Research Activities
in
NTT Basic Research Laboratories

Volume 13
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NTT Basic Research Laboratories,

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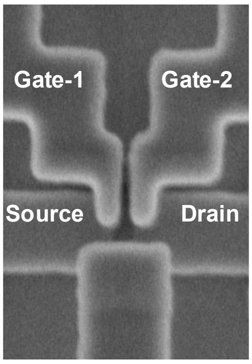
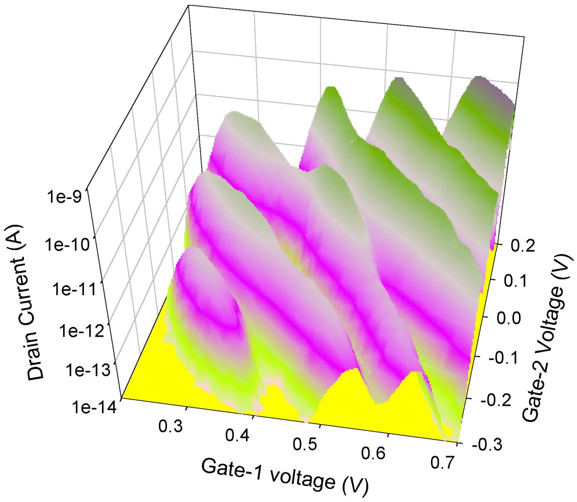
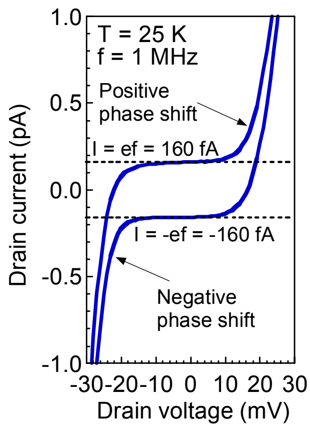


Electron microscope image



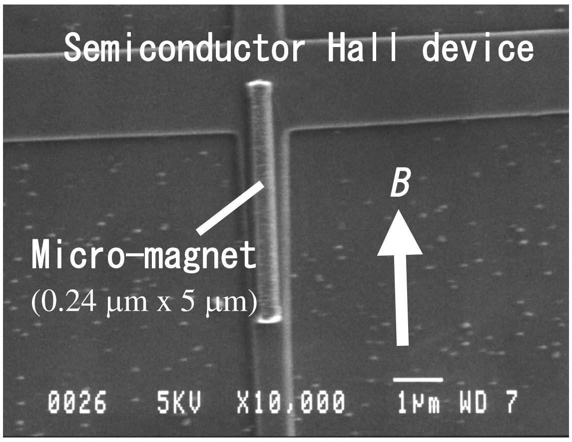
DC characteristics



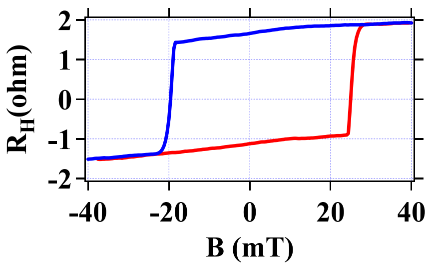
AC characteristics (pump operation)

Silicon Single-Electron Pump

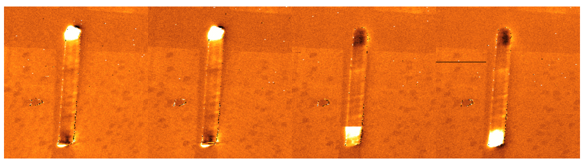
The single-electron pump can literally transfer single electrons even under reverse bias conditions, with negligibly small power dissipation and extremely high transfer accuracy. We proposed a new device structure for the pump, and fabricated the world's first silicon-based single-electron pump. (Page 16)



Semiconductor/ferromagnet hybrid structure



Hall resistance hysteresis loop

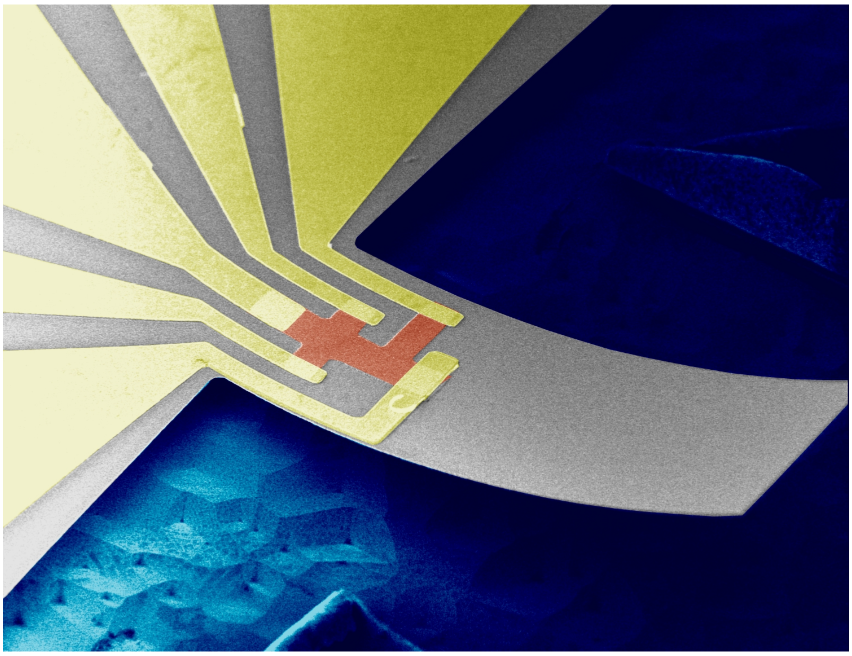


-20 mT -19.2 mT -19 mT -18mT

Magnetic force microscopy (MFM) observation for a micro-magnet

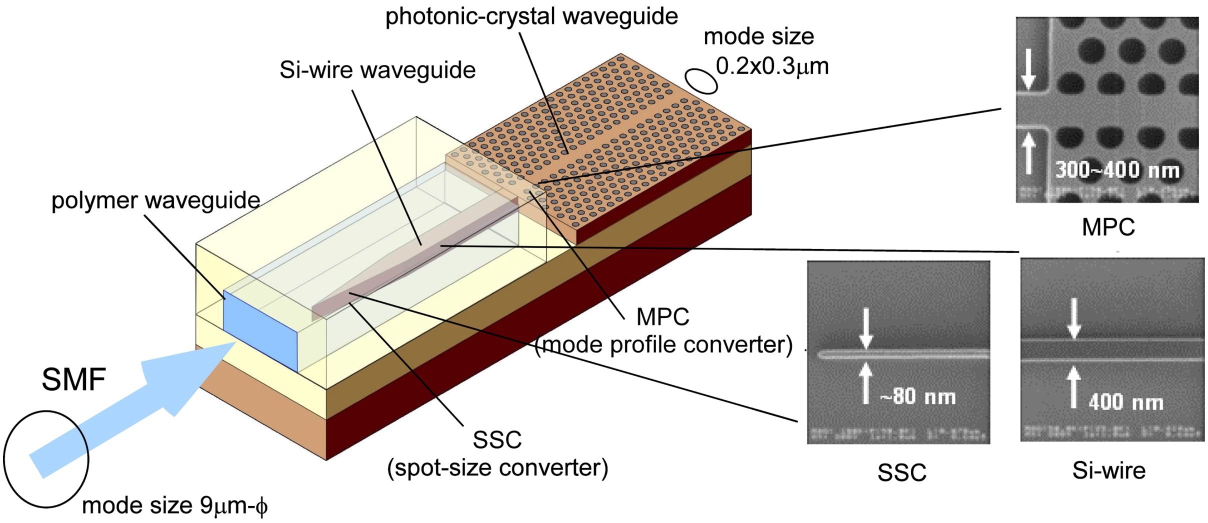
Hysteresis in micro-magnet

The hysteresis loop measurement on a micro-magnet is difficult even by using commercial SQUID susceptometers. A semiconductor/ferromagnet hybrid structure provides a sufficiently high sensitivity to measure the coercive field of individual micro-magnet. The magnetic force microscopy (MFM) observation agrees with the Hall-resistance hysteresis loop.



Compound Semiconductor Micro/Nanomechanical Devices

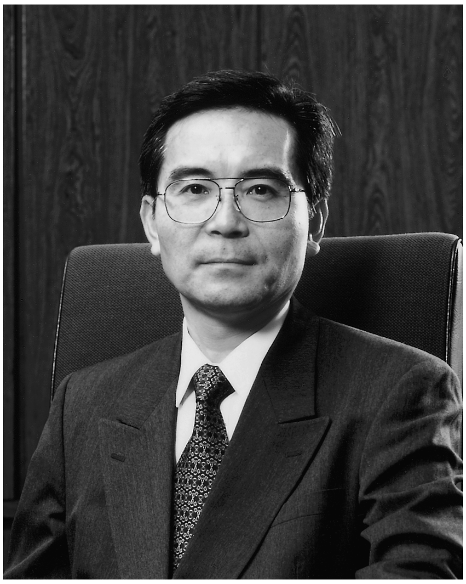
We are developing novel micro/nanomechanical devices by integrating semiconductor quantum structures into mechanical cantilevers. The figure shows a scanning electron microscope image of a heterostructure displacement sensor, where an InAs/AlGaSb two-dimensional electron Hall device is integrated in a mechanical cantilever. We confirmed a drastic improvement of displacement sensitivity induced by quantum mechanical effects. (Page 27)



Spot-Size Converters for Photonic Crystal Waveguides

Novel spot-size converters that enable efficient coupling between photonic crystal waveguides and single-mode fibers have been realized. The coupling loss had been thought to be one of major problems for photonic-crystal-based integrated circuit application, and this device has successfully reduced the coupling loss from 30dB to 3-4dB. (Page 34)

Preface



We greatly appreciate your support and interest in the research activities of NTT Basic Research Laboratories.

The objectives of the NTT Basic Research Laboratories are to find new scientific principles and create innovative technologies that will form the infrastructure of an information sharing society characterized by "Resonant Communication". As we move toward our goals, we continue to pioneer research fields by developing innovative technologies and to produce outstanding scientific achievements. Our research interests are device physics, functional material science, quantum mechanical physics, and quantum optics, and this work engages the efforts of about one hundred researchers. Nanotechnology designed to control nano-structures at molecular and atomic levels and Quantum Information Technology based on quantum mechanical principles are key words in relation to our research activities.

To maintain our innovative research activities and open the frontiers of science, we believe it is essential to pursue an open research policy and recognize the wide variety of talent that exists around the world. We run various scientific exchange programs with universities and institutes and undertake many joint projects. Moreover, international symposia are regularly held to promote further progress in specific research fields. We hosted the International Symposium, Carrier Interactions and Spintronics in Nanostructures in March this year.

This booklet, "Research Activities in NTT Basic Research Laboratories Vol. 13," provides an overview of our research activities in 2002. We hope this booklet will encourage mutual understanding and further collaboration among all scientists.

June 2003

Dr. Sunao Ishihara

Director
NTT Basic Research Laboratories
3-1 Morinosato-Wakamiya, Atsugi-shi,
Kanagawa 243-0198, Japan
Phone: +81 46 240 3300
Fax: +81 46 270 2358
Email: ishihara@nttbrl.jp

Contents

Member List

As of March 31, 2003
(*/ left NTT BRL in the middle of the year)

NTT Basic Research Laboratories

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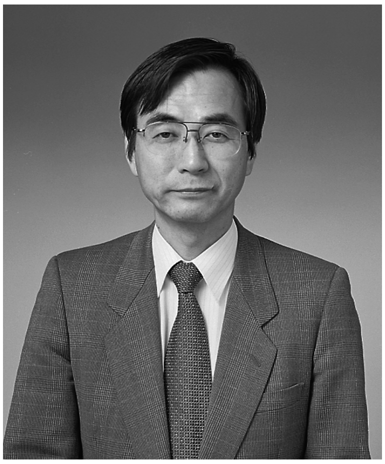
Prof. Masahito Ueda
(Tokyo Institute of Technology)
Prof. Seigo Tarucha
(The University of Tokyo)

Device Physics Laboratory



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Dr. Koji Sumitomo

Takeshi Karasawa

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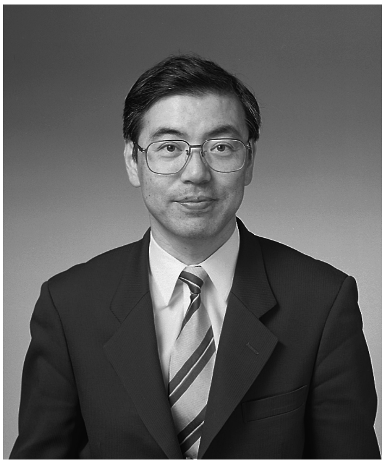

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Masami Kumagai

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Dr. Nobuhiko Susa	Dr. Masaya Notomi	Eiichi Kuramochi
Dr. Atsushi Yokoo	Dr. Akihiko Shinya	Dr. Mistugi Satoshi
Dr. Han-Youl Ryu		

Distinguished Technical Member

Toshiki Makimoto was born in Tokyo on January 16, 1960. He received the B.E., M.S. and Ph.D. degrees in electrical engineering from the University of Tokyo in 1983, 1985 and 1993, respectively. He joined NTT Basic Research Laboratories in 1985. He was a visiting researcher in University of California, Santa Barbara, USA during 1993-1994. Since 1985, he has engaged in epitaxial growth of III-V compound semiconductors using metalorganic vapor phase epitaxy (MOVPE) and flow-rate modulation epitaxy (FME), in-situ monitoring of epitaxial growth using surface photo-absorption (SPA), characterization of heavily doped semiconductors, heterojunction bipolar transistors (HBTs), and nano-structure selective area growth using scanning tunnel microscopy (STM). His current interests are epitaxial growth of nitride semiconductors and nitride semiconductor devices. He is a member of the Japan Society of Applied Physics, the Institute of Electronics, Information and Communication Engineers, and Materials Research Society.

Hiroshi Yamaguchi was born in Osaka on October 30, 1961. He received the B.E., M.S. in physics and Ph.D. degrees in engineering from the Osaka University in 1984, 1986 and 1993, respectively. He joined NTT Basic Research Laboratories in 1986. He was a visiting research fellow in Imperial College, University of London, UK during 1995-1996. Since 1986 he has engaged in the study of compound semiconductor surfaces prepared by molecular beam epitaxy mainly using electron diffraction and scanning tunneling microscopy. His current interests are mechanical and elastic properties of semiconductor low dimensional structures. He is a research coordinator of NEDO international joint research project (*Nano-elasticity*) since 2001. He is an associate editor of Japanese Journal of Applied Physics, and a member of the Japan society of Applied Physics and the Physical Society of Japan.

Toshimasa Fujisawa was born in Tokyo on May 23, 1963. He received the B.E., M.S. and Ph.D. degrees in electrical engineering from Tokyo Institute of Technology in 1986, 1988 and 1991, respectively. He joined NTT Basic Research Laboratories in 1991. He was a guest scientist in Delft University of Technology, Delft, the Netherlands during 1997-1998. Since 1991 he has engaged in the study of semiconductor fine structures fabricated by focused-ion-beam technique and electron-beam lithography technique, transport characteristics of semiconductor quantum dot. His current interests are single-electron dynamics in quantum dots, and their application to quantum information technologies. He is a member of the Japan Society of Applied Physics, and the Physical Society of Japan.

Masaya Notomi was born in Kumamoto, Japan, on 16 February 1964. He received his B.E., M.E. and Dr. Eng. degrees in applied physics from University of Tokyo, Tokyo, Japan in 1986, 1988, and 1997, respectively. In 1988, he joined Nippon Telegraph and Telephone Corporation, NTT Optoelectronics Laboratories, Atsugi, Japan. Since then, his research interest has been to control the optical properties of materials and devices by using artificial nanostructures, and engaged in research on semiconductor quantum wires/dots and photonic crystal structures. He has been in NTT Basic Research Laboratories since 1999, and is currently working on light-propagation control by use of various types of photonic crystals. From 1996-1997, he was with Linköping University in Sweden as a visiting researcher. He is also a guest associate professor of Tokyo Institute of Technology (2003-). He is a member of the Japan Society of Applied Physics, and the American Physical Society.

