Research Activities
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NTT Basic Research Laboratories

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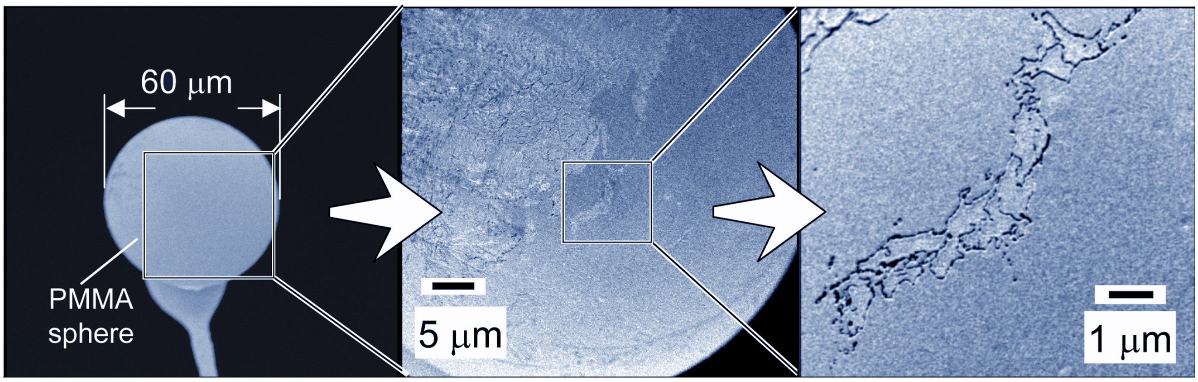
NTT Basic Research Laboratories,

Nippon Telegraph and Telephone Corporation (NTT)

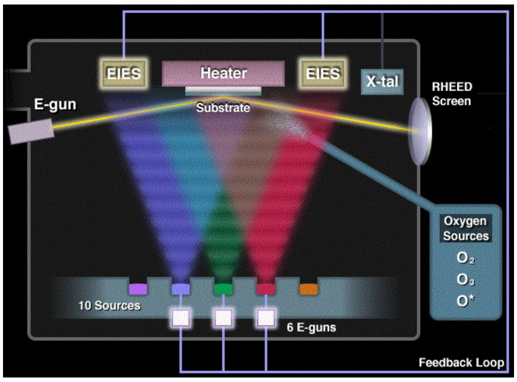
http://www.brl.ntt.co.jp



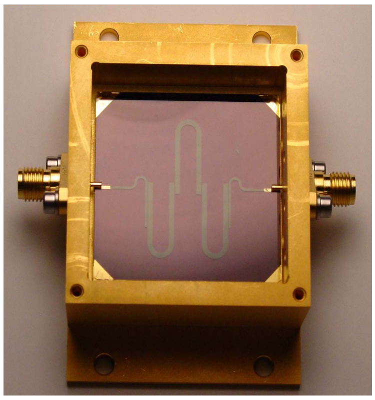
Electron microscope image of the globe

World's smallest globe (Nano-globe) made using electron beam

We made the world's smallest globe as a demonstration of a new three-dimensional nanofabrication technique using electron-beam lithography. A sphere sample was rotated, and the map of the world was written on it. The minimum linewidth is 10 nm, which corresponds to 2 km. Our technique significantly improves the resolution of 3D fabrication. (Page 19)



