

highlights

news

Jul 07, 2009
Dr. K. Ueno will be awarded "The 26th JSAP Incentive Award for Excellent presentation".

Jun 28, 2009
Professor Gessner reported his group's activity as WPI-AIMR in the "Annual Report 2008" of Fraunhofer Research Institution for Electronic Nano Systems ENAS

Jun 08, 2009
WPI-AIMR Director Y.Yamamoto will be awarded "RSC Centenary Prize 2009"

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- [Workshop WPI-INPG-Europe] August 25-28, 2009 Grenoble, France
- [IFCAM Seminar] July 10, 2009 13:30--
- [The New WPI Joint Seminar Series] The Sixth Seminar (July 15, 2009 15:00-17:15)
- [Seminar Schedule]
- [Jobs] Associate Professor, Assistant Professor, and postdoctoral research fellow

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home » research » Titanium coming out on top

Titanium coming out on top

29 Jun. 2009

keywords: surface structure, catalysts, electron microscopy

High-resolution electron microscopy settles the problem of the atomic structure at the surface of titania, an important catalyst material

Precise knowledge of the arrangement of atoms at the surface of a crystal is crucial for catalytic materials, which are used to initiate chemical reactions through interactions at the surface. Settling existing controversy, Yuichi Ikuhara and colleagues from the University of Tokyo in collaboration with the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have now determined the atomic arrangement at the surface of titania (TiO_2), which is an important material for catalytic processes.

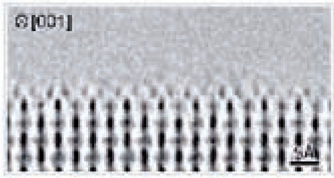

Fig. 1: High-resolution HVEM image of a TiO_2 (110) surface observed from the [001] direction (black corresponds to Ti sites). Structural reconstruction is visible at the surface.

Crystalline materials are regular three-dimensional assemblies of atoms, and study of the bulk crystal structure is generally straightforward. The surface of a crystalline material, however, is notoriously difficult to study, as the disruption to the perfect crystal symmetry leads to compromises in the positions and chemical bonds of the surface atoms. "Determining the surface structure is very important for understanding the nature and the mechanism of the catalytic properties," says Ikuhara.

Although there have been many proposals for the surface structure of titania, it has remained difficult to determine the positions of top surface atoms precisely by experimental observations. The researchers were able to derive the titania surface structure for the first time through a combination of high-voltage electron microscopy (HVEM) and scanning electron microscopy techniques (Fig. 1).

The surface structure was studied with atomic precision from two directions, and the three-dimensional image thus obtained was compared with two structures that have recently been proposed in theoretical studies. In one of the models, the outer surface is comprised predominantly of oxygen atoms, whereas in a more recent study, titanium was predicted to be located at various positions near the surface such that the surface composition is more balanced between oxygen and titanium. The experimental results clearly confirmed the latter prediction.

The findings suggest that titanium plays a more active role on the surface of titania than previously thought, which provides valuable feedback for developing a better understanding of the reaction kinetics on the surface of titania. "I believe that our findings will contribute significantly to our understanding of the surface kinetics," comments Ikuhara.

In catalytic applications, the surface of titania is often functionalized with noble metals such as gold or platinum, which act as co-catalysts. As a next step it will be important to study the structure of the interfaces between these metals and titania. "This," says Ikuhara, "will enable us to understand the origin and nature of their catalytic properties."

Reference

1. Shibata, N., Goto, A., Choi, S.-Y., Mizoguchi, T., Findlay, S. D., Yamamoto, T. & Ikuhara, Y. Direct imaging of reconstructed atoms on TiO_2 (110) surfaces. *Science* **322**, 570–573 (2009).

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Poacher turned gamekeeper: From insulator to superconductor

29 Jun. 2009
keywords: superconductor, electrochemical, doping

An insulating material has been converted into a superconductor using only an electrical field — without the need for chemical doping

Superconductivity, the capacity of certain materials to conduct electricity with zero resistance and therefore no loss of energy below a critical temperature, is a physical phenomenon of profound importance with numerous scientific and practical applications. Superconductivity is controlled by the density of charge carriers within a material — electrons in the case of negative charge and 'holes' for positive charge. Typically, materials are converted into superconductors by introducing impurities into the crystal lattice by chemical doping. However, such modification is often irreversible, and inevitably introduces structural disorder.

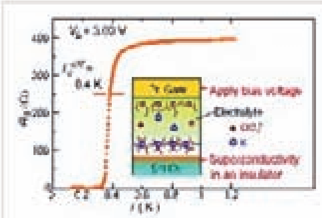

Fig. 1: Graph showing the abrupt disappearance of resistance (R_s) in $SrTiO_3$ as the temperature drops to 0.4 K at a gate voltage (V_G) of 3 V. Inset shows a schematic diagram of the structure of the electric double-layer transistor incorporating the $SrTiO_3$.

An alternative approach for making superconductors involves tuning the density of charge carriers of a material by applying an external electric field. This method has made it possible to convert metals and chemically doped insulators into superconductors, but attempts with non-doped insulators have so far been unsuccessful due to the low charge densities in these systems. Now, a team of scientists led by Masashi Kawasaki and Kazunori Ueno from the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have successfully used an electrical method to induce superconductivity in strontium titanate ($SrTiO_3$), which is better known as an insulator. "This work is the first demonstration of converting an insulating material to a superconducting one purely by electric field. That was dreamed by people for more than 50 years," says Kawasaki.

The researchers electrically doped $SrTiO_3$ using a modified electrical method inspired by electrochemical cells. Writing in *Nature Materials*, the researchers describe their work in which they constructed an 'electric double-layer transistor' field-effect device. In a conventional electrochemical cell, an electrolyte is set between two electrodes, and the application of an electrical field across the electrodes leads to charge separation as the positive and negative ions within the electrolyte migrate toward opposite electrodes. The researchers modified this technique by replacing one of the electrodes with $SrTiO_3$. When immersed in an organic electrolyte with a platinum wire electrode, the resistance of the $SrTiO_3$ declined sharply at voltages above 2.5 V, showing that the system was behaving like a conducting metal. Upon dropping the temperature to 0.4 K — near absolute zero — the normally insulating $SrTiO_3$ became a superconductor (Fig. 1). Examination of the $SrTiO_3$ surface revealed that this transition is due to the accumulation of positive charge near the surface rather than to electrochemical reactions. Furthermore, this electrically doped $SrTiO_3$ material exhibited superconducting behavior different from that of the chemically doped samples.

"Our study provides another way to search for superconductivity, and considerably widens the choice of candidate materials for possible new superconductors," says Ueno.

Reference

1. Ueno, K., Nakamura, S., Shimotani, H., Ohtomo, A., Kimura, N., Nojima, T., Aoki, H., Iwasa, Y. & Kawasaki, M. Electric-field-induced superconductivity in an insulator. *Nature Mater.* **7**, 855–858 (2008).

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In the zone

29 Jun, 2009

keywords: bulk metallic glass, mechanical behavior

Nanoscopic shear zones have been identified as responsible for plastic flow in bulk metallic glass

Metal alloys with a glassy atomic structure, known as bulk metallic glasses (BMGs), are much stronger than normal metals and have great promise for a variety of applications. Unfortunately, they are also less ductile, making them more susceptible to fracture. To try to understand why, Mingwei Chen and colleagues from the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have conducted the first experimental characterization of shear transformation zones that arise when a BMG is subject to plastic deformation.

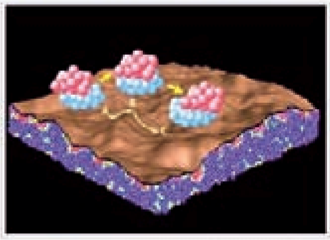

Fig. 1: Schematic diagram of the activation of an STZ in a glassy material. Mechanical failure through macroscopic shear occurs by the accumulation of a critical number of activated STZs on a slip plane.

When a conventional metal cools from its molten liquid state, its atoms arrange into well-ordered crystalline structures. This rarely results in a perfect single-crystal structure; rather, a polycrystalline matrix consisting of randomly oriented crystallites is generally formed. Owing to the weakness of the boundaries between these grains and other imperfections, the actual mechanical strength of a metal is usually much lower than the theoretical strength it would have if it were a perfect single crystal.

BMGs, on the other hand, are alloys in which the atoms have not been given time to arrange into crystallites, resulting in a non-regular structure similar to that of ceramic glass. This circumvents the problems of grain boundaries and crystal defects, making BMGs much stronger than conventional metals. However, although they are less brittle than ceramics, they are more brittle than most metals.

One of the leading explanations for this poor ductility is the emergence of 'shear transformation zones' (STZs) within a BMG. STZs are nano-scale volumes of material that undergo plastic flow (Fig. 1), and the concentration of stress at STZs is believed to cause localized shear bands to form, leading to mechanical failure and poor ductility. Until now, the nature or even the exact size of these zones has never been characterized. To address this, Chen and his colleagues developed a new 'rate-jump nanoindentation' technique for characterizing the mechanical behavior of these structures involving the measurement and modeling of the response of a BMG to a micro-sized diamond indentor with nanoscopic resolution of force and displacement.

The researchers applied this approach to a variety of different BMGs, which allowed them to determine the volumes of material involved in the plastic flow of atomic clusters in an STZ, and to correlate this with the ductility of the BMG. They found that BMGs exhibiting the smallest STZ volumes were also the least ductile. This observation should allow other scientists to improve their understanding and optimize the mechanical performance of BMGs. It is also a demonstration of a powerful technique for characterizing the mechanical behavior of other non-crystalline materials.

Reference

1. Pan, D., Inoue, A., Sakurai, T. & Chen, M.W. Experimental characterization of shear transformation zones for plastic flow of bulk metallic glasses. *Proceedings of the National Academy of Sciences* **105**, 14769–14772 (2008).

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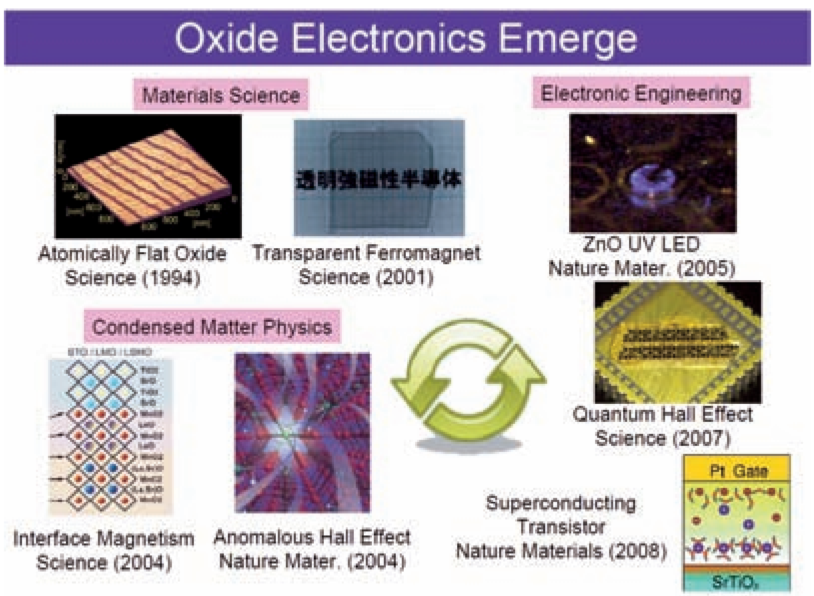
Oxide Interfaces
Tremendous Opportunities for Basic and Applied Research

Masashi Kawasaki

"The interface is the device." This is the famous words of Prof. Herbert Kromer of UCSB given in his Novel Lecture in 2001. Dr. Wolfgang Pauli who got Nobel Prize in 1945 was telling us **"God made solids, but surfaces are the work of the devil."** By hearing these two, we can anticipate the progress of semiconductor physics/device research in the latter half on 20th century. People could manipulate electron wave in solid matter by design. The big jumps occurred in the very end of 20th century was the discovery and understanding of quantum Hall effect and high Tc Cu-oxide superconductors, which lead to the modern physics of electron wave topology and exploration of oxide electronics, respectively. A merge of these two may happen in an interface of oxides. We can now see the macroscopic interference or quantum phenomena of electron wave at oxide interfaces [1, 2]. The pictures in the Figure are representative small jumps made by us in the last two decades by us [3]. We have been working on materials science, interface physics and demonstration of devices. Now the atomic scale technology and design of interface physics in oxide heterostructures emerges so that we can expect something new may happen. The excitements and expectations are nicely described in the two papers [4, 5].

1. A. Tsukazaki et. al. "Quantum Hall effect in polar oxide heterostructures," Science **315**, 1388 (2007).
2. K. Ueno et. al. "Electric-field-induced superconductivity in an insulator", Nature Materials **7**, 855 (2008).
3. M. Kawasaki, "Exploration of oxide electronics…" in "Frontiers in Materials Research" eds. Y. Fujikawa, K. Nakajima, T. Sakurai, Springer Adv. Mater. Res., **10**, 49-76 (2008).
4. A. P. Ramirez, "Oxide electronics emerge," Perspective in Science **315**, 1377 (2007).
5. J. Heber, "Enter the oxides," New Feature in Nature **459**, 28 (2009).



-Yuichi Ikuhara-

Atomic-scale imaging of individual dopant atoms in a buried interface

N. Shibata, S. D. Findlay, S. Azuma, T. Mizoguchi, T. Yamamoto, and Y. Ikuhara

Nature Materials, published on-line; 21 June 2009

ABSTRACT

Controlling interfaces at an atomic level is actively being pursued throughout a broad range of materials science and device engineering fields, but the inability to precisely determine the interface atomic structures has severely limited our understanding of the interface phenomena. Now, we have opened the possibility of full three-dimensional characterization of interface structures using advanced electron microscopy. With our new method, buried interface atoms are individually and selectively highlighted by a focused electron beam, and their positions and occupancies are identified with unprecedented resolution and sensitivity. The insight gained from direct interface atom imaging will enable us to precisely design and control materials and devices on an atomic scale.

Interface doping is one of the most promising techniques to control interface properties at the atomic scale, but it is still a great challenge to directly characterize individual dopant atoms within the buried crystalline interfaces.

Here, we have demonstrated atomic-scale plain-view observation of a buried crystalline interface (an yttrium doped alumina high-angle grain boundary) using aberration-corrected Z-contrast scanning transmission electron microscopy as shown in Fig.1. The focused electron beam transmitted through the off-axis crystals clearly highlights the individual yttrium atoms located on the mono-atomic layer interface plane. Not only is their unique two-dimensional ordered positioning directly revealed with atomic precision, but the local disordering at the single atom level, which has never been possible by conventional approaches, is also uncovered. The ability to directly probe the individual atoms within the buried interface structures adds a new dimension to the atomic-scale characterization of the internal interfaces and other defect structures in many advanced materials and devices.

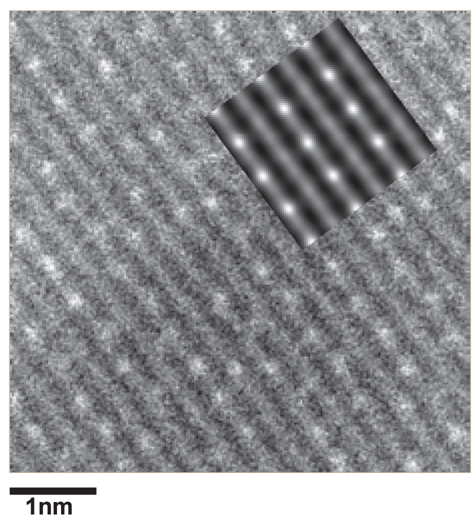


Fig.1: Plan-view imaging of buried interface atoms by HADDF STEM.

-Mingwei CHEN-

"Thermodynamic origins of shear band formation and universal scaling law of metallic glass strength"

Y. H. Liu, C. T. Liu, W. H. Wang, A. Inoue, T. Sakurai and M. W. Chen

Physical Review Letters 2009

One of the most attractive merits of glassy alloys is their ultrahigh strength relative to crystalline counterparts. Unlike dislocation slip in crystals, the room-temperature yielding and deformation of bulk metallic glasses (BMGs) occur *via* the formation of nanosized shear bands[1]. Several micro-mechanisms have been proposed to describe the spatially and temporally heterogeneous deformation. However, the physical process that governs the yielding of BMGs still remains mysterious and has been the recent topic of intense discussion [2]. It has been noticed long time ago that strength and Young's modulus of BMGs correlate with their glass transition temperatures, T_g [2, 3]. By incorporating the term of molar volume V, RT fracture strength of BMGs has been found to be associated with T_g *via* a linear relation [4]. A number of attempts have been made to explore the underlying physics of the linearity. However, these works are resorted to a number of approximations and assumptions making their analysis untransparent and resulting in the loss of the physical principle of the linearity. In the PRL paper, we report a universal scaling law that uncovers an inherent relationship of yield shear stress with glass transition temperature T_g of bulk metallic glasses. [5] This simple linear equation has been derived from fundamental thermodynamics and validated by various BMGs with pronounced macroscopic plasticity and well-defined yielding. The linearity between yield strength and T_g demonstrates the intrinsic correlation between shear-band formation and glass-liquid transition, which contributes to the fundamental understanding of the strength and deformation mechanisms of glassy materials.

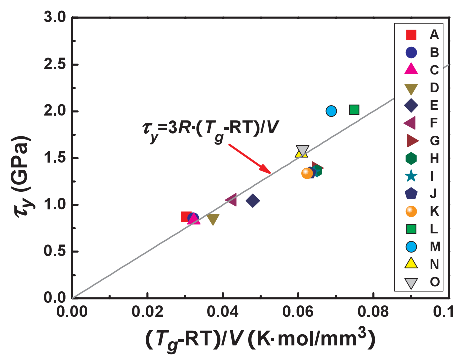


Figure 1 The relationship between yield shear stress τ_y and glass transition temperture T_g. The solid line is the plot of the linear equation, $\tau_y=3R\cdot(T_g\text{-RT})/V$, in which R is the gas constant. The symbols represent various BMGs used in this study.[5]

References

[1] M. W. Chen, A. Inoue, W. Zhang and T. Sakurai, Phys. Rev. Lett. **96**, 245502 (2006).
[2] M. W. Chen, Annu. Rev. Mater. Res. **38**, 445 (2008).
[3] H. S. Chen, *Rep. Prog. Phys.* 43 (1980).
[4] B. Yang, C. T. Liu, and T. G. Nieh, ***Appl. Phys. Lett***. **88**, 221911 (2006).
[5] Y. H. Liu, *et al.*, ***Phys. Rev. Lett***., in press (2009).

The New WPI Joint Seminar Series

by M. Tsukada and T. Hashizume

The 1st Seminar: April 14, (Tue.) 16:00~17:30

Prof. Y. Yamamoto (Director, WPI-AIMR):

" How can we achieve our mission to WPI? "

The 2nd Seminar: May 12 (Tue.) 15:00~17:00

Prof. Masahiko Yamaguchi (WPI-AIMR):

"Chemical Study on Helicene Derivatives Directed to the Development of Novel Chiral Materials."

Prof. Hiroshi Komatsu (WPI-AIMR):

"Let's make it a custom to discuss into the bottom of the problems."

("Let's set up observing teatime, at least once a day, among different research groups.")

The 3rd Seminar: May 29 (Fri.) 15:00~17:00

Prof. Masayoshi Esashi (WPI-AIMR):

"Advanced materials for MEMS"

Dr. Taketoshi Minato (IIARE, Itaya Group):

"Atomic scale investigations at surface/interface by STM/AFM"

The 4th Seminar: June 17 (Wed.) 15:00~17:30

Professor Kazuyoshi Yamada (WPI-AIMR):

"A New Era of Neutron Science"

Dr. Hiroshi Morita (AIST)

"Meso-scale simulations of soft materials- Applications to the problems in nanorheology, 3DTEM, and lithography-"

The 5th Seminar: June 29 (Mon.) 16:00~17:00

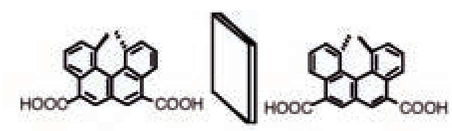
Dr. Winfried Teizer (Texas A&M University):

"Microtubule Patterning and Manipulation using Self-assembled Monolayers and Electrophoresis"

Chemical Study on Helicene Derivatives Directed to the Development of Novel Chiral Materials

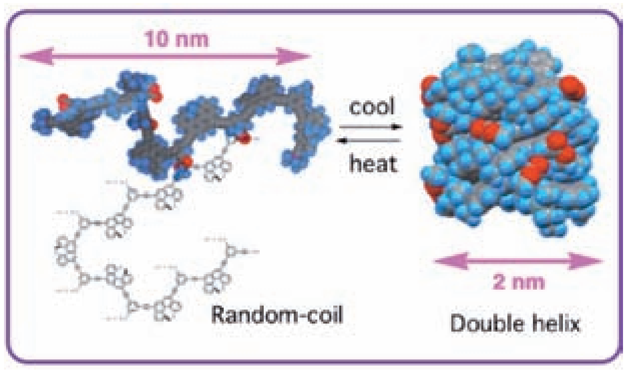
Masahiko Yamaguchi
WPI Advanced Institute for Materials Research
Department of Organic Chemistry, Graduate School of Pharmaceutical Sciences
Tohoku University, Aoba, Sendai 980-8578 Japan

Helicenes are a group of compounds, which possess conjugated helical π-electron system with chirality. Their property, however, was not well-understood, which was largely due to unavailability of such compounds. We developed a preparative method for optically pure 1,12-dimethylbenzo[*c*]phenanthrene-5,8-dicarboxylic acid (1) in multigram quantities. Synthesis, structure, and property of its derivatives including a series of oligomeric compounds are described here. In addition, potential use of such molecules in materials is discussed.



Chiral recognition by the helicene turned out to be an interesting subject. Some of the electron-deficient helicenes formed charge-transfer (CT) complexes with electron-rich arenes. Examination of the chiral recognition in the CT complexation revealed that the helicenes of the same configuration formed more stable complex. Such selectivity was observed in many phenomena of the helicene, and was named right-right and left-left rule.[1]

Oligomeric compounds containing the helicene were examined. The concept of the study was to regard the helicene as a chiral equivalent of *m*-phenylene moiety. Since many functionally interesting compounds possess this unit, replacing them with the helicene converts the achiral compound to the chiral ones. In addition, if the achiral compound possesses more than one *m*-phenylene moiety, the substitution provides a series of diastereomers. A diversity of compounds obtained by this manipulation may be used to fine-tune the properties of the original achiral compound.[2]



Oligomeric alkynes containing the helicene and *m*-phenylene were synthesized, and the oligomers containing more than six helicenes were found to form double helix in solution. Its dynamic properties in the unfolding to random-coil state were discussed.

References

1. R. Amemiya, and M. Yamaguchi, ***Org. Biomol. Chem.*** 26-35 (2008).
2. R. Amemiya, and M. Yamaguchi, ***Chem. Rec. 8***,116-127 (2008).

Let's set up observing teatime, at least once a day, among different research groups

Hiroshi Komatsu
Associate Editor, writer, WPI-AIMR Communication Center

I proposed to have teatime at least once a day. It is particularly recommended to have teatime with persons of different specialty or discipline. Teatime is an informal occasion both for brief rest and mutual communication, refreshing thoughts by proposing ideas. Our WPI-AIMR consists of researchers from five academic fields related to Materials Science. We believe that innovative thoughts will be brought about after unconfined free discussions among younger researchers and experienced elderly professors in different fields. Teatime provides daily occasion to stimulate each other.

The merits of teatime are;

1) It facilitates exchanging the ideas among diverse specialties, irrespective of generation.
2) For younger Post-Docs in WPI-AIMR, teatime provides an excellent chance to get acquainted with each other, and eventually acquiring lifelong international friends.
3) It provides time to visit other groups with less bothering since everybody is supposed to take a brief rest around 10 a.m. and 3 p.m. every day.

The style of holding teatime is free. As an example, Clarendon Laboratory in Oxford University, which is comparable to us in size, they have two types of tearooms. One is a large tearoom (common room) capable of accommodating about 150 persons, and the other is a small tearoom in each laboratory. When they have a visitor, they take the visitor to the common tearoom, introducing him to colleagues effectively.