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Dr. Vladimir Seleznev	Institute of Semiconductor Physics Siberian Branch of the Russian Academy of Sciences, Russia March – June 02
Dr. Alexander Andreev	Institute for Laser Physics Research Center "S.I. Vavilov State Optical Institute", Russia April – June 02
Prof. Zhaohui Zhang	Peking University, China July – September 02
Prof. Hai-Du Cheong	Keimyung University, Korea January - February 03

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Stephane Marcet	Institut National Des Sciences Appliquées, France (Mar. – Aug. 02)
Frank Deppe	Technische Universität München, Germany (May 02 – May 05)
Yung Joon Jung	Rensselaer Polytechnic Institute, USA (May – Nov. 02)
Jeremy Graham	University of Oklahoma, USA (Jun. – Aug. 02)
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Guillaume Lang	École Supérieure de Physique et de Chimie Industrielles, France (Jul. – Dec. 02)
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Yoshiharu Krockenberger	Technische Universität München, Germany (Nov. 02 – May 03)
Marcus Steiner	Universität Hamburg, Germany (Jan. – Jun. 03)
Sung Woo Jung	Pohang University of Science and Technology, Korea (Jan. 03 – Jan. 04)
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Name	Affiliation (Period)
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Kazuya Aoki	Tokyo University of Science, Japan (Apr. 02 – Mar. 03)
Naoki Asakawa	University of Tokyo, Japan (Apr. 02 – Mar. 03)
Shinich Amaha	University of Tokyo, Japan (Apr. 02 – Mar. 03)
Keji Ohno	University of Tokyo, Japan (Apr. 02 – Mar. 03)
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Hajime Okamoto	Waseda University, Japan (Jun. 02 – Mar. 03)
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Ⅰ. Research Topics

Overview of Device Physics Research

Yasuo Takahashi
Device Physics Laboratory

Large-scale device integration technologies, which have led to rapid progress in information processing on cellar phones and portable computers, face difficulties in further downsizing and power consumption. To overcome these problems and thereby achieve further growth of information processing, the Device Physics Laboratory conducts research on the fabrication of nanostructures and single electronics, which enable us to make small and ultimately low-power devices. There are two approaches to achieving nanostructures: one is to refine lithographic techniques (top-down approach), and the other is self-assembly based on the atomic structures of the substrate (bottom-up approach). We are also investigating other methods to create nanostructures, such as carbon nanotubes.

The Si Nanodevice Research Group is investigating the operation mechanism of Si single-electron transistors (SETs) and their circuit applications, and is seeking to establish fabrication principles. We have already proposed and fabricated single-electron inverters, adders and multiple-valued logic circuits, and actually demonstrated their functions. We recently demonstrated that our Si SETs do not have any offset-charge problems, which are thought to be the most serious obstacles to the practical use of SETs. We have also succeeded in making a new type of single-electron pump that enables us to transfer just a single-electron at high temperature. To control the potential profile in nanostructure silicon suitable for SETs, the Si oxidation process is the most important. We have investigated the oxidation mechanism theoretically by first-principles calculations and clarified the fundamental oxidation process. We are also doing simulations based on the proposed oxidation principle.

The Nanostructure Technology Research Group is investigating nanofabrication techniques based on the top-down approach and methods of evaluating the fabricated nanostructures. We have achieved ultrafine resist pattern formation by improving electron-beam lithography and optimizing resist materials and processing, and demonstrated the nanometer-scale resist patterns with a high aspect ratio by using a supercritical-fluid drying process. Recently, we clarified the origin of the line edge roughness of resist patterns, which is the most important issue in making fine patterns. By using the developed fine-pattern formation technologies, we have fabricated and demonstrated small Si SETs with a high operation temperature. We have also succeeded in making an ultrasmall four-point probe for conductance measurement of small structures.

The Surface Science Research Group is investigating wafer-scale control of atomic structures and ordered nanostructure formation based on the bottom-up approach. We have demonstrated many kinds of self-assembled nanostructures formed on Si surface by controlling the alignment of the surface atoms and/or local stress accumulated in the surface. By using synchrotron radiation, we have also succeeded in *in-situ* observation of surface structures during crystal growth. We recently clarified the step bunching mechanism theoretically and proposed a new model for Ge-atom reconfiguration on the silicon surface, which are useful for controlling the ordered nanostructures. Our research on carbon nanotubes has led to a new growth technique using microwave plasma. We also succeeded in observing the electronic states of nanotubes by photoelectron spectroscopy and detecting the defects by infrared spectroscopy. We have also investigated various kinds of materials and succeeded in making ordered CdS nanostructures and InP nanowires.

The details of some of our achievements are shown in the following four pages.

Silicon Single-Electron Pump

Yukinori Ono and Yasuo Takahashi
Device Physics Laboratory

Single-electron devices (SEDs) are promising for future ultra-large-scale integrated circuits because of their small size and ultra-low power consumption. The single-electron pump is a member of the SED family and can transfer single electrons even when the drain terminal is reversely biased (hence the name "pump"). Among SEDs, the pump dissipates the lowest energy and has the highest transfer accuracy. However, the presently available pumps, which are made of metals, have some drawbacks, including a limited (< ~100 mK) operational temperature and poor operational stability.

In order to achieve a high level of transfer accuracy, the single-electron pump commonly employs a chain of nanometer-scaled conducting materials, called Coulomb islands, which is complicated and difficult to fabricate. Technology for making multiple islands in Si is still premature. The single-electron transistor (SET), which is the simplest SED and has only one island, cannot work as a pump because of an inherent leakage current, which fatally lowers the transfer accuracy. However, Si technology has enabled us to fabricate, in a controlled way, SETs operating at high temperatures with good operational stability [1].

We thus proposed a new structure for Si-based pumps, in which we utilize a high-temperature operating Si SET in combination with two ultra-small metal-oxide-semiconductor field-effect transistors (MOSFETs) sandwiching it. These MOSFETs have extremely high off-resistance, and this makes it possible to almost completely prevent the leakage current from flowing. We have demonstrated pump operation at 25 K [2], which is two to three orders of magnitude higher than that for the metal-based ones.

Figure 1 shows a scanning electron microscope image of the pump. Figure 2 shows drain current versus drain voltage characteristics measured at 25 K for 1-MHz ac gate biases. The drain currents are quantized in units of ef at around zero drain voltage, where e is the elementary charge and f is the frequency of the voltages to the MOSFETs. In addition, a change in the polarity of the gate-voltage phase shift results in a change in the polarity of the current. These data demonstrate the single-electron transfer.

The present result is the first step towards producing practical single-electron pumps.

[1] Y. Takahashi et al., J. Phys.: Condens. Matter **14** (2002) R995.
[2] Y. Ono and Y. Takahashi, Appl. Phys. Lett. **82** (2003) 1221.

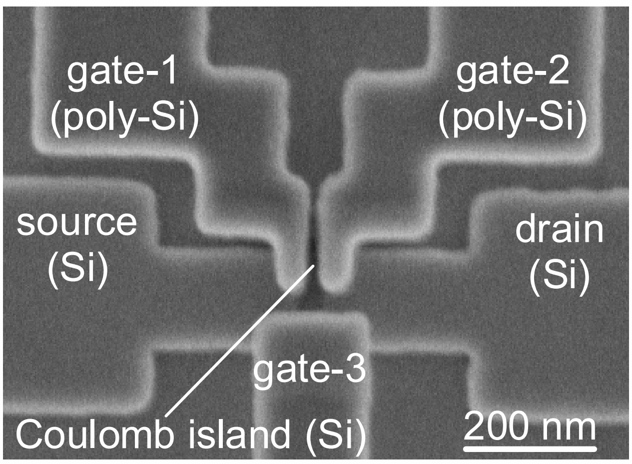


Fig. 1. Electron microscope image of the pump.

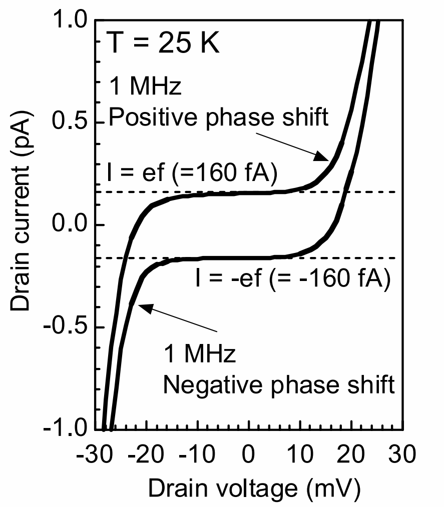


Fig. 2. Current characteristics.

Analysis of Ultrathin Resist Film

Kenichi Kanzaki, Toru Yamaguchi, Masao Nagase, and Hideo Namatsu
Device Physics Laboratory

Thinning resist film is an effective way to prevent resist pattern collapse and improve resolution. However, the characteristics of ultra-thin resist film, 100-nm thick or less, should strongly reflect surface and interface effects. They should be different from those of conventional thick resist films and affect the roughness, which is the resolution determining factor of resist patterns. Thus, an understanding of the thinning effect on resist performance is important in high-resolution nanolithography. We have, therefore, clarified quantitatively the resist thinning effect on the roughness and resist internal structure [1].

Ultrathin resist films (ZEP520) (10-, 30-, and 100-nm thick) were investigated by using an atomic force microscope (AFM). Roughness at each thickness was compared by linewidth fluctuations of delineated line patterns (designed line width of 50 nm). It was found that the linewidth fluctuation increased with decreasing resist thickness as shown in Fig. 1. There was a marked increase below 30 nm. To determine the cause of the increase, we investigated the thinning effect on the resist internal structure by focusing on the polymer aggregates. The results are illustrated in Fig. 2. The aggregates appeared to be compressed and their volume seemed to decrease with decreasing resist thickness. Owing to those change of internal structure, the dissolubility increased with decreasing resist thickness. This indicates that the surrounding polymers dissolve faster when the aggregate becomes compressed. Hence, the dissolubility contrast between the polymer aggregates and surroundings is enhanced by thinning, thus probably causing the increase of roughness. This study suggests that decreasing the dissolubility contrast is important for high-resolution nanolithography using ultra-thin resist film.

[1] K. Kanzaki et al., Jpn. J. Appl. Phys. **41** (2002) L1342.

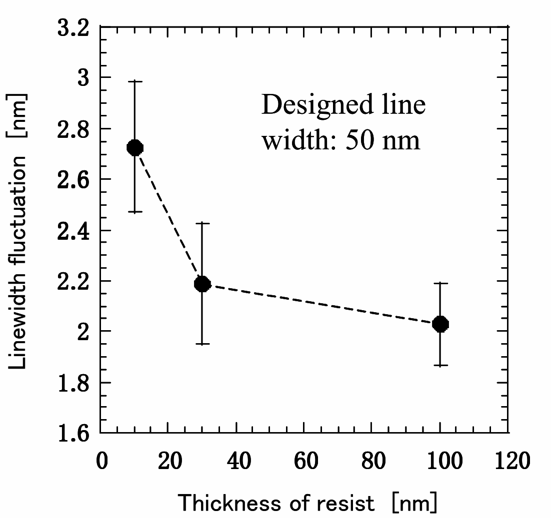


Fig. 1. Resist thickness dependence of linewidth fluctuations.

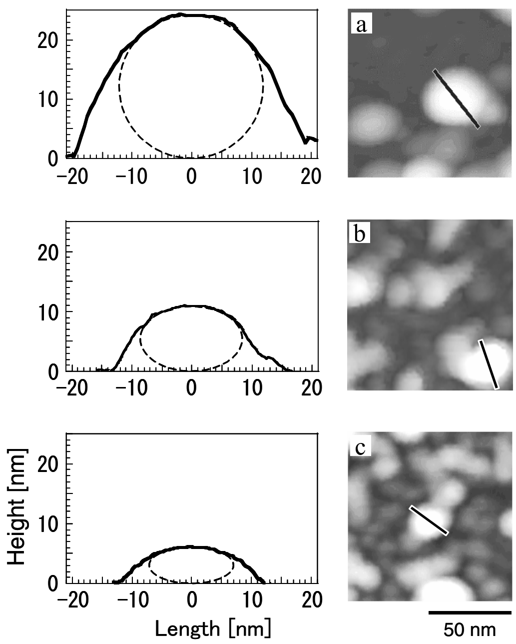


Fig. 2. AFM images of developed resist surface of (a) 100-. (b) 30-, and (c) 10-nm-thick resist. The reconstructed profiles of typical aggregate structures for each thickness are also shown.

Electronic Structure at Carbon Nanotube Tips Studied by Photoemission Microscopy

Satoru Suzuki, Yoshio Watanabe, Toshio Ogino, and Yoshikazu Homma
Device Physics Laboratory

Carbon nanotubes (CNTs) have attracted attention primarily because of the unique one-dimensional structure, and their exotic properties such as high current flow density, high mechanical strength, and chemical inertness. A specific electronic structure is expected at the tips of CNTs, where the graphene cylinders are closed by hemispherical caps. We examined the position dependence of the local electronic structure along the tube axes by means of scanning photoemission microscopy (SPEM). Our results indicate that a density of states near the Fermi level at tips is much larger than that at sidewalls.

Figure 1 shows the C1s SPEM image of multi-walled CNTs aligned perpendicularly on a Si substrate. The heights of the tips are almost uniform because the lengths of the CNTs are very similar and the CNTs are well aligned. Valence band spectra of the CNTs obtained from the spatially selected regions (denoted by numbers in Fig. 1) are shown in Fig. 2. The spectra from the sidewalls of the CNTs are reasonably similar to each other and show a very small density of states at the Fermi level. On the other hand, the two tip positions show a substantially larger density of states near the Fermi level. It has been theoretically predicted that such a larger density of states is formed by the insertion of 6 five-member rings into graphene network at tips. However, in this case, the five/six member ring ratio at the tips can be estimated to be about 1/4500 from a geometrical consideration. Thus, the contribution of the five-member rings should be negligible. These results strongly suggest that the CNTs do not have atomically close-packed structures, but have many structural defects (dangling bonds), especially in the tip region. The electronic properties of the CNTs seem to be significantly influenced by the defects, because intrinsic density of states at the Fermi level of CNTs is generally quite small.

[1] S. Suzuki et al., Phys. Rev. B **66** (2002) 035414.

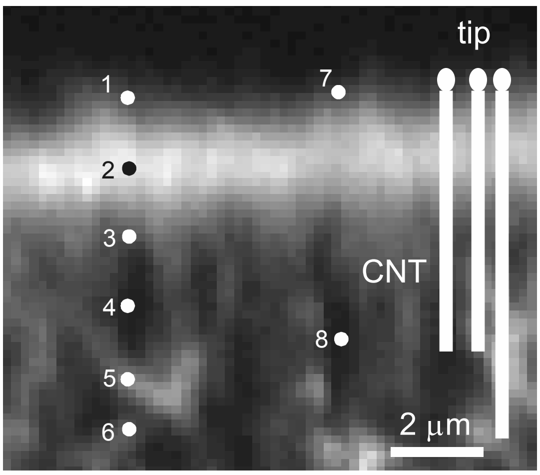


Fig. 1. C1s SPEM image of aligned CNTs.

