COE Development Program

Materials with Atomic–Scale Structures

The Report
of
The 3rd Evaluation Committee

10 March 2000

NRIM COE Evaluation Committee

Preface

Under its 5-year plan implemented in 1995, National Research Institute for Metals (NRIM) is conducting research on the creation of advanced materials with atomically controlled structures exhibiting quantum phenomena. This research is promoted as one of the Center of Excellence Development Program (COE project) of the Japanese Government, and is financed with the special coordination fund from the Science and Technology Agency (STA).

The main part of our COE project is progressed at the Center for Advanced Physical Fields (APF) of NRIM, equipped with some stations which provide extreme experimental environments such as high magnetic fields, high resolution beams and extreme high vacuum. The project is in fact designed to make use of the advantages of these facilities in researches on advanced materials

The NRIM COE project is roughly divided into two parts. One is "Creation and physical properties of atomic scale structure materials". This research is defined as "COE core research". The core research is funded by the Special Coordination Funds for Promoting Science and Technology (COE fund). However, self-supporting effort of each institute is required to promote the core research. The techniques provided by the Center for APF are important to carry out the research on materials with atomic scale structure. Therefore, the other one is "Improvement of techniques to establish advanced physical fields", and is defined as "COE supporting research". These two researches cooperate to make COE project a success.

An Evaluation Committee for the NRIM COE project was established in 1995 for the purpose of assessing the project. The committee consists of 10 prominent scientists in the field of nano-meter scale technology. The main objective of the Committee is to assess the feasibility of this project and to advise the research planning. Immediately after its establishment, the Committee assessed the planning of the Project and reported that its goals and plans for pursuing them were appropriate, but project leaders should cooperate with each other and reports their results regularly. According to this suggestion, NRIM changed the project structure and published COE Progress Report once a year and held meetings regularly. The second assessment by the Evaluation Committee was carried out in September 1997. The objective of the second meeting was to vender judgment as to whether the project was worth continuing for its final two years. The Committee evaluated the accomplishment level at the intermediate stage, and found that the level was excellent. Then the Committee recommended proceeding to the second stage. However, the Committee advised that considerably more work needed to be done in promoting interactions among the various COE sub projects. Based on this advice, NRIM proceeded to the second stage of the project, which started in April 1998 and will end in March 2000. NRIM also started some joint sub-projects among sub-project leaders.

This COE project will be terminated in March 2000. Therefore the third Evaluation Committee was held on 10 March 2000 in succession to the 5th International Symposium on Advanced Physical Fields, which was held in 6 to 9 March 2000. At the Symposium the sub-project leaders of the COE project of NRIM presented their summarized research results. The members of the Committee attended the symposium and evaluated their research results. On 10 March 2000, the committee interviewed sub-project leaders and completed the evaluation.

During these 5 years, we believe that NRIM has established the research field to create materials with atomically controlled structures, and given many young scientists chances to work in this research field. We hope NRIM will continue the research within the framework of the COE project even after April 2000.

Chairperson of the NRIM COE Evaluation Committee

Masaru Tsukada
Professor of The University of Tokyo

1 Members of the 3rd Evaluation Committee

Chairperson

M. Tsukada	Professor	The University of Tokyo

Members

M. Aono	Professor	Osaka University The Institute of Physical and Chemical Research (RIKEN)
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H. Mori	Professor	Osaka University
F. Phillipp	Dr.	Max-Planck Institute for Metals Research
L.E. Rehn	Dr.	Argonne National Laboratory

2 Management system

(1) Research organization

The NRIM COE Project is divided into two parts. One is “Creation and physical properties of atomic scale structure materials”. This research is defined as “Core research”. The core research is funded by the Special Coordination Funds for Promoting Science and Technology (COE fund). However, self-supporting effort of each institute is required to promote the core research. The techniques provided by the Center for APF are important to carry out the research on materials with atomic scale structure. Therefore, the other one is “Improvement of techniques to establish advanced physical fields”, and is defined as “Supporting research”. These two research categories cooperated to make COE project a success.

Materials with atomically controlled structures are categorized into quantum dot, quantum wire and thin film, so “COE core research" was divided into 5 sub-projects, which cover quantum dot, quantum wire and thin film.

Dr. Okada, the project leader of COE project, supervised both “Core research” and “Supporting research”.

Score (Votes)

Grade A (Well organized) 10 Grade B (Fair) 0 Grade C (Poorly organized) 0

(2) Research fundamentals

The total budget of COE project was 1,799 million yen for 5 years. About 70% of the budget was used for equipment and consumable goods, and about 25% was spent to employ fellows. Over 20 fellows are employed every year and the participation of young scientists both from foreign countries and from Japan activated COE research substantially. As for “Core research”, the ratio of technical supporting staff, fellows and students is larger than that of other research groups in NRIM.

(a) Budget for the COE project:

Score (Votes)

Grade A (Sufficient) 8 Grade B (Fair) 2 Grade C (Insufficient) 0

(b) Facilities and equipments available for the COE project:

Score (Votes)

Grade A (World-class excellent) 10 Grade B (Fair) 0 Grade C (Poor) 0

(c) Research support system, such as assistance by technicians:

Score (Votes)

Grade A (Appropriate) 3 Grade B (Fair) 6 Grade C (Inappropriate) 1

(3) Cooperation

To encourage the mutual communication, International Symposia on Advanced Physical Fields were held at NRIM every year. NRIM invited 129 scientists from all over the world to hold seminars on the COE research field. NRIM have published the "Progress Report" 5 times to announce the recent research results.