Here in our WPI-AIMR, we have two special buildings; Integration Laboratory and the Annex Laboratory in Katahira Campus. The laboratories in Aobayama Campus are remote from Katahira. This geographical situation hampers observing teatime together. At the moment, we cannot help holding teatime separately in each area; Katahira and Aobayama. But at least on Friday afternoon it is recommended to have teatime together at the common room in Integration Laboratory in Katahira Campus.

I welcome your comment or constructive advice and suggestion about teatime.

2009 年 4 月 24 日片平さくらホールにて

2009 MEXT Research Grant List (As of June 1, 2009)

(Unit: thousand yen)

Categories	Researchers' Name	budget distribution
Scientific Research on Priority Areas	IKUHARA, Yuichi (PI)	**42,800**
	TSUKADA, Masaru (PI)	**35,000**
	TANIGAKI, Katsumi (PI)	**34,200**
	LOUZGUINE, Dmitri V.	**9,300**
	AKIYAMA, Kotone	**2,200**
	Total	**123,500**
Scientific Research (S)	YAMAGUCHI, Masahiko (PI)	**61,100**
	ADSCHIRI, Tadafumi (PI)	**51,220**
	INOUE, Akihisa (PI)	**50,180**
	ESASHI, Masayoshi (PI)	**25,220**
	Total	**187,720**
Scientific Research (A)	MIYAZAKI, Terunobu (PI)	**34,710**
	TSUKADA, Masaru (PI)	**18,720**
	ITAYA, Kingo (PI)	**16,900**
	NAKAZAWA, Masataka (PI)	**16,770**
	TANIGAKI, Katsumi (PI)	**3,900**
	Total	**91,000**
Scientific Research (B)	NISHI, Toshio (PI)	**18,720**
	YAMAMOTO, yoshinori (Director)	**6,500**
	YAMADA, Kazuyoshi (PI)	**1,950**
	Total	**27,170**
Scientific Research (C)	SHIMOMURA, Masatsugu (PI)	**2,080**
	TAKEUCHI, Akira	**1,170**
	TOKUYAMA, Michio (PI)	**1,040**
	Total	**4,290**
Exploratory Research	ADSCHIRI, Tadafumi (PI)	**1,700**
	YAMADA, Kazuyoshi (PI)	**900**
	Total	**2,600**
Young Scientists (A)	UENO, Kazunori	**15,990**
	ISHII, Daisuke	**11,310**
	SOUMA, Seigo	**8,710**
	Total	**36,010**
Young Scientists (B)	AL-MAHBOOB, Abdulla	**2,990**
	LIU, Hongwen	**2,990**
	HOJO, Daisuke	**2,730**
	HAMADA, Ikutaro	**2,600**
	MINAMI, Kimitaka	**2,470**
	YASUI, Yoshizumi	**2,080**
	MUROYAMA, Masanori	**2,080**
	SIMDYANKIN, Sergey	**1,690**
	HIRATA, Akihiko	**1,690**
	NOUCHI, Ryo	**1,430**
	KUZUME, Akiyoshi	**1,430**
	SATO, Toyoto	**1,040**
	FUJITA, Takeshi	**910**
	Total	**26,130**
Young Scientists (Start-Up)	SUSHKO, Peter V.	**1,560**
	SAITO, Mitsuhiro	**1,560**
	YOSHIDA, Shinya	**1,560**
	RICHARD, Pierre	**1,534**
	Total	**6,214**
Total		**504,634**

2009 MEXT Research Grant List
(As of June 1, 2009)

(Unit: thousand yen)

Group	Researchers' Name	Total	Scientific Research on Priority Areas	Scientific Research (S)	Scientific Research (A)	Scientific Research (B)	Scientific Research (C)	Exploratory Research	Young Scientists (A)	Young Scientists (B)	Young Scientists (Start-Up)
	YAMAMOTO, yoshinori (Director)	**6,500**				6,500					
Metallic glasses	INOUE, Akihisa (PI)	**50,180**		50,180							
	LOUZGUINE, Dmitri V.	**9,300**	9,300								
	TAKEUCHI, Akira	**1,170**					1,170				
	NAKAYAMA, Koji S.	**0**									
	QIN, Chunling	**0**									
	ZHANG, Qingsheng	**0**									
	CHEN, Na	**0**									
	SANCHEZ, Sergio Gonzalez	**0**									
	YU, Jinshan	**0**									
	MADGE, Shantanu Vijay	**0**									
	KONSTANTINOS, Georgarakis	**0**									
	TOKUYAMA, Michio (PI)	**1,040**					1,040				
	SIMDYANKIN, Sergey	**1,690**								1,690	
	XU, Limei	**0**									
	CHUTIA, Arunabhiram	**0**									
	CHEN, Mingwei (PI)	**0**									
	FUJITA, Takeshi	**910**								910	
	HIRATA, Akihiko	**1,690**								1,690	
	CHEN, Luyang	**0**									
	GUAN, Pengfei	**0**									
	Total	**65,980**	**9,300**	**50,180**	**0**	**0**	**2,210**	**0**	**0**	**4,290**	**0**
Nanophys	TAKAHASHI, Takashi (PI)	**0**									
	SOUMA, Seigo	**8,710**							8,710		
	RICHARD, Pierre	**1,534**									1,534
	SUGAWARA, Katsuaki	**0**									
	KAWASAKI, Masashi (PI)	**0**									
	MAKINO, Takayuki	**0**									
	UENO, Kazunori	**15,990**							15,990		
	HIRAGA, Hiroki	**0**									
	YAMADA, Kazuyoshi (PI)	**2,850**				1,950		900			
	SATO, Toyoto	**1,040**								1,040	
	HORIGANE, Kazumasa	**0**									
	TANIGAKI, Katsumi (PI)	**38,100**	34,200		3,900						
	NOUCHI, Ryo	**1,430**								1,430	
	JU, Jing	**0**									
	TANG, Jun	**0**									
	TSUKADA, Masaru (PI)	**53,720**	35,000		18,720						
	AKAGI, Kazuto	**0**									
	TAMURA, Hiroyuki	**0**									
	HAMADA, Ikutaro	**2,600**								2,600	
	MASAGO, Akira	**0**									

ics	SUSHKO, Peter V.	**1,560**									1,560
	TREVETHAN, Thomas Pasco	**0**									
	MCKENNA, Keith Patrick	**0**									
	HASHIZUME, Tomihiro (PI)	**0**									
	HITOSUGI, Taro	**0**									
	IWAYA, Katsuya	**0**									
	OHSAWA, Takeo	**0**									
	FUKUI, Nobuyuki	**0**									
	AL-MAHBOOB, Abdulla	**2,990**								2,990	
	LIU, Hongwen	**2,990**								2,990	
	IKUHARA, Yuichi (PI)	**42,800**	42,800								
	TSUKIMOTO, Susumu	**0**									
	SAITO, Mitsuhiro	**1,560**									1,560
	WANG, Zhongchang	**0**									
	Total	**177,874**	**112,000**	**0**	**22,620**	**1,950**	**0**	**900**	**24,700**	**11,050**	**4,654**
Nanochemistry	ITAYA, Kingo (PI)	**16,900**			16,900						
	KUZUME, Akiyoshi	**1,430**								1,430	
	KOMINO, Takeshi	**0**									
	JUNG, Changhoon	**0**									
	WEN, Rui	**0**									
	SHIMOMURA, Masatsugu (PI)	**2,080**					2,080				
	ISHII, Daisuke	**11,310**							11,310		
	HIGUCHI, Takeshi	**0**									
	YAMAGUCHI, Masahiko (PI)	**61,100**		61,100							
	YASUI, Yoshizumi	**2,080**								2,080	
	AN, Zengjian	**0**									
	ADSCHIRI, Tadafumi (PI)	**52,920**		51,220				1,700			
	MINAMI, Kimitaka	**2,470**								2,470	
	HOJO, Daisuke	**2,730**								2,730	
	NISHI, Toshio (PI)	**18,720**				18,720					
	NAKAJIMA, Ken	**0**									
	FUJINAMI, So	**0**									
	WANG, Dong	**0**									
	Total	**171,740**	**0**	**112,320**	**16,900**	**18,720**	**2,080**	**1,700**	**11,310**	**8,710**	**0**
Device/System	ESASHI, Masayoshi (PI)	**25,220**		25,220							
	AKIYAMA, Kotone	**2,200**	2,200								
	MUROYAMA, Masanori	**2,080**								2,080	
	YOSHIDA, Shinya	**1,560**									1,560
	LIN, Yuching	**0**									
	CHEKHOVSKIY, Aleksandr	**0**									
	MIYAZAKI, Terunobu (PI)	**34,710**			34,710						
	MIZUKAMI, Shigemi	**0**									
	WATANABE, Daisuke	**0**									
	WU, Feng	**0**									
	SAJITHA, Eddekepavan Puthanveetil	**0**									
	OHMI, Tadahiro (PI)	**0**									
	NAKAZAWA, Masataka (PI)	**16,770**			16,770						
	Total	**82,540**	**2,200**	**25,220**	**51,480**	**0**	**0**	**0**	**0**	**2,080**	**1,560**
	Total	**504,634**	**123,500**	**187,720**	**91,000**	**27,170**	**4,290**	**2,600**	**36,010**	**26,130**	**6,214**

Research Prospect

Advanced materials for MEMS

Masayoshi Esashi, Shinya Yoshida and Masanori Muroyama
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1. Micromechanical resonator using AlN (Esashi)

Aluminum nitride (AlN) is a piezoelectric material which can be used on LSI chip [1.1]. The AlN has been applied to on-chip multi-frequency time-frequency generators and multiband filters.

Figure 1.1 shows the fabrication process and photographs of AlN Lamb wave resonators for the on-chip multi-frequency time-frequency generators [1.3]. This is fabricated by a LSI compatible process using a Ge sacrificial layer. The resonant frequencies are determined by the pitches of the Al electrode on the AlN, which enables multi-frequency on a common chip.

Multi-band wireless communication systems are required for the efficient use of frequency resources. Figure 1.2 shows the fabrication process and photographs of the

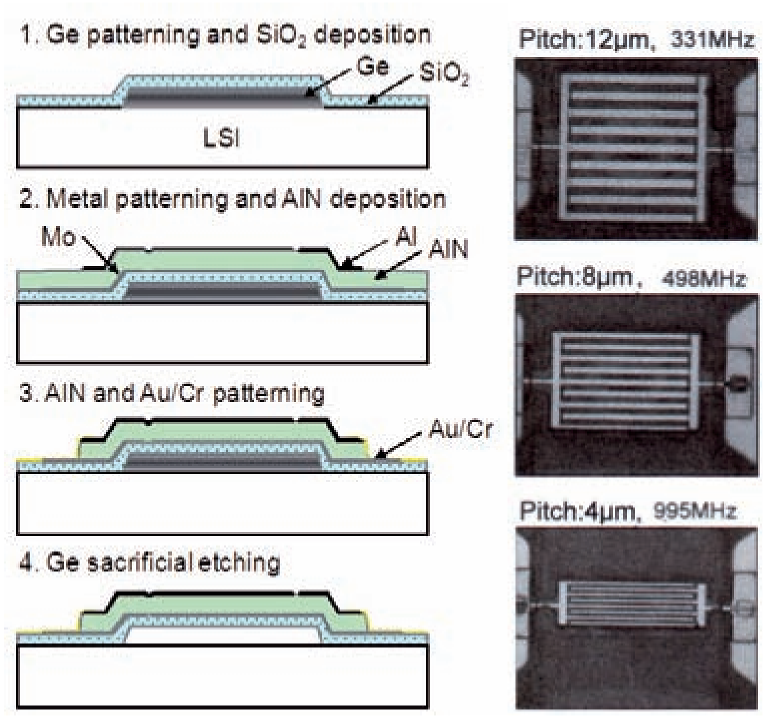


Fig. 1.1. Multi-band Lamb wave resonator for time-frequency generation.

on-chip multi band filter. Disk-type resonators of which resonant frequencies are determined by the patter size and a FBAR (Film Bulk Acoustic Resonator) of which resonant frequency is determined by the thickness of the AlN film are fabricated on a common chip [1.3].

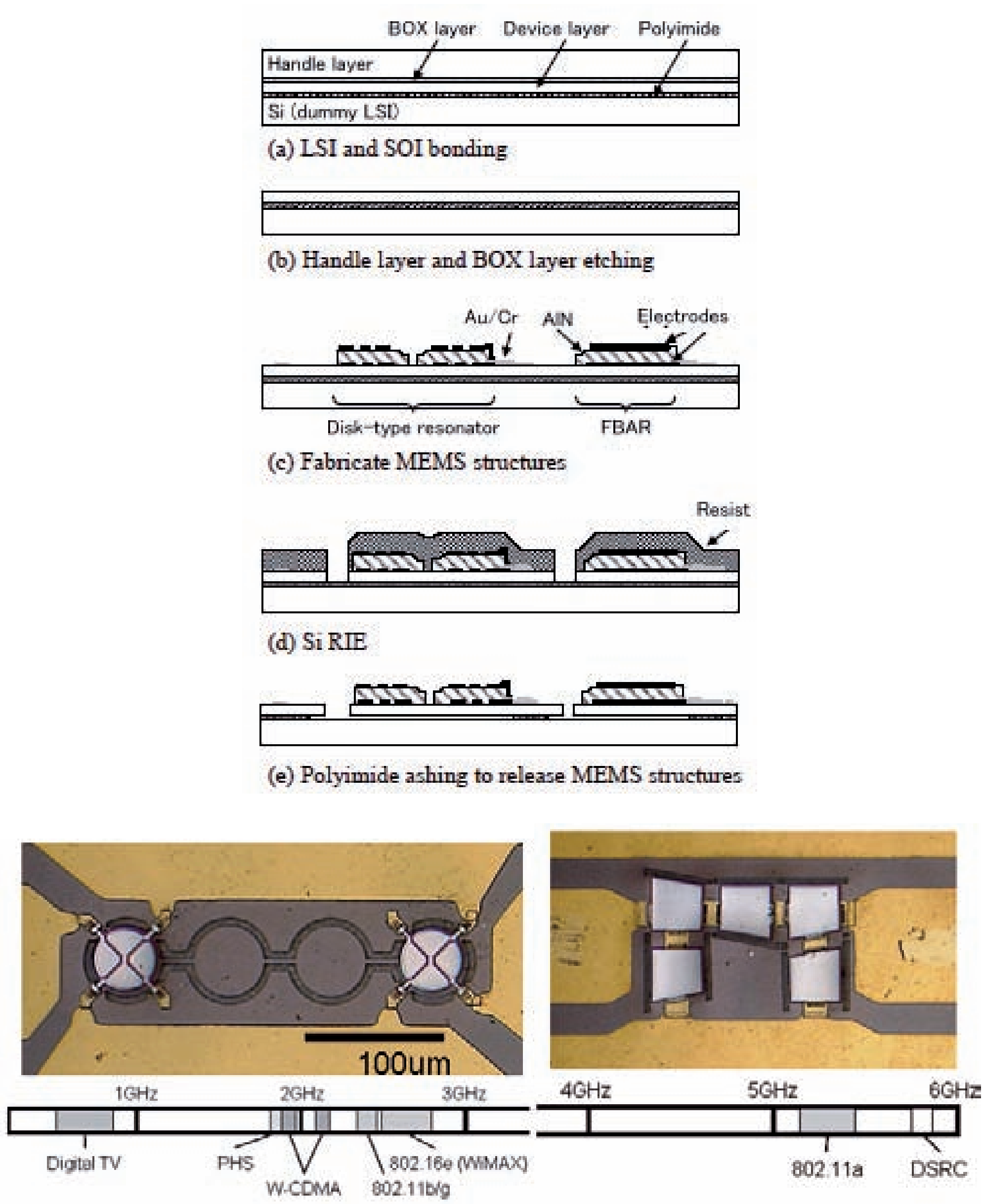


Fig. 1.2. Multi-band AlN filters fabricated on a common chip.

References

[1.1] M.Hara, J.Kuypers, T.Abe and M.Esashi, Sensors & Actuators A, 117, 211-216 (2005)

[1.2] K.Hirano, S.Tanaka and M.Esashi, Proceedings of the 25th Sensor Symposium, Okinawa, 195-198 (2008 Oct.22-24)

[1.3] T.Matsumura, M.Esashi, H.Harada and S.Tanaka, Piezoelectric material and device symposium, Sendai, 59-62 (2009 Feb.3) (in Japanese)

2. Scanning multiprobe data storage system based on reversible conductance change of conductive polymer (Yoshida)

2.1 Introduction

Scanning probe microscopy (SPM) has been used for surface observation as well as for surface modification and lithography on a nanometer scale. It is expected that this capability will provide the next generation of data storage method of which recording density beyond 1 Tb inch^{-2}. However, using only a single probe, the processing speed and data transfer rate of the SPM-based storage system is limited. Thus, multiprobe consisting of a two-dimensional array of cantilevers has been developed by microelectromechanical system (MEMS) technology. As a result, the data transfer rate can be dramatically improved by the parallel data processing with the probe array. Figure 2.1 shows the schematic of the scanning multiprobe data storage system.

Various data recording principles for the scanning multiprobe data storage system have been proposed and demonstrated. The recording principle of "Millipede" system of IBM (Zurich), which is the pioneer work of the probe-based data storage system, is based on thermomechanical deformation on a thermoplastic film [2.1]. In addition,

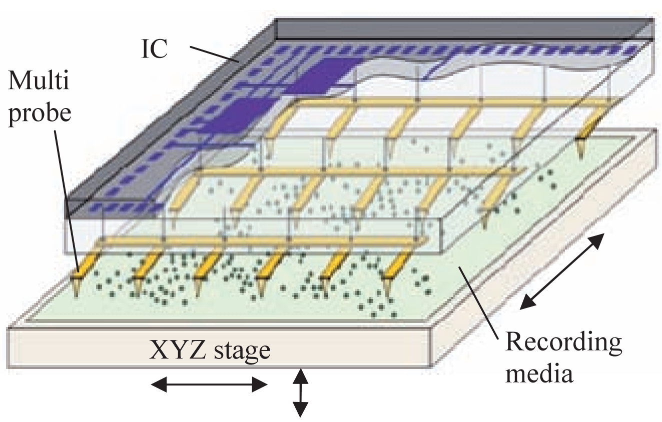


Fig. 2.1. Scanning multiprobe data storage system.

other recording principles based on such as changes of crystalline phase [2.2], ferroelectric polarization [2.3] are also researched by many research groups.

So far, we have developed conductive-polymer recording media for the data storage system [2.4~2.7]. The recording principle is based on the electrical conductance change of the conductive polymer due to an electrochemical reaction. This electrochemical reaction is caused by applying a voltage to the conductive polymer with a conductive SPM probe. One of the advantages of this recording method is the simplicity of relying on the electrical conductance change of the conductive polymer, which can miniaturize the recording system size. In addition, it is expected that the soft polymer can reduce the wear of the recording tip.

2.2 Experiments and results

In preliminary study, we demonstrated the reversible conductivity chang of polyaniline (PANI) film using SPM [2.5]. PANI was chosen as the conductive polymer of which conductance depends on the redox level. The conductivity of PANI is changed by applying voltages with SPM. In this study, a thin PANI film as a recording test sample was formed on Au surface by surface-graft polymerization using a self-assembled monolayer (SAM) of 4-aminothiophenol, as shown in Fig.2.2. The electrical modification of the film was demonstrated by a conventional SPM system in the atmosphere, as shown in Fig.2.3. In the modification experiment, a dc voltage was applied to the sample as the probe was scanned over the film. Then, conductance images were obtained by applying a low voltage to the substrate. The flowing current was detected by an amplifier, and conductance images were obtained by mapping the current. Figure 2.4 shows sequential experiments on the electrical modification under

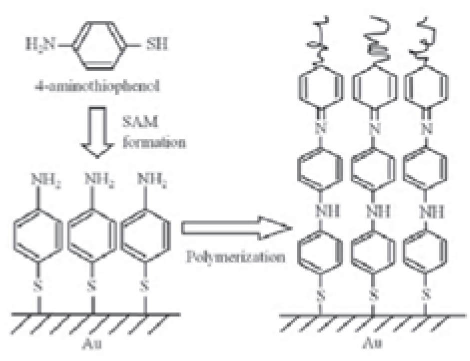


Fig. 2.2. Scheme of surface-graft polymerization of PANI film.

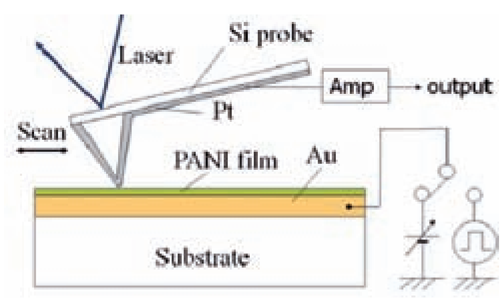
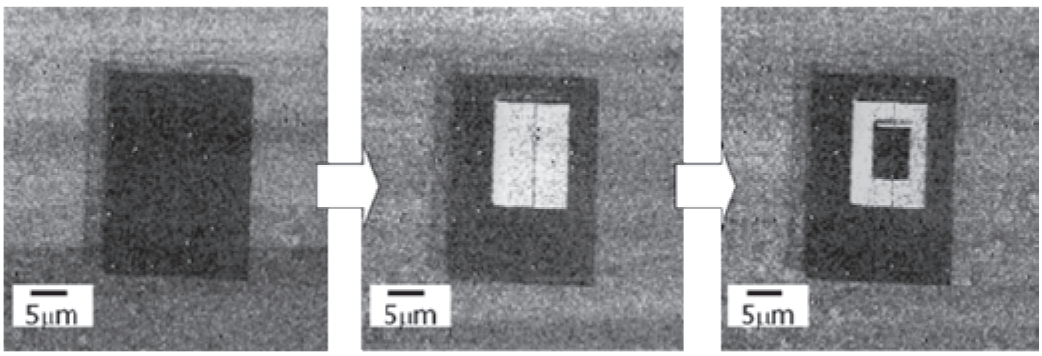


Fig. 2.3. Schematic diagram of the electrical modification experiment with SPM.

various voltages. All images are conductance images, of which bright part corresponds to high conductance areas. From the experiment, it is found that the conductivity of the PANI film can be reversibly changed by applying a voltage between the SPM probe and the film, depending on the polarity of the applied voltage. This achievement indicates that the conductive polymer has a potential ability for rewritable recording media.



(a) application of 3 V (b) application of -3 V (c) application of 3 V

Fig. 2.4. Reversible conductive change of PANI by modification voltage.

In addition, we have developed a conductive-polymer patterned medium, which is made of conductive polymer islands surrounded by an insulator matrix, as shown in Fig.2.5 [2.6][2.7]. The patterned medium prevents the random aggregation of the conductive polymer chains because the aggregation is limited by the inner hollows. Thus, the patterned medium can reduce the number of defects and improve the electrical uniformity, resulting in an improvement of recording reliability compared with unpatterned conductive polymer films. In addition, it is expected that recording bits with nanoscale size can be achieved more easily because the patterned medium can confine the spreading of recording areas in electrical modification. Therefore, a patterned medium can realize higher recording density than that of an unpatterned conductive polymer film. In the fundamental study, we fabricated PANI dot patterns as a conductive polymer patterned medium using diblock copolymer lithography (DCL). DCL utilizes the nanostructures of diblock copolymers in a microphase separation as a template for the fabrication process. This lithography technology can make it easy to fabricate periodic nanostructures on a large area. The fabrication process is shown in Fig.2.6.