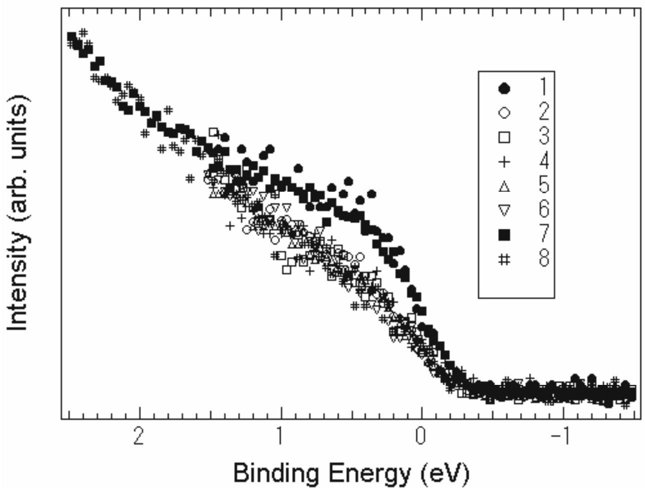


Fig. 2. Valence band spectra of CNTs obtained from spatially selected regions. The positions of the measurements are shown in Fig. 1.

Anisotropic Strain for Controlled Growth of Nanostructures

Koji Sumitomo, Zhaohui Zhang, Hiroo Omi, and Toshio Ogino
Device Physics Laboratory

Nanostructure self-assembly is expected to be one of the key techniques in the bottom-up approach to realize futuristic semiconductor nanotechnology. In order to utilize the self-assembly process in Si integrated systems, however, it is important to control the fluctuations in size, shape, and position of such nanostructures. Here, we report that the anisotropic surface stress and strain relaxation of the 3D islands lead to elongation of the islands.

Si(113) covered with 2-ML Ge forms the stable 2×2 reconstructed surface. Figure 1 shows the 2×2 structural model we proposed and scanning tunneling (STM) images (experimental and simulations) [1]. The rows indicated an A-type are attributed to rebonded atoms due to removal of the topmost Ge atoms and the B-type row to tilted pentamers of five Ge atoms surrounding an interstitial atom at the subsurface. The simulated STM images based on an optimized structure from the first-principles calculations are in good agreement with the experiments. We also found that anisotropic surface stress resulting in such unique surface reconstruction plays a crucial role in nanostructure formation after further Ge deposition. The elongation of 3D islands along $[33\bar{2}]$ is energetically favorable because of tensile stress in spite of the 4% larger lattice constant of Ge than Si. Once the nanowires begin to form (Fig. 2), the strain inside the nanowire is relaxed across the wire and leading to stability [2]. Strain field generates long-range repulsive interaction between the Ge nanowires and results in uniform spacing between the wires. These results suggest the possibility of atomically precise control of the shape, size, and position of nanostructures by controlling anisotropic stress and strain.

[1] Z. Zhang et al., Phys. Rev. Lett. **88** (2002) 61011.
[2] K. Sumitomo et al., Phys. Rev. B **67** (2003) 35319.

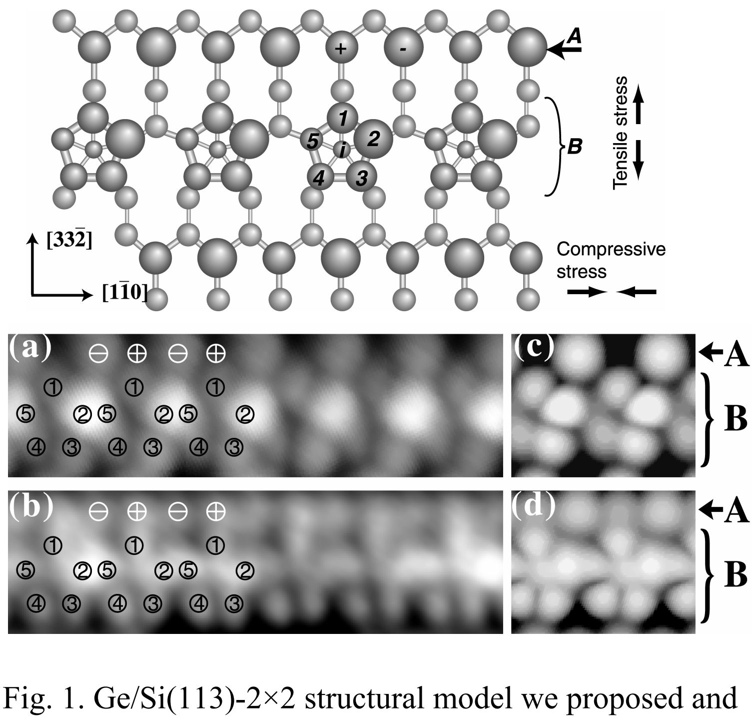


Fig. 1. Ge/Si(113)-2×2 structural model we proposed and STM images (a,b) experiment and (c,d) simulation.

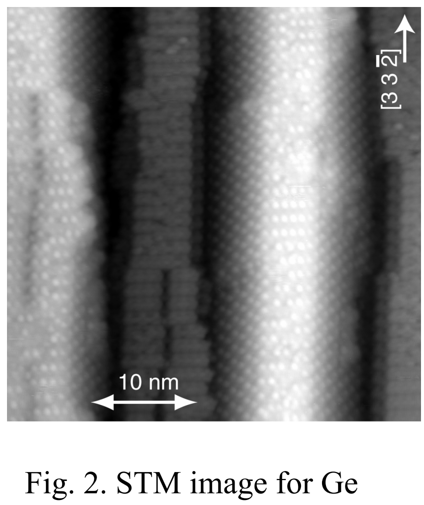


Fig. 2. STM image for Ge nanowires.

Overview of Materials Science Research

Hideaki Takayanagi
Materials Science Laboratory

The Materials Science Laboratory (MSL) aims at producing new materials to discover quantum phenomena for new functions. The materials including those that do not exist in nature are produced by controlling the configuration and coupling of atoms and molecules. To accomplish these goals from different perspectives the following four MSL groups are formed. They cover research fields of various materials ranging from inorganic matter, such as semiconductors, to organic matter, such as neurotransmitters. The characteristic feature of MSL is the effective sharing of the unique nanofabrication and measurement techniques of each group. This enables fusion of research fields and techniques, which leads to innovative material research for the IT society.

Molecular and Bio-Science Research Group
Create new organic materials by manipulating single molecules, and investigate information processing devices based on neural functions.
Superconducting Thin Films Research Group
Study high-Tc superconductors by fabricating top quality samples through the molecular beam epitaxy(MBE) method and develop its applications to microwave communication.
Superconducting Quantum Physics Research Group
Investigate theoretical and experimental research on a quantum computers superconductors and new magnetic devices using quantum dot arrays.
Spintronics Research Group
Aim to control the spin degrees of freedom in semiconductors to achieve new device functions for the next generation electronics.

The following are four major results obtained in the fiscal year 2002.

1. The response of the neural circuit grown from rat brain neuron is measured by means of unique microelectrode arrays with newly developed stimulation technique that guarantees excellent reproducibility. The obvious correlation between stimulus pattern and the response infers that the brain memory is based on neural level mechanism.
2. First growth of Nd_2CuO_4-type structured La_2CuO_4 succeeded, which has been known as K_2NiF_4-type only since low temperature growth is difficult without our MBE technique. The growth parameters to choose each structure are fully investigated.
3. Plaquette super lattice formed by InAs quantum wires embedded in InGaAs substrates is predicted to be a superconductor at the transition temperature 2 times higher than that of simple square lattice. The difference is large enough to be observed experimentally. This shows that material property can be designed by controlling dot structural parameters.
4. Modification of Rashba spin-orbit interaction strength in InGaAs quantum wells is observed as a function of structural asymmetry. The interaction coefficients first systematically obtained by measuring magnetic resistance show good agreement to the theoretical values.

Plasticity in Neuronal Networks

Yasuhiko Jimbo, Nahoko Kasai, Chunxi Han, and Keiichi Torimitsu
Materials Science Laboratory

It is widely accepted that synaptic plasticity is one of the major candidates for learning and memory in biological systems. In the central nervous system, where sparse coding is the key for information processing, the mechanisms for integrating these synaptic changes are still unknown. Here we developed cultured neuronal networks on microelectrode-array (MEA) substrates. Combining MEA based recording of neuronal activity with the novel multi-site electrical stimulation system [1], highly reliable evoked response recording was achieved. Using this system, we studied activity-dependent modification of evoked responses in cultured rat cortical neuronal networks.

Cultured cortical networks showed strong spontaneous activity. Its characteristics are highly dependent on the developmental stages [2]. To detect activity-dependent changes accurately, we used stable mature networks cultured for more than two months. The cell-plated MEA was kept in the CO_2 incubator. The electrical recording/stimulation system and the medium perfusion system were directly connected to the MEA in the incubator. Using continuous perfusion at a quite slow rate (0.1 ml/h), the neurons could be maintained at a steady state for some weeks. Figure 1 (a) shows the cultured neurons on the MEA. We can see that a number of neurons extended their neurites, and connected one another. Constant electrical stimulation was applied from a specific site and the evoked responses were recorded. The stimulus was applied every ten seconds. A single session consisted of 360 trials and total three sessions were carried out. Fifty three neurons could be identified by spike sorting. The evoked responses of one of the 53 neurons are shown in Fig. 1 (b) as raster plots. A certain temporal structure gradually emerged, which indicated that the reliability of the evoked response of this neuron increased. Modifications in the evoked responses of the other neurons were not uniform but we found a common rule underlying these changes.

[1] Y. Jimbo et al., IEEE Trans. Biomed. Engng. **50** (2003) 241.
[2] T. Tateno et al., Phys. Rev. E **65** (2002) 051924.

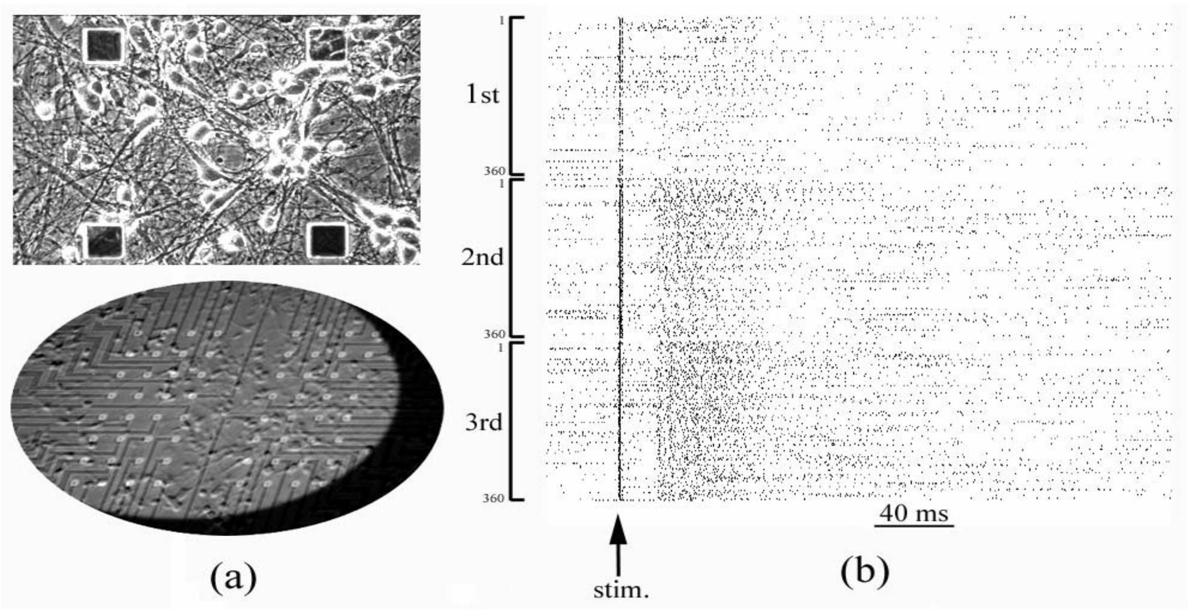


Fig. 1. (a) Cultured cortical networks on an electrode-array substrate
(b) Gradual modification of evoked responses induced by repetitive electrical stimulation

Artificial Coordination Control in Copper Oxides by Molecular Beam Epitaxy
– New Strategy for Material Synthesis –

Akio Tsukada and Michio Naito
Materials Science Laboratory

The rare-earth (RE) copper oxides of general chemical formula RE_2CuO_4 are known to be parent compounds of prototype high-T_c superconductors. They take two different crystal structures: K_2NiF_4 (6-fold Cu-O coordination) and Nd_2CuO_4 (4-fold) as shown in Fig. 1. The former accepts only hole doping, the latter only electron doping. The radius of RE^{3+} ions primarily determines which of the two structures forms. The K_2NiF_4 structure forms with large La^{3+} ions, while the Nd_2CuO_4 structure forms with smaller RE^{3+} ions, such as RE = Pr – Gd. Because of the thermal expansion mismatch between ionic RE-O and covalent Cu-O bonds, however, Nd_2CuO_4-type La_2CuO_4 is predicted to stabilize below around 425ºC [1]. There have been a few attempts by bulk synthesis to stabilize Nd_2CuO_4-type La_2CuO_4 in the past [2]. However, a conventional solid-state reaction method requires a firing temperature of at least 500ºC, so it could not produce single-phase Nd_2CuO_4-type La_2CuO_4. We demonstrate that low-temperature molecular-beam epitaxy indeed crystallizes La_2CuO_4 in the Nd_2CuO_4 structure [3].

Figure 2 shows the phase diagram on the selective stabilization of the K_2NiF_4 structure (white) versus the Nd_2CuO_4 structure (gray). The vertical axis is the growth temperature and the horizontal axis is the substrate lattice constant (a_0). This is the first demonstration of artificial coordination control in copper oxides, which may open up the next strategic material search.

[1] A. Manthiram and J. B. Goodenough, J. Solid State Chem., **92** (1991) 231.
[2] F. C. Chou et al., Phys. Rev. B, **42** (1990) 6172.
[3] A. Tsukada, T. Greibe, and M. Naito, Phys. Rev. B, **66** (2002) 184515.

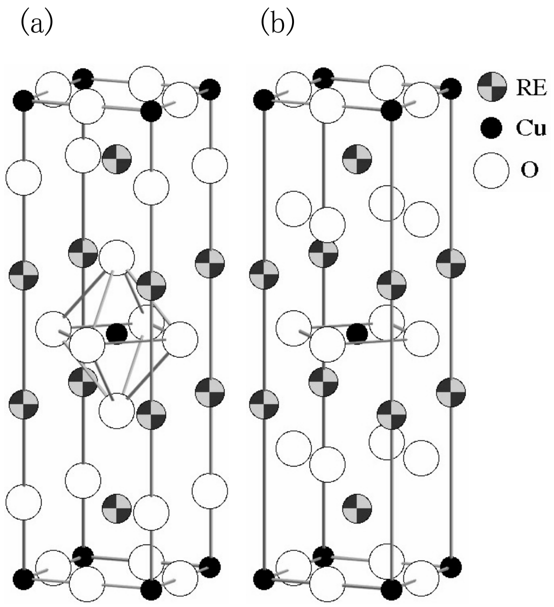


Fig. 1. Crystal structures of RE_2CuO_4.
(a) K_2NiF_4 structure, (b) Nd_2CuO_4 structure.

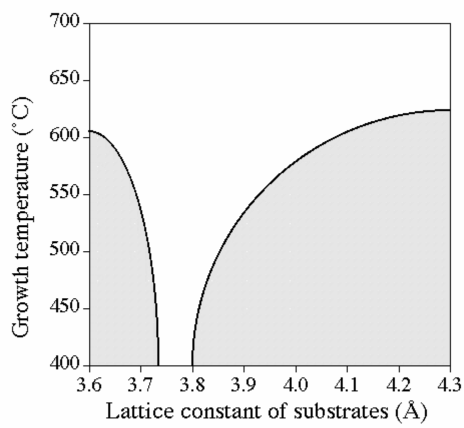


Fig. 2. Phase diagram of stabilized crystal structures of La_2CuO_4.
The gray areas indicate that the La_2CuO_4 is stabilized in the Nd_2CuO_4 structure.

Design of Superconductor in Quantum Dot Superlattices

Hiroyuki Tamura and Hideaki Takayanagi
Materials Science Laboratory

The electronic properties of solids are closely related to their crystal structure which is strictly determined by the atomic nature of the individual elements. However, the imposition of a superstructure on a given lattice makes the controlled fabrication of structures with chosen properties possible. One approach discussed more recently is to place quantum dot (QD), also known as artificial atoms, on the points of a lattice to form an artificial crystal called a quantum-dot superlattice (QDSL) [1,2].