According to the advice given by the Evaluation Committee held in 1997, NRIM organized the cooperative research among sub-groups.

Openness to outside researchers (number of COE research fellows, number of short term foreign researchers, number of invited speakers at COE International Symposium) has been enhanced.

Score (Votes)

Grade A (Sufficient) 9 Grade B (Fair) 1 Grade C (Insufficient) 0

(4) Evaluation system

The Evaluation Committee (Chaired by Prof. Tsukada) checks the planning and accomplishment. The Evaluation Committee was held in March 1996 to check the objective and planning, in September 1997 to check the accomplishment at the intermediate stage, and in March 2000 to check the accomplishment of the project. NRIM has its own evaluation committee called COE Promotion Committee chaired by the Director of Advanced Physical Fields. This committee was held 4 or 5 times a year, and checked the progress status, budget proposal and administrative affairs,

Score (Votes)

Grade A (Appropriate) 9 Grade B (Fair) 0 Grade C (Inappropriate) 0

Comments from the Evaluation Committee members

Activities of young researchers, including those from overseas, have been well enhanced. I hope this attitude should be continued in other areas in the institute.

Research subjects in the COE projects should be continued even after the end of the project. However, after the combination with NIRIM, new research subjects should be added especially in the field of ceramics.

(My comments do not represent a priority list.)

Balance of core program is good, however it that the program could benefit from increased synergism between programs; also programs could benefit from shared characterization across programs.

Impact on scientific out of NRIM appears to have been leveraged by COE. For example, publications from COE is ～20% of NRIM with ～5% budget;

Fellowship program has been one of the most significant strengths of program; certainly there may have been benefits beyond COE program due to fellowship and seminar program: It probably has had a significant impact on NRIM general intellectual activity: It probably helped to stimulate activities beyond COE programs.

Efforts should be explored to continue investment in fellowship and more active seminar program.

COE and interactions of this program across Japan and outside Japan has significantly elevated NRIM as an international institute: NRIM's visibility as a center for science and technology has been significantly enhanced due to COE.

I have some concerns about the lack of organic/soft matter materials within many of the efforts. With the joining of NRIM and National Research Institute for Inorganic Materials, the joint institute should also aggressive pursue collaborations with other institutes and universities to strength this aspect. More and more organic materials are impacting future nano science and technologies.

There is good balance across program and thoughtful supportive programs.

Management have been hard working and diligent. They have followed recommendations of the evaluation committee and done an excellent job. They have generated synergy and also increased the international profile of NRIM and Japanese science. They have effectively at low cost transformed NRIM to a lab with state of the art facilities for future nano technologies based on metallic and inorganic systems.

As far as it can be judged from outside, management was good. The general quality of the installation is outstanding. There still seems to be a shortage of manpower (better: person-power).

The facilities are excellent. Perhaps the COE project and the NRIM itself would need more young researchers to use them. In this regard, it is highly appreciated that they started the collaboration with universities, and that the COE project invited short-term visitors.

Research support system: The assistance by technicians, though increased in the 2nd period, appears still not quite appropriate.

Cooperation: see comments [Overall evaluation].

The management has shown a strong commitment to making the COE project a success. I hope the future changes involving supporting agencies and the unification with the Inorganic Materials Institute will have a positive impact on this process. It was an excellent decision to have money in the budget to support visitors (COE Fellows). The number of technical supporting staff (6) seems too low.

3 Core Research

3-1 Analysis and characterization of single atom layers and dimensionally controlled materials

Leader: K. Furuya

The research is mainly concerned with atomic scale synthesis and characterization of nanostructures embedded into the matrix and deposited on the surface using high-resolution transmission electron microscopy. Three microscope-systems were used in the project; 1000 keV TEM with dual ion-implanters (ION/HVTEM), 200 keV ultrahigh-vacuum field emission TEM (UHV-FE-TEM) and 200 keV TEM with focused ion beam (FIB/TEM). After the development of the UHV-FE-TEM, the microscope was interfaced with evaporators for metal and semiconductor deposition. Pb, In and Ge were deposited in UHV condition and anomalous structural changes occurred in small particles less than about 5 nm in diameter, there were analyzed with high-resolution transmission electron microscopy (HRTEM). The transition between fcc and bct structures was often observed. Using fine focused and strong electron beams of the UHV-FE-TEM, the position- and size-controlled Si nanocrystals were successfully fabricated in SiO_2 thin films. This method provides for the creation of array structures of Si dots for applications to quantum devices. ION/HVTEM was used to characterize metastable inert gas precipitates embedded into Al. The clear images of Xe nanocrystals revealed the {111}- and {100}-facetted cuboctahedron shapes, and the position relationship between Xe and Al in sub-angstrom magnitude was measured. Using FIB/TEM, semiconductor materials such as Si, GaAs, Sic were successfully microfabricated in 200 nm resolution with 25 keV Ga ions, and subsequent microstructural changes were evaluated with conventional TEM. Because of the limited size and significant structural changes, the fabrication with conventional FIB system is limited in sub-micron scale. The fabrication and analysis of dimensionally controlled materials are still under way to create position- and size-controlled nanostructures. For this purpose, The UHV-FE-TEM is now interfacing to UHV scanning tunneling microscope (UHV-STM) and the ION/HVTEM is being used to create and control metal-metal nanostructures.