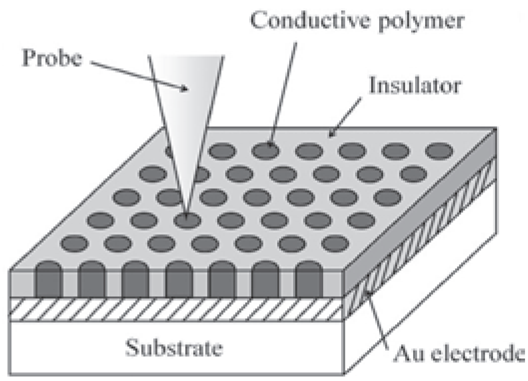


Fig. 2.5. Structure of a conductive polymer patterned medium for scanning multiprobe data storage

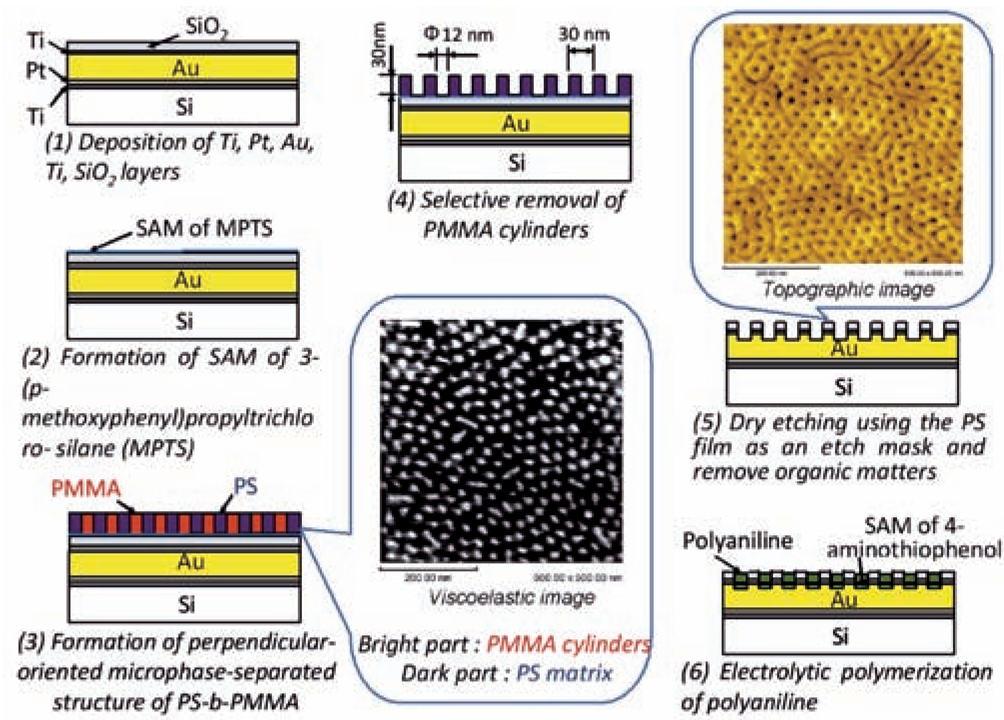


Fig.2.6. Fabrication process of the conductive polymer patterned medium.

Figure 2.7 shows conductance images obtained from the electrical modification experiment on the fabricated PANI dot pattern with 80 nm pitch. In Fig.2.7 (a), it can be seen that four high conductive areas are aligned at the initial state. Then, on the second dot from left, the SPM tip was scanned with an applied voltage of 3 V. As the result of this electrical modification, only the second dot was erased without erasing neighboring dots, as shown in Fig.2.7 (b). In other words, the conductivity of the second dot was selectively decreased by the modification. Then, single dot erasing of the third dot was carried out as well, as shown in Fig.2.7 (c). Finally, the conductivity of the erased dots could be raised by applying a negative voltage of −3 V, as shown in Fig.2.7 (d). Therefore, reversible single-bit recording with 80 nm pitch was demonstrated.

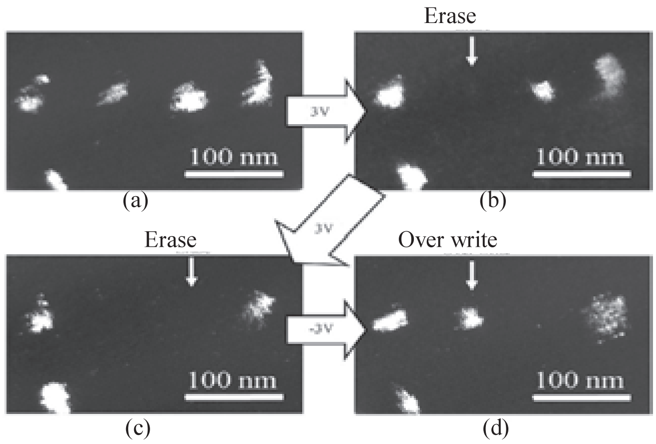


Fig. 2.7. Conductive polymer patterned medium for scanning multiprobe data storage

Figure 2.8 shows the electrical modification on the PANI dot pattern with more narrow pitch. In Fig.2.8 (a), five high conductive dots exist with approximately 30 nm pitch. Then, the SPM tip was scanned along the direction shown by the arrow with an applied voltage of 3 V on the centered two dots, as shown in Fig.2.8 (b). As a result, only two dots were erased without erasing neighboring dots, as shown in Fig.2.8 (c). The pitch of 30 nm corresponds to a recording density of more than 700 G bits inch^{-2}.

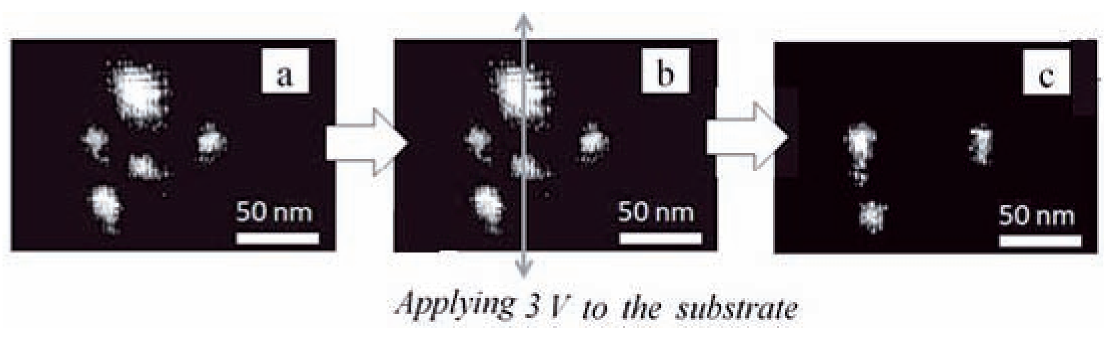


Fig. 2.8. Conductance images of the PANI dots in electrical modification experiment. (a) Before the modification (b) Applying a voltage of 3 V along arrow (c) After the modification

2.3 Conclusion and future prospect

We have researched the conductive-polymer recording media for the scanning multiprobe data storage system. So far, we achieved to demonstrate from these fundamental studies that the conductive polymer has potential ability to provide rewritable and ultrahigh-density recording for the scanning probe data storage system. It is believed that such a conductive-polymer recording medium has the capability to provide high-density recording beyond 1~10 Tbits inch−2. In future work, both species of conductive polymer and fabrication method of the recording media will be optimized for achieving higher density data storage and enough recording repeatability to use practically.

References

[2.1] Binnig G, et al., Applied Physics Letters, Vol. 74, 1329-1331 (1999)
P. Vettiger, M. Despont, U. Drechsler, U. Durig, W. Haberle, M. I. Lutwyche, H. E. Rothuizen, R. Stutz, R. Widmer, and G. K. Binnig, IBM Journal of Research and Development, 44, 323-340 (2000)
[2.2] Hamann HF, O'Boyle M, Martin YC, Rooks M, Wickramasinghe K, Nature Materials, Vol. 5, 383-387 (2006)
[2.3] Tanaka K, et al., Japanese Journal of Applied Physics, Vol. 47, 3311-3325 (2008)
[2.4] Ono T, Yoshida S, and Esashi M, Nanotechnology, Vol. 14, 1051-1054 (2003)
[2.5] Yoshida S, Ono T, Oi S, and Esashi M, Nanotechnology, Vol. 16, 2516-2520 (2005)
[2.6] Yoshida S, Ono T, and Esashi M, Nanotechnology, Vol. 18, 505302 (2007)
[2.7] Yoshida S, Ono T, and Esashi M, Nanotechnology, Vol. 19, 475302 (2008)

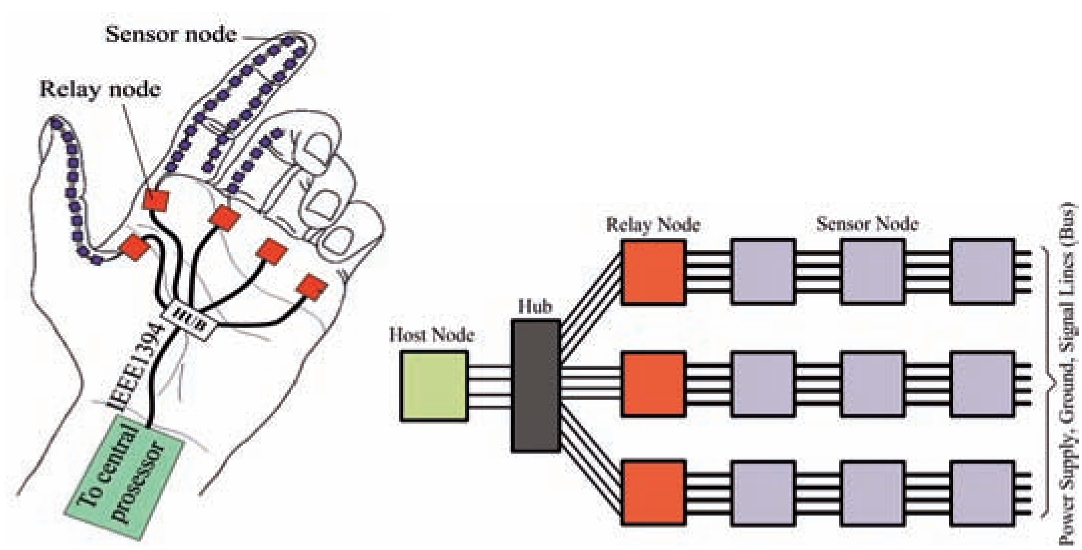
3. LSI circuits for bus-based tactile sensor systems (Muroyama)

Tactile sensor systems enable robots to behave like a human such as understanding shapes of objects and grasping the objects for applications of robot hands [3.1]. Human-friendly touch and touch communication can be realized by implementing tactile sensors of the entire body [3.2]. Existing tactile sensor systems such as mesh type ones [3.3][3.4] have a limitation on the number of tactile sensor elements because of low response time, high power consumption and inflexible network morphology. To tackle these issues, we propose a bus-based tactile sensor network system. Decentralized serial bus communication and the integration of a MEMS capacitive sensor and a signal processing LSI realize low power consumption, high speed response and flexible network morphology. In addition to the system architecture and analysis of the system, details of LSI design for the system are explained in this news letter.

3.1 Proposed system architecture

Figure 3.1 shows the proposed system architecture. The main components of the system are sensor nodes (MEMS capacitive sensor and signal processing LSI), relay nodes (data relay from sensor nodes to a host node), a host node (final data processing) and bus lines (power supply, ground, and one or two signal lines). Each sensor node detects force periodically and judges autonomously whether to transmit sensing data to the relay node or not. The judgment is done based on the threshold value of the sensing data, bus transmission status and the history of own transmission. To realize this system effectively in terms of response time and power consumption, the sensor node must have several functions and is made from the integration of the MEMS sensor and the LSI.

Figure 3.2 shows the functions and a data processing flow. Capacitance change of the sensor is directly converted to frequency change with the capacitance-to-frequency converter. The counter counts the frequency, which means digitalization. For asynchronous transmission, additional information in addition to the sensing data is required. Preamble, start bits, ID, CRC(Cyclic Redundant Check) code, stop bits are used for synchronous, delimiter for the data start, node identification, error detection,



(a) An application for the robot hand (b) The entire network architecture

Fig. 3.1. A concept of the proposed system.

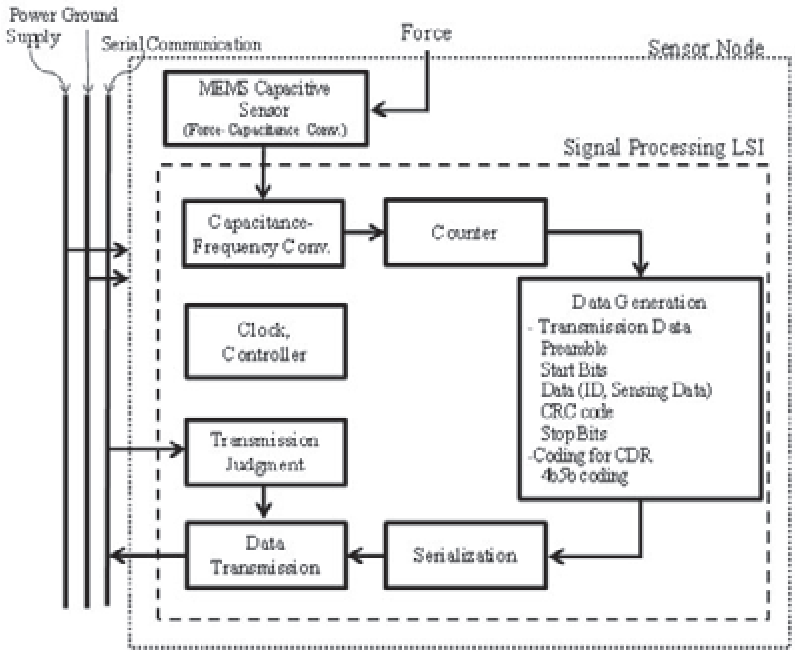


Fig. 3.2. An overview of a sensor node.

delimiter for the data end, respectively. Serialization with 4b5b coding and NRZI (Non-Return to Zero Inversion) makes receivers (the relay node and the host node) easy to recover clock and data from the transmitted signals. Before the transmission, the system checks the bus status for avoiding collisions.

3.2 Computational Results

Currently, we have designed the LSI circuits of the sensor node. Figure 3.3 shows a power consumption estimation of the LSI obtained by circuit and gate-level simulation. The clock frequency is 50MHz. Just after turning on power, the sensor node transmits data for activation check (initial transmission). At 40μs, a strong force of 7.4N, which is larger than the threshold, is applied to the sensor node, and the sensor node starts transmitting sensing data. When transmitting sensing data, this system shows local peaks of power consumption. The simulation result shows that the response time and data transmission time of the sensor node are 21μs and 1.2μs, respectively. The computational experiments proved that more than thousands of the sensor elements can be mounted in the system. Next work is fabrication and implementation of the LSI and MEMS sensor [3.5].

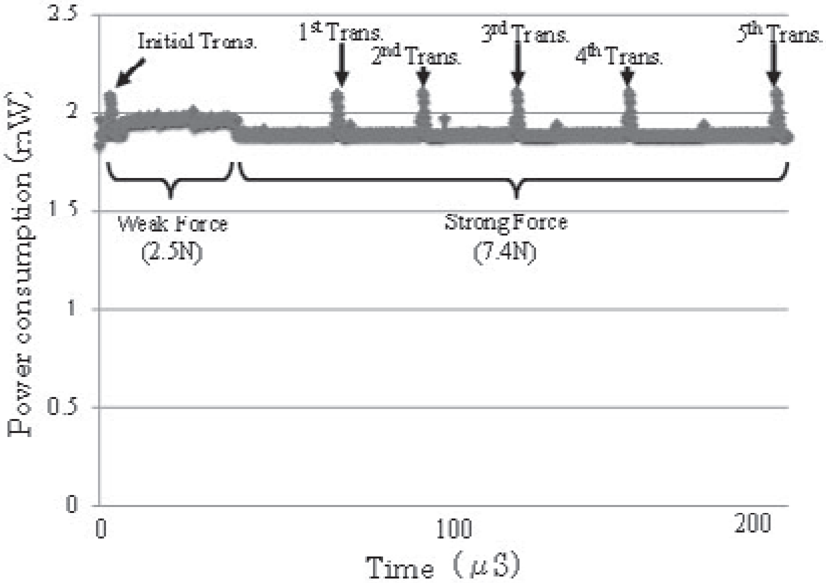


Fig. 3.3. A result of power consumption estimation.

References

[3.1] G. Cannta, M. Maggiali, IEEE-RAS Internl. Conf. on Humanoids 2005, 80-85 (2005 Dec.).

[3.2] T. Mukai, M. Onishi, T. Odashima, S. Hirano, Z. Luo, IEEE Trans. on Robotics, 24, 505-512 (2008).

[3.3] K. Weiss. H. Worn, Industrial Electronics Society, 2005 IECON, 1949-1954 (2005 Nov.).

[3.4] O. Kerpa, K. Weiss, H. Worn, 2003 IEEE/RSJ Internl. Conf. on Intelligent Robots and Systems, 1-6 (2005 Nov.)

[3.5] Y. Matsumoto, M. Esashi, IEICE Transactions on Electronics, J75-C-II, 451-461 (1992).

Atomic Structures and Properties of Ceramic Interfaces
- Combination of Cs-corrected STEM and First Principles Calculations -

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Naoya Shibata[2], Teruyasu Mizoguchi[2] and Takahisa Yamamoto[2,3]
[1]WPI Research Center, Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan
[2]Institute of Engineering Innovation, The University of Tokyo, Tokyo 113-8656 Japan.
[3]Nanostructures Research Laboratory, Japan Fine Ceramic Center, Nagoya 456-8575, Japan.

1. Introduction

Grain boundaries and interfaces of crystals have peculiar electronic structures, caused by the disorder in periodicity, providing the functional properties that cannot be observed in a perfect crystal [1, 2]. In the vicinity of the grain boundaries and interfaces around the order of one nanometer, dopants or impurities are often segregated, and they play a crucial role in the material properties. We call these dopants “function providing elements”, which have the characteristics to change the macroscopic properties of the materials drastically.

To obtain a guideline for designing material by the atomic scale modification, an understanding of the atomistic mechanism for the functional properties is required as well as precise measurement of the present state of trace elements segregated in the nanoscale region. In recent nano-characterization technologies, there has been remarkable progress by Scanning Transmission Electron Microscopy (STEM) utilizing the spherical aberration (Cs) corrector [3]. This technique enables us not only to identify the locations of the dopants but also to analyze the local electronic state for the single atomic column on grain boundaries and interfaces. In this paper, we focus our attention on grain boundaries and interfaces of various ceramics, to which “function providing elements” are doped, and introduce the latest results of the microstructure analyzed in detail by STEM. Furthermore, by the first-principles calculation based on these observation results, the analyzed results of the mechanism of the “function providing elements” will be described as well.

2. Scanning Transmission Electron Microscopy (STEM)

STEM (Scanning Transmission Electron Microscopy) is a technique to scan a specimen by an electron probe, which is focused down to 1 nm or less on the sample. The STEM image is formed with the collected scattered electrons in each probe position by the Annular Dark Field (ADF) detector at the bottom of the sample on the monitor in synchronism with the scanning probe [4]. The atomic resolution image can be obtained by focusing the electron probe down to below the atomic column interval. The advantages of this method are those: there is no inversion of the image contrast with the defocusing and the change in the sample thickness, and thus the positions of the atomic columns can be determined directly from the image. These excellent characteristics are very useful to determine the complicated atomic structures in the grain boundaries and interfaces. In addition, the intensity of the image obtained by detecting the electrons scattered to higher angles is known to correspond to about the square of the atomic number Z. The contrast of High Angle Annular Dark Field (HAADF) STEM is therefore called "Z-contrast" as well, making it possible to observe the element distribution at an atomic column level in the region where local composition is changed. Figure 1 shows an example of HAADF-STEM image for $SrTiO_3$ projected along the [001]. As seen in Fig. 1, the contrast of Sr atoms (Z=38) is brighter than that of Ti atoms (Z=22), which indicates that atomic species can be discriminated in one image. Moreover, in recent years, by combining STEM method with the C*s* correction technology, drastic improvement in resolution has become possible. At present, with the STEM using the Cs corrector, the electron probe diameter of 1 Å or less has been

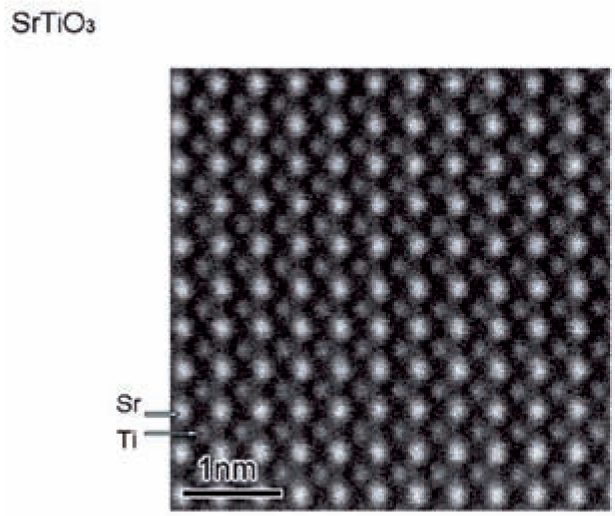

Fig. 1. HAADF-STEM image for $SrTiO_3$ projected along the [001] direction, in which the contrast of Sr atoms (Z=38) is brighter than that of Ti atoms (Z=22).

already achieved [5]. Furthermore, since the intensity of the electron probe can be increased by the C*s* correction technology, there are advantages that the S/N ratio of the STEM image will be increased and hence the image quality also can be improved drastically. STEM method using the C*s* corrector is thus expected as a powerful tool to characterize the atomic structures in grain boundaries and interfaces.

3. SiC/Ti_3SiC_2 Functional Interface [6)]

Obtaining atomistic understanding of the impact of buried interface structures on electronic and electric properties is a long-standing goal in materials physics, especially in semiconductor physics. SiC is a very promising semiconductor for next-generation high-power and -temperature electronics because of its various unique intrinsic properties [7]. The key technologic issue in fabrication of the reliable and high-performance devices is to develop low-resistance ohmic contact. Most studies to date on obtaining the ohmic contacts have focused on TiAl-based metals, which indeed yield significant low contact resistance [8]. The formation of ohmic contact has been ascribed empirically to a functional interface between SiC and Ti_3SiC_2 generated after annealing, serving a primary current pathway to lower the Schottky barrier between metal and semiconductor. However, an understanding of role of the SiC/Ti_3SiC_2 interface on the mechanism whereby Schottky becomes ohmic has not yet been well developed. It is not even clear how the two materials atomically bond together. Detailed knowledge on the atomic and electronic structure and their impact on electric property are essential to elucidate the mechanism so as to better design the device and control its performance.

The HAADF-STEM image in Fig. 2(a) depicts the atomic structure of the SiC(0001)/Ti_3SiC_2(0001) interface (JEOL JEM-2100F (200 kV) with Cs corrector (CEOS)) [6]. The interface is atomically abrupt and coherent without reaction layers, contaminants, or transition regions, which means that we have successfully produced epitaxially grown Ti_3SiC_2 on the SiC substrate [9]. Bright spots in the image represent atomic columns of Ti, while the darker spots are Si columns, since the intensity of an atomic column in the HAADF-STEM image, to good approximation, is directly proportional to the square of atomic number [10]. However, C columns are not scattered strongly enough to be visualized, making the image incomplete. To complement the image and understand the interface nature, we also carried out first principles calculations, taking into account all of the 96 possible interface models [11]. Among these models, figure 2(a) can only be intuitively fitted by two models shown in Figs. 2(b) and 2(c). The difference between these two models is that their local environments

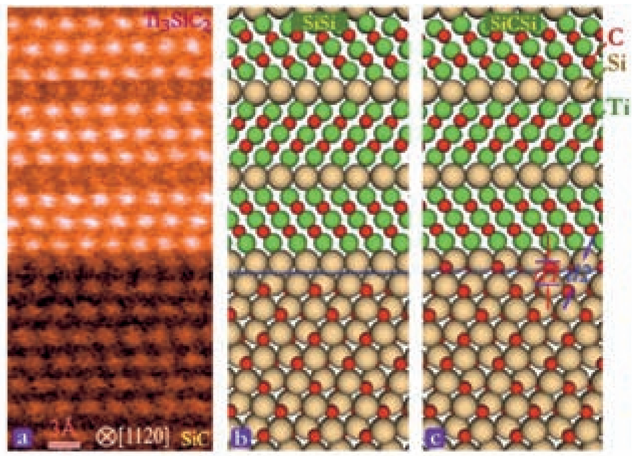

Fig. 2. (a) HAADF-STEM image of the SiC/Ti_3SiC_2 interface in the ohmic contact sample. The optimized $SiC(0001)/Ti_3SiC_2(0001)$ interface models (b) without interfacial C atoms (*SiSi*), and (c) with interfacial C atoms (*SiCSi*) [6].

around interface are totally different, as the C unseen by the STEM is trapped at the *SiCSi* interface (Fig. 2(c)) but not at the *SiSi* interface (Fig. 2(b)).