Here, we propose a method for forming QDSLs in a quantum wire network of square and plaquette lattices shown in Fig. 1 [3]. The plaquette lattice has a square plaquette in each unit cell with four lattice-points at the vertices, as shown in the inset of Fig. 2. We have used the spin dependent local density approximation to obtain the band structure of the wire network. It can be shown that both QDSLs are well represented by the Hubbard model. An interesting difference between the two QDSLs is that the Fermi surface of the plaquette QDSL has disconnected pieces whereas the square QDSL is formed of one piece. To find a correlation effect that reflects both the Coulomb interaction and the structures of the Fermi surface, we studied the existence of superconductivity for both lattices within the framework of the Hubbard model. We found a superconducting ground state where the transition temperature T_c of the plaquette lattice is more than double that of the square lattice as shown in Fig. 2, and is sufficiently high to allow superconductivity to be observed experimentally.

[1] H. Tamura, K. Shiraishi, T. Kimura, and H. Takayanagi, Phys. Rev. B **65** (2002) 085324.
[2] K. Shiraishi, H. Tamura, and H. Takayanagi, Appl. Phys. Lett. **78** (2001) 3702.
[3] T. Kimura, H. Tamura, K. Kuroki, K. Shiraishi, H. Takayanagi, and R. Arita, Phys. Rev. B **66** (2002) 132508.

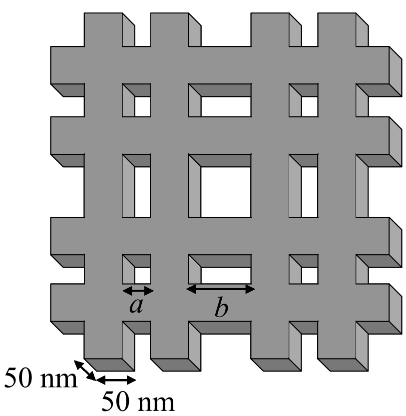


Fig. 1. Diagram of a quantum wire network with spacings a and b between adjacent wires. We assume InAs quantum wires buried in $In_{0.776}Ga_{0.224}As$ barrier regions. The case where a=b (a<b) corresponds to the square (plaquette) lattice.

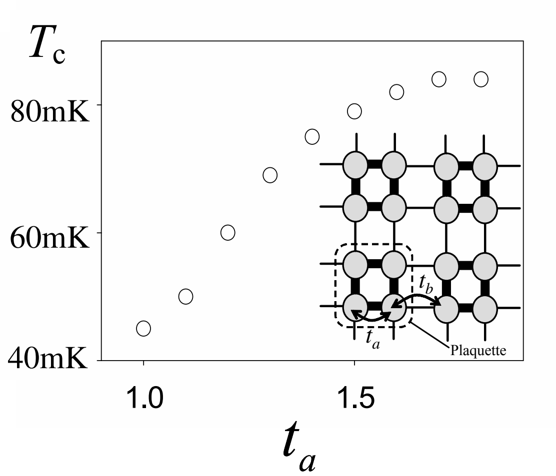


Fig. 2. Superconducting transition temperature T_c plotted as a function of the transfer energy t_a. T_c of the plaquette lattice (t_a=1.5, t_b=0.5) is more than double that of the square lattice (t_a=t_b=1). Inset: Corresponding tight-binding model with hopping parameters t_a and t_b.

Control of Spin-Orbit Interaction in a Semiconductor

Takaaki Koga and Junsaku Nitta
Materials Science Laboratory

Spin-orbit (S.O.) interaction is an important parameter responsible for the spin precession and spin splitting in semiconductors. Therefore, its control in a semiconductor is considered to be a key for the development of the recently growing research area, "spintronics," where spin degrees of freedom are explored for the realization of new device functionalities [1,2]. The so-called Rashba S.O. interaction (R.S.O.I.) is caused by the structural inversion asymmetry (SIA) in semiconductor heterostructures, of which magnitude is controllable by the applied gate voltages. However, the magnitude of the R.S.O.I. is generally so small that few experimental techniques are readily available for the determination of its magnitude. In this regard, we have been using the weak antilocalization (WAL) analysis successfully, for the first time, for systematic and quantitative evaluation of the strength of the R.S.O.I. [3].

Shown in Fig. 1 are the potential diagrams for the four $In_{0.53}Ga_{0.47}As$ quantum well (QW) samples designed for the present investigation, where carrier supplying layers are introduced both above and below the QW for the systematic control of the QW potential shapes. The results of the magneto-resistance (MR) measurements of these samples at low temperatures (0.3 K) are shown in Fig. 2(a), where we find the weak localization (resistance maximum at zero magnetic field) to WAL (resistance minimum at zero magnetic field) transition as the degree of the SIA increases. Hence, the larger the SIA of the sample, the stronger the S.O. interaction. Shown in Fig. 2(b) are the values of the R.S.O.I. parameter α deduced from the theoretical fitting of the MR data as shown in Fig. 2(a), together with the predicted α values obtained from the **k·p** perturbation calculations. We see an excellent agreement between the experimental and theoretical α values.

[1] S. Datta and B. Das, Appl. Phys. Lett. **56** (1990) 665.

[2] T. Koga, J. Nitta, H. Takayanagi and S. Datta, Phys. Rev. Lett. **88** (2002) 126601.

[3] T. Koga, J. Nitta, T. Akazaki and H. Takayanagi, Phys. Rev. Lett. **89** (2002) 046801.

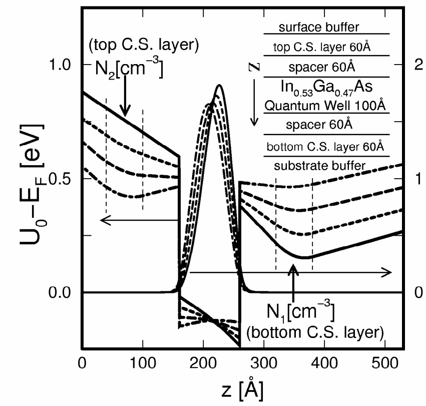


Fig. 1. Potential profiles for the $In_{0.53}Ga_{0.47}As$ quantum wells. Solid, short-dahsed, long-dashed and dash-dotted curves denote samples 1-4, respectively.

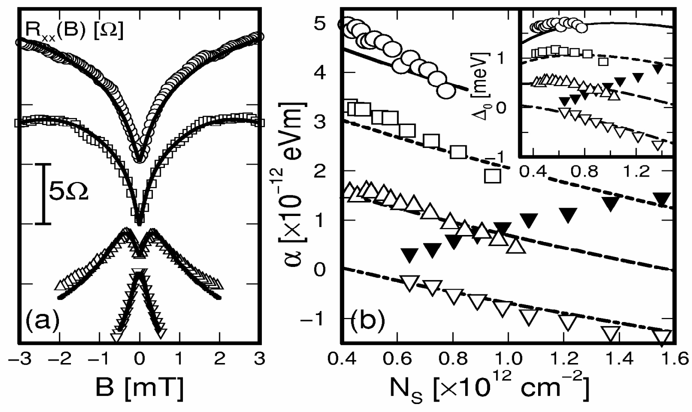


Fig. 2. (a) Low temperature (0.3 K) magneto-resistance data of the quantum well samples shown in Fig. 1. ○□△▽ denote samples 1-4, respectively. (b) α values estimated from the weak antilocalization analysis. The inset shows the same results as in the main plot in zero-field spin splitting energy Δ_0.

Overview of Quantum Electron Physics Research

Yoshiro Hirayama
Physical Science Laboratory

Our research in the fields of quantum physics and electronics is based on semiconductor nano-structures fabricated by high-quality semiconductor crystal growth and advanced device fabrication techniques. We use these nanostructures to investigate quantum coherent control, carrier interactions, and wide-bandgap semiconductor physics. Our aim is the development of innovative semiconductor devices. The Quantum Solid State Physics Research Group and Wide-Bandgap Semiconductor Research Group are working in the following areas.

Quantum Solid State Physics Research Group

(1) Carrier interactions in low-dimensional semiconductor heterostructures (carrier interactions in bilayer systems; interactions between nuclear-spin and conduction electrons).
(2) Quantum electronic state control in quantum dot systems (spin control & carrier dynamics of quantum dots; fundamental properties of solid-state quantum computers).
(3) Semiconductor nano-mechanical systems (fabrication and characterization).
(4) Direct nano-scale imaging of electronic states by low-temperature STM.

Wide-Bandgap Semiconductor Research Group

(1) Optical device physics in ultra-violet LEDs and optical devices using micro-facets.
(2) Electronic device physics, such as carrier transport in nitride FETs and HBTs.
(3) Impurity doping into wide-bandgap semiconductors and its characterization.
(4) Developing new semiconductor materials such as InN and diamond.

Major results obtained fiscal-year 2002 are reported in the following pages.

We have successfully carried out electrical pump and probe measurements of quantum dot systems. We precisely measured electron relaxation time from the excited state to the ground state and found an extremely long relaxation time when electron relaxation is accompanied by spin flip. This means that electron spin is well separated from circumstances in a quantum dot system. We have also succeeded in observing coherent oscillation of an electron in a coupled quantum dot. This is the first demonstration of all-electrical control of a semiconductor qubit.

We have studied interaction between a two-dimensional electron system and nuclear spins. In a certain condition, a driving current flowing in the electron layer polarizes nuclear spins. We have successfully demonstrated all-electrical control of nuclear spin polarization and relaxation. In nanomechanical systems, we have fabricated InAs based mesoscopic-scale cantilevers and have found high sensitivity arising from quantum effects.

We have successfully fabricated an npn-type GaN/InGaN heterojunction bipolar transistor (HBT) using the base regrowth technique to improve ohmic characteristics. The HBT characteristics were drastically improved. This demonstrates that nitride HBTs are promising for the future high-power electronic devices.

We have clarified the bandgap energy of InN, which was believed to be about 1.9 eV for more than a quarter century. We discovered that our experimental data did not support the previous value, so we grew a high-quality InN epitaxial layer to investigate its bandgap energy. Then, we showed that the real bandgap energy of InN is about 0.9 eV, which indicates that InN is a promising material for optical devices for communications.

Long-lived Spin States in a Quantum Dot

Toshimasa Fujisawa
Physical Science Laboratory

A semiconductor quantum dot, which is often referred to as an artificial atom, accommodates tunable number of electrons that occupy well-defined orbitals. Dynamical behaviors of electrons and electron spins in a quantum dot are growing interests for novel spintronics devices and quantum computing applications, as well as for fundamental characteristics of electrons and spins in nanostructures. The energy relaxation process, which is one of the most fundamental dynamical properties, is very important for spin based information storage (quantum bit). We successfully measured the energy relaxation time in a quantum dot and compared to the theories. The results indicate that the spin and orbital degrees of freedom are well separated in our system. This is desirable for potential applications to spin based information storage.

We employ novel electrical pump-and-probe measurements to investigate the relaxation time from an excited state to the ground state in one- and two-electron semiconductor quantum dot artificial atoms [1]. We repeatedly applied voltage pulses to push the system out of equilibrium, and measure the time-integrated non-equilibrium transient current to determine the energy relaxation time. We find that the relaxation time of the one-electron artificial hydrogen atom is 3 - 10 ns, which is understood by spontaneous emission of acoustic phonons. This process can be regarded as an allowed transition in artificial atoms. However, the relaxation time of the two-electron artificial helium atom can be longer than 200 μs, which is 4 or 5 orders of magnitude longer than that for the allowed transition. This transition is forbidden by total-spin conservation. Although the relaxation is actually dominated by cotunneling process in our sample, the spin relaxation time is comparable to the theoretical predictions based on spin-orbit coupling, indicating the high quality of our sample. The large ratio of the allowed and forbidden transition rates indicates that the total spin is an excellent quantum number in artificial atoms.

For the application to a spin quantum bit, in which just a single-electron spin occupy the lowest orbit in a magnetic field, the spin-orbit interactions can determine the energy relaxation time of a spin quantum bit. We estimate from our observation that this spin relaxation time can be longer than 1ms, which is extremely (about 9 orders of magnitude) longer than the time required for typical one- and two-qubit manipulations (a few ps) [2]. Our results therefore encourage further research in the use of the spin degree of freedom in QDs.

[1] T. Fujisawa et al., Nature **419** (2002) 278.
[2] J. Gupta et al., Science **292** (2001) 2458.

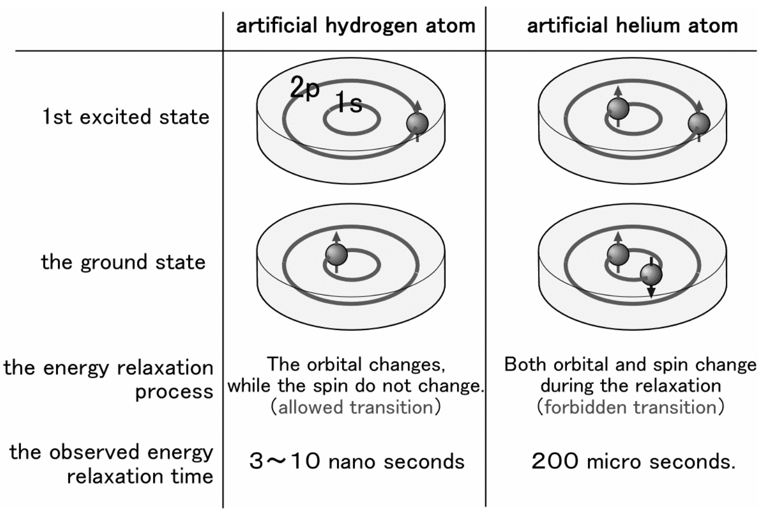


Fig. 1. Energy relaxation processes in a semiconductor quantum dot.

Compound Semiconductor Micro/Nanomechanical Devices

H. Yamaguchi and Y. Hirayama
Physical Science Laboratory

Compound semiconductor heterostructures have been used in a wide variety of optical and electronic devices such as semiconductor lasers and ultra high-speed transistors, because their structure dimensions can be controlled down to the nanometer scale. In particular, functionalities based on quantum mechanical principles appear with structures that have dimensions comparable to electron waves. We integrate these "quantum structures" into microscopic mechanical structures in order to develop novel semiconductor devices. Figure 1 shows a scanning electron microscope (SEM) image of an InAs/AlGaSb displacement sensor that is an example of such a mechanical device fabricated from a compound semiconductor quantum structure. The single heterostructure consists of 15-nm-thick InAs and 285-nm-thick AlGaSb layers that were released from a GaAs (111)A substrate to form a cantilever beam by using photolithography and selective etching. The deflection of the cantilever can be detected from the change in resistance, for which we obtained a sensitivity as high as 0.01 nm/$Hz^{0.5}$ [1]. Figure 2 shows the SEM image of another example, nanoscale InAs cantilevers, which were fabricated using a self-assembled growth technique. These have a thickness of 6-30 nm, a width of 20-100 nm, and a length of 50-500 nm. InAs has the unique property of electron surface accumulation, which enables us to fabricate conductive nanoscale cantilevers. It is expected that the energy of such a nanoscale cantilever is quantized at low temperatures and that such new quantum mechanical phenomena will bring about a revolution in the physics and technology of semiconductor fine structure devices.

[1] H. Yamaguchi, S. Miyashita, and Y. Hirayama, Appl. Phys. Lett. **82** (2003) 394.
[2] H. Yamaguchi and Y. Hirayama, Appl. Phys. Lett. **80** (2002) 4428.

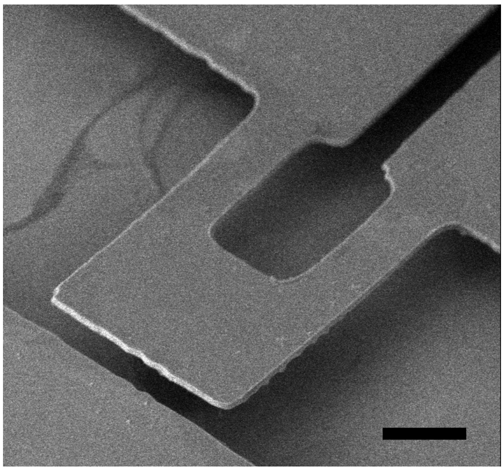


Fig. 1. SEM image of fabricated InAs/AlGaSb displacement sensor.