Score (Votes)

Overall evaluation:

Grade A (Good) 10	**Grade B (Fair) 0**	**Grade C (Poor) 0**

(a) Originality of research:

Grade A (Good) 8	Grade B (Fair) 2	Grade C (Poor) 0

(b) Scientific value:

Grade A (Good) 8	Grade B (Fair) 2	Grade C (Poor) 0

(c) Level of accomplishment:

Grade A (Good) 8	Grade B (Fair) 2	Grade C (Poor) 0

(d) Quality of publication:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

Comments from the Evaluation Committee members

Various significant achievements, such as nano crystals of Si in $SiO_{2,}$ P_b:MTP, G_e:MTP, and Noble Gas Particles have been obtained. The results are impressive and might be applicable for practical applications.

TEMs are used in very good ways, and interesting studies have been done in the aspect of fundamental research. As the next step, application of the research accomplishment should be considered.

Quantity of publication is fair.

Program has developed impressive facilities which should continue to make significant contributions.

The program appears to be well managed with the ① development of world class fabrication and characterizations facilities, ② good collaborations with external groups, ③ good simulations activities which have had a significant impact on characterizations and interpretations; ④ has already introduced plans to incorporate STM along with TEM as part of characterization tools.

The program may benefit from strong collaborative interaction with other parts of core research effort.

Management; facilities development; executions of research effort has been good but program should devote more time to looking at future vision and goals.

The Furuya group has established beautiful facilities for nano fabrication of semiconductor for nano electronics test devices. They have worked hard and effectively. They have made very positive collaborations with foreign research organizations. The effort invested will continue to pay-off in future research in nano technology.

Good presentation. Taking into account both quantity and quality, publications account for about 20% of the output of the core group. Outstanding instrumentation has been set up, and novel techniques have been developed. Some of the work is not yet completely finished, there is an excellent potential for further development. The extent of co-operation is not quite clear, this could perhaps be improved.

The UHV-TEM-STM system will be a world-class system. Very good research in producing and characterizing nanoparticles. One should be more careful in predicting future applications! For a single electron transistor the nanoparticle is the simplest part. Equally important are well characterized tunneling barrier!

FIB damages semiconductors and is not the best tool to fabricate nanostructures.

This group has developed nice techniques to fabricate nano structures. The work is probably world-class excellent. More study concerning the characterization of the fabricated structures would be necessary for achieving real usable devices.

The results obtained in the field of nano particles deposited on Si are of interest. I hope in the next step some efforts to connect the results to the practical device development will be done in your laboratory.

One interesting instrumentation achieved in the COE project is the ION/HVEM apparatus, which would possess a high potential in the study of ion/electron irradiation effects. I hope in the next step in your group emphasis should be placed also on work with the use of this very excellent unique apparatus.

This project has built up a state-of-the-art instrumentation for nano characterization of materials. The combination of FE-TEM with STM, thin film growth, nano lithography integrated in the UHV system is a unique facility.

The results in fabrication and characterization of various nano structures are impressive through their thorough evaluation and discussion.

Co-operation with COE project partners proved to be helpful.

This group has shown excellent advancement over the five years of the COE project. They have been quite successful in establishing international collaborations, and as a result their work is now well recognized and appreciated in the international community. Their publication record is now impressive, with several important publications in prestigious international journals (APL, PRL, JAP, NIM-B, etc.), and they have co-authored several invited talks at important international meetings. Their research facilities for HVEM and UHV-TEM are among the best in the world.

3-2 Measurements of quantum effects using high resolution beam probes: Metal nanoparticle structures controlled with ion-induced kinetics and the linear-nonlinear optical properties