To investigate which interface is more likely, we first examined the interface stability by calculating the adhesion energy (W_{ad}). The calculations show that the W_{ad} of the *SiSi* interface (1.62 J/m^2) is much less than that of the *SiCSi* interface (6.81 J/m^2), indicating that the *SiSi* interface is not favored and that the interfaces are strengthened substantially after trapping C. Next, we calculated the optimal distances of interfacial Si-Si planes ('*d1*' in Fig. 2(b)) and interfacial Si-Si atoms projected on the paper plane ('*d2*' in Fig, 2(b)) at both the *SiSi* and *SiCSi* interfaces, and found that the distances for the *SiCSi* interface are very close to the experimental values obtained from the STEM image shown in Fig. 2(a), while those for the *SiSi* interface deviate clearly from the experimental values. Hence, the interface with incorporated C is inferred to better match the HAADF-STEM image both qualitatively and quantitatively. We further confirmed the interface with C to be of less Schottky character by calculating the *p*-type Schottky barrier height (SBH) form the difference between the Fermi level (E_F) and the valence band top of the bulk SiC region in the supercell. The *SiCSi* interface has an SBH value of 0.60 eV, lower than the *SiSi* interface (1.05 eV) [6].

The origin of the decrease in SBH and the junction strengthening in the *SiCSi* interface can be clarified by carefully analyzing its electronic structures, as shown in Fig. 3 [6]. We first observe from Fig. 3(a) that planar-averaged density differences in the

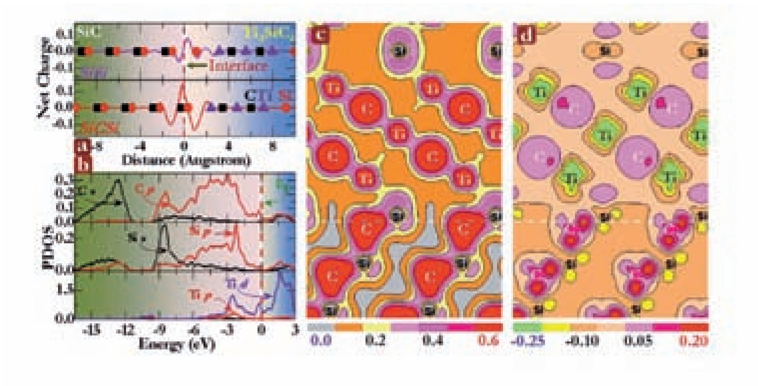

Fig. 3. (a) Planar-averaged charge density along the [0001] direction for the *SiSi* and *SiCSi* interfaces, (b) density of states projected on the atomic layers proximal to the *SiCSi* interface, (c) charge density and (d) its difference along the $(11\bar{2}0)$ plane of the *SiCSi* interface [6].

SiCSi deviate more prominently from zero around the interface, reflecting more significant charge transfer. Next, interfacial Si-C bonds exhibit a character practically identical to that of the Si-C bonds deeper in SiC (Fig. 3(c)): most of charges are localized on interfacial C with distortion directed toward interfacial Si, suggesting that the interfacial bonds are of mixed covalent-ionic nature. This, together with the large charge accumulation along interfacial Si-C bonds (Fig. 3(d)), explains the strong adhesion in the *SiCSi* interface. Furthermore, the partial ionicity and considerable charge transfer at the *SiCSi* interface also generate a large dipole shift, which lowers the electrostatic potential of interfacial Si in Ti_3SiC_2 downward relative to the SiC region, thus reducing the SBH. Finally, we note in Fig. 3(b) a strong interaction between the Ti *d* and Si *p* states in the *SiCSi* interface. This interaction continues well into the SiC, inducing pronounced gap states in the interfacial C at E_F, which means that the interfacial C layers are metalized, suggestive of possible electrical conductivity through the *SiCSi* interface.

We further devised a two-probe system, Ti/Ti_3SiC_2/SiC/Ti_3SiC_2/Ti, and investigated quantum transport in order to bridge the structures to electric properties. The SiC/Ti_3SiC_2 interface could be either *SiSi* or *SiCSi*, whereas other interfaces are maintained as identical for the two systems. Figure 4(a) shows the transmission spectra of the two relaxed systems, where one can see that they differ from each other, suggesting changes in electron states with interface geometry. Of the two cases, the *SiCSi* case shows a larger transmission coefficient at E_F, implying that electrons

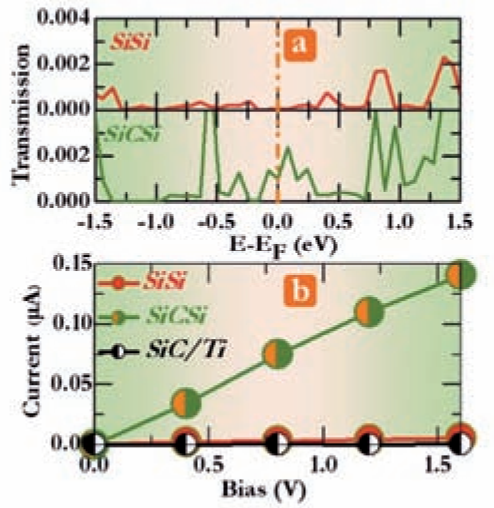

Fig. 4. (a) Transmission spectra under 0 V and (b) current-voltage curves for the two relaxed systems including the *SiSi* and *SiCSi* interfaces [6].

permeate this interface more easily, in agreement with the relatively lower SBH. In addition to the transmission, the current also increases faster in the *SiCSi* case as voltage increases, as shown in Fig. 4(b). Further, we also calculated the current-voltage curve for the system including SiC/Ti interface and found that this system clearly exhibits Schottky behavior ('SiC/Ti' in Fig. 4(c)), meaning that the SiC/Ti_3SiC_2 interface plays an essential role in reducing the Schottky barrier. Therefore, a combination of the state-of-the-art HAADF-STEM and accurate atomistic modeling is an important advance in the atomic-scale determination of a buried functional interface structures, in addition to bridging structures to properties on a quantum level.

4. Grain Boundary of Pr-doped ZnO Varistor[12,13)]

As an example of the grain boundary segregation in electro ceramics, Pr-doped ZnO grain boundary is shown in this section. Since ZnO ceramics show high nonlinear current-voltage characteristics by doping secondary elements such as Pr and Bi, they are widely used for varistors. It has been reported that Pr and Bi etc., doped to ZnO ceramics segregate in grain boundaries and it is believed that they have an important role for providing varistor properties. However, its segregation behavior has not been understood in detail at atomic level. It is therefore required to characterize an atomic level analysis of the Pr segregation in ZnO grain boundaries to clarify the atomistic mechanism of the varistor properties.

Figure 5 shows a HAADF-STEM image of the Pr-doped Σ7 grain boundary [12]. Here, Σ represents the degree of geometrical coherency at grain boundaries [1]. The small Σ number indicates high coherency, and the large Σ number indicates low coherency at grain boundaries. As described above, in the HAADF-STEM image, the atomic column position emerges as white dots. Pr with a higher atomic number than Zn shows the brighter contrast. Accordingly, the bright spots, indicated by the arrows at the grain boundary, show the segregated Pr atoms. It can be recognized from the image that Pr does not have the wide distribution but segregates only at the special atomic sites. With substituting Pr atoms, suggested from the HAADF-STEM image, to the Zn sites in the Σ7 grain boundary, the most stable atomic structure was calculated by the first principles method as shown in Fig. 6 [13]. It is confirmed from Fig. 6 that the

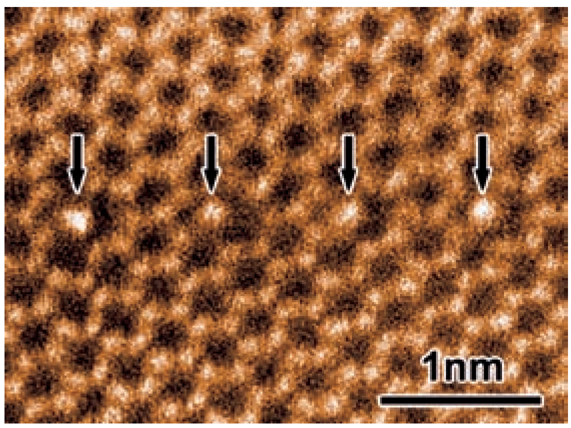

Fig. 5. HAADF-STEM image of Pr-doped ZnO Σ7 grain boundary, showing that Pr segregation sites can be observed as bright spots indicated by the arrows [12].

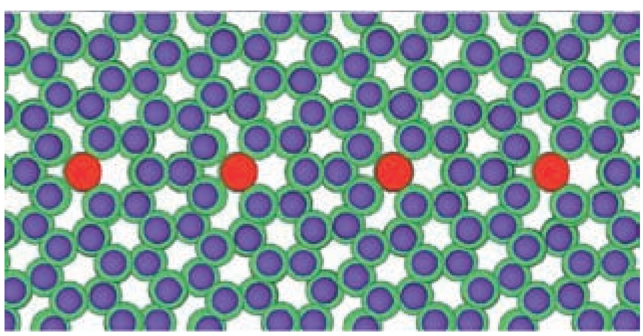

Fig. 6. The stable atomic structure of Pr-doped ZnO Σ7 grain boundary obtained by the first principles calculation (green circle: O, blue circle: Zn, red circle: Pr) [13].

experimentally observed Pr atoms segregate at the most stable position in the grain boundary. In addition, by the systematic first principles calculations, it was found that due to Pr presence in the grain boundary, acceptor type defects such as Zn vacancy and interstitial O atom are easily formed as well [12, 13]. These defect formations must be related to the mechanism of the varistor properties, which is believed to be an important role of Pr addition. Furthermore, it has been shown by the similar calculations that Pr segregates preferentially at the Zn sites (the locally tensile sites), in which the bonding length at the grain boundary is long [13].

5. Grain Boundary of Y-doped Alumina Ceramics [14)]

It has been known that the high-temperature strength of alumina ceramics is improved drastically by doping small amount of rare earth elements such as Y and Lu [14, 15]. Although it has been proposed that these minor doping elements segregate in the grain boundaries in the alumina polycrystal and prevent grain boundary from sliding at high temperature, there are many unknown issues regarding the intrinsic mechanism yet. Here, the grain boundary structure of the Y-doped alumina was observed by STEM method. The results demonstrate the grain boundary strengthening mechanism by Y. Figure 7 shows HAADF-STEM image of the Y-doped Σ31 alumina grain boundary [14]. Here, Σ31 grain boundary can be classified into a general grain boundary. It can be recognized that very strong contrast is observed at the particular atomic sites along the grain boundary. It corresponds to the position of Y atoms segregated in the grain boundary cores, which indicates that Y atoms segregate selectively and periodically only at the special sites in the grain boundary cores. Figure 8 shows the results of the theoretical analysis by the first principles calculation based on this structure, showing

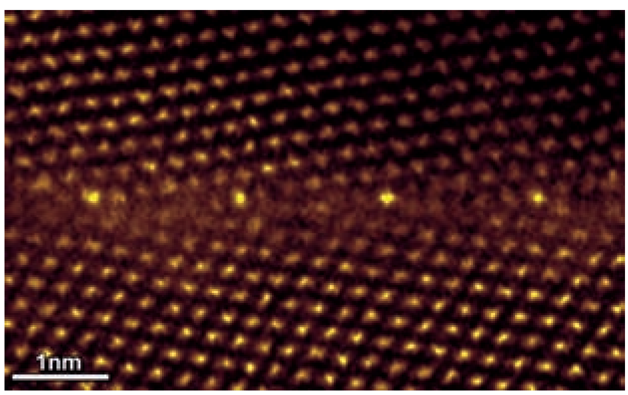

Fig. 7. HAADF-STEM image of Y-doped Σ 31 [0001] tilt grain boundary in alumina. The brightest columns indicate the presence of the heavy Y ions.

the electron density distribution around the Y atoms segregated in the center of the seven member ring [14]. From Fig. 8, it is recognized that the electron distribution is oriented around Y atoms to form covalent-like chemical bonds in the seven member ring, which is confirmed to be significant by comparing with the fact that the bonds without segregation are mainly ionic bonding [14]. In this way, it has become evident that due to the segregation of rare earth elements in the grain boundaries, surrounding chemical bonds change drastically, which has the effect to improve the grain boundary strength. In other words, it is believed that the effect of rare earth element doping to alumina ceramics is originated from the change in the local chemical bonding state at the grain boundary.

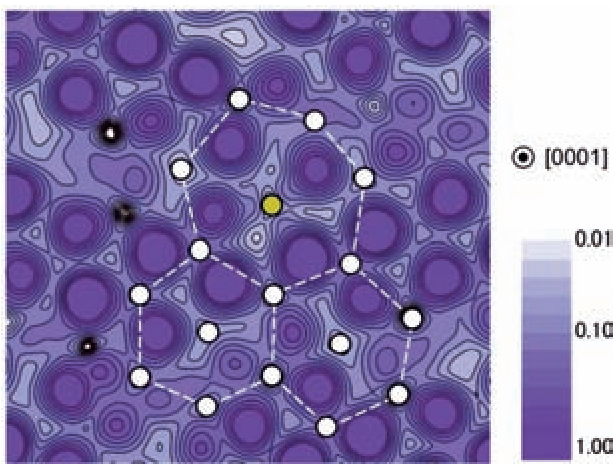

Fig. 8. Electron density map around Y atoms segregated in Σ31 Al_2O_3 grain boundary, which was obtained by the first principles calculation [14].

6. Dislocation Structure of Sapphire [16)]

To understand the mechanical properties of sapphire, many studies have been performed for the dislocations so far. It has been shown that the basal dislocation is dissociated to two partial dislocations. However, there are many unknown matters concerning the structure at the atomic level, and the atomistic mechanism of dislocation gliding has not been quantitatively understood yet. Since sapphire is composed of Al and O, an analysis of sublattice including the oxygen is required to understand its dislocation core structure at the atomic level. Therefore, using the Cs-corrected STEM, the dislocation core structure including the oxygen column was directly observed by combining BF and HAADF-STEM techniques.

Figure 9 shows (a) the crystal structure model of sapphire crystal viewed from $[1\bar{1}00]$ direction, (b) the HAADF-STEM, and (c) the Bright Field (BF) STEM images (VG HB603U STEM (300 kV) with C*s* corrector (Nion)) [16]. By STEM, the BF and HAADF images can be obtained from the same area simultaneously. As shown in the crystal structure model, the atomic columns of Al and O can be distinguished with the present incident axis. In the HAADF-STEM image shown in (b), the positions of the O columns and the Al columns are apparently discriminated. Although the S/N ratio of the HAADF-STEM image is lower than the one of the BF-STEM image of (c), the atom position can be determined directly, since the image is the image under incoherent conditions. On the other hand, the S/N ratio of the BF-STEM image is pretty high, and the BF-STEM image is optically equivalent to the image obtained by high-resolution transmission electron microscopy (HRTEM) due to the reciprocity theorem. Although the contrast of BF-STEM image varies widely according to the defocusing and the thickness of the sample, the correspondence of the contrast of the BF-STEM image and the atom position can be determined directly by taking the BF-STEM image and the HAADF-STEM image simultaneously to compare their contrast. Under the present observation condition, the position of the bright contrast in the BF-STEM image directly corresponds to the atomic column position. The structure determination including so far as the light element like oxygen thus becomes possible by simultaneous observation utilizing the image formation by both HAADF and BF STEM imaging.

The basal dislocation of sapphire has the Burgers vector of **b**=1/3<$11\bar{2}0$>, but it has been confirmed that the dislocation core is dissociated by climb mechanism along the [0001] direction and is composed of partial dislocations of $\mathbf{b_1}$=1/3<$01\bar{1}0$> and $\mathbf{b_2}$=1/3<$10\bar{1}0$> and stacking faults on the {$11\bar{2}0$} plane [17]. Figure 10 shows the

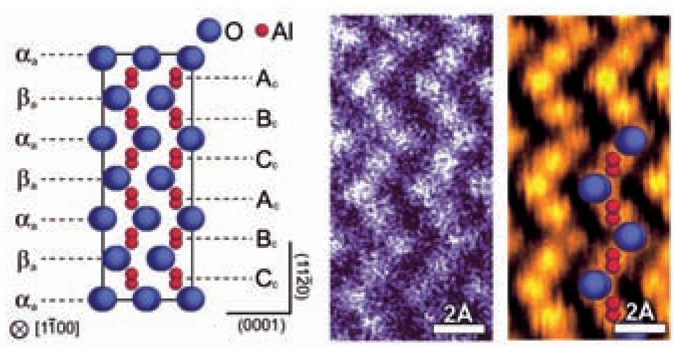

Fig. 9. (a) Atomic structure model of sapphire projected along $[1\bar{1}00]$ direction, (b) HAADF- and (c) BF-STEM images of a sapphire single crystal viewed from $[1\bar{1}00]$ direction [16].

BF-STEM image of each dislocation edge of the dissociated partial dislocations. In the BF-STEM image, since the oxygen column and the aluminum column can be identified, the atomic columns at the dislocation edge can be directly determined. As apparent from the experimental image, two partial dislocations terminate at the aluminum and the oxygen atomic columns, respectively. It is thus shown that each partial dislocation core has the structure with local composition shift of aluminum surplus or oxygen surplus from the stoichiometric ratio.

In case of ionic crystals, although the structure like this has been considered to be energetically unstable, the present results first demonstrate that the nonstoichiometric local structure can exist in the crystal. If the perfect dislocation is composed of two partial dislocations, the stoichiometric ratio is satisfied in total. In other words, the stoichiometry is maintained when the basal dislocation glides. By the direct observation of the dislocation core structure like this, the gliding mechanism of the basal dislocation of sapphire can be understood [16], which will bring a great breakthrough to the study of ceramics dislocation in future. The development of the new functional materials utilizing the ceramics dislocation also has already developed [18]. It is expected that STEM observation, which combines the BF image with the HAADF image, will become a useful method in future.

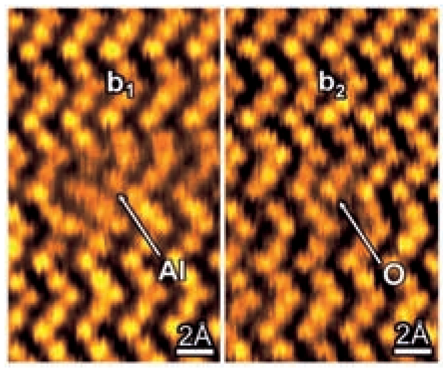

Fig.10. BF-STEM images of the core structures of the dissociated basal dislocations (b_1 and b_2), indicating that each core terminates at Al and O, respectively [16].

7. Interface Structure of $SrTiO_3$/Nb-$SrTiO_3$/$SrTiO_3$ Superlattice [19)]

Figure 11 shows HAADF-STEM image of the $SrTiO_3$/Nb-doped $SrTiO_3$/$SrTiO_3$ superlattice film [19]. As described above, since the image intensity of HAADF-STEM image is proportional to about the square of Z, it is recognized that Sr (Z=38) columns are observed brightly compared with the Ti (Z=22) columns. In this case, Nb-doped $SrTiO_3$ layers deposited at every 24 unit cell are observed as stripe contrast (Fig. 11(a)). Figures 11(b) and 11(c) show the magnified HAADF-STEM image around the

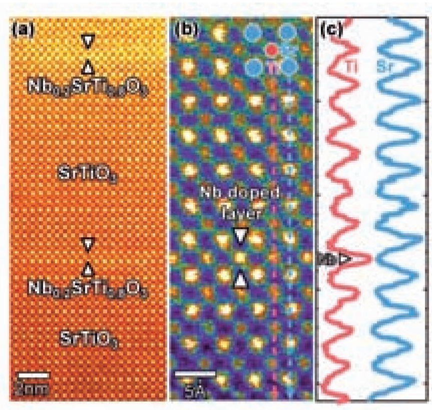

Fig. 11. (a) HAADF-STEM image of $SrTiO_3$/Nb-$SrTiO_3$ superlattice, (b) magnified image of the region (a) and (c) image intensity profile of Ti and Sr layers [19].

Nb-doped $SrTiO_3$ layer and a line profile of the image intensity of the Sr atomic row and the Ti atomic row in the same region. From these figures, it is recognized that the image intensity does not change in the Sr atomic row; however, the image intensity becomes high in the Ti atomic row at the Nb-doped $SrTiO_3$ layer. Taking into consideration that the atomic number of Nb is 41, it is considered that Nb exists at the Ti sites by substitution. On the other hand, since the atomic numbers of Nb and Sr are close, whether Nb exists in the Sr sites or not cannot be judged only by the contrast of the HAADF-STEM image. Then, the solubility energy of Nb was calculated by the first principles Projector-Augmented-Wave (PAW) method. It is then clarified that the solubility energy of Nb to the Sr sites is 7.6 eV higher compared with the one to the Ti sites. This result also shows the solubility of Nb to the Ti sites.

Figure 12 shows the spectra of Ti-$L_{2,3}$ ELNES (Energy Loss Near Edge Structure) obtained from the $SrTiO_3$ layer and the Nb-doped $SrTiO_3$ layer in the $SrTiO_3$/Nb-doped $SrTiO_3$/$SrTiO_3$ superlattice. The upper figure corresponds to the experimental spectra, and the bottom figure corresponds to the theoretically calculated spectra. Although four peaks (t_{2g}, e_g split) are apparent in the spectra obtained from the $SrTiO_3$ layer, it is recognized that the peaks are broadened in the spectrum from the Nb-doped $SrTiO_3$ layer. Comparing the theoretical ELNES calculated by the first principles relativistic multi-electron method with the experimental ELNES, it is found that the change in the experimental spectra is due to the transition from Ti^{4+} to Ti^{3+}, which is accompanied by doping Nb.

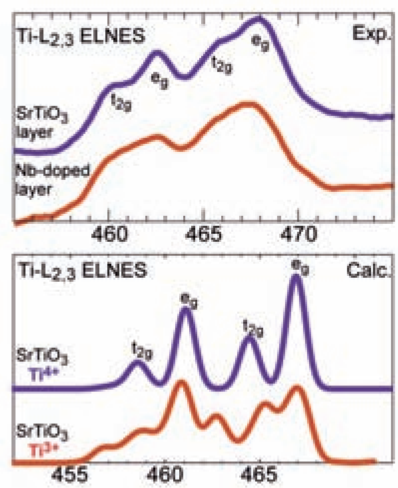

Fig. 12. (top) Experimental and (bottom) theoretically calculated Ti-$L_{2,3}$ ELNES obtained from the $SrTiO_3$ layer and the Nb-doped $SrTiO_3$ layer in the $SrTiO_3$/Nb-doped $SrTiO_3$ superlattice. The calculations were made by the first principles relativistic multielectron method.

8. Direct Observation of Li Ion Site in Lithium Battery [20)]

Lithium (Li) battery is widely used for the battery of cellular phone and personal computer. Recently, it is also intensively studied for the application of the automobile battery. The properties of Li battery are strongly dependent on the positive electrode active material. The cobalt or nickel-compounds such as $LiCoO_2$ or $LiNiO_2$ have been mainly used as industrial products so far. However, it has been pointed out that they have problems on the stability, lifetime, and reliability. $LiFePO_4$ with the stable olivine structure is therefore expected as the lithium battery for the next generation. Since the properties of the positive electrode active material is related to the behavior of Li ions in the crystal, direct visualization of Li site is needed to understand the mechanism of the properties. However, it is impossible to directly observe Li atoms even by HAADF-STEM technique because the atomic number 3 for Li is too small to scatter electrons. We therefore exchanged a part of Li sites with Fe atoms in $LiFePO_4$ crystal by chemical modification–annealing technique, and tried to directly observe the Li sites by HAADF-STEM. Figure 13 shows HAADF-STEM image for the $LiFePO_4$ crystals observed along the [010] direction. In the sample, about 15% of Li sites were substituted by Fe atoms [20]. In Fig. 13, the model crystal structure composed of Fe, Li, P, and O is shown, and the inset shows the simulated HAADF image for the olivine with 15% Li-Fe exchange. As can be seen in the image, Li sites, which are substituted by Fe atoms, can be observed as weak spots in the center of hexagonal framework composed of Fe and P. It is also found that such exchange defects appear to be locally aggregated rather than homogeneously dispersed in the crystal. In addition, the distribution of the exchange defect was not homogeneous in the vicinity of the grain boundaries, which indicates that the direct visualization of Li sites will clarify the behavior of lithium ions, conductor and breakdown mechanism of lithium battery in the future. Similar materials have been also characterized to determine the sites of “function providing elements” by the C*s*-STEM technique [21-23].