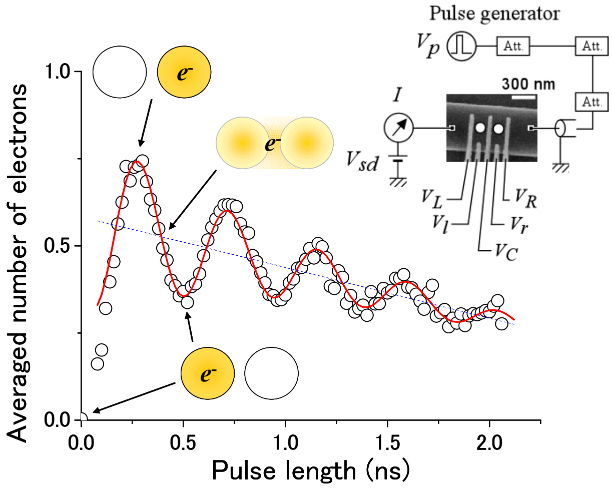
NTT-original High-T_c MBE



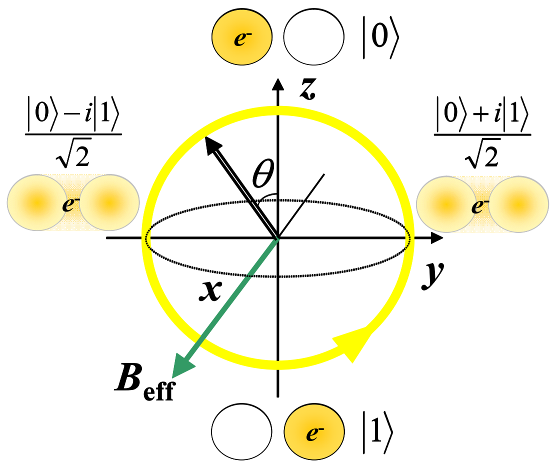
Superconducting bandpass filters

High-T_c Superconducting Filters for Wireless Communication

Superconducting microwave devices can realize future wireless communication systems with higher selectivity, higher sensitivity and smaller power consumption. We firstly fabricated microwave bandpass filters of a high-temperature superconducting oxide $NdBa_2Cu_3O_7$, which is superior to the widely-used superconductor $YBa_2Cu_3O_7$ in various properties including the superconducting transition temperature T_c and the surface resistance R_s. The filters were fabricated using high-quality films obtained by NTT-original thin film-growth technique for molecular-beam epitaxy (MBE) of high-T_c superconducting oxides. Improving the performance of the new filters, we may realize application of superconducting filters for transmitting parts in wireless systems, which is supposed to give remarkable reduction in size and power consumption of the systems.



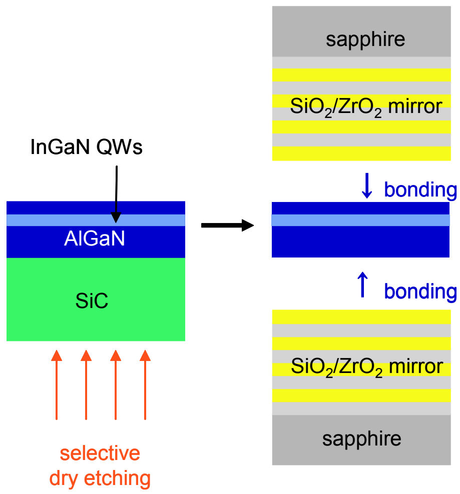
Coherent charge oscillation (inset: sample set-up)



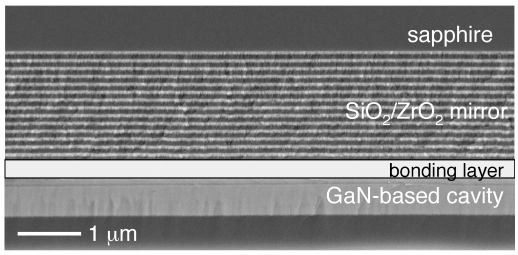
Bloch sphere (rotation gate operation)

Semiconductor charge qubit

Coherent charge oscillation in a semiconductor double quantum dot is induced by voltage pulse, which corresponds to rotation gate operation on the charge qubit. In the Bloch sphere representation of the qubit, the pseud spin rotates along the effective magnetic field. (Page 28)



Fabrication procedure of III-Nitride VCSELs



Cross-sectional SEM image of fabricated VCSEL

GaN-Based Vertical Cavity Surface Emitting Lasers

A serious problem with GaN-based vertical cavity surface emitting lasers (VCSEL) is that the crystal quality of the cavity layer is degraded by the large lattice mismatch between the GaN-based mirror layers. A high quality GaN-based VCSEL was fabricated and its lasing action at room temperature demonstrated by using a wafer bonding technique with a GaN-based cavity layer and oxide-based mirrors that were prepared separately. (Page 33)

From Science to Innovative Technology

We sincerely appreciate your interest in NTT Basic Research Laboratories.