Leader: N. Kishimoto

Research activities of the subprogram have been dedicated to unique spatial control and characterization of nanostructures, i.e., two-dimensional arrangement of metal nanoparticles with ion-induced kinetics and evaluation of the linear-nonlinear optical properties. Negative Cu ions of 60 keV, at high doses, have generated nanocrystals in amorphous/crystalline SiO_2 and a spinel oxide, $MgAl_2O_4$, with a size of ~10 nm suitable for nonlinear optical devices. The kinetic processes of both inside the solid and at the surface are studied by cross-sectional TEM and tapping AFM, respectively. The in-situ spectroscopy of photon and X-ray during the nanoparticle formation is conducted as well. Nanoparticles in the insulators spontaneously grow with increasing dose rate, being controlled by the Ostwald ripening. Nanoparticle- and surface morphologies are significantly dependent not only on dose rate but also on the boundary conditions. With increasing dose rate, the in-beam growth of nanoparticles becomes pronounced and the atomic profile shows effects of narrowing and shallowing toward the surface. It is pointed out from the kinetic results that changing dose rate can control not only particle size but also the spatial distribution due to a depth-directional driving force on implants. In a critical condition, the nanospheres give rise to a self-assembled two-dimensional (2D) arrangement. A self-assembling mechanism for 2D-arrangement of nanospheres is proposed on the basis of the energy-gradient driven driving force and the sputtering process. In accordance with these variations of nanoparticle morphology, linear and nonlinear optical properties vary with dose rate and boundary conditions. The linear optical properties, especially the plasmon peak, are studied with respect to kinetic changes of nanoparticles and are analyzed into dielectric components, with the Maxwell-Garnett theory. The nonlinear optical properties are evaluated by a degenerate-four-wave mixing method and a pump-probe method. The nanoparticle system of a small mass is evaluated to have large and ultrafast nonlinearity due to the surface plasmon resonance, promisingly for photonic device applications. As an alternative to obtain a total mass, a dynamic mixing method with negative ions is also developed. Thus, they have developed a methodology to spatially control nanoparticles embedded in insulators and demonstrated that the nanostructures have large and ultrafast optical nonlinearity.

Score (Votes)

Overall evaluation:

Grade A (Good) 9	**Grade B (Fair) 1**	**Grade C (Poor) 0**

(One member voted for both (Good and Fair))

(a) Originality of research:

Grade A (Good) 5	Grade B (Fair) 4	Grade C (Poor) 0

(b) Scientific value:

Grade A (Good) 7	Grade B (Fair) 2	Grade C (Poor) 0

(c) Level of accomplishment:

Grade A (Good) 9	Grade B (Fair) 0	Grade C (Poor) 0

(d) Quality of publication:

Grade A (Good) 5	Grade B (Fair) 4	Grade C (Poor) 0

Comments from the Evaluation Committee members

Work is with high originality and excellent achievement has been obtained.

It is interesting that a unique technique to make 2D spatial control of nano structures has been developed. Application of the new technique should be considered more strongly.

This program has not only developed good synthesis effort what has also developed characterizations capabilities which should benefit other COE efforts and NRIM programs.

Kishimoto et al have applied a wide variety of techniques to a range of potential areas of application. The researchers are clearly looking for direct applications of nano technologies to effect improvements in fabrication methods and devices and are more closely related to potential industrial applications. They have established a state-of-the-art set of tools and techniques that will play important roles in future nano technologies of hard materials.

Publication ～9% of core total. Good instrumentation has been set up, this appears to be working well. Scientific value is uncertain to me. Co-operation appears to be good. There are good prospects for further development.

The cooperation with Tsukuba University is positive! (students) Investigation of beam-substrate interaction is of fundamental importance. 3 patents! Good national and international cooperation!

This group has made a significant progress in research since the time of the last evaluation meeting. They characterized well the fabricated devices. It is desired to demonstrate some examples of the useful application such as non-linear optical devices.

I hope in the next step the atomic mechanism behind the Cu-colloids formation in SiO_2 and spinel will be made clear.

It will be nice if this group could propose a vision on how to apply the present nano-structured material to practical nonlinear optics devices in the future.

The project is well organized, many new instrumental developments have been accomplished.

Collaboration with many institutions outside of Japan is a special feature and certainly helped to the success.

The negative ion Cu implantations have progressed to the point where useful microstructures have been obtained. It is unclear, however, that the use of negative ions is important in order to obtain the desired properties. The patent applications that have been generated by this research are a positive sign. Another positive accomplishment is the significant number of inside and outside collaborations that have been initiated.

3-3 Quantum phenomena of atomic scale materials: Fabrication of Nano-wires and Connection to the Macroscopic Pads

Leader: H. Nejo

They have succeeded in fabricating the nanometer-scale wires and connecting them to the macroscopic electric pads in three ways:

(1) Lead atoms aligned on Si(111)

Silicon dangling bond of the Si(111) surface was terminated by atomic hydrogen followed by lead deposition on it. An STM tip was scanned over it in such a pattern of a nanometer-scale wire with macroscopic pad on the both ends. By giving higher voltage between the tip and the substrate, the hydrogen was extracted and the remaining pattern shows the lead nano-wire with pads. This was demonstrated by an STM image of a nano-wire with macroscopic pads at the both ends made of lead on a Si(111) substrate.

(2) Nano-wire fabrication by making contact of an AFM cantilever

A tip of an AFM cantilever was coated by gold beforehand. By making contact to a Si(111) surface and drawing between two macroscopic pads made of silver, a gold nano-wire connected these two pads. This was demonstrated by an STM image of macroscopic pads and a gold nano-wire between them. A cantilever was switched to an STM tip in UHV for making image.

(3) Putting a series of gold dots extracted from an STM tip

Two macroscopic pads were fabricated by evaporating gold through a through-hole mask above a Si(111) surface. An STM tip was held above a gap of the electrodes and gold clusters were extracted from the tip by high electric field. A series of gold dots connected the macroscopic pads. This was demonstrated by an STM image of macroscopic pads and gold nano-wire between them. Note that the gold clusters were deposited even at the edge of pads. They are measuring electric conductance through these nano-wires in UHV at various temperatures.