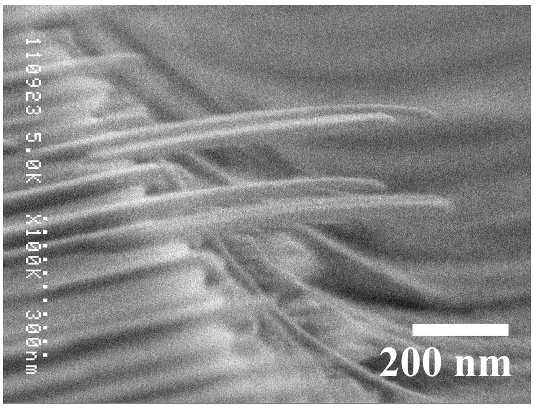


Fig. 2. SEM image of nanoscale InAs cantilevers fabricated using a self-assemble growth technique.

Nitride Heterojunction Bipolar Transistor with Regrown Base Layer

Toshiki Makimoto, Kazuhide Kumakura, and Naoki Kobayashi
Physical Science Laboratory

A high-power microwave transistor is getting more important, since it is used for the communications between the base stations for cellular phones. Compared with Si and GaAs, nitride semiconductors have high breakdown voltage due to their wide bandgap. On the other hand, a heterojunction bipolar transistor (HBT), a kind of electronic devices, is suitable for a high-power microwave transistor due to its capabilities such as the high breakdown voltage, the high current density, and the good threshold voltage uniformity. Therefore, a nitride HBT is a promising electronic device in terms of both materials and devices. However, there are two issues to be addressed for this nitride HBT. One is a relatively lower current gain, compared with HBTs composed of other semiconductors such as Si/SiGe and AlGaAs/GaAs. The other is that the offset voltage in the common-emitter current-voltage (I-V) characteristics is much higher than the value expected from the conduction-band discontinuity between the emitter and the base layers. To solve these two issues, we have used the base regrowth technique, resulting that the nitride HBT characteristics have been drastically improved.

Figure 1 shows a schematic illustration of an HBT structure fabricated in this work. This structure has two features. One is that the low resistive p-InGaN layer is used as a base layer instead of the conventional p-GaN [1]. The other is that a double heterostructure is used to obtain a high breakdown voltage [2]. As shown in Fig. 1, many defects were produced on the base surface during the HBT fabrication process and they are considered to degrade the nitride HBT characteristics. In this work, p-InGaN was regrown on the surface to eliminate the effect of these defects. Figure 2 shows the common-emitter I-V characteristics at room temperature. The maximum current gain is 2000, which is 100 times as high as the previously reported value for the nitride HBTs [3,4]. Furthermore, the minimum offset-voltage (the turn-on voltage of the collector current in the common-emitter I-V characteristics) is 0.3 V, which is one tenth of the previously reported value [3,4].

[1] K. Kumakura et al., Jpn. J. Appl. Phys. **39** (2000) L337.
[2] T. Makimoto et al., Appl. Phys. Lett. **79** (2001) 380.
[3] T. Makimoto et al., Proceeding of The Fifth International Conference on Nitride Semiconductors (ICNS-5), Nara Japan, May 2003.
[4] T. Makimoto et al., Proceeding of 2003 Device Research Conference (2003 DRC), Salt Lake City USA, June 2003.

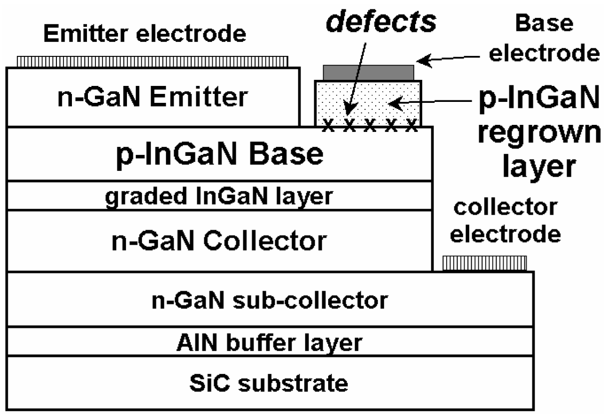


Fig. 1. Schematic illustration of an HBT structure.

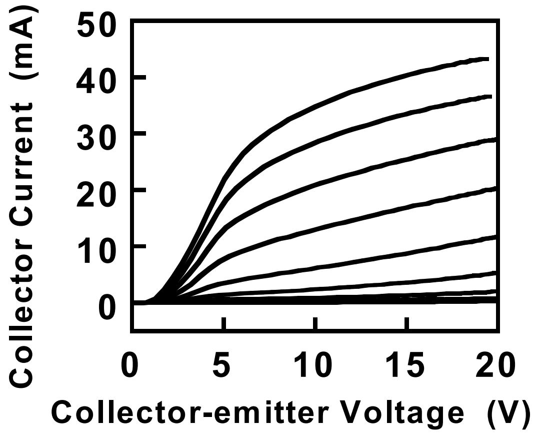


Fig. 2. Common-emitter I-V characteristics at room temperature.

Optical Band-Gap Energy of Wurtzite InN

Takashi Matsuoka
Physical Science Laboratory

In the InGaAlN system we proposed [1], which has been applied for blue-green LEDs and so on, InN remains the most mysterious compound, due mainly to difficulty in growing high-quality crystals because of the extremely high equilibrium vapor pressure of nitrogen. A typical issue is the fundamental band gap E_g. Early absorption studies on poly-crystalline films reported E_g=1.8-2.0 eV at room temperature. All of those samples showed no corresponding band-edge photoluminescence (PL). On the other hand, based on a series of absorption experiments on high-quality wurtzite $In_xGa_{1-x}N$ films, E_g decreased monotonically from 3.4 eV (x=0) to 2.1 eV (x=0.42), and it was pointed out that InN single crystals would have a much smaller Eg than commonly believed [1]. In this report, it is described that single crystalline InN has a band-gap energy of 0.8 eV.

High-quality wurtzite InN was successfully grown on a (0001) sapphire substrate using metalorganic vapor phase epitaxy (MOVPE) at ambient pressure. The growth temperature was 500ºC. Trimethylindium (TMI) and ammonia as were the source gases, and their flow rate was 1 to 6 μmol/min and 15 slm, respectively. The V/III flow rate ratio was adopted to be large enough to suppress the indium precipitation in the film. As a carrier gas, nitrogen was used instead of hydrogen to promote ammonia decomposition.

A typical result of the absorption at room temperature is shown in Fig. 1, which plots as absorbance squared versus photon energy. Extrapolation of the linear region to the horizontal axis gives E_g = 0.8-1.0 eV. In PL spectra measured at room temperature as shown in Fig. 2, the PL peak was observed at 0.76 eV. Even under the high power excitation of 0.6 MW/cm^2, no PL was observed near the previous "band gap" energy. Eg for InGaN containing InN are plotted in Fig. 3, including InN [2]. Eg for polycrystals is larger than that for single crystals. By fitting a quadratic curve to the data from optical absorption using least-squares method, Eg of 0.85 eV for InN was obtained.

To conclude, the above mentioned results strongly suggest that Eg of InN should be near 0.8 eV. Precisely determining Eg of InN will require a thicker InN film of higher quality with low carrier density. The discrepancy from previous data could be due to differences in crystallinity. Due to this work, the application field of InGaAlN is extended to infrared.

[1] T. Matsuoka et al., in: Proc. Int. Symp. on GaAs and Related Comps, Karuizawa, Japan, 1989, 141.
[2] T. Matsuoka et al., Appl. Phys. Lett. **81** (2002) 1246.

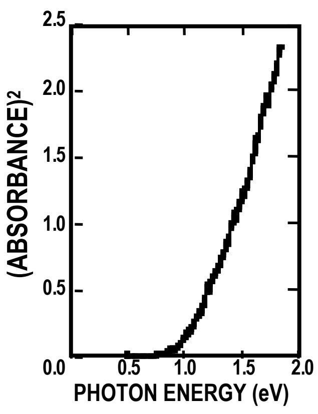


Fig. 1. Squared absorbance vs. photon energy.

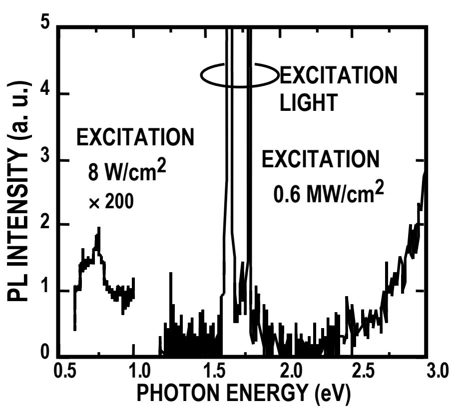


Fig. 2. Photoluminescence.

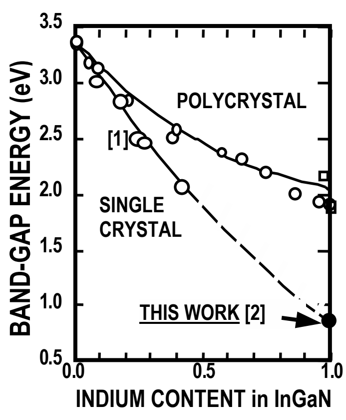


Fig. 3. Bowing of band-gap energy in $In_XGa_{1-X}N$.

Overview of Quantum Optics and Optical Materials Research

Yoshiro Hirayama
Physical Science Laboratory

In the fields of quantum optics and optical materials we pursue the development of core-technologies that will innovate optical communications and optical signal processing and seek fundamental scientific progress.

Quantum Optical State Control Research Group
(1) Quantum communication and information processing (quantum cryptography/protocols, entanglement, and computing).
(2) Atom optics (Bose-Einstein condensation of alkali atoms).

Ultrafast Optical Physics Research Group
(1) High-irradiance, short-pulse soft X-ray generation from femtosecond laser-produced plasma and its application to materials science.
(2) Ultrafast laser pulse induced terahertz radiation and its application.

Optical Device Physics Research Group
(1) Optical properties in nitride-semiconductors and their device applications.
(2) Coherent control of excitonic and spin states in quantum dots.

Photonic Nanostructure Research Group
(1) Photonic crystal optical circuits (2D SOI photonic crystals, organic photonic crystals, and higher-dimensional structures).
(2) Interaction between photonic nanostructures and materials (negative refraction, extremely-large group velocity dispersion, and photonic quasicrystal lasers)
(3) Direct nanoprinting lithography

Major results obtained fiscal year 2002 are reported in the following pages.

We have carried out quantum key distribution experiments using a single-photon source in collaboration with a Stanford group. A single photon source, which emits exactly one photon per pulse, is essential to completely prevent the eavesdrop action by a beam splitter.

We have demonstrated a change in the spectral shape of high-order surface harmonics at an extreme ultraviolet wavelength by varying the spectral shape of a pump laser. We have also observed a drastic increase in solid-surface harmonic intensity for glass targets. These results show that active control of solid-surface harmonics is possible through pump and target control, which will become important for single attosecond pulse generation.

We proposed a novel structural design for an InGaN/GaN laser using a deeply etched semiconductor/air DBR mirrors. The optimum design for practical DBR mirrors with tilted sidewalls is different from the conventional design using $\lambda/(4n)$ semiconductor and $\lambda/4$ air. We achieved a mirror reflectivity of 62% using the properly designed DBR structure.

We realized spot-size converters for photonic-crystal optical circuits, which enable us to efficiently couple light from conventional single-mode fibers to photonic-crystal waveguides. This overcomes one of main obstacles for photonic-crystal circuits. We also proposed and demonstrated novel nano-electrode lithography technique, which will be applied for various nanostructured devices.

Quantum Cryptography Experiment Using a Single-Photon Source

Kyo Inoue
Physical Science Laboratory

Quantum cryptography, which guarantees unconditional security based on the law of quantum mechanics, is extensively studied. It is a system that provides a secret key for ciphering messages to two legitimate parties, utilizing the fact that non-orthogonal quantum states cannot be fully identified by an eavesdropper. Several experiments have been demonstrated, using attenuated laser light with an average photon number of, for example, 0.1 per pulse. However, the photon number statistics of laser light follows the Poisson distribution, and there is a finite probability of two photons in one pulse, from which an eavesdropper can steal a part of information. It is known that the amount of leaked information is larger for larger transmission loss. Thus, experiments using a single-photon source, that emits no more than two photons per pulse, are desired for long-distance systems. We successfully demonstrated a quantum cryptography experiment using a single-photon source for the first time.

The photon source was an InAs semiconductor quantum dot fabricated at Stanford University. In order to extract photons efficiently, the dot was embedded in a post-shaped microcavity (Fig. 1). When illuminated by pump pulses, it emitted one photon per pulse via spontaneous emission between particular energy levels. The emission efficiency was 6 %, and the probability that it emitted two photons per pulse was one tenth of conventional laser light. Using this light source, we carried out an quantum cryptography experiment based on the uncertainty among four polarization states (called BB84), and obtained desired correlation between the transmitter and receiver with an error rate of 2.5 %. Then, applying error correction and privacy amplification to these data, we successfully created an unconditionally secured secret key for ciphering messages. The final key creation rate was 25 kbit/s. We also carried out the same experiment for various channel losses between the transmitter and receiver both for our single-photon source and a laser source (Fig. 2). The results showed that, though the key creation rate was lower in the low loss region because of the low emission efficiency, the single-photon source could achieve longer transmission distance than laser light.

[1] E. Waks et al., Nature **420** (2002) 762.

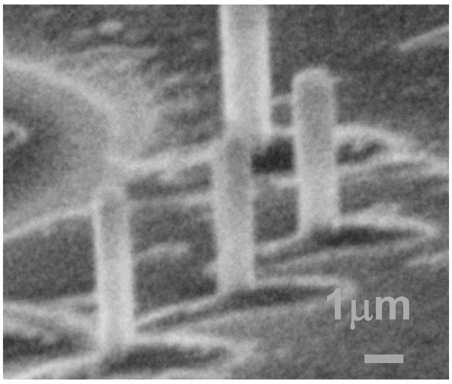


Fig. 1. Single-photon source.

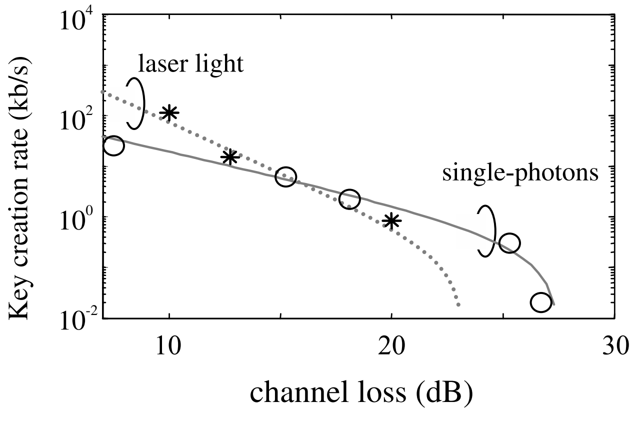


Fig. 2. Key creation efficiency as a function of channel loss.

High-order Harmonic Generation from Surface Plasma

Tsuneyuki Ozaki, Atsushi Ishizawa, and Hidetoshi Nakano
Physical Science Laboratory

Coherent soft x-ray sources are indispensable tools for the development of novel technologies related to generation and control of attosecond pulses and nanometer resolution observation. Accordingly, many institutions throughout the world are now working energetically for their realization, using various schemes such as x-ray lasers and high-order harmonic generation. In the present work, we investigate a novel method called solid surface harmonic generation, and try to achieve breakthrough in this field using targets with novel characteristics and surface structures.