Basic Research Laboratories (BRL) was established in 1998, when the former BRL was divided into the Communication Science Laboratories and laboratories devoted to basic research in the area of hardware. BRL's mission is to 1) discover novel concepts in network technology that will overcome present limitations in speed, capacity, and size and 2) pioneer basic technology that will become a foundation for future business.

Two of our most promising projects are quantum information processing and the nano-bio project.
The main topics of research in quantum information processing are quantum computation and quantum cryptography. Taking advantage of our ability to run projects ranging in scope from small to huge, NTT BRL's research on quantum bits using solid-state components has achieved world-class success. In quantum cryptography, we are accelerating research using single photons. The nano-bio project fuses neuroscience, bio-molecular science, and nanotechnology in the search for hybrids of comprising molecular and protein-based devices.

While promoting these projects, we are also conducting exploratory research in the following fields: quantum correlation within low-dimensional electron systems, systems that use the spin of individual electrons as an information carrier, material design that uses quantum dots as building blocks, electrical properties of carbon nanotubes, and MEMS (microelectromechanical systems) related to superconductivity. As we research these fields, we emphasize the need for good communication between researchers and managers as a way to judge whether or not they will bear fruit in the future.

Alongside such exploratory research, we are putting effort into creating innovative technology. For instance, in the field of diamond semiconductors, whose ability to handle high power and high-frequency waves make them promising for various applications, we have developed technology that produces diamond thin films of high quality and succeeded in operating a diamond transistor at 80 GHz. In addition, we are engaged in research on single-electron devices for their extremely low power consumption, photonic crystal for use as active optical circuits, and optical devices using wide-bandgap semiconductor materials. We see these as innovative technologies that will overcome the limitations of the present network.

To maintain fruitful research activities, we believe it is essential to have an open research policy. We not only keep in close touch with other NTT Laboratories, but also run various scientific exchange programs with institutes inside and outside Japan. Our collaborative work on quantum dots and quantum bits with Delft University and Stanford University has led to several interesting discoveries, and nano-bio research with the University of Tokyo has also been producing promising results. Moreover, we hold International Symposiums, Summer Schools, and International Advisory Board Meetings to disseminate our research information worldwide and encourage greater understanding of it.

This brochure provides annual review of our research activities and achievements in 2003. We hope it will contribute to the promotion of scientific exchange throughout the world.

June 2004

髙柳 英明

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Contents

Member List

As of March 31, 2004
(*/ left NTT BRL in the middle of the year)

NTT Basic Research Laboratories

Director, **Dr. Hideaki Takayanagi**
Dr. Sunao Ishihara (~ June 30, 2003)

Research Planning Section

Senior Research Scientist, Supervisor, **Dr. Itaru Yokohama**

Senior Research Scientist, Supervisor, Dr. Yasuyuki Kobayashi

Senior Research Scientist, Dr. Yuichi Harada

NTT R&D Fellow

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(Stanford University, U.S.A)
Dr. Hideaki Takayanagi
(Director, Bacic Research Laboratories)

NTT Research Professor

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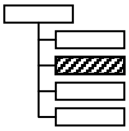
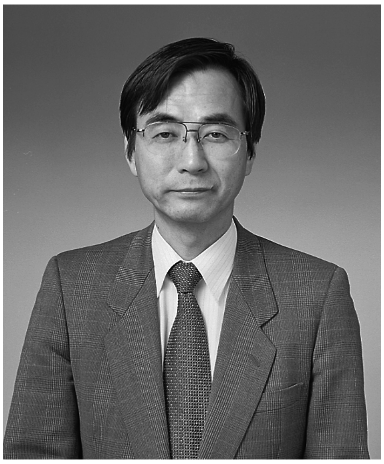
Prof. Masahito Ueda
(Tokyo Institute of Technology)
Prof. Seigo Tarucha
(The University of Tokyo)
Dr. Fujio Shimizu
(The University of Electro-Communications)
Prof. Yoshihisa Yamamoto
(Stanford University, U.S.A)

Device Physics Laboratory





Executive Manager, **Dr. Yasuo Takahashi**

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Takeshi Karasawa

Silicon Nanodevices Research Group:

Dr. Yasuo Takahashi (Group Leader)