Score (Votes)

Overall evaluation:

Grade A (Good) 8	**Grade B (Fair) 2**	**Grade C (Poor) 0**

(a) Originality of research:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

(b) Scientific value:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

(c) Level of accomplishment:

Grade A (Good) 4	Grade B (Fair) 5	Grade C (Poor) 1

(d) Quality of publication:

Grade A (Good) 6	Grade B (Fair) 4	Grade C (Poor) 0

Comments from the Evaluation Committee members

Substantial progress has been made, though we expect further future developments.

It is extremely important to measure the conductivity of various metal nano wires at various temperatures. For this purpose the four-point probe system developed in this group seems to be very useful. The system should be completed as soon as possible.

This has been a very impressive effort with significant potential for new science and technological impact.

The development of fabrications of long, metallic Pb-atom chains could represent a significant opportunity to study fundamental issues in superconductivity.

I am impressed with Dr. Nejo, he has been a significant addition to NRIM staff.

I am truly impressed by accomplishments and feel the opportunities for outstanding science on significant issues is high. As program moves further into characterization there are numerous opportunities to impact fundamental science questions, e.g. quantum effects in quantum wires.

The Nejo group are leading innovators of new ideas and concepts. They are an important part of the COE project in promoting new approaches to research at NRIM. They have established important links with international research institutes and also industrial research laboratories such as the IBM Zurich Research Laboratory. They have achieved ultra-nano technologies of self assembling single atom wires as well as nano techniques to interface nano devices with nano wires. They have excellent publications and have promoted much international exchange. During the COE project, NRIM has gained a wide range of Scanned Probe methods which are essential core research and fabrication techniques for atomic scale structures required for ultimate limits of fabrication and measurement. Excellent.

Publications ～18% of core total. Presentation not so good, somewhat confused. With respect to the investment and compared to results presented by other groups at the symposium, research output still appears poor to me. Results are fragmentary and the quality of pictures appears to be inferior. It is not yet clear how the results obtained so far can contribute to the development of the single electron transistor. Considerable efforts ought to be made in order to improve on this.

Dr. Nejo is the most active scientist within the COE in organizing seminars and inviting foreign scientists. The preparation of nano wires (Pb chain) is one of the most difficult problems in nano-electronics with great potential for interesting physical phenomena. The presentation at the symposium was not the best one.

This project is extremely important and interesting, and should play a key role in the entire COE project. In this sense, it is a shame that the group has not shown one or two remarkable new results. Particularly, as the title of the research group is "Quantum phenomena of Atomic Scale Materials", it is strongly required that some new quantum phenomena be studied and observed in fabricated devices.

The results obtained are very interesting. I hope this group continues the fundamental studies on this subject. I feel there is no need to think of the applications at this moment and work should be focused on the findings of unknown phenomena.

In this project great effort has been made to fabricate nano-wires by using various techniques. Certain progress has been achieved, however, there is a certain lack of prospects on which of the method will be most promising for future “routine” application. Likewise, the characterization of results is not very far developed.

Nejo has undertaken a very difficult challenge. Unfortunately, despite a tremendous amount of effort, this project seems no closer to its goal than it was at the last review. Perhaps too many different systems and techniques are being attempted. Focusing on just one or two of the most promising techniques would be a good idea.

3-4 Fabrication of monolayer thin film for advanced substrate: Preparation of hexagonal boron nitride for advanced surface modification

Leader: M. Tosa

The basic technology for the fabrication of advanced nanostructured materials with atomic scale manipulation depends not only on the atomically super clean environment for the continuous manipulations on the substrate but also depends on the advanced substrate suitable for the smooth epitaxial nano crystal growth without lattice mismatching. The research is therefore carried out on the preparation of the advanced substrate for atomically controlled structure and on the construction of the XHV integrated process for the fabrication of nano-structures with quantum properties under the vacuum pressure less than 10^{-10} Pa.

(1) Hexagonal boron nitride layer segregation

Co-sputtering deposition technology using helicon radio frequency wave with a sintered disc of BN and Cu disc deposited the mixture of Cu and BN (Cu/B/N) on the Cu substrate. By annealing the Cu/B/N film, h-BN segregated uniformly on the entire surface of the deposited film. The diffraction image revealed that segregated BN layers had the preferred orientation and tended to cover the segregated surface with the basal c plane (0001). Atomic force microscope (AFM) measurement shows that the surface of the segregated h-BN layer has the same value of van der Waals' force as that of a sintered h-BN disc (~1nN). The segregated h-BN layer on the film shows good electric insulation property up to about 3eV. It is therefore concluded that the prepared h-BN layer can be a promising film substrate for nano structure fabrication due to the small vertical and lateral atomic interaction and good electrical insulation.

(2) Nanostructure of BN layer

Nanostructure of BN layer formation process by surface segregation in the co-deposited film was observed in collaboration with Dr. Furuya's group by the 1MeV high-resolution transmission electron microscopy (TEM). TEM photos show that BN with hexagonal crystal structure forms from the co-deposited amorphous structure. The strained structure in co-deposited film could drive the surface segregation of h-BN in order to reduce its strain energy.