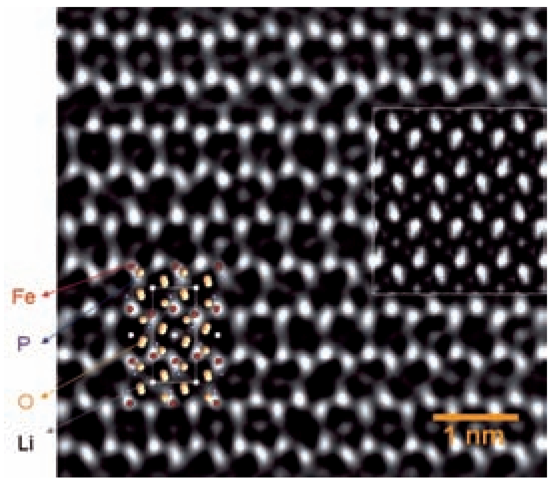

Fig. 13. HAADF-STEM image for the $LiFePO_4$ crystals, in which a part of Li sites was exchanged by Fe atoms, showing that some of the Li columns have a bright contrast in significant intensity [20]. The inset shows the simulated HAADF image for the olivine with 15% Li-Fe exchange.

9. Conclusion

Various kinds of dopants have been used for industrial materials to improve the functional and mechanical properties. However, many of such dopants have been considered and selected on the basis of the long-term experience and empirical background, and it is hence unclear for the effect of the function providing dopants on the atomistic mechanism. If the atomistic mechanism can be intrinsically understood, it will be possible to reasonably design material by controlling atoms, electrons, and function providing elements in the materials. The appearance of C*s*-corrected STEM enables us to determine the location of dopants and the local electronic states at a single atomic level.

In this paper, we introduce our recent results obtained for ceramic grain boundary and interface by Cs-corrected STEM. Several examples are demonstrated for the interfaces in semiconductor, gain boundaries of varistor and structural ceramics, dislocation in alumina, oxide superlattice, lithium battery and so on. These results indicate that the atomistic mechanism of the properties can be unraveled by combination of STEM characterization and the first principles calculations. This approach must be a breakthrough for new materials science and engineering in the next generation.

Acknowledgements

The authors would like to acknowledge the collaboration with Y. Sato, A. Nakamura, H. Ohta, S-Y. Choi, S-Y Chung, K. Matsunaga, W. Y. Ching, M.F. Chisholm, S.J. Pennycook and T. Hirayama. Part of this work was supported by the Grants-in-Aid for Scientific Research on Priority Areas "Nano Materials Science for Atomic-scale Modification" (No.19053001) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Reference

1) Y. Ikuhara Ed. "Physics of Ceramics" Nikkan-Kogyo-Shinbun Pub.Co. (1999).
2) Y. Ikuhara, J. Ceram. Soc. Jpn., **110**, 139 (2002).
3) M. Haider, H. Rose, S. Uhlemann, B. Kabius, and K. Urban, J. Electron Microsc. **47**, 395 (1998).
4) S. J. Pennycook and D. E. Jesson, Phys. Rev. Lett. **64**, 938 (1990).
5) P.D. Nellist, M.F. Chisholm, N. Dellby, O.L. Krivanek, M.F. Murfitt, Z.S. Szilagyi, A.R. Lupini, A.Y. Borisevich, W.H. Sides, and S. J. Pennycook, Science **305**, 1741 (2004).
6) Z. Wang, M. Saito, S. Tsukimoto, and Y. Ikuhara, Adv. Mater. In Press.
7) J. B. Casady and R. W. Johnson, Solid State Electron. **39**, 1409 (1996).
8) S. Tsukimoto, K. Nitta, T. Sakai, M. Moriyama, and M. Murakami, J. Electron. Mater. **33**, 460 (2004).
9) S. Tsukimoto, K. Ito, Z. Wang, M. Saito, Y. Ikuhara, and M. Murakami, Mater. Trans. **50**, 1071 (2009).
10) S. J. Pennycook and L. A. Boatner, Nature (London) **336**, 565 (1988).
11) Z. Wang, S. Tsukimoto, M. Saito, and Y. Ikuhara, Phys. Rev. B **79**, 045318 (2009).
12) Y. Sato, J. P. Buban, T. Mizoguchi, N. Shibata, M. Yodogawa, T. Yamamoto, and Y. Ikuhara, Phys. Rev. Lett. **97**, 106802 (2006).
13) Y. Sato, T. Yamamoto, and Y. Ikuhara, J. Am. Ceram. Soc. **90**, 337 (2007).

14) J. P. Buban, K. Matsunaga, J. Chen, N. Shibata, W.Y. Ching, T. Yamamoto, and Y. Ikuhara, Science **311**, 212 (2006).
15) H. Yoshida, Y. Ikuhara, and T. Sakuma, Acta. Mater. **50**, 2955 (2002).
16) N. Shibata, M. F. Chisholm, A. Nakamura, S. J. Pennycook, T. Yamamoto, and Y. Ikuhara, Science **316**, 82 (2007).
17) A. Nakamura, T. Yamamoto, and Y. Ikuhara, Acta Mater. **50**, 101 (2002).
18) A. Nakamura, K. Matsunaga, J. Tohma, T. Yamamoto, and Y. Ikuhara, Nature Mater. **2**, 453 (2003).
19) H. Ohta, S. W. Kim, Y. Mune, T. Mizoguchi, K. Nomura, S. Ohta, T. Nomura, Y. Nakanishi, Y. Ikuhara, M. Hirano, H. Hosono and K. Koumoto, Nature Mater. **6**, 129 (2007).
20) S.-Y. Chung, S.-Y. Choi, T. Yamamoto, and Y. Ikuhara, Phys. Rev. Lett. **100**, 125502 (2008).
21) S.-Y. Chung, S.-Y. Choi, T. Yamamoto, and Y. Ikuhara, Adv. Mater. **21**, 88 (2009).
22) R. Huang, T. Mizoguchi, K. Sugiura, H. Ohta, T. Saito, K. Koumoto, T. Hirayama, and Y. Ikuhara, Appl. Phys. Lett. **93**, 181907 (2008).
23) R. Huang, T. Mizoguchi, K. Sugiura, S. Nakagawa, H. Ohta, T. Saito, K. Koumoto, T. Hirayama, and Y. Ikuhara, J. Mater. Res. **24**, 279 (2009).

Overview of our spintronics group

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1. Introduction

The role that the semiconductor and the magnetic substance play in the electron device that supports today's information industry is very large. Both fields have been developed independently.

The discovery of a giant tunnel magnetoresistance effect [1,2] and the giant magnetoresistance effect of the metallic artificial superlattice [3,4] at room temperature became a trigger and not only the application of the magnetic substance proper of the old type but also the close-up of the research to take the contribution of conduction to the magnetism study has been made. On the other hand, the importance of the spin was recognized so that it was shown in the research of the magnetic semiconductor to break down the limit of an existing semiconductor device as for the research field of the semiconductor. The processing technique was made the best use of and the research of a new device is paid to attention in this field. Spintoronics is aimed at creating a new electron device, by paying attention to both the spin and the electric charge of the electron. And, the function of both to its maximum by using the latest processing technique is tried to be activated. The concept chart is shown in figure 1. In general, it tends to be distinguished from Spintoronics of the metal system and Spintoronics of the semiconductor system. However, the target in which it aims is the same. It is thought that the semiconductor system puts it aiming at ahead of that of tomorrow the metal system aimed at. For instance, GMR is only a metal system among GMR and TMR of the spin dependent conduction in the figure. A large magnetoresistance effect is reported about TMR in not only the junction of the metal system but also the junction using the ferromagnetic semiconductor. Moreover, the value increases every year.

This spintronics is a boundary research region that is new and wide in which both a magnetic technology and the semiconductor technology are the base. Therefore, it is impossible to deal only in an existing technological special region. It is a new field supported by quantum mechanics not to mention the fusion of the research of magnetism and the semiconductor field, interfacial physics, solid state spectroscopy, the crystal growth, and the field of engineering furthermore called micro-fabrication. By

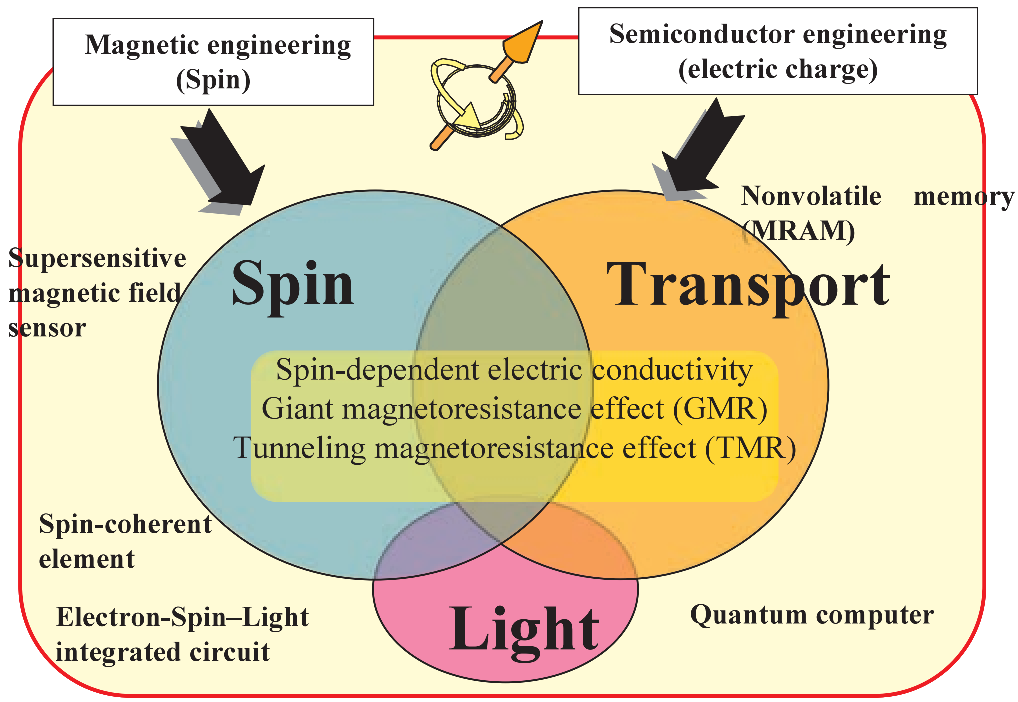


Fig. 1. Concept chart of spintoronics.

the way, the discovery of the GMR effect of the metallic artificial super-lattice gave a big impact to the artificial lattice researcher who had been expecting the new feature at that time. Because this effect was greatly big. It is clear because it is put to practical use as HDD read head before it is for ten years and it contributed to industry greatly. Further, the HDD read head using TMR junction was realized in 2004 and at present all the read head was replaced bu the TMR head.

On the other hand, magnetic memory MRAM (Magnetoresistive Random Access Memory) development has been increased every year, i.e., 1 kbit in 2000 (IBM), and 2 Mbit in 2004 (Motolola) and 16 Mbit in 2006 (Toshiba-NEC). However, power consumption is as large as about 4 mA per cell in switching of the magnetization due to the magnetic field by the conventional wiring current method. The achievement of the large capacity MRAM was considerably difficult by the cell structure. However, the reversal of magnetization was proven to be possible by spin transfer torque as will be mentioned in chap. 3, and the development of magnetic memory (especially, spin-RAM in distinction from the conventional type) has come to be paid to attention. The spin memory can be 4 kbit (Sony) [5] in 2005, and 2 Mbit in 2007 (Hitachi-Tohoku University) [6].In addition, using the cell of perpendicular magnetization to plane than in plane, an excellent spin-RAM technology has been made in the research of the most recently by Toshiba [7]. The research for the target has been studied intensely all over the world. The current trend from MRAM to spin-RAM is schematically shown in figure 2.

Our research objective is developing the basic technologies including finding a new material for out of plane magnetization Spin-RAM. The research thema running at present in our group is as follows.

1. Fabrication of new heusler alloy films with perpendicular magnetic anisotropy.
2. Investigation of spin transfer switching for various kinds of films with perpendicular magnetic anisotropy.
3. Measurement of spin dynamics for various kind of manetic thin films.

Detail for each theme will be explained in following chapters.

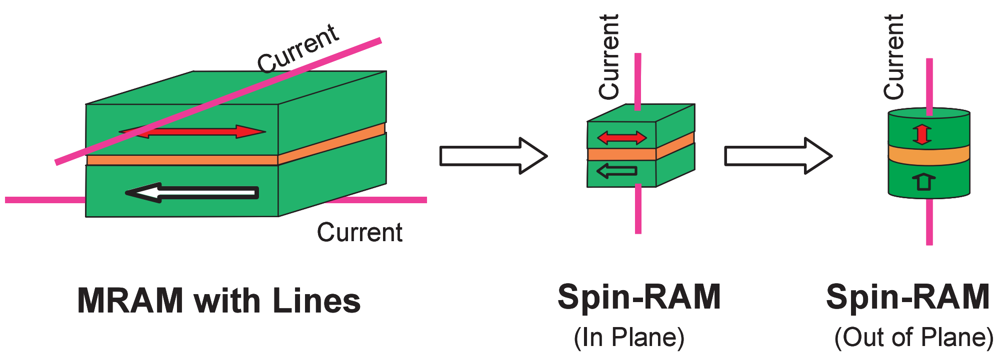


Fig. 2. Change of TMR cell in research of magnetic memory.

2. New Heusler alloy films with perpendicular magnetic anisotropy

Recently, tremendous progress has been achieved to improve the TMR ratio by using half-metallic ferromagnetic (HMF) materials as electrodes in the MTJ structures [8]. The HMF materials are characterized by an energy gap at the Fermi level (E_F) for the minority-spin band, leading to complete spin polarization at E_F. Up to now, various HMF films have been used, including CrO_2, (La, Sr)MnO_3, Hesuler alloy, etc. Notable among the HMF candidates are a number of the Heusler alloys owing to their high Cuire temperature, e.g. for Co_2MnSi it reaches 985 K, which is very important for devices' practical applications. The Heusler alloys are inter-metallic compounds with the stoichiometric composition and crystallize in the space group Fm3m with a unit cell composed of 4 interpenetrating FCC sublattices (Fig. 3(a)). The growth of TMR ratio of the MTJs with Heusler electrodes vs. year is presented in Fig. 3b. To realize gigabit-MRAM devices, the MTJs should have low critical switching current density and maintain high thermal stability factor [9].

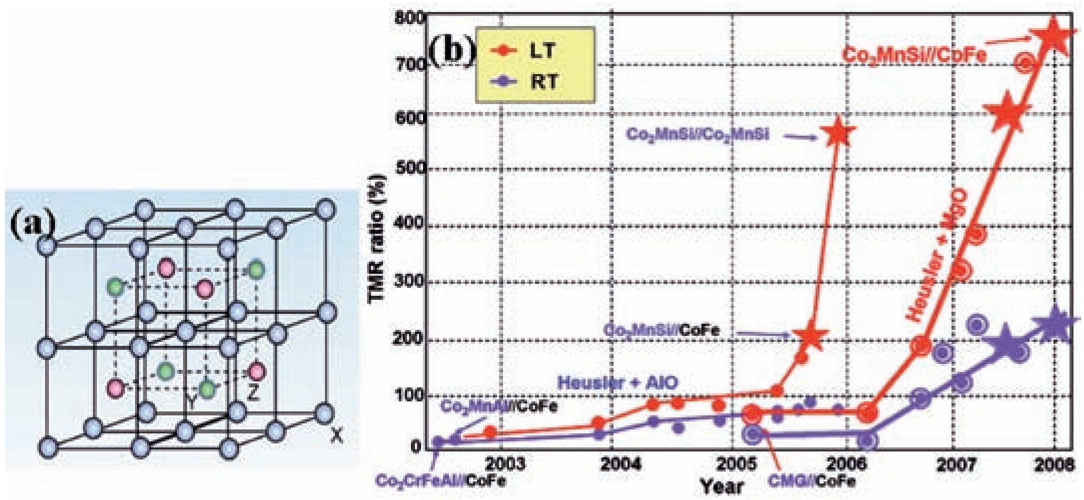


Fig. 3. (a) Crystal structure of Heusler alloy, (b) Development of TMR ratio of the MTJs with Heusler electrodes.

However, the MTJs with presently used Heusler electrodes can not satisfy such requirements due to following facts. Usually, the Heusler films with high spin polarization (*P*) values have high saturation magnetizations (M_s≈1000 emu/cm^3), and these materials naturally have their magnetization oriented in the film plane to avoid magnetic poles at the surfaces. On the contrary, the perpendicular MTJs (p-MTJs) made of materials with perpendicular magnetic anisotropy (PMA) has been put forward to solve such problems [10]. But, the reported TMR ratios of these p-MTJs are quite small since the low *P* value of presently known PMA materials. Therefore, it is strongly desired to explore new Heusler materials possessing large PMA, high *P* and low M_s simultaneously.

Mn_xGa (x=2~3) with DO_{22} structure has great potential to possess such superior properties owing to its special crystal and magnetic structure [11]. The DO_{22} structure is a tetragonal distorted DO_3 structure. Thus, DO_{22} structured Mn_3Ga can be viewed as being a tetragonally distorted binary Heusler compound. In this structure, an atomic layer of Mn and a layer containing both Mn and Ga atoms are arranged periodically along the *c*-axis (Fig. 4a). Classic neutron scattering experiments showed that this material had a ferrimagnetic structure, and the magnetic moments of Mn atoms at site I and II (Fig. 4a) was 2.8 ± 0.3 μ_B and 1.6 ± 0.2 μ_B, respectively. Consequently, a low M_s can be observed at room temperature though the Curie temperature is higher than

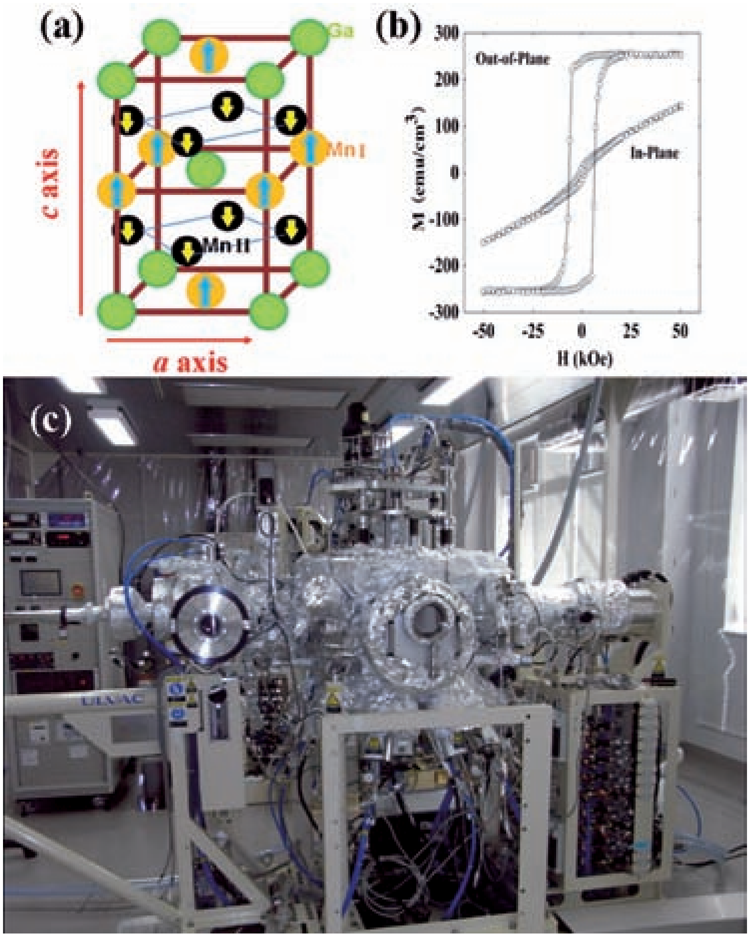


Fig. 4. (a) Crystal and magnetic structure of Mn_3Ga, (b) Photograph of dc magnetron sputtering equipment, (c) *M-H* curves of epitaxial $Mn_{2.5}Ga$ films.

770 K. The theoretically calculated *P* value, as high as 88% at the Fermi level, originates from the strong difference in conductivity for minority and majority electrons, which is a typical feature in type-III half metals. To better comprehend the intrinsic properties of this material and realize its practical applications, epitaxial $Mn_{2\sim3}Ga$ single crystalline films are preferable, although they are still unavailable.

In our group, we perform thin films preparation by dc magnetron sputtering equipment, as exhibited in Fig. 4b. Using this technique, epitaxial DO_{22} structured $Mn_{2.5}Ga$ films were successfully grown on Cr-buffered MgO substrates, although there are a few of crystalline structure existed in Mn-Ga binary system, i.e., DO_{19}, $L1_0$, etc. At optimum growth condition, the $Mn_{2.5}Ga$ film exhibits giant PMA property (K_u^{eff}=1.2×10^7 erg/cm^3) and low saturation magnetization (M_s=250 emu/cm^3) (Fig. 4(c)) [12].

Further experiments are being carried out to testify its high spin polarization. We believe that this new developed material will push forward the development process of gigabit-MRAM devices.

3. Spin transfer switching for junctions with out of plane magnetization

Manipulation of magnetic moments in a nano-scale ferromagnet with current is one of the most important techniques for future spintronics devices. Especially, current induced magnetization switching in MgO-based magnetic tunnel junctions (MTJs) makes a breakthrough for achieving gigabit-MRAM as a writing method.

The conduction electrons flowing through a fixed magnetic layer (F1 as shown in Fig.5 illustrates a MTJ using two magnetic layer and a metallic spacer) in a magnetoresistive device are spin polarized along the magnetization of F1. When these spin-polarized electrons pass through another ferromagnetic layer (F2), the polarization direction will change depending on relative orientation of F1 and F2. In this re-polarization process, the nanomagnet experiences a torque (called spin torque) associated with the transfer of a spin angular momentum from conduction electrons. On increasing the current, spin torque amplifies the cone angle of spin precession and leads to magnetic switching. In this case, the spin torque overcomes a magnetic damping. The magnetization of nano-sized free layer can be controlled by the flowing current direction (experimental result is shown in Fig. 6).

The critical current required for the spin transfer switching decreases as the free-layer volume decreases, while conventional writing method using magnetic fields generated by a current flowing in an extra wire needs a huge current due to a large coercive field of nanomagnet. Although the spin transfer switching have a potential to provide a

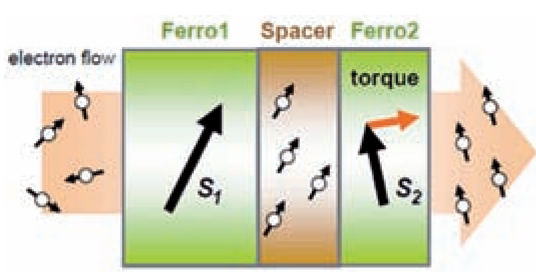


Fig. 5. Schematic illustration of spin transfer torque.