First we observed the surface harmonics spectrum in the extreme ultraviolet (XUV) region. The pump laser is a terawatt Ti:sapphire laser (55 fs pulse width, 4×10^{16} W cm^{-2} peak intensity, P-polarized), and is focused onto silicon wafer targets at an incidence angle of 45º using off-axis paraboloid. Fig.1 shows the time-integrated XUV spectrum observed in the specular direction of reflection. (a) is the spectrum observed for pump laser with a smooth spectral profile, while (b) is for that observed using pump laser with a similar spectrum but with an additional narrow spectral component. High-order harmonics corresponding to the 14th through 16th order of the 790 nm wavelength fundamental is clearly observed. The narrow spectral component of the fundamental is also reflected in the harmonics shown in (b), which indicates that these spectra are actually harmonics.

We have also observed a new phenomenon, where the second-order harmonic intensity drastically increases for certain target material. Fig.2 shows the integrated second harmonic intensity observed using Pyrex glass and aluminum deposited targets, both with a surface flatness of $\lambda/4$. Surprisingly, the second harmonic intensity from Pyrex targets are more than two-orders of magnitude larger than that observed using aluminum mirror. The second harmonic intensity tends to show large shot-to-shot variation with Pyrex targets, and disappears completely when using S-polarized pump lasers. We presently attribute this phenomenon to the effects of preplasma scalelength produced on the target surface by prepulse or pedestal.

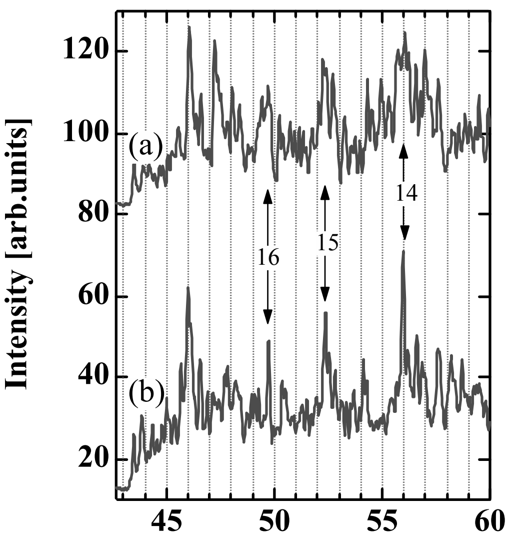


Fig. 1. XUV harmonic spectrum observed using silicon wafer target.

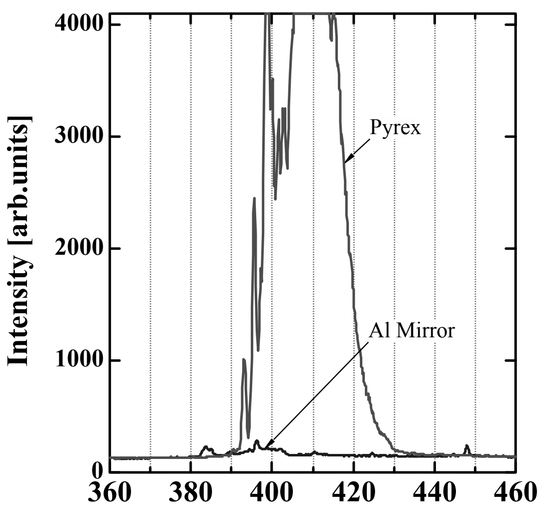


Fig.2. Second-order surface harmonics observed using Pyrex and aluminum mirror targets.

High Reflective Distributed Bragg Reflectors Using a Deeply-Etched Semiconductor/Air Grating for InGaN/GaN Laser Diodes

Tadashi Saitoh, Masami Kumagai, Hailong Wang, Takehiko Tawara, Toshio Nishida, Testuya Akasaka, and Naoki Kobayashi
Physical Science Laboratory

InGaN/GaN lasers are attracting a great deal of attention as blue-violet light sources for the next generation of storage systems such as the Blu-ray Disc. However, the operating current of InGaN/GaN lasers is much higher than that of conventional GaAs/AlGaAs or GaInAsP/InP lasers. One reason for this high threshold is their low facet reflectivity of only about 18%, which results from the low refractive indices of GaN-based materials of about 2.5. The lifetime of InGaN/GaN lasers is strongly dependent on the operating current, which must therefore be reduced. To achieve this, multiple dielectric films are usually coated on the facets, but this adds extra processing steps to laser fabrication. A promising alternative structure for laser mirrors is a deeply etched distributed Bragg reflector (DBR)[1].

We have achieved high reflectivity by deeply etched InGaN/GaN DBR mirrors with tilted sidewalls, which are appropriately designed by using the finite-difference time-domain method[2] (Fig.1). The predicted optimal structure is different from the simple design consisting of a $\lambda/(4n)$ semiconductor and $\lambda/4$ air. If the sidewall of the grating is tilted by 4º, the reflectivity of the DBR mirrors decreases to less than 40% (dashed line, dotted line). However, any degradation in the reflectivity of a perfectly vertical sidewall can be suppressed to just a few percent even with a sidewall tilt of 4º, if the DBR structure is properly designed (solid line). We fabricated InGaN/GaN multiple-quantum well lasers based on the optimal design. The devices operate as lasers with optical pumping at a lower threshold than devices without DBR mirrors. The DBR mirror reflectivity is characterized by the relation between the threshold pump intensity and the inverse of the cavity length, resulting in a high reflectivity of 62% (Fig. 2).

[1] H. Wang et al., Jpn. J. Appl. Phys. Part 2, **41** (2002) L682.
[2] H. Wang et al., Appl. Phys. Lett., **81** (2002) 4703.

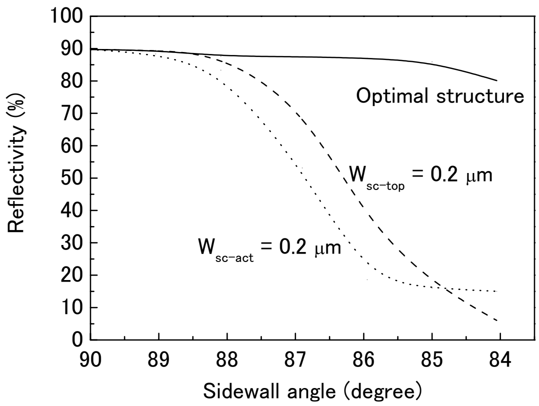


Fig. 1. Dependence of reflectivity on sidewall angle.

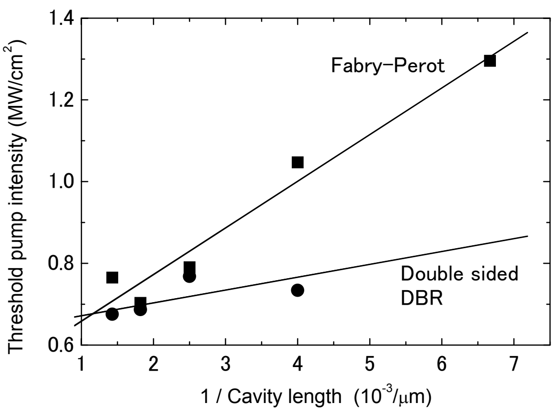


Fig. 2. Dependence of threshold pump intensity on inverse cavity length.

Spot-Size Converter of Photonic Crystal Waveguide

Akihiko Shinya, Eiichi Kuramochi, and Masaya Notomi
Physical Science Laboratory
(in collaboration with T. Tsuchizawa, T. Watanabe, T. Shoji, and K. Yamada in NTT Microsystem Integration Laboratories)

Photonic crystal having a photonic band gap is expected to one of possible candidates for basic platform of future ultra-small photonic large-scale integrated circuits, and we have been investigating two-dimensional photonic crystals fabricated from SOI (silicon-on-insulator) substrates. We have already realized single-mode waveguides that operate within the photonic band gaps, and demonstrated their exotic dispersion characters [1,2]. The mode size of these waveguides is extraordinarily small, which is one of main reasons why ultrasmall circuits are possible, but it has been pointed out that it is too small to effectively couple the light to ordinary photonic transmission systems, such as optical fibers. In fact, the coupling loss between photonic crystal waveguides and single-mode fibers is larger than 30dB, which is unacceptable for practical application.

To solve this problem, we have realized photonic-crystal waveguides incorporating spot-size converters, in collaboration with NTT Microsystem Integration Laboratories. They are consisting of three parts, namely photonic crystal waveguides, Si-wire waveguides, and polymer waveguides, and the boundaries between these parts have adiabatic spot-size (or mode-profile) converting regions, as shown in Fig. 1. The ultrasmall mode in the photonic crystal waveguide is adiabatically transformed to that in the Si-wire, and then to that in the polymer waveguide that has a spot size comparable to that of a single-mode fiber. We have directly measured and confirmed that the coupling loss of this structure is just 3-4dB, which is far better than that without spot-size converters [3]. This result is a very important step towards future application of photonic crystals, but also important for current research of photonic crystals because it enables us to do various optical measurements which had been practically impossible due to inherent large coupling loss.

[1] M. Notomi et al., Phys. Rev. Lett. **87** (2001) 253902.
[2] M. Notomi et al., IEEE J. Quantum Electron. **38** (2002) 736.
[3] A. Shinya et al., SPIE Photonics West 2003, 5000-21, San Jose, USA. (2003).

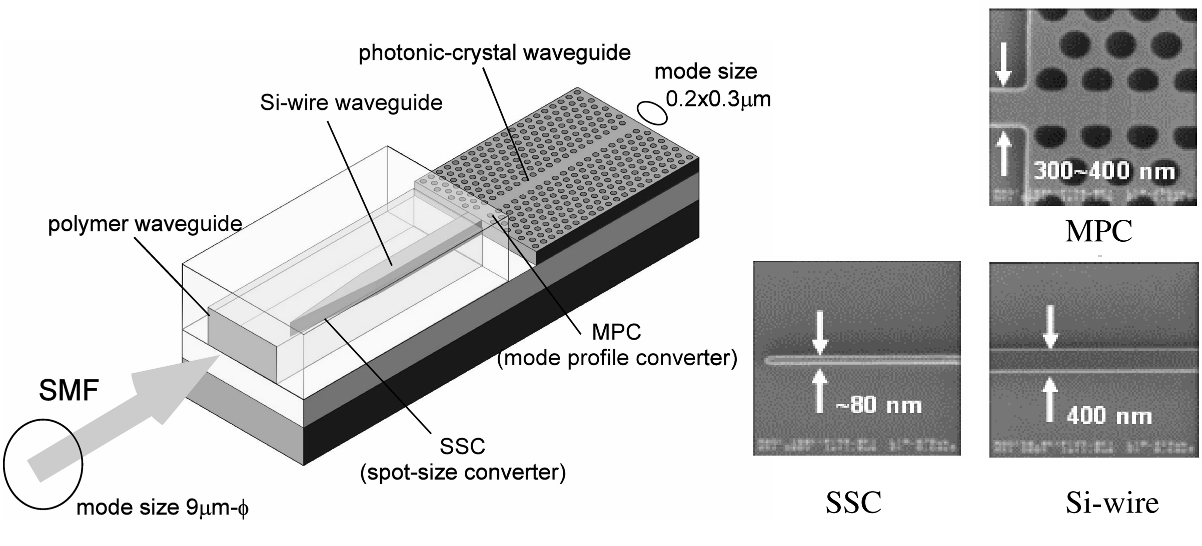


Fig. 1. Schematic view of a spot-size conveter for photonic crystal waveguide (left), and electron micrographs of the adiabatic tapers in this device (right).

Ⅱ. Data

International Symposium on Carrier Interactions and Spintronics in Nanostructures

The symposium was held March 10-12, 2003, at the NTT Atsugi R&D Center in collaboration with New Energy and Industrial Technology Development Organization (NEDO) and Core Research for Evolutional Science and Technology (CREST) sponsored by Japan Science and Technology Corporation (JST).

Carrier interactions are receiving strong interest due to their possibility for novel and dream devices, such as solid-state quantum computers. Spin is the most important factor determining the carrier interactions in solid-state systems and spin-electronics (spintronics) have been extensively studied. Research on the coherent control of charge and spin has also progressed very rapidly. To further enhancing these studies, this symposium was organized by Dr. Yoshiro Hirayama (Executive Manager) and Dr. Junsaku Nitta (Group Leader) of NTT Basic Research Laboratories especially putting emphasis on carrier interactions and spintronics. NTT Basic Research Laboratories leads these fields, and the symposium aspired to gather leading scientists in these fields and discuss the most recent topics.

On the 10th, after opening and welcoming remarks by Dr. Sunao Ishihara, Director of NTT Basic Research Laboratories, Prof. D. D. Awschalom (UCSB) and Prof. K. H. Ploog (Paul-Drude Institute) gave plenary lectures on spin manipulation of electrons and nuclears in semiconductors and on ferromagnetic-semiconductor heterostructures, respectively. There were nine oral presentations on nano-materials, heterostructures, and spintronics. And there were 23 poster presentations.

On the 11th, the 15 oral presentations discussed nano-wires, spin-related phenomena, nanomechanics, nanoprobing, quantum Hall effects, and quantum information processing. Single photon emission was discussed by the Stanford University group and two-qubit operation of superconductor charge qubit was reported from the NEC group.

On the 12th, there were nine oral presentations on superconductor proximity effects, diluted magnetic semiconductors, and quantum information processing. The first demonstration of a semiconductor charge qubit was reported by an NTT group. There were 24 poster presentations on that day.

There were totally 162 participants [including 69 from NTT]. All participants greatly enjoyed the high-quality presentations and discussions on carrier interactions and spintronics.

Workshop on Surface & Nano-Science in NTT

An International Workshop on Surface & Nano-Science was organized by NTT and was held on November 29, 2002, at the NTT Atsugi R&D Center. This workshop was a satellite to the 2nd International Workshop on Nano-Scale Spectroscopy and Nanotechnology, which was held in Tokyo. This satellite workshop covered a whole range of aspects of nanoscience and nanotechnology including various spectroscopic methods employed to understand nanoscale phenomena. There were 51 participants (14 (overseas), 17 (domestic), 20 (NTT)). Although the workshop was rather short, leading scientists discussed their most recent topics intensely.

Dr. S. Ishihara, Director of NTT Basic Research Laboratories, gave the opening address and welcomed the participants. This was followed by interesting presentation by Dr. M. Kiskinova, Sincrotrone Trieste, and Dr. G. Salviati, IMEM-CNR in Parma. They described their recent progress in the area of nano fabrication and their spectroscopic characterizations. From NTT, there were 4 presentations; discussing topics such as the self-assembly of nanostructures and interconnection, synchrotron radiation based materials science, nanolithography for nano-device fabrication, and coherent control in semiconductor nanostructures for semiconductor quantum computers. In addition, we arranged a lab tour and participants had a unique opportunity to see some of the important R&D activities in this center.

Science Plaza 2002

“Science Plaza 2002”, the annual open house event of NTT Basic Research Laboratories was held on August 30, 2002, at the NTT Atsugi R&D Center.

After the opening remarks by Dr. Sunao Ishihara, the director of NTT Basic Research Laboratories, the “Symposium session” was held. In the symposium, there were three talks from the fields of physical science, device physics, and material science. The “Poster session” consisted of 41 presentations, which was followed by lively discussions. The “Laboratory tour” gave the participants an opportunity to see the equipments and various research facilities. In addition, major research findings were presented as a movie in the “Video theatre”. At the party held after all the presentations, we enjoyed Japanese drum performance and promoted mutual friendship with the participants.

There were 218 participants. We would like to thank all the participants of “Science Plaza 2002” for their fruitful discussion and comments.