Dr. Hiroshi Inokawa	Dr. Seiji Horiguchi*	Dr. Masashi Uematsu
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Dr. Hiroyuki Teramae	Dr. Katsuhiko Nishiguchi	Dr. Nicolas Clement

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Toru Yamaguchi		

Surface Science Research Group:

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Akio Tokura	Dr. Satyaban Bhunia*	

Materials Science Laboratory

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Dr. Kazuhiro Igeta

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Dr. Akio Tsukada		

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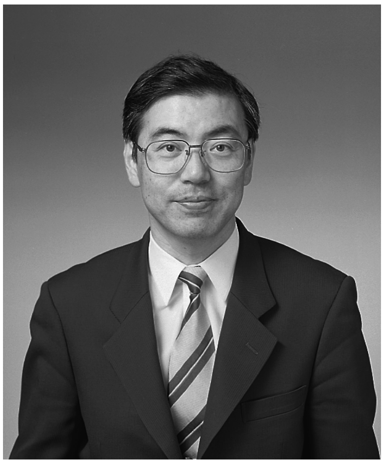
Dr. Hiroyuki Tamura	Dr. Tetsuya Mukai	Hirotaka Tanaka
Dr. Shiro Saito	Dr. Andreas Richter*	Dr. Masumi Yamaguchi
Dr. Taro Eichler	Dr. Alexander Kasper	

Spintronics Research Group:

Dr. Junsaku Nitta (Group Leader)

Dr. Yoshiaki Sekine	Dr. Yiping Lin

Physical Science Laboratory



Executive Manager, **Dr. Yoshiro Hirayama**

Masami Kumagai

Quantum Solid State Physics Research Group:

Dr. Yoshiro Hirayama (Group Leader)

Dr. Hiroshi Yamaguchi	Dr. Toshimasa Fujisawa	Dr. Koji Muraki
Dr. Kiyoshi Kanisawa	Dr. Satoshi Sasaki	Dr. Akihito Taguchi
Dr. Kyoichi Suzuki	Dr. Toshiaki Hayashi	Dr. Norio Kumada
Dr. Takeshi Yusa	Dr. Lionel Houlet	Dr. Kei Takashina

Wide-Bandgap Semiconductor Research Group:

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Yoshiharu Yamauchi	Dr. Tetsuya Akasaka	Dr. Kazuhide Kumakura
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Dr. Atsushi Ishizawa	Dr. Tsuneyuki Ozaki*	

Optical Device Physics Research Group:

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Dr. Takehiko Tawara	Dr. Takeshi Kutsuwa	Dr. Stephen Hughes

Photonic Nano-Structure Research Group:

Dr. Yoshiro Hirayama (Group Leader)

Dr. Masaya Notomi	Dr. Atsushi Yokoo	Eiichi Kuramochi
Dr. Hideaki Taniyama	Dr. Kouta Tateno	Dr. Akihiko Shinya
Dr. Satoshi Mitsugi	Dr. Han-Youl Ryu*	Dr. Tetsu Ito

Distinguished Technical Member

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 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 2003, he is also a guest associate professor at Tokyo Institute of Technology. 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.

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), heterojunction bipolar transistors (HBTs), and so on. His current interests are epitaxial growth of nitride semiconductors and nitride semiconductor devices. He is an associate editor of Japan Society Applied Physics and JSAPI, and a member of the Japan Society of Applied Physics, the Institute of Electronics, Information and Communication Engineers, and Materials Research Society.

Invited / Guest Scientists (2003 Fiscal Year)

Name	Affiliation Period
Dr. Takaaki Koga	Japan Science and Technology Agency (JST), Japan December 2001 – March 2004
Prof. Thierry Martin	Université de la Méditerranée, France April – May 2003
Dr. Michael Thorwart	Delft University of Technology, The Netherlands June – July 2003
Prof. Emilio Mendez	State University of New York at Stony Brook, U.S.A. June – August 2003
Dr. Vesselin Tonchev	Institute of Physical Chemistry, Bulgarian Academy of Sciences, Bulgaria July – September 2003
Prof. Rosario Fazio	Scuola Normale Superiore, Italy October – November 2003
Dr. Hiroshi Yaguchi	Kyoto University, Japan December 2003 – November 2004
Dr. Tobias Nyberg	University of Tokyo, Japan January – December 2004
Dr. Jan Johansson	Japan Science and Technology Agency (JST), Japan February 2004 – January 2005
Prof. Wu Peiheng	University of Nanjing, China February – March 2004
Prof. Tord Claeson	Chalmers University of Technology, Sweden February – April 2004
Dr. Giuseppe Falci	Università di Catania, Italy February – March 2004