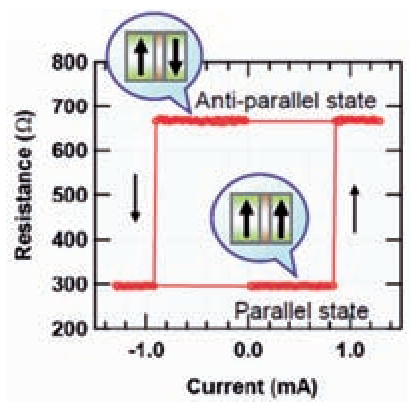


Fig. 6. Typical TMR loop driven by pulsed current.

gigabit-MRAM, the critical writing current should be reduced because of a bias current limitation of a CMOS transistor. According to a theoretical prediction [13] and related experiment [14], the critical current can be reduced by designing ferromagnetic materials to a low saturation magnetization, low damping constant and high spin polarization, while they should have a large magnetic anisotropy to maintain high thermal stability as a reliable device. Thus, perpendicularly magnetized ferromagnets having large magnetic anisotropy and its MTJs have attracted enormous studies in recent years.

In our works, perpendicularly magnetized ferrimagnetic materials and multilayer structures are focused because of its small saturation magnetization compared with conventional in-plane magnetized ferromagnet. The former is the MnGa of Heusler alloy as mentioned in previous chapter. The later is synthetic ferrimagnetic (SyF) structures consisting of perpendicularly magnetized CoCrPt, Ru spacer and high spin polarized CoFeB as shown in Fig. 7. The artificial ferromagnetic structure is expected that the CoCrPt gives a high perpendicular magnetic anisotropy (also thermal stability) to the CoFeB layer by interlayer exchange coupling through the Ru thin layer. Here, CoFeB generally provide a high output voltage in MgO-based MTJ.

The CoCrPt films prepared by dc magnetron sputtering system at low substrate temperature (T_s = 250ºC) were grown to c-axis orientation on a Ru buffer layer with a sufficient magnetic anisotropy (K_u^{eff} = 1.6 × 10^6 erg/cm^3) and low saturation magnetization (M_s = 350 emu/cm^3). By using the CoCrPt film in the SyF structure (CoCrPt/Ru/CoFeB), the interlayer exchange coupling perpendicular to the film plane was successfully observed after annealing at 300ºC as shown in Fig. 8. It was also

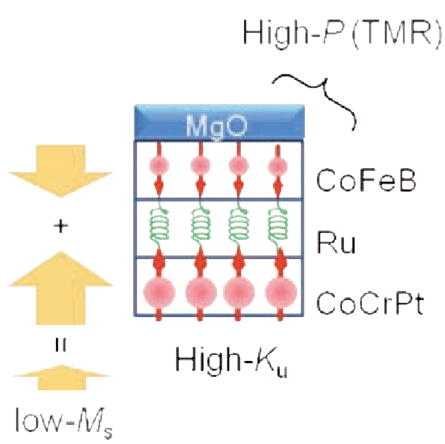


Fig. 7. Concept of perpendicular synthetic ferromagnetic structure

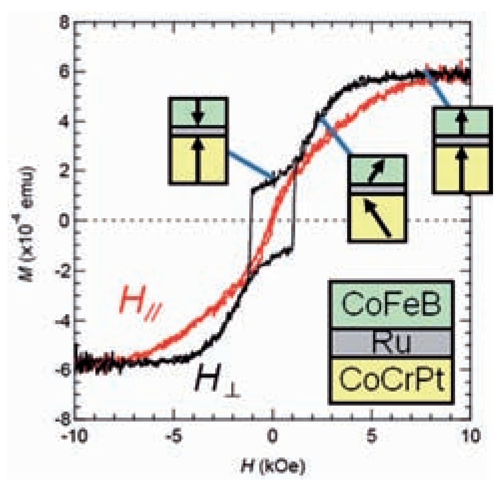


Fig. 8. Magnetization curves of SyF structure with magnetic field in-plane and perpendicular.

found out that the coupling strength depended on the Ru thickness as well as on the in-plane magnetized SyF structure. MgO-based MTJs having such SyF structures with CoCrPt layers were fabricated into micron order size by photolithography technique. They showed obvious changes in the resistance with magnetic field applied perpendicular to the film plane [15]. The resistance change ratio of 6.7% was observed primarily as shown in Fig. 9. We plan to optimize the growth condition and multilayer structure to obtain high TMR ratio and to perform the spin transfer switching of the perpendicular SyF-MTJ.

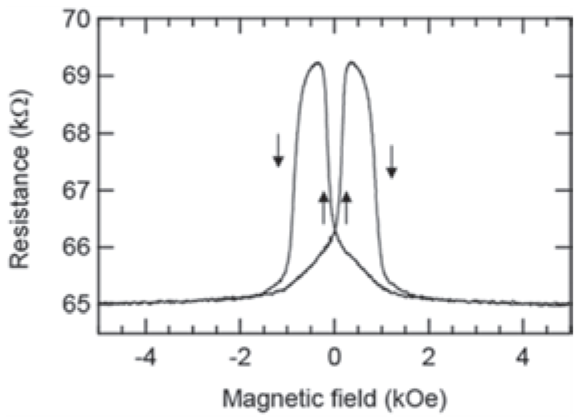


Fig. 9. TMR curves of the MTJ having SyF structures with magnetic field perpendicular.

4. Measurement of spin dynamics

Basic motion of magnetization in ferromagnets is damped precession around an internal magnetic field, which is similar to oscillation of a pendulum. Precession frequency is several GHz for the conventional ferromagnetic metals, eg. iron, while it exceeds more than 100 GHz in magnetic materials having large PMA field which is of the order of 10 kOe. Magnetization precession frequency determines the performances of spintronics devices, for example, output frequency of microwave generator made of a nano-scaled magnetic tunnel junction (MTJ) or writing speed for MTJ memory cells in MRAM. Furthermore, relaxation time of damped magnetization precession is also a key factor for devices, which is ruled by friction coefficient for magnetization motion, namely Gilbert magnetic damping constant. For example, the critical current density for spin-transfer switching in spin-RAM is proportional to the damping constant. Therefore, study on spin dynamics is one of the important issues in the field of spintronics. "All optical pump-probe detection" is the current state of art technique for the investigation of spin dynamics, which is based on pump-probe spectroscopy with ultrafast pulse laser. The motion of spins can be induced only by laser light pulse without any coils or inductor, which is required commonly to generate pulsed magnetic field in the other techniques. This coil-free method allows us to investigate spin dynamics with the time resolution down to hundred femtosecond (fs), whose equivalent frequency bandwidth is more than 1 THz. Figure 10 shows schematic illustration for principle of all-optical measurement.

When an intense light pulse hits on film surface, electron system is heated significantly within hundred fs, and then saturation magnetization and magneto-crystalline anisotropy suddenly decreases within several picoseconds (ps), which acts as ultra-short effective pulsed magnetic field and induces magnetization precession around an initial magnetization direction. Magnetization precession is observed by magneto-optical Kerr effect for probe light pulse with varying delay time against pump pulse [16].

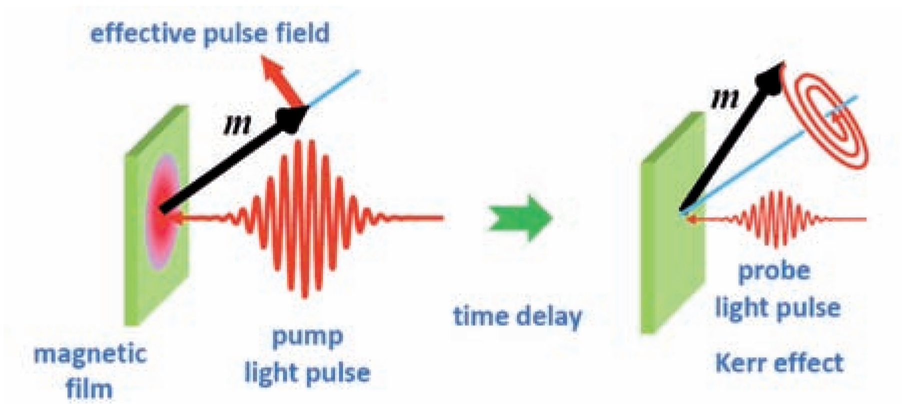
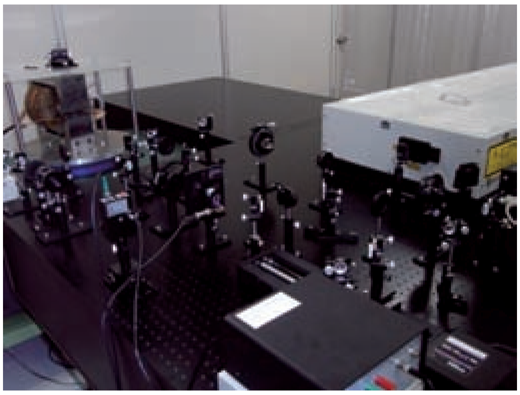


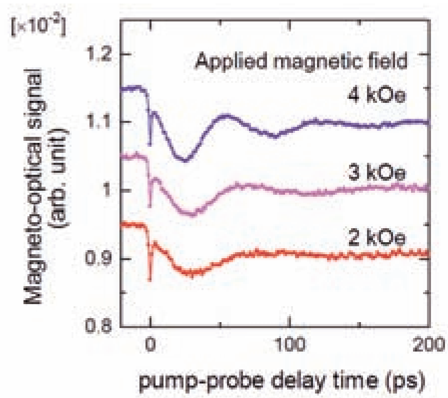
Fig. 10. Schematic illustration of measurement principle of all-optical detection of magnetization precession.

In our group we have constructed the set-up of all-optical pump-probe detection as shown in Fig. 11(a). Pulse light source is Ti:sapphire laser combined with a regenerative amplifier, where wavelength, maximum pulse energy, minimum pulse width, and repetition rate are 800 nm, ~1 mJ, ~100 fs, and 1 kHz, respectively. Laser beam is divided to pump and probe beam using beam splitter.

Pump beam moves towards the film through movable optical stage, by which we are able to vary delay time between pump and probe pulse. Polarization of probe beam is adjusted by polarizer before probe pulse moves towards the film, and rotation of polarization vector of probe pulse reflected by a film is detected sensitively by optical bridge consisting of wave plate, Wollaston prism (analyzer), and balanced photo-detector. Fig. 11(b) shows typical examples of all-optical pump-probe detection of magnetization precession for perpendicularly magnetized 4 nm thick CoCrPt alloy films deposited by magnetron sputtering on Ru/Ta buffered thermally oxidized Si substrate. Damped oscillations are shown clearly within hundred ps, and the period and decay time of oscillation varies systematically with various external field, from which we are able to determine various material parameters [17].

We are now investigating spin dynamics for magnetic thin films of transition metals, half-metals, PMA materials, and also we are constructing a new optical system combined with three axis vector superconducting magnet with maximum applied vector field of 2 T.





(a) (b)

Fig. 11. (a) Photograph of measurement set-up in the Integration Laboratory and (b) the typical data of all-optical detection of magnetization precession in CoCrPt alloy films with various external magnetic fields.

References

1) T. Miyazaki and N. Tezuka, J. Magn. Magn. Mater. **139**, L231 (1995).
2) J. S. Moodera, L. R. Kinder, T. M. Wong and R. Meservey, Phys. Rev. Lett.**74**, 3273 (1995).
3) G. Binasch, P. Grunberg, F. Saurenbach and W. Zinn, Phys. Rev. B **39**, 4828 (1989).
4) M. N. Baibich, J. M. Broto, A. Fert, F. Ngugen Van Dau, F. Petroff, P. Eitenne, G. Creuzet, A. Friederich and J. Chazelas, Phys. Rev. Lett. **61**, 2472 (1988).
5) M. Hosomi et al., IEDM Technical Digest., IEEE International 5-5, 459-462 (2005).
6) T. Kawahara et al., IEEE ISCC, 26.5 (2007).
7) M. Nakayama et al., J. Appl. Phys. **103**, 07A720 (2008).
8) Y. Sakuraba, M. Hattori, M. Oogane, Y. Ando, H. Kato, A. Sakuma, T. Miyazaki, Appl. Phys. Lett. **88,** 192508 (2006).
9) S. Ikeda et al, IEEE transactions of electron devices 54, 991 (2007)
10) S. Mangin, D. Ravelosona, J. A. Katine, M. J. Carey, B. D. Terris, and E. E.

Fullerton, Nature Mater. **5**, 210 (2006).
11) J. Winterlik, B. Balke, G. H. Fecher, and C. Felser, Phys. Rev. **B. 77,** 054406 (2008).
12) Feng Wu, Shigemi Mizukami, Daisuke Watanabe, Hiroshi Naganuma, Mikihiko Oogane, Yasuo Ando, and Terunobu Miyazaki, Appl. Phys. Lett. **94**, 122503 (2009).
13) J. C. Slonczewski, J. Magn. Magn. Mater. **159**, L1 (1996).
14) D. Watanabe, M. Oogane, S. Mizukami, Y. Ando, and T. Miyazaki, Jpn. J. Appl. Phys. **48**, 013001 (2009).
15) D. Watanabe, S. Mizukami, M. Oogane, H. Naganuma, Y. Ando, and T. Miyazaki, J. Appl. Phys. **105**, 07C911 (2009).
16) M. van Kampen, C. Jozsa, J. T. Kohlhepp, P. LeClair, L. Lagae, W. J. M. de Jonge, and B. Koopmans, Phys. Rev. Lett. **88**, 227201 (2002).
17) S. Mizukami, H. Abe, D. Watanabe, M. Oogane, Y. Ando, and T. Miyazaki, Appl. Phys. Express **1**, 121301 (2008).

Neutron scattering, a material-friendly tool for the study of novel materials at different time and length scales

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1. Introduction

The main experimental tool employed by our group is neutron scattering which is applied towards the study of atomic and magnetic structures and dynamics of novel materials ranging from quantum magnets, high-temperature superconductors, hydrogen storage materials and disordered alloys with unusual properties. In this report, following a brief introduction to neutron scattering, recent applications of various neutron techniques to probe the microscopic properties of materials will be provided as an example of the diverse nature of the field.

1-1 Why neutron scattering?

Neutron is an elementary particle and plays a role as glue inside a nucleus to stabilize individual atoms. One can free neutrons out of the nucleus either by fission reaction of ^{235}U in a reactor or by bombarding high energy protons into heavy atoms in a process called spallation that can produce intense neutron beam.

The neutron beam is an important tool for materials science. There are three distinct ways that the beam can be used for: neutron transmission, neutron absorption, and neutron scattering (see Fig. 1.).

Method of neutron transmission is often referred to neutron radiography or imaging. The neutron beam can penetrate materials easier than x-ray beam due to the charge neutrality. Furthermore, the absorption coefficient of neutrons is highly element-dependent. Thus, by taking a transmitted image of

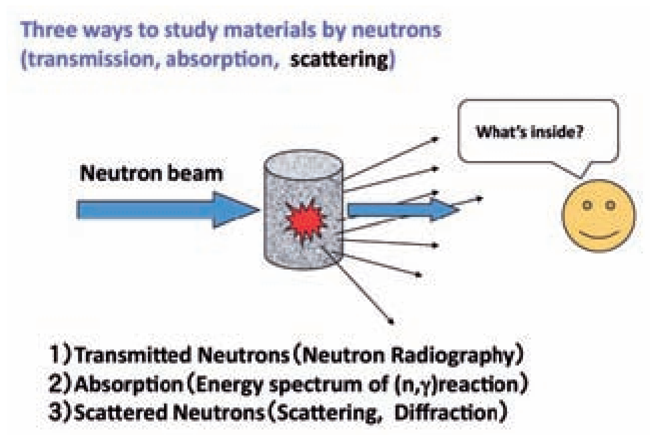


Fig. 1. Typical three techniques to investigate materials by using neutron beam

neutrons, one can study the status and motion of the different atoms in the material.

When neutrons are absorbed by an element in materials, gamma ray with a characteristic energy is emitted. By measuring energy and intensity of the emitted gamma rays one can identify and quantitatively determine amounts of different elements in materials even if the amount is tiny as long as the element absorbs neutrons.

Neutron scattering is the most popular technique among the three. Due to both the scattering effect and the interference effect of neutrons (Neutron has both character of particle and wave) one can analyze the atomic and magnetic structure and their dynamical motions in materials.

1-2 Why material-friendly?

Neutron scattering is a “material-friendly” or a “user-friendly” tool in the sense that neutron scattering techniques can be used for almost all the materials in nature with conditions under which the materials exhibit novel properties. Advantages of neutron beam over other scattering techniques originate from 1) its high material-transmittance, 2) its sensitivity to light elements such as hydrogen atoms and sensitivity to the isotopes, 3) its sensitivity to magnetic moments in materials, and 4) its sensitivity to the dynamical motion of atoms, molecules and magnetic moments. The last point (4) is the most unique property of the neutron scattering compared to other scattering techniques such as x-ray or electron scattering, and it will be discussed in more details later. It is also to be emphasized that the neutron scattering cross section is directly proportional to the two-body correlation function, often called dynamical structure factor, that contains the most detail information in understanding the collective phenomena in materials. As a result, neutron scattering provides invaluable framework in interpreting other data obtained by different experimental probes (Fig. 2.).

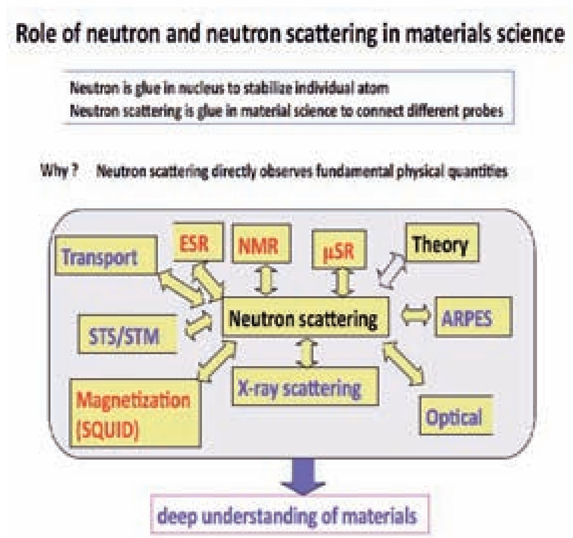


Fig. 2. Role of neutron scattering among different types of probes in material science.

1-3 Properties of neutron match the characteristics of materials

In nature, there are materials with different length and time scales. There is a general trend in their motion: materials with larger structural unit, such as polymers and biological molecules, move slowly (longer time or lower energy scale) than materials with smaller structural unit, such as atoms in a solid, move (shorter time or higher energy scale). Investigating structure and dynamics of a material, therefore, requires a probe with similar length and time scales. Properties of neutron nicely match the characteristics of materials in nature. As shown in Fig. 3, for a give wavelength the energy of neutron is much smaller than that of x-ray, and the energy of neutron is comparable to the characteristic energy of materials (see the red line in Fig.3). This provides neutron beam an enormous advantage in studying dynamics of materials. For example, in order to study the lattice vibrations of atoms in solids that have a characteristic length scale of ~ 1 A (10^{-10} m) and energy scale of 1 meV to 1 eV, we can use neutrons with similar length and energy scales. On the other hand, for x-ray beam with similar wavelength we need to use the energy of x-ray beam of ~ 10KeV that is much higher than the characteristic energy of the motions. Therefore, it is more difficult to study lattice dynamics with x-ray compared to with neutron because an ultra high energy-resolution of an order of 10^{-6} times the energy of x-ray is required to detect the small excitation energies of lattice dynamics. On the other hand, for neutron scattering since the energy is comparable to that of lattice dynamics an energy resolution of an order of 1~10% of the energy of neutron is sufficient. In the case of dynamics of magnetic moments, neutron has another advantage that other scattering techniques cannot compete: neutron has spin (x-ray does not have spin) and thus can interact with the magnetic moments in materials via dipole-dipole interaction. Thus, neutron scattering is the far best and realistic tool to investigate materials where magnetism plays an important role in their physics, such as magnetic materials and novel superconductors.

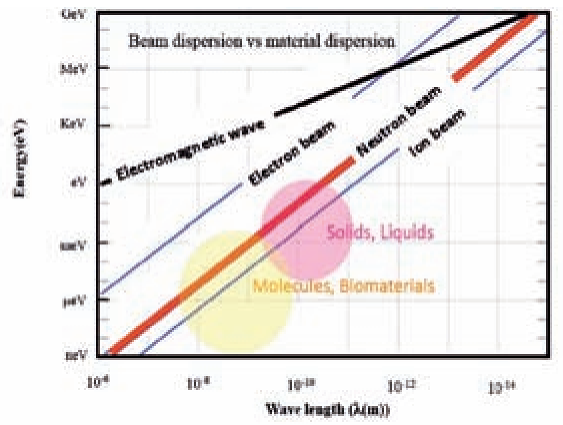


Fig. 3. Matching between beam dispersion and material dispersion for various types of quantum beams

1-4 What is dynamical structure factor S(Q,ω) ?

During the scattering process between neutrons and atoms or magnetic moments in materials, neutrons can loss or gain energy and momentum. In the experiment, we measure neutron scattering intensity as a function of energy (w) and momentum (**Q**) transfers. The intensity is directly proportional to the dynamical structure factor S(Q,**ω**) that is the Fourier transform of nuclear-nuclear (when neutrons interact with atoms) or spin-spin (when neutrons interact with magnetic moments) pair correlation function in time t and space r. When the scattering is elastic, i.e. neutron energy does not change during the scattering process, the static structure factor S(Q,**ω=0**) is measured, that provides information on time-averaged structure. When the scattering is inelastic, S(Q,**ω**) provides information on instantaneous correlations between atoms or magnetic moments in their motion.

2. Application of neutron scattering

2-1 Quantum magnets

Emergent dynamical spin molecules in geometrically frustrated magnets measured by inelastic neutron scattering

The concept of geometric frustration (GF) was first pointed out about 60 years ago by Wannier[1)] for the classical spin systems in the two-dimensional triangular lattice, and has attracted much interest as a paradigm to bring out novel magnetism. In a GF magnet, static magnetic ordering is highly suppressed because of the topology of the magnetic interactions. In many GF systems such as spinel, pyrochlore, kagome, triangular systems, however, at low temperatures a magnetic long-range order emerges accompanied by lattice distortion. It has been commonly considered that the effect of GF can be seen only in the paramagnetic phase. A pioneering neutron scattering work by Lee *et al*. clarified that the magnetic quasielastic scattering in the paramagnetic phase of Cr-spinels originates from the spatial correlation confined in antiferromagnetic fluctuating six-spin clusters (hexamers)[2)].

Our group has recently studied the nature of spin fluctuations in the long range ordered state and discovered similar dynamical spin molecules. First, we observed clear magnetic excitation multiplets in the ordered phase. Figure 4 shows the inelastic powder neutron scattering data taken by the pulsed neutron spectrometer INC in KENS at KEK. The two discrete levels of excitation are observed around E = 4.5 and 9.0 meV. By using single crystalline samples, we revealed the wave vector dependence of the intensity of each excitation for the first time. Very interestingly, it turns out that the

Q-dependence of each energy excitation can be almost perfectly reproduced by using spin correlations confined in spin molecules: the antiferromagnetic hexamer for the E = 4.5 meV mode and the antiferromagnetic heptamer for the E = 9.0 meV mode. by the antiferromagnetic heptamer (see Figs. 5 and 6).

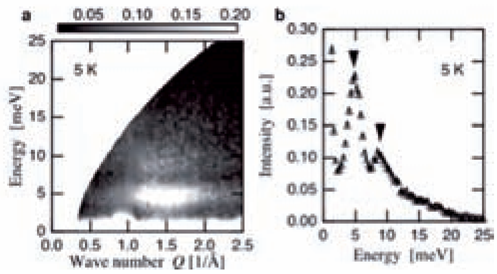


Fig. 4. Resonance-like magnetic peak measured by inelastic scattering on a powder specimen of $MgCr_2O_4$, (a) contour images in wave number and energy space and (b) energy spectrum at around Q=1.5 A^{-1}.