Award Winner's List (Fiscal 2002)

Japanese Society of Electron Microscopy Award (Setoh Award)	Y. Homma	"Development of ultrahigh vacuum in situ scanning electron microscope and its application to the study of crystal growth processes"	May 14, 2002
The prize of the Japan Society for the Promotion of the Machine Industry in 2002	H. Namatsu	"Development of Supercritical Dryer for Ultra-fine Patterning"	Dec. 4, 2002
The Japan Society of Applied Physics Young Scientist Award for the Presentation of an Excellent Paper	K. Kanzaki	"Effect of Resist Thickness on the Linewidth Fluctuations"	Sept. 24, 2002
23rd Int. Conf. on Low Temperature Physics POSTER AWARD	E. Huefeld T. Bauch V. Krasnov P. Delsing H. Takayanagi	"Critical Current Distributions in Ballistic Andreev Junctions"	Aug. 27, 2002

In-house Award Winner's List (Fiscal 2002)

NTT R&D Award	N. Kobayashi T. Nishida T. Makimoto N. Maeda M. Kasu K. Kumakura	"Research on Crystal Growth and Band Engineering of Nitride Semiconductors"	Feb. 12, 2003
Award for Achievements by Director of Basic Research Laboratories	N. Kasai Y. Jimbo K. Torimitsu Y. Furukawa	"Effect of Magnesium on Neuronal Processing"	Mar. 20, 2003
Award for Achievements by Director of Basic Research Laboratories	T. Fujisawa Y. Tokura	"Measurement of Carrier Dynamics in Quantum Dots"	Mar. 20, 2003
Award for Achievements by Director of Basic Research Laboratories	H. Omi K. Sumitomo D. J. Bottomley	"Control of Nanostructure Self-Organization through Strain Engineering"	Mar. 20, 2003
Award for Excellent Papers by Director of Basic Research Laboratories	K. Prabhakaran	"Ultrafine and Well-Defined Patterns on Silicon Through Reaction Selectivity" Advanced Materials Vol. 14, 1418 (2002)	Mar. 20, 2003
Award for Excellent Papers by Director of Basic Research Laboratories	T. Matsuoka	"Optical Band-Gap Energy of Wurtzite InN" Appl. Phys. Lett. Vol. 81, 1246 (2002)	Mar. 20, 2003
"Resonant" Award by Director of Basic Research Laboratories	K. Suzuki K. Furukawa	Proposal of the Word "Resonant Communication" -Vision for a New Optical Generation	Mar. 20, 2003

List of Visitor's Talks (Fiscal 2002)

I. Device Physics

Date		Speaker	Affiliation "Topic"
May	16	Dr. Toshiaki Munakata	RIKEN "Time-resolved photoemission microspectroscopy based on fs-VUV laser light"
May	23	Prof. T. Gustafsson	Rutgers University (State University of New Jersey), USA "Medium energy ion scattering studies of thin films for microelectronic applications"
May	28	Prof. Takanori Koshikawa	Osaka Electro-Communication University "Present status and future prospects of surface studies by LEEM and PEEM"
Sept.	3	Prof. Adarsh Sandhu	Tokyo Institute of Technology "Room temperature magnetic imaging of ferromagnetic domains by scanning micro-hall probe microscopy"
Sept.	20	Prof. Zhaohui Zhang	Peking University, China "Structure transition of Ge/Si(113) surfaces during Ge epitaxial growth"
Sept.	20	Mr. Florian Meneau	Royal Institution of Great Britain, UK "Real-time observation of CdS nanoparticle Synthesis" "Self-organization of CdS nanoparticles on silicon"
Oct.	1	Dr. Mark Baxendale	University of London, UK "The physics and applications of carbon nanotubes"
Oct.	9	Mr. Kosuke Tatsumura Dr. Takanobu Watanabe	Waseda University "Large-scale modeling of SiO_2/Si interface atomic structures by molecular dynamics"
Dec.	5	Prof. E. Bauer	Arizona State University, USA "LEEM and XMCDPEEM Studies of MX layers on semiconductor surfaces (M=Ga, Mn, X=N, As)"
Dec.	18	Dr. Bingqing Wei	Rensselaer Polytechnic Institute, USA "Tailoring and modification of carbon nanotube architectures

March	26	Dr. Philip J. Poole	National Research Council, Canada “Growth of InAs/InP nanostructures by selective area CBE”

II. Materials Science

Date		Speaker	Affiliation "Topic"
April	17	Dr. Kuniaki Amemiya	The University of Tokyo “Observation of intracellular boron distribution using Boron Neutron Capture Therapy: BNCT”
May	24	Dr. Y. Lin	SUNY at Stony Brook, USA “Magnetotunneling in an electron-hole system”
May	27	Dr. Simon Pedersen	Chalmers University of Technology, Sweden “Competition of phase-breaking and thermal broadening in few-mode mesoscopic rings”
June	21	Prof. Shintaro Nomura	Tsukuba University “Photoluminescence spectroscopy of semiconductor quantum dot arrays”
Aug.	12	Dr. F.J. Jedema	University of Groningen, The Netherlands “Spin transport and spin precession in mesoscopic metal spin valve devices”
Aug.	15	Dr. L.M.K. Vandersypen	Delft University of Technology, The Netherlands “Spin qubit experiments - from room temperature nuclei to mK electrons”
Aug.	23	Dr. Takahiro Seki	Nagoya University “Formation of hydrophobic polysilane monolayer on water surface assisted by liquid crystal molecules”
Aug.	28	Dr. Marija Drndic	Massachusetts Institute of Technology, USA “Transport in CdSe nanocrystal solids”
Sept.	2	Dr. Lambert Alff	Walther-Meissner-Institut and Technische Universitaet Munichen, Germany “Electron-doped high-Tc superconductors: pairing symmetry and pseudogap as viewd from grain boundary Josephson junctions”
Sept.	20	Dr. Thomas Schaepers	Institut fuer Festkoeperforschung Forshungszentrum Juelich, Germany “Quantum structures based on InGaAs/InP layer systems: quantum wires and Josephson junctions”

Oct.	9	Dr. Masumi Yamaguchi	Kyoto University "Sound velocity and attenuation in nuclear-ordered solid ^{3}He"
Nov.	15	Dr. Wenping Hu	Stuttgart University, Germany "Organic light-emitting diodes and field-effect transistors"
Nov.	28	Dr.Tobias Nyberg	Linkopings Universitet, Sweden "Nano and micro patterned organic devices - from neural interfaces to optoelectronic devices"
Dec.	5	Dr. Irinel Chiorescu	Delft University of Technology, The Netherlands "Coherent quantum dynamics of a superconducting flux-qubit"
Jan.	29	Prof. B. Altshuler	NEC Laboratories America & Princeton University, USA "Dephasing of interacting electrons"
March	7	Dr. Cristian Urbina	CEA-Saclay, France "Steering the quantum state of an electrical circuit"

III. Quantum Electron Physics

Date		Speaker	Affiliation "Topic"
April	11	Prof. G. E. W. Bauer	Delft University of Technology, The Netherlands "AC-DC magnetoelectronics"
May	8	Prof. G. E. W. Bauer	Delft University of Technology, The Netherlands "Elements of semiconductor magnetoelectronics"
May	17	Dr. Chul Huh	Kwangju Institute of Science and Technology, Korea "Chemical treatment for metal contact to n- and p-GaN"
June	18	Dr. Chengxin Wang	Simon Fraser University, Canada "Growth and characterization of nitride and other III-V semiconductors for device applications"
Aug.	20	Dr. Nicolas Freytag	Max Planck Institute for Solid State Research, Germany "Measurements of the electron spin degree of freedom in 2D electron systems"
Aug.	29	Dr. Maarten Wegewijs	Institut fur Theoretische Physik A, Germany "Negative differential conductance in a benzene-molecular device"

Sept.	2	Prof. Yshai Avishai	Ben Gurion University, Israel “Dynamical symmetries in Kondo tunneling through complex quantum dots”
Sept.	10	Dr. Akira Kawaguchi	Osaka University “Magnetic properties of a one-dimensional electron system near quantum phase transition”
Sept.	13	Prof. A. Asenov	University of Glasgow, UK “Nanotechnology research and nanoscale device simulation at University of Glasgow”
Oct.	1	Dr. V. Seleznev	Russian Academy of Sciences Novosibirsk, Russia “Rolled-up heterostructures: fabrication, properties, applications”
Oct.	10	Dr. C. Fuhner	University of Hannover, Germany “Kondo and Fano resonances in semiconductor quantum dots”
Nov.	13	Dr. Xuedong Hu	Riken and University of Maryland, USA “Spin-based quantum dot quantum computing approaches”
Jan.	15	Dr. M. Henini	University of Nottingham, UK “Structural and optical properties of self-assembled quantum dots grown by molecular beam epitaxy”
Jan.	20	Prof. A. R. Hamilton	University of New South Wales, Australia “1. Macroscopic quantum coherence in bilayer quantum Hall systems 2. Fast twin-SET readout for semiconductor based quantum computation”
Jan.	22	Prof. C. H. Nam	KAIST, Korea “Coherent Control of High-order Harmonics”
Jan.	29	Dr. Joshua Folk	Harvard University and M.I.T., USA “Spin measurements in lateral GaAs quantum dots”

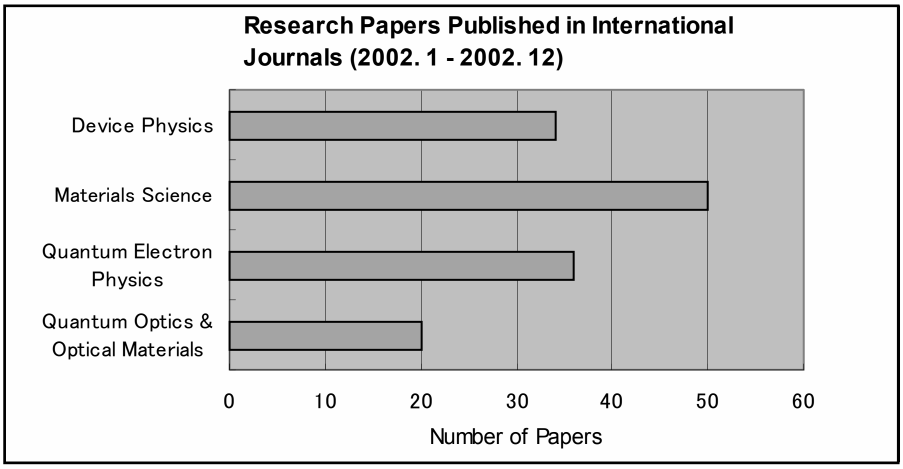
IV. Quantum Optics & Optical Materials

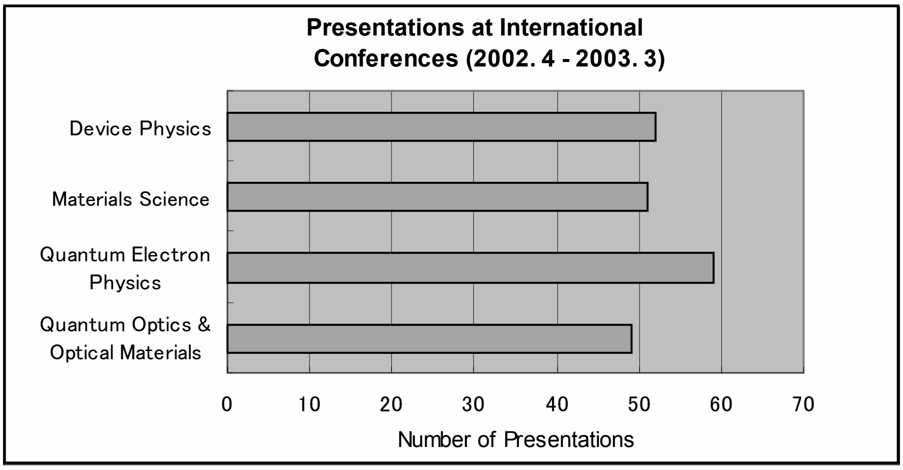
Date		Speaker	Affiliation "Topic"
June	25	Prof. A. A. Andreev	Research Institute for Laser Physics, Russia “Femtosecond x-ray line emission from multilayer targets irradiated by ultrashort laser pulses”
July	9	Prof. Y. H. Lee	Korea Advanced Institute of Science and Technology, Korea “Toward the ultimate light source via 2-D photonic crystal lasers”

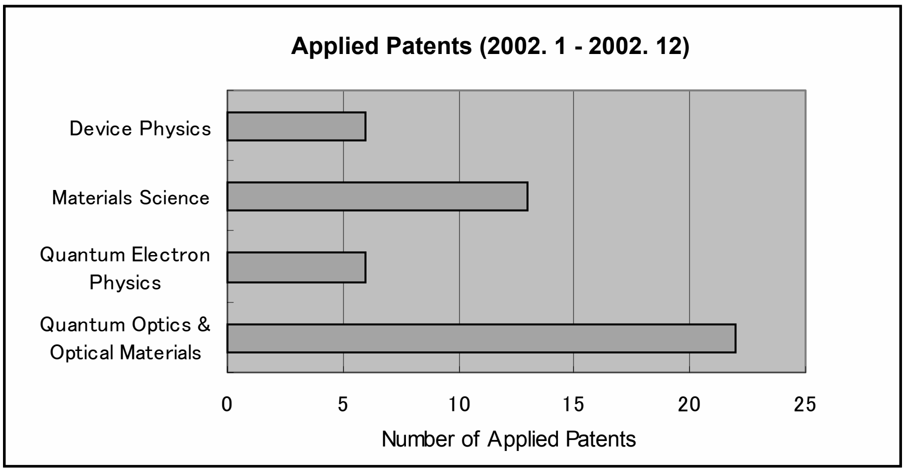
Aug.	9	Alexandre Soujaeff	CNRS, France "Research & Development of Quantum Cryptography system in CNRS"
Aug.	9	Dr. Yutaka Yoshikawa	University of Tokyo "Electric distortion of BEC under off-resonant laser light"
Oct.	30	Dr. B. Zhang	Stanford University, USA "Single photon emission source: fabrication of a single quantum dot in a micropost microcavity"
Nov.	5	Dr. A. V. Gopal	FESTA "1.35µm Intersubband transition in InGaAs/AlAs/AlAsSb"
March	3	Prof. S. John	Toronto Univesity, Canada "Photonic band gap materials: semiconductors of light"
March	5	Dr. S. Sebban	Ecole Polytechnique, France "X-ray sources using fs lasers at the LOA"
March	20	Prof. F. Meseguer	Universidad Politecnica de Valencia, Spain "Photonic crystal based on opals"

Research Activities of Basic Research Laboratories in 2002

The numbers of research papers, presentations at the international conferences and applied patents amounted to 140, 215, and 47 in Basic Research Laboratories as a whole. All numbers according their research areas are as follows.







The major journals and the number of published papers are shown below.

General Science Journals

Name	(IF2001)*	Numbers
Nature	(27.955)	4
Science	(23.329)	2

Specialized Journals

Name	(IF2001)*	Numbers
Physical Review B	(3.07)	16
Physical Review Letters	(6.668)	14
Applied Physics Letters	(3.849)	14
Physica E	(1.009)	14
Japanese Journal of Applied Physics	(1.248)	12
Physica C	(0.806)	12
Surface Science	(2.189)	4
Journal of Applied Physics	(2.129)	4
Macromolecules	(3.733)	3
Journal of The American Chemistry Society	(6.079)	1
Advanced Materials	(5.579)	1

*IF2001: Impact factor 2001（Journal Citation Reports, 2001）

The average impact factor for individual research papers from all NTT Basic Research Laboratories is 3.53.

The major international conferences and their number of presentation are shown below.

Conferences	Numbers
The 23rd International Conference on Low Temperature Physics	12
26th International Conference on the Physics of Semiconductors	12
Carrier Interactions and Spintronics in Nanostructures (CISN 2003)	12
The 2002 International Conference on Solid State Devices and Materials	7
2002 Material Research Society Meeting	7
The 29th International Symposium on Compound Semiconductors (ISCS 2002)	5
Second International Conference on Molecular Electronics and Bioelectronics (M&BE2)	4
2002 International Workshop on Nitride Semiconductors (IWN2002)	4
Electorochemical Society Spring Meeting 2002	4
Conference on Laser and Electro-Optics/Quantum Electronics and Laser Science Conference	3

List of Invited Talks at International Conferences (Fiscal 2002)

I. Device Physics

(1) H. Kageshima, A. Taguchi, and K. Wada, "Theoretical investigation of nitrogen-doping effect on native defect aggregation", MRS Spring Meeting, San Francisco, USA (Apr. 2002).