Prof. David Haviland	KTH – The Royal Institute of Technology, Sweden February – March 2004
Prof. Frank Hekking	Joseph Fourier University, France February – March 2004

Advisory Board (2003 Fiscal Year)

Name	Title Affiliation
Dr. Johan E. Mooij	Professor Department of Applied Physics Delft University of Technology, The Netherlands
Dr. C. Tord Claeson	Professor Physics Department Chalmers University of Technology, Sweden
Dr. Klaus von Klitzing	Professor Max-Planck-Institut für Festkörperforschung Germany
Dr. Klaus H. Ploog	Director Paul-Drude-Institut für Festkörperelektronik Germany
Dr. Michel H. Devoret	Professor Department of Applied Physics Yale University, U.S.A
Dr. Christos Flytzanis	Professor Physics of Condensed Matter Laboratory Ecole Normale Supérieure, France
Dr. Chung L. Tang	Professor School of Electrical Engineering Cornell University, U.S.A

Trainees (2003 Fiscal Year)

Name	Affiliation (Period)
Frank Deppe	Technische Universität München, Germany (May 2002 – May 2005)
Oliver Regenfelder	Technische Universität Graz, Austria (Sep. 2002 – Aug. 2003)
Yoshiharu Krockenberger	Technische Universität München, Germany (Nov. 2002 – Jun. 2003)
Marcus Steiner	Universität Hamburg, Germany (Jan. 2003 – Jun. 2003)
Sung Woo Jung	Pohang University of Science and Technology, Korea (Jan. 2003 – Jan. 2004)
Sandrine Buhours	INSA (Institut National des Sciences Appliquées), France (Feb. 2003 – Jun. 2003)
Antonio Ballestrazzi	Università degli Studi di Modena e Reggio Emilia, Italy (Mar. 2003 – May 2003)
Nicolas Gaillard	Ecole Nationale Supérieure de Physique de Grenoble, France (Mar. 2003 – Jul. 2003)
Sang-jin Kim	Chungbuk National University, Korea (Mar. 2003 – Mar. 2004)
Sreejeesh S. G.	L.B.S. College of Engineering, India (May 2003 – Oct. 2003)
Jennifer Chan	University of British Columbia, Canada (Jun. 2003 – Dec. 2003)
Jeff Liu	Simon Fraser University, Canada (Jun. 2003 – Apr. 2004)

Joyce Yat-Ling Wong	University of Toronto, Canada (Jul. 2003 – Jun. 2004)
Gael Robert	ESPCI (École Supérieure de Physique et de Chimie Industrielles), France (Jul. 2003 – Dec. 2003)
Elise Laffosse	INSA (Institut National des Sciences Appliquées), France (Jul. 2003 – Sep. 2003)
Niti Goel	University of Oklahoma, U.S.A. (Jul. 2003 – Aug. 2003)
Guk-Hyun Kim	KAIST (Korea Advanced Institute of Science and Technology), Korea (Aug. 2003 – May 2004)
Nicolas Thillosen	Aachen University of Technology (RWTH) / Research Center Jülich, Germany (Nov. 2003 – Apr. 2004)
Christopher Schierholz	Universität Hamburg, Germany (Jan. 2004 – Jul. 2004)
Julien Duvernay	INSA (Institut National des Sciences Appliquées), France (Feb. 2004 – Sep. 2004)

Japanese Students (2003 Fiscal Year)