These results suggest the following two points. First, a geometrically frustrated magnet can have more than one magnetic excitation modes. Second, even though the lattice is distorted due to spin-lattice coupling in the ordered phase, magnetic excitations resemble the excitations in the undistorted paramagnetic phase. It is possible that both spin-lattice coupling and orbital hybridization might induce the local itinerancy of 3d electrons (charge freedom) within the molecules as the mechanism for the formation of the spin-molecule states. This situation is similar to the quantum resonance in benzene. Benzene is represented by the Kekule structure, in which every vertex possesses three branches (chemical bonds), but the molecular orbital hybridization with non-localized electrons stabilizes

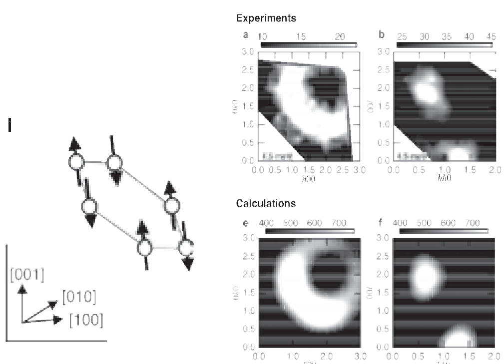


Fig. 5. The upper two panels show contour images of single-crystal inelastic neutron scattering intensities of $MgCr_2O_4$ measured at 4.5 meV at 6 K in the hk0 zone(left) and the hhl zone(right), respectively. The lower two panels show the corresponding calculated images based on the spin correlation confined in the hexamer shown in the left.

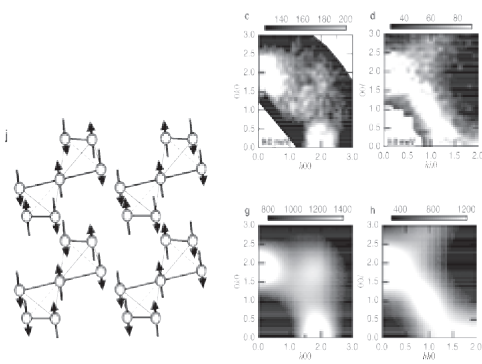


Fig. 6. The upper two panels show contour images of single-crystal inelastic neutron scattering intensities of $MgCr_2O_4$ measured at 9 meV at 6 K in the hk0 zone (left) and the hhl zone(right), respectively. The lower two panels show the corresponding calculated images based on the spin correlation confined in the heptamer shown in the left.

the resonance structure of the real benzene, as described by a circle in a hexagon in the chemical structure studied by Pauling[3] in 1939. This example clearly demonstrates how crucial neutron inelastic scattering technique is in the field of geometrical frustration. For the next project, we are planning to perform neutron scattering measurement to search for novel phonon modes that may be involved in the spin-lattice coupling in the Cr spinels.

K. Tomiyasu who was in our group until last March has conducted this neutron scattering study. The main part of this work has already been published in recent two papers in Phys. Rev. Lett. [4] and J. Phys. Soc. Jpn.[5] The inelastic neutron scattering data on single crystals were taken at several 3-axis spectrometers (HER, PONTA, TOPAN, and AKANE) located at the JRR-3 reactor.

References

1) G. H. Wannier: Phys. Rev. 79 (1950) 357.
2) S.-H. Lee, C. Broholm, W. Ratcli, G. Gasparovic, Q. Huang, T. H. Kim, and S.-W. Cheong, Nature (London) 418, 856 (2002).
3) L. Pauling, The Nature of the Chemical Bond and the Structure of Molecules and Crystals (Cornell Univ. Press, Ithaca, 1960), 3rd ed., Chap. 6.
4) K. Tomiyasu, H. Suzuki, M. Toki, S. Itoh, M. Matsuura, N. Aso and K. Yamada: Phys. Rev. Lett. 101 (2008) 177401.
5) K. Tomiyasu, H. Hiraka, K. Ohoyama and K. Yamada :J. Phys. Soc. Jpn. 77 (2008) 124703.

2-2 High temperature superconductors

Relationship between structure and superconductivity in $FeSe_{1-x}Te_x$

The recent discovery of superconductivity in the iron oxypnictide family of compounds has generated considerable interest in the mechanism of superconductivity.[1] In contrast to cuprate superconductivity, superconductivity in the ferrous compounds is highly dependent on the structural properties. Upon doping, several compounds exhibit a maximum in the superconducting transition temperature T_c when the $FeAs_4$ tetrahedral units become more regular where the As-Fe-As bond angle, $\alpha = 109.47°$ [2]. Whether or not this relationship is a universal feature of the ferric superconductor has not been verified yet, with only a few reports on the crystal structure analysis of materials with lower α angle (α>105°) such as in the recently discovered superconducting α-$FeSe_x$ system. The crystal structure of $FeSe_{0.92}$ is tetragonal (space group: *P4/nmm*) at room temperature, and the Se-Fe-Se angle of $FeSe_4$-tetrahedra at

~105° is considerably smaller than that of the iron oxypnictide family. T_c increases up to 27 K when a pressure of 1.48 GPa is applied on α-$FeSe_x$. Similarly, T_c increases when Se^{2-} is substituted with the isovalent Te^{2-} that introduces no charge carrier. Thus $FeSe_{1-x}Te_x$ is a suitable candidate for studying the effect of crystal structure on superconductivity since T_c is correlated to x. To determine the structural parameters of $FeSe_{1-x}Te_x$, we performed neutron powder diffraction experiments on the powder diffractometer for high efficiency and high resolution measurements, HERMES in IMR, Tohoku University, installed at the JRR-3M reactor in Japan.

We determined the crystal structural parameters of $FeSe_{1-x}Te_x$ (x= 0.5, 0.625, 0.75, 0.875) and FeSe. The relationship between T_c and X-Fe-X (X=As, P, Se and Te) angle is shown in Fig. 7 with data from other compounds. The T_c of the $FeSe_{1-x}Te_x$ system increases with increasing α, indicating that the bond-angle to T_c relationship is a universal feature and the crystal structure plays an important role in the ferric superconductor[3]. However T_c of FeSe clearly deviates from this relationship. To investigate this deviation further, we studied the temperature dependence of the z-position of the chalcogen ions, which is strongly coupled to the spin fluctuations according to theoretical calculations. The z-position of Se in FeSe shows a remarkable shift at low temperatures, indicating that strong spin fluctuations can degrade the superconductivity in FeSe.

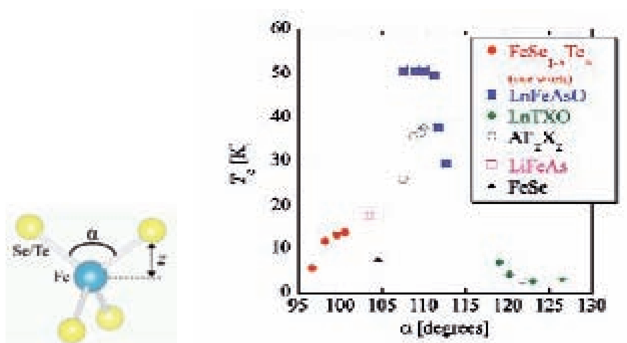


Fig. 7. X-Fe-X (X:As, P, Se and Te) angle α (left) dependence of superconducting transition temperature T_c.

The structural analysis additionally showed that the $Fe(Se,Te)_4$-tetrahedra are significantly distorted but become more regular under pressure while T_c goes up. Coupled with these measurements, we performed high-pressure resistivity experiments in $FeSe_{0.5}Te_{0.5}$ that has the higher T_c (=14K) at ambient pressure. Figure 8 shows the temperature dependence of the resistivity of $FeSe_{0.5}Te_{0.5}$ at various pressures up to 7.5 GPa. The onset temperature of T_c increases rapidly from 14 to 26 K up to 2 GPa and a metallic phase is observed at 4 GPa. This experiment presents the first observation of a phase transition from a superconducting to metallic phase on the P-T_c phase diagram.[4] In the ferric superconductors, magnetism is considered to be deeply involved into the superconducting mechanism. Thus neutron scattering is an important tool for determining not only the crystal structure but also the spin excitation spectrum in this class of compounds.

K. Horigane in our group conducted this neutron scattering study. The main part of this work was already accepted in two papers of J. Phys. Soc. Jpn. One of them was selected as a paper of the Editor's Choice (No15904). This work was done in collaboration with H. Hiraka and K. Ohoyama in IMR and N. Takeshita and Chul-Ho Lee in AIST.

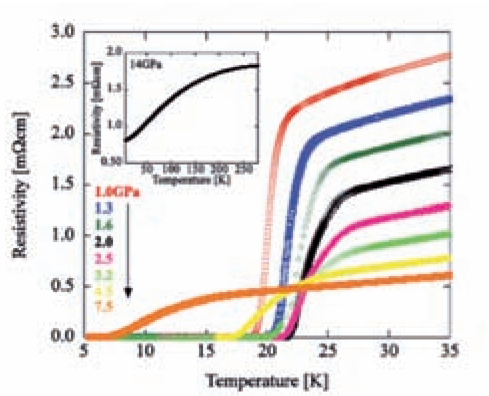


Fig. 8. Superconducting transition in $FeSe_{0.5}Te_{0.5}$ under high pressure. Inset shows the temperature dependence of electrical resistivity under 14GPa

References

1) Y. Kamihara, T. Watanabe, M. Hirano, and H. Hosono: J. Am. Chem. Soc. **130**, 3296 (2008).

2) C. H. Lee, A. Iyo, H. Eisaki, H. Kito, M. Teresa, F. Diaz, T. Ito, K. Kihou, H. Matsuhata, M. Braden, and K. Yamada: J. Phys. Soc. Jpn. **77**, 083704 (2008).

3) K. Horigane, H. Hiraka and K. Ohoyama: J. Phys. Soc. Jpn. in print.

4) K. Horigane, N. Takeshita, Chul-Ho Lee, H. Hiraka, and K. Yamada: J. Phys. Soc. Jpn. in print.

2-3 Hydrogen containing material (Ongoing project)

Investigations of hydrogen release mechanism in high gravimetric hydrogen density hydrides by neutron scatterings

Aluminum based complex hydrides (so-called alanates, e.g. $NaAlH_4$) have been extensively studied both experimentally and theoretically as candidate materials for hydrogen storage materials because of their high gravimetric hydrogen densities and their ability to undergo reversible reactions under moderate conditions (temperature and hydrogen pressure) and release hydrogen without impurity gases.[1,2] Syntheses of the alanates are, however, generally difficult because alanates are mostly thermodynamically unstable (i.e. low hydrogen release temperature). We have recently discovered a systematic synthesis method for the alanates by using mechanochemical milling of MH_n and AlH_3.[3)] Using the synthesis method, the first crystallographic characterization of $Ca(AlD_4)_2$ and $CaAlD_5$ have been performed by using powder neutron diffraction.[4] At the same time, the mechanism of hydrogen release from complex hydrides is still unknown. Presently, we are trying to experimentally clarify the mechanism of hydrogen release from the alanates (i.e. dynamics of hydrogen/diffusion path of hydrogen in the alanates) (see Fig. 9.) by using neutron scattering.

This project is supported by an "Exploratory Research Program for Young Scientists" at Tohoku University. T. Sato in our group is one of the principle members in this Program and we tightly collaborate with Orimo's group in IMR.

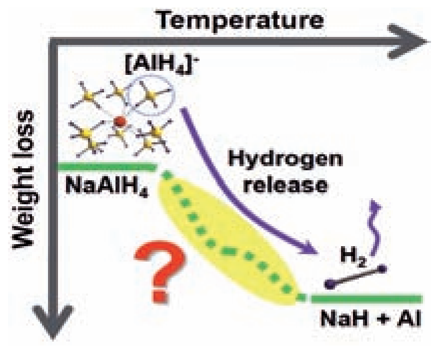


Fig. 9. Schematic of hydrogen release procedure from $NaAlH_4$

References

1) B. Bogdanović and M. Schwickardi, J. Alloys Compd. **253-254**, 1 (1997).
2) S. Orimo, Y. Nakamori, J.R. Eliseo, A. Züttel, and C.M. Jensen, Chem. Rev. **107**, 4111 (2007).
3) T. Sato, K. Ikeda, H.-W. Li, H. Yukawa, M. Morinaga, and S. Orimo, Mater. Trans. **50**, 182 (2009).
4) T. Sato, M.H. Sørby, K. Ikeda, S. Sato, B.C. Hauback, and S. Orimo, Inorg. Chem. Submitted.

2-4 Metallic glass alloys (Ongoing project)

Short-to-intermediate range atomic order of protonated Ni-Nb-Zr glassy alloy by total neutron scattering

In spite intense interest in metallic glasses as potential materials in a variety of engineering application, details of their microscopic structure and its relation to the physical properties remains a mystery. Motivated by the recent discovery of a mysterious phenomenon in the electrical resistivity of the metallic alloy of $(Ni_{42}Nb_{28}Zr_{30})_{1-x}H_x$, in which a *dc* current-induced *ac* oscillation of the voltage was observed[1], we commenced a total neutron scattering study to investigate the local structure and the effects due to the protons in the glassy alloy. In order to characterize the short-to-intermediate range order structure, we employed the atomic pair distribution function (PDF) analysis. For disordered materials, the PDF method of analysis is preferred because it does not assume a crystal periodicity and the sharp PDF peaks in real space are more suitable for fitting parameters than the broad diffraction peaks in reciprocal space[2]. In order to obtain a well-defined PDF pattern, however, it is necessary to collect data as high in momentum transfer as possible to avoid termination errors from the limited momentum range. Last year, we performed the first neutron experiment on this system by using SANDALS, the total scattering instrument at ISIS in Rutherford Appleton National Laboratory.

The experiment was performed by S. Iikubo, a member of our group last year in collaboration with Inoue's group in WPI, M. Fukuhara and Ohoyama in IMR and K. Tomiyasu in Department of Physics in Tohoku University.

References

1) M. Fukuhara, A. Kawashima, S. Yamaura, and A. Inoue, Appl. Phys. Lett. **90**, 203111 (2007).

2) T. Egami, S. J. L. Billinge, Underneath the Bragg Peaks Structural Analysis of Complex Materials, Pargamon: Amsterdam, 2003

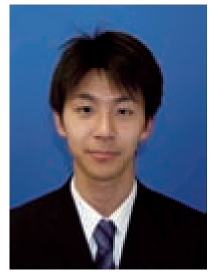
3. Future of neutron scattering

Two new spallation neutron sources have been commissioned last year, one in Japan and another in the UK. The facility is located in the JAEA campus in Tokai and is operated by two organizations, JAEA and KEK. Prior to these two sources, the Oak Ridge National Laboratory in the USA commissioned and is now operating a pulsed neutron source, the SNS. Therefore, neutron scattering science has entered a new era. Presently in Japan, with two types of neutron sources for material researches, J-PARC with its pulsed source and the steady neutron research reactor JRR-3, the neutron science community has an unprecedented opportunity. The complementary use of both types of neutron sources will contribute to the development not only in materials science and technology, but also in the education of young scientists who will become the leaders for new scientific endeavors.

WPI-AIMR

Newly Appointed Research Staff

Hiroyuki FUJII



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CURRENT RESEARCH:

✦ Simulation and Theory of Glass transition
✦ Study of supercooled liquids on ternary metallic glasses by molecular dynamics simulations

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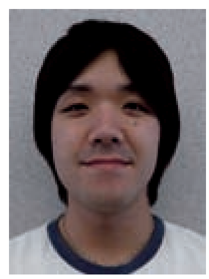

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1973-1976	Assistant Professor, University of Pennsylvania, USA
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2003-present	UT-ORNL Distinguished Scientist/Professor and Director, Joint-Institute for Neutron Sciences, The University of Tennessee, USA

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✦ John Wheatley Scholar, Los Alamos National Laboratory (2002)

✦ Bertram Eugene Warren Diffraction Physics Award, Amer. Crystallographic Assoc. [Festschrift in Z. Krstallogr. No. 3, 117-185 (2004)] (2003)

✦ Senior Researcher Prize, International Symposium on Metastable and Nano Materials (ISMANAM) (2006)

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2003-2008	Research Director, JST/SORST
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✦ Asahi Award, The Asahi Shinbun Cultural Foundation, Japan (1996)
✦ Tsukuba Prize, The Science and Technology Promotion Foundation of Ibaraki, Japan (1999)
✦ J.C.McGroddy Prize for New Materials, American Physical Society (2002)
✦ Agilent Europhysics Prize, European Physical Society (2002)
✦ Benjamin Franklin Medal in Physics, The Franklin Institute (2002)
✦ Honorary Doctor of the University of Antwerp (2002)
✦ Japan Academy Award and Imperial Award, The Japan Academy (2002)
✦ Honorary Doctor of Ecole Polytechnique Federale de Lausanne (2003)
✦ Person of Cultural Merits, Japanese Government (2003)
✦ Society's Medal of Achievement in Carbon Science and Technology, The American Carbon Society(2004)
✦ Honorary Professor of Peking University (2005)
✦ Gregori Aminoff Prize in crystallography 2007, Royal Swedish Academy of Sciences (2007)
✦ Fujiwara Award, The Fujiwara Foundation of Sciences, Japan (2007)
✦ Foreign Associate, National Academy of Sciences, USA (2007)
✦ 2007 Balzan Prize for Nanoscience, International Balzan Prize Foundation, Italy and Switzerland (2007)
✦ The Kavli Prize Nanoscience 2008, The Kavli Foundation, Norway (2008)
✦ The Prince of Asturias Award for Technical Scientific Research 2008, The Prince of Asturias Foundation, Spain (2008)
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2003-present	Professor, Head of Structural Chemistry, Stockholm University, Sweden
2009-present	Invited Guest Professor of WCU, Graduate School of EEWS, KAIST, Republic of Korea

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1982-1984	Guest Research Fellow of the Royal Society (UK). University of Cambridge
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2007	Guest Professor, Waseda University, Japan
2008	Honarary Professor, Jilin University, P.R. China

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- ✦ Y.S. Kuno Prize, Honor Prize of Tohoku University (1964)
- ✦ First Place, Int Metallographic Exhibit in the electron microscopytransmission class (International Metallographic Society and American Society for Metals) (1982)
- ✦ Seto Award, Award of Japanese Society of Electron Microscopy (1993)
- ✦ Daiwa Adrian Prize, Daiwa Anglo-Japanese Foundation, London (1996)
- ✦ The Best Paper Award, Japanese Society of Electron Microscopy (2001)
- ✦ Friendship Award, State Administration of Foreign Experts Affairs of the P.R. China (2003)
- ✦ The Donal W Breck Award, International Zeolite Association (2007)
- ✦ Humboldt Research Award, Alexander von Humboldt Foundation (2008)

WPI-IFCAM

WPI-IFCAM

International Frontier Center for Advanced Materials (IFCAM) was inaugurated in Institute for Materials Research (IMR), Tohoku University, in October 2001 to function, simply stated, as the world-first “materials science think-tank.” With wise steering by past directors, IFCAM has been performing well in its mission until now by 1) bringing in many world-renown researchers to IMR in the greater field of materials science/engineering, 2) enlightening / encouraging young scientists, post-doctoral fellows and graduate students by organizing and supporting workshops/summer schools, and 3) establishing and coordinating IFCAM branch offices around the world, including those in Cambridge University, Harvard University, Stanford University, and Institute of Physics, P.R. China.

We were also so fortunate to have had a government initial-equipment fund in 2002 to acquire several advanced tools, such as 3-dimention atom-probe tomography (3-D AP) and low energy electron microscope (LEEM). With untiring effort of able faculty members and their staff / graduate students, the LEEM program of IFCAM, for instance, has quickly become one of the most active and successful research centers in the world.

Realizing that IFCAM and newly established WPI-AIMR have essentially the same mission: namely, further promote international collaboration and cooperation in innovative research on advanced materials on a global bases, IFCAM was transferred from IMR to WPI-AIMR, effective of April 2008.

Briefly stated, WPI-IFCAM has following function and service.

1. Visiting Professorship
2. Workshops / summer schools

Ⅰ. Visiting Professorship

Qualified researchers who may be interested in IFCAM visiting professorship should first contact the WPI principal investigator(s) of the related research fields. Your contact PIs will initiate the further process to materialize the joint research.

(1) Tenure: For a period of minimum one month to a maximum of 3 months.

(2) Financial: The salary varies, depending on the qualifications, based on the Tohoku University regulations. Roughly speaking, “full professor” receives Y600,000 per month and “Associate Professor” receives Y500,000 per month.

Ⅱ. Workshops / summer schools

WPI-IFCAM will financially support the workshops and summer schools, if the scientific aims are along the WPI-AIMR missions. For more information, please contact WPI Administrative Office.

2009-2010 WPI-IFCAM Visiting Scholars

	Candidate	Host	Position	Term							Term	Affiliation	Position	Graduated from	Diploma	Nationality	Age	Research Proposal
				From			~	Through										
1	CHALLAPALLI, Suryanarayana	A. Inoue	Visiting Professor	H21	4	13	~	H21	7	12	3m	University of Central Florida	Professor	Banaras Hindu University, India	Ph. D	USA	64	Synthesis, Processing, and Characterization of Nanomaterials and Bulk Metallic Glasses
2	LEE, Seung-Hun	K. Yamada	Visiting Professor	H21	5	28	~	H21	7	15	1m18d	University of Virginia	Professor	Johns Hopkins University, USA	Ph. D	South Korea	45	Novel quantum phenomena in complex transition metal oxides
3	TEIZER, Winfried	T. Adschiri	Visiting Associate Professor	H21	6	1	~	H21	8	31	3m	Texas A&M University	Associate Professor	University of Massachusetts, USA	Ph. D	Austria	38	Biophysical applications of magnetic nanoparticles
4	JIA, Jinfeng	M. Chen & T. Hashizume	Visiting Professor	H21	7	1	~	H21	9	30	3m	Tsinghua University	Professor	Peking University, P.R. China	Ph. D	P.R. China	43	Growth mechanism of Pb film by LEEM and LTSTM
5	WANG, Weihua	M. Chen & A. Inoue	Visiting Professor	H21	7	15	~	H21	10	14	3m	Institute of Physics, Chinese Academy of Sciences	Professor	Institute of Physics, Chinese Academy of Sciences, P.R.China	Ph. D	P.R. China	46	Understanding of deformation mechanism of bulk metallic glasses
6	XU, Wenlian	M. Chen	Visiting Associate Professor	H21	7	15	~	H21	10	14	3m	Johns Hopkins University	Research Scientist	Monash Uinversity, Australia	Ph. D	P.R. China	43	Explore the potency of Surface-Enhanced Raman Scattering in the detections of bio-molecular markers
7	ORESHKIN, Andrei Ivanovich	T. Hashizume	Visiting Professor	H21	9	4	~	H21	12	3	3m	Moscow State University	Research Fellow	Moscow State University	Ph. D	Russia	42	
8	CHEN, Ho Sou	A. Inoue	Visiting Professor	H21	10	1	~	H21	11	30	2m	Bell Laboratories, Lucent Technologies	Adviser	Harvard University, USA	Ph. D	USA	76	Development of mechanical properties by fundamental approaches of fragility and relaxation control in metallic glasses.

Announcement

Daily Tea-Time (Get together)

In order to facilitate free discussions among different specialties, tea time will be set every day starting from September 1st, 2009, during 5-6 p.m. (except Saturday, Sunday & holidays) in the 5th floor of the Integration Laboratory in Katahira Campus.

All researchers of WPI-AIMR are expected to come to the tea time at least on Friday afternoon.