Score (Votes)

Overall evaluation:

Grade A (Good) 6	**Grade B (Fair) 2**	**Grade C (Poor) 0**

(a) Originality of research:

Grade A (Good) 6	Grade B (Fair) 2	Grade C (Poor) 0

(b) Scientific value:

Grade A (Good) 6	Grade B (Fair) 2	Grade C (Poor) 0

(c) Level of accomplishment:

Grade A (Good) 4	Grade B (Fair) 4	Grade C (Poor) 0

(d) Quality of publication:

Grade A (Good) 4	Grade B (Fair) 3	Grade C (Poor) 1

Comments from the Evaluation Committee members

Well characterized h-BN surface has not been formed yet, though suggregation method is interesting enough. We expect further development to reach the goal of the project, i.e., to fabricate atomically clean and smooth layer/surface of h-BN.

It could be interesting to make similar studies for different substrate materials.

I am less familiar with this field. Group seems productive and appears to have made significant achievements. However, I do not know the status of development worldwide to adequately evaluate this area.

The XHV integrated process is one of the world leading achievements that are unique to NRIM. I would encourage the further development of XHV techniques which may have technological significance in the eventual fabrication methods for nano electronic devices. The learning experience of problems that had to be overcome and solutions achieved are important knowledge data bases and will be valuable in future systems. The work has vision and I give it a high commendation. The research of BN coatings is important for operation of devices in XHV and the research group has made a detailed research activities in this area using s wide range of characterization techniques. Atomically super-clean environments should be pursued with high priority. I would like to see more stringent testing of the XHV process to really evaluate areas of the machine and fully analyze its operation. Excellent work.

Publications ～4% of core total. The installation for UHV levitation transport is impressive and will be useful, so far it has only been tested. This group seems to suffer from a severe lack of person-power. This should perhaps be taken into account when looking at the evaluation. The installation has much promise to be useful for future research in the general area covered by the COE project.

BN seems to be very important for different applications but I am not able to judge the originality and scientific value of the research. The connection to the general topic “Atomic-Scale Structure” is not very clear.

This group has not spent as much budget as the other groups, but accomplished good results.

As a next step of this research project, it would be valuable to find out a research theme where the very inert nature of h-BN substrate will be fully utilized in the construction of nano-structures on top of the substrate.

This project convinced by:

- competent leader
- state-of-the-art technology
- ingenious ideas
- clearly defined goals

- well structural schedule
- impressive results

It is unclear to me who at NRIM will utilize the surfaces that have been created. The next step should involve other groups who have already learned how to make and characterize nano structures.

3-5 Quantum effects in materials of two dimensional and strongly correlated electron system

Leader: G. Kido

They have studied quantum phenomena in a variety of advanced materials using NRIM high field magnets, where they developed various techniques for measurements and sample preparations.

(1) Optical and transport properties have been intensively investigated for GaAs/AlGaAs systems. They found a significant change in the luminescence spectra at the quantum Hall state.

(2) Photo-luminescence and cyclotron resonance have been measured in CdTe/CdMgTe and CdMnTe/CdMgTe quantum wells and characteristic phenomena were found at the filling factor equaling to integers.

(3) BEDT-TTF salt series were investigated at very low temperature by means of magneto-transport effects and new quantum phenomena were found: rapid oscillations, quantum Hall effect in bulk substance through the formation of chiral surface state etc.

(4) The inorganic spin-Peierls system $CuGeO_3$ and related materials have been studied magneto-optically at far infrared range and they found a characteristic phonon line which has filed dependence at the incommensurate phase

(5) The magnetic properties in CeP were studied exhaustively by means of de Haas-van Alphen experiments and NMR technique. An extremely complicated magnetic phase diagram was determined for the first time.

(6) They studied magnetic properties of rare-earth compounds based on high-field magnetization processes, Shubnikov-de Haas and de Haas-van Alphen effects, specific heat as well as the neutron scattering experiments.

(7) Band calculations were carried out by first principle method with GW approximation for wide-gap semiconductor series such as GaN, ZnS, ZnO and they succeeded to reproduce experimental values for the first time.

(8) A scanning probe microscope enclosed in a large bored superconducting magnet was invented and magnetic domain behavior was observed in a high magnetic field.

(9) A technique to measure heat capacity in the double extremes (down to 200 mK and high magnetic field up to 20 T) was developed. Oscillation due to the de Haas effect was clearly observed in the field-dependent-heat-capacity for the first time.

Score (Votes)

Overall evaluation:

Grade A (Good) 10	**Grade B (Fair) 0**	**Grade C (Poor) 0**

(a) Originality of research:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

(b) Scientific value:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

(c) Level of accomplishment:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

(d) Quality of publication:

Grade A (Good) 10	Grade B (Fair) 0	Grade C (Poor) 0

Comments from the Evaluation Committee members

Many interesting phenomena important for the materials science have been clarified. They contribute very much to basic science of materials.

Two years ago, this group had only high-field magnets and no equipment for physical measurement of samples. In these two years, various equipments have been developed, and the equipments have begun to produce various interesting results. I look forward to further development of this group.

The amount of publication of this group is impressive.

Materials development, e.g., Cu-Ag, has had a significant impact across the world; the accomplishments at NRIM have been essential to successes at other magnet centers.