(2) S. Uematsu, "Processes in silicon simulation of transient enhanced diffusion in silicon taking into account Ostwald ripening of defects", MRS Spring Meeting, San Francisco, USA (May 2002).

(3) Y. Takahashi, Y. Ono, S. Fujiwara and H. Inokawa, "Silicon single-electron transistors and their applications to logic", Electorochemical Society Spring Meeting 2002, Philadelphia, USA (May 2002).

(4) S. Uematsu, H. Kageshima and K. Shiraishi, "Unified theory of silicon oxide growth", Electorochemical Society Spring Meeting 2002, Philadelphia, USA (May 2002).

(5) T. Ogino, Y. Homma, Y. Kobayashi, H. Hibino, P. Kuniyil, K. Sumitomo, H. Omi, D. Bottomley, A. Kaneko and F. Lin, "Integration of semiconductor nanostructures and interconnections of future self-assembled nanoarchitecture", Electorochemical Society Spring Meeting 2002, Philadelphia, USA (May 2002).

(6) T. Ogino, Y. Homma, Y. Kobayashi, H. Hibino, P. Kuniyil, K. Sumitomo and H. Omi, "Control of nanostructure self-assembly by atomic-structure and strain engineering", IUVSTA Workshop, Trofaiach, Austria (Jun. 2002).

(7) Y. Watanabe, S. Suzuki, T. Ogino and S. Heun, "Spectromicroscopy of carbon nanotubes", E-MRS, Strasbourg, France (Jun. 2002).

(8) T. Ogino, Y. Homma, Y. Kobayashi and H. Hibino, "Atomic-structure and strain engineering for control of self-organized Ge quantum nanostructures", E-MRS, Strasbourg, France (Jun. 2002).

(9) A. Fujiwara and Y. Takahashi, "Si nano-devices using an electron-hole system", 5th European Workshop on Low Temperature Electronics (WOLTE-5), Grenoble, France (Jun. 2002).

(10) P. Kuniyil and T. Ogino, "Synthesis of nanomagnets on semiconductor surfaces", Int. Conf. Comp. Eng., San Diego, USA (Jul. 2002).

(11) Y. Takahashi, Y. Ono, A. Fujiwara and H. Inokawa, "Silicon single-electron devices", Euro. Sol. Stat. Circ. Conf., Firenze, Italy (Sep. 2002).

(12) A. Fujiwara and Y. Takahashi, "Single-charge detection and manipulation in a Si nanowire", Int. Conf. on Semiconductor Quantum Dots (QD2002), Tokyo, Japan (Sep.

2002).

(13) Y. Takahashi, "Silicon single-electronics", The 3rd Workshop for Terabit-level Nano-Electronics, Cheongju, Korea (Oct. 2002).

(14) H. Kageshima, S. Uematsu and K, Shiraishi, "Si injection model for the Si thermal oxidation", 5th Asian Workshop on First-Principles Calculation, Seoul, Korea (Oct. 2002).

(15) P. Kuniyil and T. Ogino, "Versatile functionality to silicon by nanoparticle incorporation", Nanoparticles 2002, New York, USA (Oct. 2002).

(16) T. Ogino, Y. Homma, Y. Kobayashi, H. Hibino, P. Kuniyil, K. Sumitomo, H. Omi and Z. Zhang, "Strain engineering for control of Ge quantum nanostructures on Si surfaces", The 10th international Colloquim on SPM, Waikiki, USA (Oct. 2002).

(17) Y. Homma, H. Takenaka, F. Tojou, S. Hayashi, N. Goto, M. Inoue and R. Shimizu, "Evaluation of BN-delta-doped multilayers as the reference material for SIMS shallow depth profiling", The 2nd China-Japan Joint Seminar on Atomic Level Characterization, Guillin, China (Nov. 2002).

(18) T. Yamaguchi, K. Yamazaki, M. Nagase and H. Namatsu, "Line-edge roughness: Characterization and material origin", MNC2002, Tokyo, Japan (Nov. 2002).

(19) S. Suzuki, Y. Watanabe, T. Ogino and S. Huen, "Photoemission spectromicroscopy of carbon nanotubes", 2nd Int. Workshop on Nano-scale Spectroscopy and Nanotechnology, Tokyo, Japan (Nov. 2002).

(20) Y. Watanabe, S. Suzuki, T. Ogino, S. Huen, L. Gregoratti, A. Barinov, B. Kaulich, M. Kiskinova, W. Zhu, C. Bower and O. Zhou, "Electronic properties of carbon nanotubes studied by photoemission spectroscopy and spectromicroscopy", Int. Symp. on photoelectron micro-PES, Tsukuba, Japan (Dec. 2002).

(21) Y. Takahashi, Y. Ono, A. Fujiwara and H. Inokawa, "Development of silicon single-electron devices", Nano MES 2003, Tempe, USA (Feb. 2003).

(22) P. Kuniyil, "Nanoparticles as potential candidates for bottom-up approach", JSPS-DST Symposium, Tokyo, Japan (Mar. 2003).

II. Materials Science

(1) H. Takayanagi, R. Shaikhaidarov, A. F. Volkov, V. T. Petrashov, P. Delsing and T. Cleason, "π - state in a S-N-S junction with a dangling superconducting arm", First International Workshop on the Symmetry in Macroscopic Quantum States, Augsburg, Germany (Apr. 2002).

(2) H. Takayanagi, S. Saito, H. Tanaka and H. Nakano, "Squid Qubit and its Readout", Euroworkshop "Quantum computers: mesoscopic implementations, perspectives and open problems", Torino, Italy (Jun. 2002).

(3) M. Naito, “Phase control of La_2CuO_4”, International Conference on Electronic Materials International Conference on Electronic Materials (IUMRS-ICEM2002), Xian, China (Jun. 2002).

(4) J. Nitta, “Rashba spin-orbit interaction and its applications”, NATO Advanced Research Workshop “Frontiers of spintronics and optics in semiconductors: A synposium in honor of E. I. Rashba", Boston, USA (Jun. 2002).

(5) K. Torimitsu, Y. Furukawa and H. Tabei, “Nanostructure controlled substrates: Surface modified substrates for nerve cell growth”, 9th Int. Conf. Comp. Eng., San Diego, USA (Jul. 2002).

(6) M. Naito, A. Tsukada, T. Greibe and H. Sato, “Phase control in La-214 epitaxial thin films”, SPIE Annual meeting 2002, Seattle, USA (Jul. 2002).

(7) K. Torimitsu, “Analysis of brain functions and nano-bio device architecture”, Swedish-Japanese Workshop on Bioelectronics, Sigtunastiftelsen, Sweden (Aug. 2002).

(8) A. Matsuda, T. Fujii and T. Watanabe, “Gap inhomogeneity, phase separation, and a pseudogap in $Bi_2Sr_2CaCu_2O_8$+δ”, 23rd International Conference on Low Temperature Physics (LT23), Hiroshima, Japan (Aug. 2002)

(9) H. Takayanagi, H. Tamura, K. Shiraishi, T. Kimura, T. Akazaki and A. Richter, “Ferromagnetism and superconductivity in artificial crystals”, International Workshop on Electron Interference and Decoherence in Nanostructures Ferromagnetism in quantum-dot array system, Dresden, Germany (Nov. 2002).

(10) Y. Jimbo, N. Kasai and K. Torimitsu, “MEA-based recording of neuronal activity”, International Forum on Biochip Technologies 2002, Beijing, China (Nov. 2002).

(11) H. Takayanagi, S. Saito, H. Tanaka and H. Nakano, “Readout of the qubit state with a SQUID”, 5th Sweden-Japan Joint Workshop on Quantum Nanoelectronics, Yokohama, Japan (Dec. 2002).

(12) M. Naito, S. Karimoto, K. Ueda, H. Yamamoto and J. Kurian, “MBE growth of high-Tc superconductors - cuprates to borides”, MRS Fall Meeting, Boston, USA (Dec. 2002).

(13) H. Takayanagi, S. Saito, H. Tanaka and H. Nakano, “Readout of the qubit state with a SQUID”, International Conference on Nanoelectronics Ferromagnetism in quantum-dot-array systems, Lancaster, UK (Jan. 2003).

(14) H. Takayanagi, S. Saito, H. Tanaka and H. Nakano, “Readout of the qubit state with a dc-SQUID”, Int. Symp. on Advanced Physical Fields 8y, Tsukuba, Japan (Jan. 2003).

(15) J. Nitta, “Rashba spin-orbit interaction and spin-interference in nano-structures”, International Workshop “Coherence in Nanosystems, Spin-related Transport in Semiconductors”, Seoul, Korea (Jan. 2003).

III. Quantum Electron Physics

(1) Y. Hirayama and Y. Tokura, “Point contact conductance in backgated heterostructures”, The Electrochemical Society, Philadelphia, USA (May 2002).

(2) T. Fujisawa, “Spin relaxation in semiconductor artificial atoms — energy relaxation time and nonequilibrium transport — ”, 7th International Conference on Nanometer-scale Science and Technology (NANO-7), Malmo, Sweden (Jun. 2002).

(3) T. Fujisawa, “Inelastic spin relaxation in a quantum dot”, 26th Int. Conf. Phys. Semicond. (ICPS), Edinburgh, UK (Jul. 2002).

(4) Y. Hirayama, “Electrical manipulation of nuclear spin polarization by quantum Hall states”, ERATO Workshop: Mesoscopic Correlation in Nanostructures, Delft, Holland (Jul. 2002).

(5) T. Fujisawa, “Inelastic spin relaxation and non-equilibrium transport in quantum dots”, ERATO Workshop: Mesoscopic Correlation in Nanostructures, Delft, Holland (Jul. 2002).

(6) K. Muraki, T. Saku, and Y. Hirayama, “Charge excitation and transport in pseudo-spin quantum Hall ferromagnets”, LT-23, Hiroshima, Japan (Aug. 2002).

(7) T. Fujisawa, “Dynamics of single-electron charge and spin in quantum dots”, Int. Colloquium on Scanning Probe Microscopy (ICSPM10), Hawaii, USA (Oct. 2002).

(8) Y. Tokura, “Point contact conductance in backgated heterostructures”, The Electrochemical Society, Philadelphia, USA (Oct. 2002).

(9) H. Yamaguchi, K. Kanisawa, Y. Tokura, and Y. Hirayama, “Structural and Electrical Characterization of InAs/GaAs (111)A Heterostructures by Scanning Tunneling Microscopy and Spectroscopy”, 2nd International Workshop on Nano-scale Spectroscopy and Nanotechnology, Tokyo, Japan (Nov. 2002).

(10) K. Kanisawa, Y. Tokura, H. Yamaguchi and Y. Hirayama, “Scanning tunneling spectroscopy study of zero-dimensional structures at the InAs surface”, 30th Conference on the Physics and Chemistry of Semiconductor Interfaces (PCSI-30), Salt Lake City, USA (Jan. 2003).

(11) K. Kanisawa, Y. Tokura, H. Yamaguchi and Y. Hirayama, “Direct probing of local-density-of-states in semiconductor nanostructures”, Photonics West 2003, San Jose, USA (Jan. 2003).

(12) H. Yamaguchi, S. Miyashita and Y. Hirayama, “Fabrication and characterization of InAs-based electromechanical systems”, 2002 RCIQE International Seminar on Quantum Nanoelectronics for Meme-Media-Based Information Technologies, Sapporo, Japan (Feb. 2003).

(13) M. Kasu, A. Aleksov, M. Kubovic, N. Teofilov, E. Kohn, R. Sauer, N. Kobayashi, “High

crystalline quality (111) homoepitaxial diamond layer grown by MOCVD", Surface and Bulk Defects in CVD Diamond Films VIII, Hasselt, Belgium (Feb. 2003).

(14) T. Fujisawa, "Single electron dynamics in quantum dots", Sweden-Japan Nanotechnology Colloquium, Lund, Sweden (Mar. 2003).

IV. Quantum Optics & Optical Materials

(1) M. Notomi, A. Shinya, I. Yokohama and K. Yamada, "SOI photonic crystals and photonic band gap waveguides", MRS Spring Meeting, San Francisco, USA (Apr. 2002).

(2) H. Kamada, H. Gotoh, H. Ando, T. Takagahara and J. Temmyo, "Exciton rabi oscillation : Coherently manipulate zero-dimensional quantum states by light", CLEO/QELS, Long Beach, USA (May 2002).

(3) M. Notomi, A. Shinya, E. Kuramochi, I. Yokohama, K. Yamada, C. Takahashi and J. Takahashi, "Highly dispersive nature of photonic-band-gap waveguide", CLEO/QELS 2002, Long Beach, USA (May 2002).

(4) M. Notomi, A. Shinya, E. Kuramochi, I. Yokohama, K. Yamada, C. Takahashi and J. Takahashi, "Photonic crystal waveguide", Opto-Electronics and Communications Conference (OECC 2002), Yokohama, Japan (Jul. 2002).

(5) M. Notomi, "Wavelength and spatial dispersion in photonic crystals", EOS Topical Meeting on Two-dimensional Photonic Crystals, Ascona, Switzerland (Aug. 2002).

(6) H. Kamada, H. Ando, T. Takagahara, H. Gotoh and J. Temmyo, "Quantum mechanical time-evolution of exciton states in semiconductor quantum dots: Quantum gate operation of exciton qubits", International Conference on Solid State Devices, Nagoya, Japan (Sep. 2002).

(7) H. Nakano, T. Nishikawa and K. Oguri, "Time-resolved absorption spectroscopy using ultrashort soft x-ray pulses from femtosecond laser-produced plasma", JST International Symposium on Control of Molecules in Intense Laser Fields, Tokyo, Japan (Sep. 2002).

(8) H. Nakano, T. Nishikawa, K. Oguri and N. Uesugi, "Time-resolved absorption spectroscopy using ultrashort soft x-ray pulses from femtosecond laser-produced plasma", JAERI Symposium on Control of Lasers for Strong Field Phenomena, Kyoto, Japan (Sep. 2002).

(9) H. Kamada, H. Gotoh, H. Ando, T. Takagahara and J. Temmyo, "Single quantum dots exciton : Application to quantum optics", QD2002, Tokyo, Japan (Sep. 2002).

(10) K. Inoue, E. Waks and Y. Yamamoto, "Differential phase shift quantum key distribution", Photonics Asia 2002, Shanghai, China (Oct. 2002).

(11) M. Notomi, "Dispersive behavior of photonic crystals (Dispersion control and negative refraction)", The 4th International Meeting on Photonic and Electromagnetic Crystal Structures (PECS IV), Los Angeles, USA (Oct. 2002).

(12) M. Notomi, "Wavelength and spatial dispersion in photonic crystals", CIAR Nanoelectronics Program Fall Workshop, Banf, Canada (Oct. 2002).

(13) M. Notomi, A. Shinya, E. Kuramochi, K. Yamada, T. Shoji, T. Watanabe, T. Tsuchizawa and J. Takahashi, "Novel properties of photonic band gap waveguides", The 15th Annual Meeting of IEEE/LEOS (LEOS 2002), Glasgow, UK (Nov. 2002).

(14) H. Kamada, H. Gotoh, H. Ando, and T. Takagahara, "Quantum dot exciton Rabi oscillation and quantum gate operation", APF8, Tsukuba, Japan (Jan. 2003).

(15) H. Kamada, H. Gotoh, H. Ando, T. Takagahara and J. Temmyo, "Quantum gate operation of exciton qubits in semiconductor quantum dots", Photonics West 2003, San Jose, USA (Jan. 2003).

NTT Basic Research Laboratories

3-1 Morinosato Wakamiya, Atsugi-shi

Kanagawa 243-0198 Japan

Phone: +81-46-240-3312

URL: http://www.brl.ntt.co.jp

E-mail: kensui@will.brl.ntt.co.jp