Director Professor Yamamoto

Grenoble 25 - 28 August 2009

WPI-Europe Workshop on Metallic Glasses and Related Materials

Preliminary Program

(At the Maison du Tourisme- Grenoble)

Tuesday 25

19:30	*Welcome dinner and Registration (departure from Hotel d'Angleterre)*

Wednesday 26

09:10	*Registration*
09:20	Michel Pons: Opening remarks
09:25	A. L. Greer (UK)
09:55	D. H. Kim (Korea)
10:25	K. Georgarakis (Japan/France)
10:45	*Coffee break*
11:00	M W. Chen (Japan)
11:30	K. Nakajima (Japan)
11:50	D. Dudina (Russia)
12:05	A. Caron (Germany)
12:20	T. Narumi (Japan)
12:35	*Lunch break*
14:00	J.Z. Jiang (China)
14:30	Y. Yokoyama (Japan)
14:50	K. Hajlaoui (Tunisia)
15:10	Q. Zhang (Japan)
15:25	C.L. Qin (Japan)
15:40	S. Vaucher (Switzeland)
15:55	A. Novakova (Russia)
16:10	Closure
16:20	*Bus departure for Mountain Visit (departure from conference site)*
19:20	*Return from Mountain Visit*

Grenoble 25 - 28 August 2009

WPI-Europe Workshop on Metallic Glasses and Related Materials

Thursday 27

9:10	H. Fecht (Germany)
9:40	T. Zhang (China)
10:10	C. Lekka (Greece)
10:30	J. J. Blandin (France)
10:50	*Coffee break*
11:05	R. Tournier (France)
11:25	M. Tokuyama (Japan)
11:45	E. Blanquet (France)
12:05	N. Lupu (Romania)
12:25	T. Spassov (Bulgaria)
12:45	*Lunch break*
14:00	M. Atzmon (USA)
14:30	G. Vaughan (France)
14:50	A. Takeuchi (Japan)
15:10	M. Brunelli (France)
15:25	L. Xu (Japan)
15:40	N. Chen (Japan)
15:55	*Bus departure for lake excursion and banquet*
22:20	*Return from lake excursion and banquet*

Friday 28

09:10	A. Inoue (Japan)
09:40	W. J. Botta (Brazil)
10:10	M. Stoica (Germany)
10:30	*Coffee break*
10:45	G. Evangelakis (Greece)
11:15	D. Rodney (USA)
11:35	D. Louzguine (Japan)
11:55	M. Calin (Germany)
12:15	K. Laws (Australia)
12:35	*Lunch*
14:00	D. Miracle (USA)
14:30	J. Perepezko (USA)
15:00	L. Battezzati (Italy)
15:30	J. Antonowicz (Poland)
15:50	*Coffee break*
16:05	D. J. Browne (Ireland)
16:25	M. Aljerf (France)
16:40	G. Goerigk (Germany)
16:55	D. Pan (Japan)
17:10	Y. Terada (Japan)
17 :25	K-W. Park (Korea)
17:40	General discussion
18:00	*Workshop Closure*

***Poster Presentations**: Posters will be exposed in front of the Workshop conference hall in permanence during the Workshop, in the same area where we will hold coffee breaks.*

Poster presentations

Punching surface patterns onto aluminium foils using BMG stamps surface-structured in the super-cooled liquid temperature range
M. Aljerf, A. LeMoulec, J. P. Gabathuler, P. Deneuville, A. R. Yavari.

Cu rich nanostructured alloys with enhanced mechanical properties
K. Georgarakis, K. Ota, A. LeMoulec, F. Charlot, A.R. Yavari, G. Vaugan, A. Inoue.

Atomic structure of Zr-Cu based amorphous alloys and the effect of Al and Ti addition using synchrotron radiation in transmission
K. Georgarakis, A. R. Yavari, D.V. Louzguine, A. Le Moulec, G. Vaughan, A. Inoue.

Chill-Zone Aluminum Alloys with GPa Strength and Good Plasticity
Y. Li, K. Georgarakis, S. Pang, M. Aljerf, J. Antonowicz, A. LeMoulec, A. R. Yavari, T. Zhang.

Isothermal and continous heating study of nanocrystallization kinetics in Finemet-type alloys
H. Asghari Shivaee, Alberto Castellero, Hamid Reza Madaah Hosseini, Marcello Baricco.

Magnetic Properties of Amorphous Alloys of Rhenium with Rare-Earth Metals
A. V. Bondarev, V. V. Ozherelyev, I. L. Bataronov, A. I. Bocharov and Y. V. Barmin.

Multilayer Structures on ZrAlNiCu Bulk Glasses Induced by Pulsed Electron Beam Surface Treatments
J. Wu, N. Allain-Bonnasso, S. Hao, T.Grosdidier, and Ch. Dong.

Study of mechanical property of iron rich metallic glasses prepared by melt spinning method
S. Habibi and A. Baharvand.

Simulation Study of Relation between Long-time Self Diffusion and Local Structure in CuZr
Y. Kimura and M.Tokuyama.

Thermoactivated crystallization of a new $Ni_{88}Si_7B_{3,5}Fe_{0,5}Cr_1$ amorphous alloy
T. Yu Kiseleva, A. O. Polyakov, G. N. Kozhemyakin, D. A. Kolesnikov, O.N. Maradudina.

Microwave Crystallization of Amorphous $Fe_{85}B_{15}$ Alloys: Time-Resolved Synchrotron Radiation X-ray Diffraction Experiments
R. Nicula, K. Ishizaki, M. Stir, and S. Vaucher.

Surface and Metallic Glass: two aspects of the influence of a surface treatment on a metallic glass.
J. Paillier, A. Gebert, P. F. Gostin, O. Gutfleisch, M. Uhlemann, L. Schultz.

Magnetic Behaviour and Crystallization Kinetics of FeBSi, A Metallic Glass
A. Rosales–Rivera, O. Moscoso–Londoño , and D. Muraca.

Glass-Crystal Composites in La-Zr-Cu-Ni-Al Alloys

S. V. Madge

Shear band melting and serrated flow in metallic glasses
M. Aljerf, K. Georgarakis, Y. Li, A. LeMoulec, A. R. Yavari, G. A. Evangelakis, D. B. Miracle, A. L. Greer, T. Zhang.

Shear band melting in metallic glasses
K. Georgarakis, A. R. Yavari, K. Chornokhvostenko, Y. Li, M. Aljerf, A. Inoue.

Structural characterization and thermodynamic properties of LiBH4-MgH2 complex hydride system
A. El Kharbachi, I. Nuta, C. Chatillon, A. R. Yavari.

Glass Formation in the Nb-Si binary system
K. Georgarakis, Y. Li, M. Aljerf, D. Dudina, A. LeMoulec, A. R. Yavari, D. V. Louzguine-Luzgin, G. Vaughan, A. Inoue.

Junior Faculty/Post-doctoral Positions

Tohoku University
WPI-AIMR

Effective October 1, 2007, Tohoku University created a new Research Institute, the Advanced Institute for Materials Research (AIMR), based on an initiative of the Japanese Department of Education (MEXT) for World Premier International Research Center Initiative (WPI) to bring together scientists involved in research on nano-science and technology.
In the 21st century, material science, broadly defined as the study of how complex/novel properties arise in matters/materials from the interactions of individual components, will comprise of inter-discipline collaboration.
(*HTTP://WWW.WPI-AIMR.TOHOKU.AC.JP*).
Over the next few years, as many as one hundred new appointments at the levels of post-doctoral fellows and junior faculty will be available. All innovative researchers are welcome as active promoters of basic/applied sciences in the fields of physical metallurgy, physics, chemistry, precision mechanical engineering and electronic / informational engineering.

We are continuously looking for excellent applicants throughout the year.
Please submit
1) **a curriculum vitae,**
2) **research proposal (<3,000 words),**
3) **summary of previous research accomplishments (<2,000 words),**
4) **copies of 5 significant publications, and**
5) **2 letters of recommendation**

by email to **yoshi@mail.tains.tohoku.ac.jp,**
sakurai@imr.tohoku.ac.jp, and
wpi-office@bureau.tohoku.ac.jp.
All files must be submitted electronically in pdf or Word format.

Applications from, or nominations of, women and minority candidates are encouraged. Tohoku University WPI-AIMR is an affirmative action / equal opportunity employer.

Graduate Student scholarship
In Materials Science/Engineering

WPI-AIMR
Graduate Student scholarship

Effective October 1, 2007, Tohoku University created a new Research Institute, the Advanced Institute for Materials Research (AIMR), based on an initiative of the Japanese Department of Education (MEXT) for World Premier International Research Center Initiative (WPI) to bring together scientists involved in research on nano-science and technology.
In the 21st century, material science, broadly defined as the study of how complex/novel properties arise in matters/materials from the interactions of individual components, will becomes an essential and most important research topics
(*HTTP://WWW.WPI-AIMR.TOHOKU.AC.JP*).
TU WPI-AIMR is now looking for young motivated Ph.D. graduate student candidates in the fields of physical metallurgy, physics, chemistry, mechanical engineering and electronic / informational technology. All innovative M. S. students are welcome as active promoters of basic/applied sciences in these fields.

Applications are continuously screened throughout the year.
Please submit
1) **a curriculum vitae,**
2) **research proposal (<1,000 words),**
3) **2 letters of recommendation,**

by email to
yoshi@mail.tains.tohoku.ac.jp,
sakurai@imr.tohoku.ac.jp, and
wpi-office@bureau.tohoku.ac.jp.
All files must be submitted electronically in pdf or Word format.

WPI-AIMR

Workshop Guideline

Tohoku University's new Research Institute, the Advanced Institute for Materials Research (WPI-AIMR) solicits several applications per year for International Workshops in the field of "broadly defined Materials Science."

Guidelines:

1) Organizers

Qualified research staff of academic institutions and public or private research establishments can submit the application for an international workshop to be held at WPI-AIMR or its Satellite branches, jointly with the WPI-AIMR principal investigator(s) whose research interest overlaps with the scope of the workshop.

2) Financial support

Under normal circumstances, WPI-IMR supports up to 2/3 of the workshop budget, while the organizer is expected to cover the rest.

3) deadline

The application must be received at least four months in advance

to

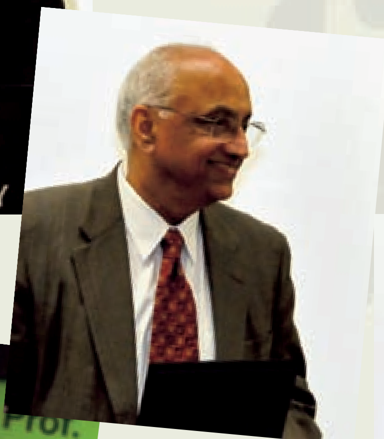
yoshi@mail.tains.tohoku.ac.jp,
sakurai@imr.tohoku.ac.jp, and
wpi-office@bureau.tohoku.ac.jp.
All files must be submitted electronically in pdf or Word format.

Appendix

Dr. M. Matsuo's seminar on May 22, 2009

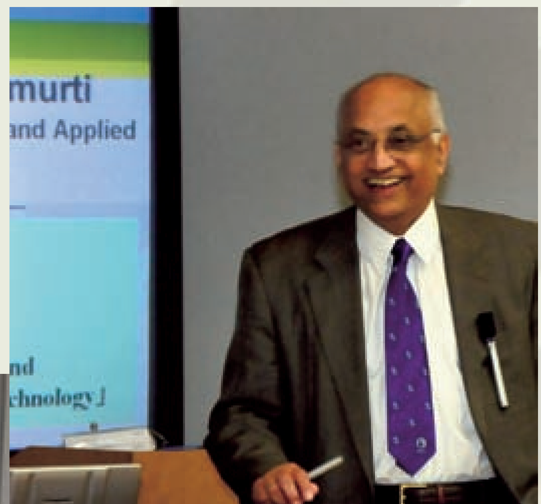
Honorary Degree Ceremony for Prof. V. Narayanamurti on May 22, 2009


東北大学
TOHOKU UNIVERSITY



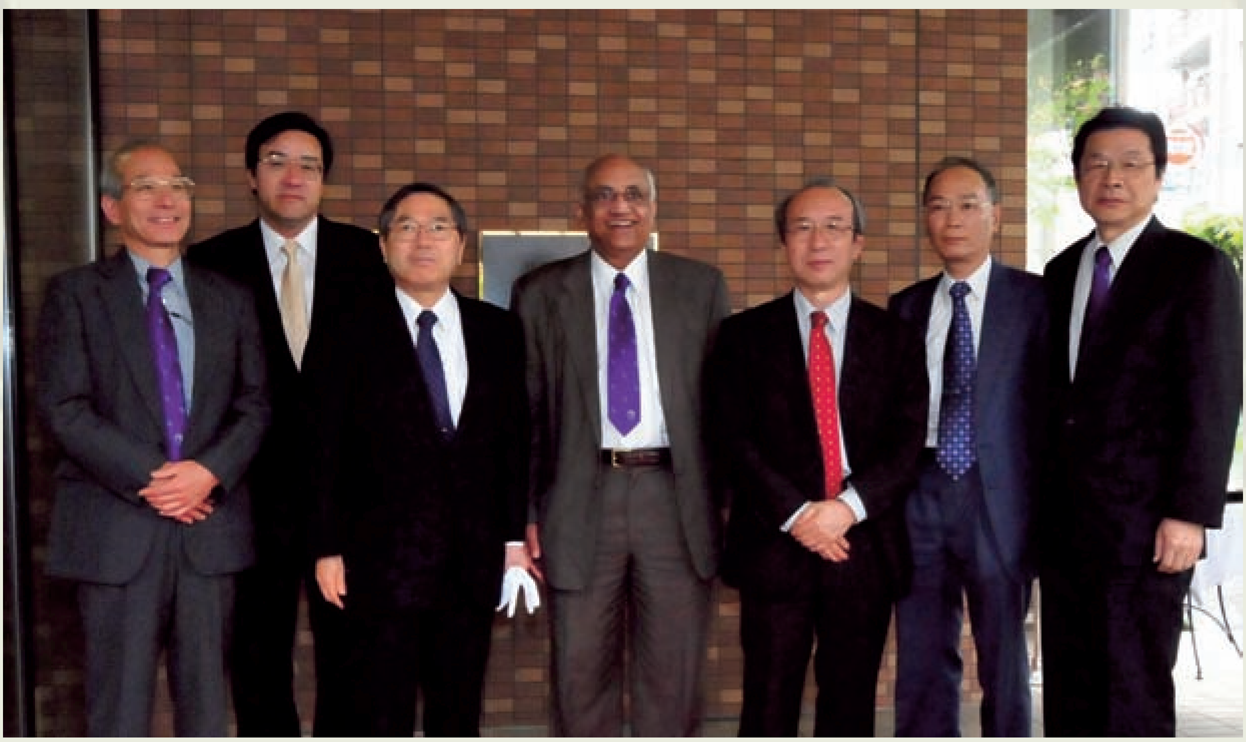

東北大学
TOHOKU UNIVERSITY

Ceremonial Lecture

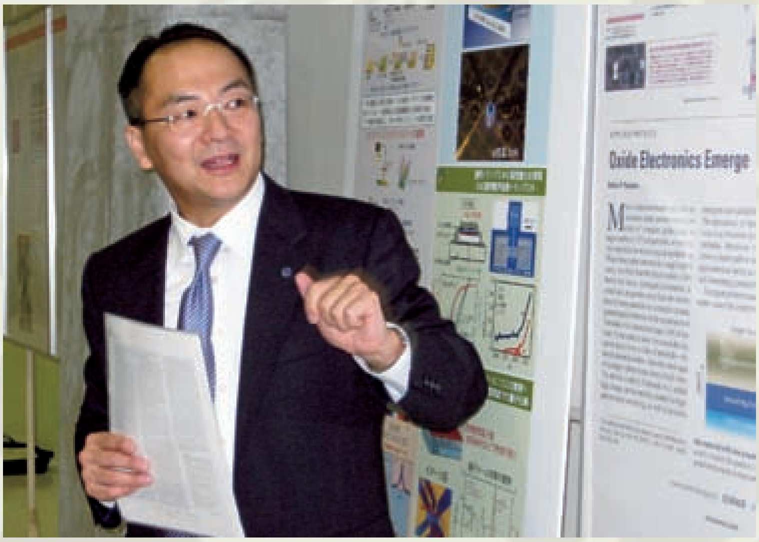

murti
and Applied

Open-House Ceremony of Integration Laboratory on May 22, 2009

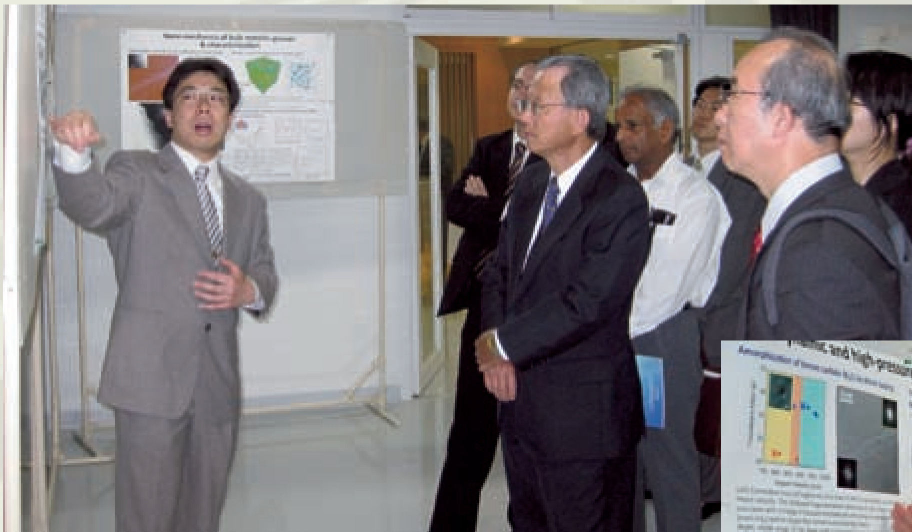
Tape-cut in front of the building

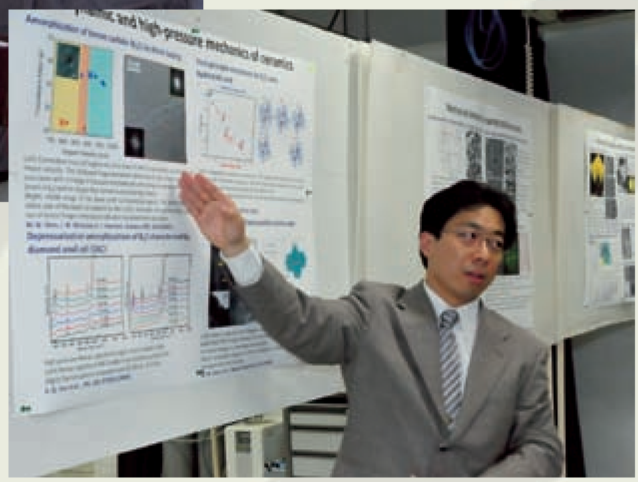


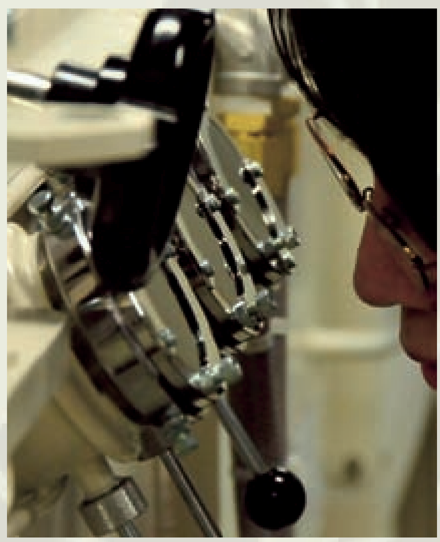
Open-House Laboratory Tour

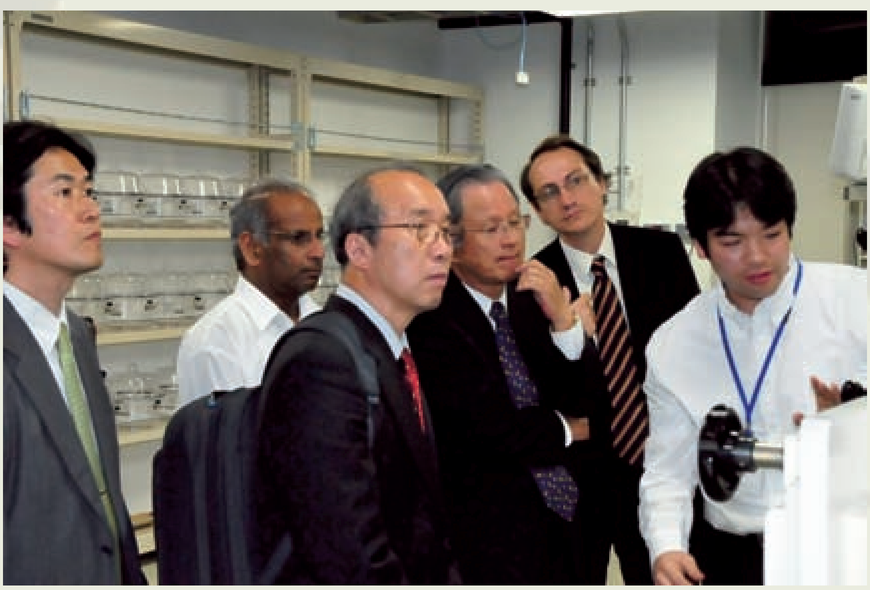

Oxide Electronics Emerge

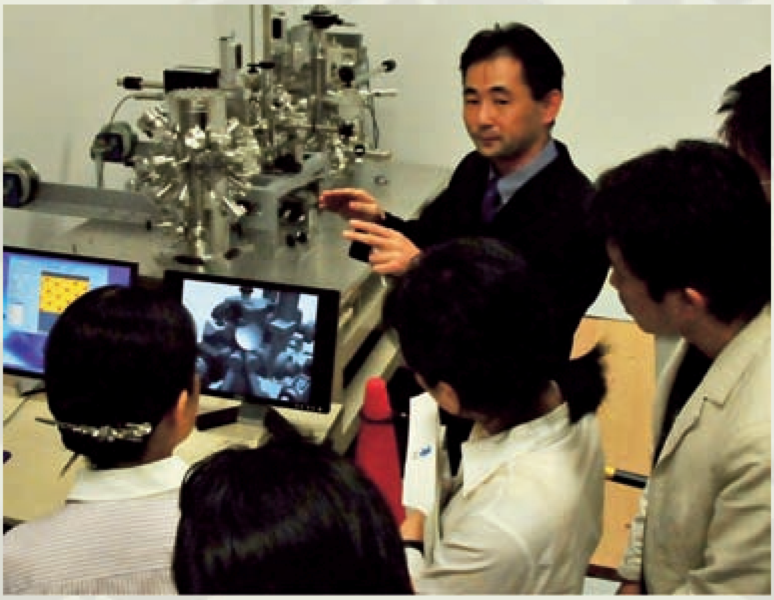

IMR

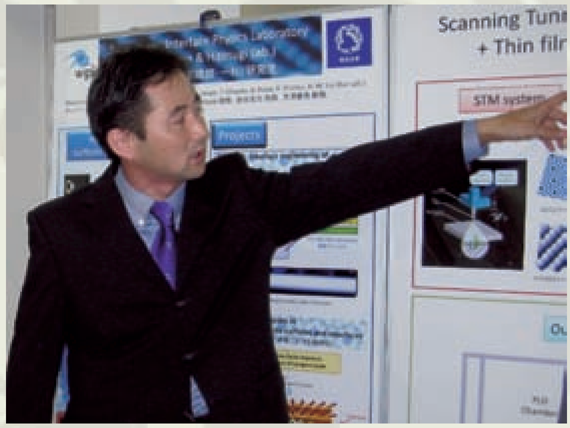


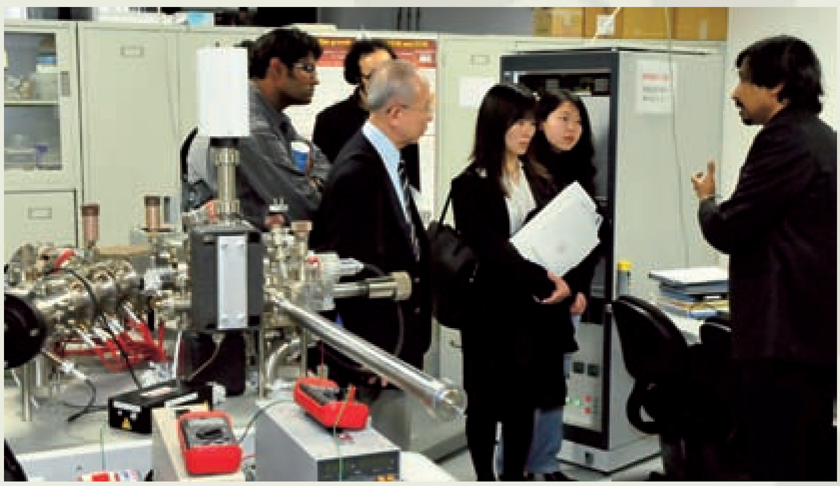












Get-Together after Open House Ceremony





Outside Appearance of Integration Laboratory

DIRECTORY

As of July 31, 2009

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