The balance of science has been particular strong; program has included studies of some of the most challenging topics in highly correlated systems - Strong examples include far infrared, phonon studies in $CuGeO_3$ (incommensurate phase); work on organic conductors has been strong.

Interactions with external research community and involvement of students driven by G. Kido is also a significant strength.

The loss of Aoki is significant and unfortunate.

Development of measurement techniques and facilities are truly first class leading to well balance capabilities – G. Kido has been a key driving force in the development instrumentation capabilities which are essential to the success of the magnet lab.

Emphasis on materials growth, especially single crystal, will be critical the future of the magnet lab as a leading world facility.

The magnet lab has developed truly unique capabilities, e.g., scanning probe microscope in magnetic fields.

Development of 900MHz/1GHz magnet is an absolutely outstanding achievements.

Publications productivities of this effort is truly outstanding in quality and number.

Openness of program to external collaborations is also impressive.

High Tc super conducting materials and magnet development is world class. Achievements are truly world records in many areas. The achievement of 900MHz should be put in the context of efforts worldwide. Oxford and US effort at the NHMFL have worked on this technology for over 6 years. NRIM has accomplished a 900MHz NMR is record time and is positioned well to move to the 1GHz NMR.

Prof. Kido has built an LT STM for operation in a high magnetic field. With his experience in high magnetic fields I believe this is an important new direction in his research activities. His research group have been extremely productive and are internationally recognized experts in this field.

<u>Excellent</u> publication record: ～49% of core total, this increased by a factor of 2/3 since the first year of the COE project.

A great variety of measuring technique has been developed, some of these are very innovative and unique.

Many experiments have been performed that are internationally competitive, some of them based on new and original ideas.

A most valuable asset of this group is the great variety of excellent equipment for sample preparation, a prerequisite for world-class experiments. The research appears to go further into the direction of nano-scale materials, as can be seen from the sample preparation techniques (MBE, ion beam lithography) and diagnostics. The array of different furnace is impressive. SPM in a magnet is unique.

A world class laboratory with unique equipment. Very active group with excellent publications.

Very positive:

a) Many students from universities

b) The engagement in crystal growth is extremely important for the future of the whole institute.

c) New developments of systems like scanning probe microscopy with closed cycle super conductor magnet, NMR-magnet.

I am skeptical whether the MBE will be operated in an optimal way since the manpower is not enough.

This group has produced a large number of excellent results and their level is world-class. It is noted that the number of publication is almost a half of that of the entire COE project. As this group is associated with the excellent facilities of high magnetic fields, more interaction with outside users would increase their activities even more in future.

It seems nice if the nice instruments developed in this project could be opened to researchers in this country as a nation-wide use facility.

Special feature: Due to professorship of leader, students of universities in Tokyo and Tsukuba could be involved. This could act as example how in future more research-man-powers could be brought into projects.

Very productive group.

4 Supporting Research

4-1 High magnetic fields

(1) Magnetic Development at Tsukuba Magnet Laboratory

Leader: T. Kiyoshi

The important role of the Tsukuba Magnet Laboratory (TML) is to provide high-field environments for the NRIM COE project. For that purpose, the TML has developed new magnets and improved its facilities. Fields up to 30 T in a 52 mm room temperature bore are now available. Generation of 37.3 T in a 32 mm bore was successfully carried out. By using newly developed superconductors, an NMR magnet beyond 900 MHz was fabricated.

(2) Development of magnetic chromatography in COE supporting research

Leader: T. Ohara

From the viewpoint of improvement of techniques to establish extreme physical field, they proposed magnetic chromatography technique, and made clear its interesting mechanisms by computer simulation. With their successfully developed simulator in this project they can accurately simulate the transient behavior of fine particles undergoing both convection (due to fluid flow and magnetic forces) and diffusion. This tool did and will contribute not only to detailed assessment of design and operating conditions about magnetic chromatography but also to prediction of particle behavior under high intensity high gradient magnetic fields and fluid flow.

4-2 Surface Analysis

Generation of Spin-polarized Metastable Helium Atom Beams for Surface Analysis: Measurements of quantum effects using neutral atom probes

Leader: Y. Yamauchi

Nano-structures fabricated on a surface are expected to exhibit stronger magnetism than in a bulk, because of pronounced isolation of electrons. They have developed the spin-polarized metastable deexcitation spectroscopy and successfully demonstrated its capability to probe the electron spin right on the surface which leads to the bit information of spin quantum devices.

4-3 Surface alteration

(1) Fabrication and Characterization of Compound Semiconductor Nanometer Structures

Leader: N. Koguchi

This theme supported mainly the Core research of Dr. Kido's project. Quantum size effects of GaAs/AlGaAs and InGaAs/GaAs quantum dots, which were fabricated by the novel techniques developed in the supporting research, were distinctly observed by the measurements of the photoluminescence spectra in high magnetic fields. Three papers were published as a result of the collaboration.

(2) Self-control of Surface Composition on Thin Films and Its Application to Field Emitter

Leader: M. Yoshitake

The thermodynamics and kinetics of the formation of surfaces with segregation, that have atomic scale structure with self-composition-control property, have been investigated. The general method to predict surface segregation behavior of substrate metal on a film deposited from estimated adsorption energies was established. This atomic scale structure with self-composition-control property has applied to fabricate surface with reduced and self-stabilized work function.

Score (Votes)

Do you think the supporting research contributed well to promote COE core research?

Yes 10 **No 0**

Comments from the Evaluation Committee members

Many significant accomplishments. It is not clear what NRIM is going to clue with high field NMR program. NRIM should probably focus on medium resolution NMR because that will couple more directly with their efforts in materials and nano technology.

The supporting research staff has done an excellent job. They have significantly enhanced their mode of operation following the recommendations of the review committee to excellent effect. Now that such a wide range of excellent equipment has been established, I would like to encourage researchers from each group to share facilities and continue to increase their interaction and synergy. The changes I have seen over the past 5 years astound me. I would expect that if suitably funded and advised they could be one of the top 10 international labs in nano technology in the world. To do this they would have to continue the same exponential increase in productivity development and change.

The magnet laboratory is a most valuable asset of NRIM. In particular, the development of super-conducting magnets is outstanding. This is likely to result in big further progress. The hybrid magnet will soon have reached its limitations. However, pulsed magnet development at NRIM has great promise. This seems to have been reduced in recent years and it can be recommended to reactivate this again. Kido's group appears to be working on this.

The development of world-class facilities and state-of-the-art instrumentation is truly impressive.

5 Overall evaluation

Sub-project groups of "Core research" have published about 315 papers and presented research results 239 times at international conferences. The number of publications dramatically increased during these 5 years. The collaboration among sub-projects has been enhanced and a number of visiting researchers and COE fellows has contributed to the cooperative research with institutes outside of NRIM. The COE project has succeeded in establishing the nano-technology research center and stimulated the total research activity of NRIM. NRIM should continue the research within the framework of the COE project.

Score (Votes)

Grade A (Good) 10 **Grade B (Fair) 0** **Grade C (Poor) 0**

Comments from the Evaluation Committee members

The COE project successfully started a new important research direction as nano-structures and novel materials in NRIM. Activities have been in very high level. The way of advertising the scientific or technical achievements to general audience (tax payers) should be searched.

(Since I could not attend the APF-5 conference on the first two days, my comments are based only on the short presentations made on March 10 and the book of summary of the Research Results.)

In most groups of Core Research, very interesting studies have been done. Especially, studies using STM, TEM, and high-field magnets have produced impressive results. If possible, however, application of the research results should be considered more strongly in this kind of research project.

Publication of research results seems to be good.

The COE program has been an outstanding success and has significantly elevated NRIM's stature in the world science community.

One of the real strengths of COE has been the fellowship program and seminar program.

These have probably played a significant role in stimulating research across NRIM. There should be more effort to involve NRIM and its programs and facilities in education of the next generation of Japanese scientist. The number of students supported by core research and supportive programs is depressing low. This may change with the proposed merger of STA and Ministry of Education.

Since its start the COE project has shown dramatic positive changes on a wide range of criteria relevant to the evaluation of scientific and sociological excellence for the future of Japanese research in nano-technology. These positive changes have clearly shown also a dramatic positive change in the scientific productivity of NRIM as a whole as well as collaborating institutes within Japan that are linked to the COE, specifically scientific publications has shown exponential growth to an impressive level of quality and quantity. Infrastructure for future research has been achieved through establishment of state-of-the-art techniques. The large number of foreign visiting researchers, post docs etc has contributed to this and also stimulated communication skills and approaches through the education and experiences of young Japanese researchers. Quality of communication skills in English and presentation techniques have improved dramatically. The COE project members have worked hard and followed in full recommendations of the evaluation committee. Excellent.

Program has much improved in the course of the project and is generally good overall. Co-operation has improved, internationally it was excellent, internally it could still be improved. Advice of evaluation committee has been followed.

The infrastructure is very good. The COE Project has strongly contributed to a positive image of NRIM and to an increase in scientific publications.

I think that the project as a whole has ended with a good success. It has produced a large number of significant results. It is very impressive that the number of publication from the NRIM has increased dramatically during these 5 years. The comments given at the last evaluation committee 2 years ago were taken into consideration in the project for these 2 years. Namely, collaboration between the groups and with outside groups has been enhanced. As this research project has given a basis of the new direction more effort should be continually devoted in the next few years to realize the actual device application. It is strongly desired that one or two good examples of new devices will come out of this project. At the same time, it would be nice if some new concepts in physics would be created.

In general the researchers of the COE project are competent in their fields and lead their projects to considerable success. Within this project some unique installations have been built up that way act in future as world-leading facilities.

It is recommended that the project leaders are supported in the future in the frame work of a similar program in order to further enhance their activities in the COE project field. For more efficient development and usage of the facilities it is suggested that medium-term (1-2 years), clearly specified international co-operations are specifically supported.

I am very impressed with the progress that has occurred over the past five years in the COE project. The strong increase in publications provides one good example of this progress. Another is the open interest expressed by many COE members in collaborating with other groups in the project. Finally, the international reputations of the COE groups have increased substantially as a result of the stimulation provided by the COE project. I hope new funding will emerge to continue this remarkable record of improvement.