Name	Affiliation (Period)
Mami Asaka	Tokai University, Japan (Jun. 2003 – Mar. 2004)
Shinich Amaha	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Tomohiro Amemiya	University of Tokyo, Japan (Jul. 2003 – Aug. 2003)
Yuichi Igarashi	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Taishi Ishihara	The University of Electro-Communications, Japan (Apr. 2003 – Mar. 2004)
Yasuaki Iwai	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Yasuhiro Uchiyama	Meiji University, Japan (Apr. 2003 – Mar. 2004)
Miyuki Oshita	Toyohashi University of Technology, Japan (Jan. 2004 – Feb. 2004)
Keji Ohno	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Yasuaki Okano	Tokyo Institute of Technology, Japan (Feb. 2004 – Mar. 2004)
Hajime Okamoto	Waseda University, Japan (Apr. 2003 – Mar. 2004)
Masahiro Kashiwa	Shonan Institute of Technology, Japan (Apr. 2003 – Mar. 2004)
Akira Kawaguchi	Osaka University, Japan (Apr. 2003 – May 2003)
Yoshiyuki Kawata	Tokyo Institute of Technology, Japan (Jul. 2003 – Aug. 2003)
Koya Kitagawa	Tokyo University of Science, Japan (Nov. 2003 – Mar. 2004)
Takatoshi Kido	Shonan Institute of Technology, Japan (Apr. 2003 – Mar. 2004)
Go Kira	University of Tokyo, Japan (Jun. 2003 – Mar. 2004)
Tatsuya Kutsuzawa	Tokyo University of Science, Japan (Apr. 2003 – Mar. 2004)
Tetsuo Kodera	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)

Naofumi Kobayashi	Meiji University, Japan (Apr. 2003 – Mar. 2004)
Shingo Kondo	Tokai University, Japan (Apr. 2003 – Mar. 2004)
Seiji Saito	Shonan Institute of Technology, Japan (Jul. 2003 – Mar. 2004)
Daisuke Sato	University of Tsukuba, Japan (Apr. 2003 – Mar. 2004)
Masafumi Shimizu	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Yoshihiro Sugio	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Daisuke Takagi	Meiji University, Japan (Apr. 2003 – Mar. 2004)
Akio Takahashi	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Yoshiyuki Takahashi	Hokkaido University, Japan (Jul. 2003 – Aug. 2003)
Izumi Takesue	Aoyama Gakuin University, Japan (Apr. 2003 – Dec. 2003)
Kazunori Tawaraya	Hokkaido University, Japan (Mar. 2004)
Yoshifumi Nishi	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Jiro Nishinaga	Waseda University, Japan (Apr. 2003 – Mar. 2004)
Aihiko Numata	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Masumi Noda	Tokyo University of Science, Japan (Nov. 2003 – Mar. 2004)
Shigeto Fukatsu	Keio University, Japan (Apr. 2003 – Mar. 2004)
Shinya Fukuba	Meiji University, Japan (Apr. 2003 – Mar. 2004)
Seiji Fujikawa	Himeji Institute of Technology, Japan (Jul. 2003 – Aug. 2003)
Naoki Funagayama	Toyohashi University of Technology, Japan (Jan. 2004 – Feb. 2004)
Yusuke Furukawa	University of Tokyo, Japan (Feb. 2004 – Mar. 2004)
Munekazu Horikoshi	The University of Electro-Communications, Japan (Jun. 2003 – Mar. 2004)
Motonari Honda	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Tetsunori Matsumoto	Tokyo University of Science, Japan (Apr. 2003 – Mar. 2004)
Jun Mizubayashi	Aoyama Gakuin University, Japan (Sep. 2003 – Dec. 2003)

Shinichiro Miyadai	Aoyama Gakuin University, Japan (May 2003 – Dec. 2003)
Takuya Mouri	Tokyo University of Science, Japan (Apr. 2003 – Mar. 2004)
Ryusuke Morita	The University of Electro-Communications, Japan (Apr. 2003 – Mar. 2004)
Shin Yabuuchi	Keio University, Japan (Oct. 2003 – Mar. 2004)
Shimpei Yamaguchi	University of Tokyo, Japan (Apr. 2003 – Mar.2004)
Akira Yamazaki	Meiji University, Japan (Apr. 2003 – Mar. 2004)
Michihisa Yamamoto	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)
Tomoo Yokoyama	Yokohama National University, Japan (Apr. 2003 – Mar. 2004)
Hiroyasu Yokoyama	University of Tokyo, Japan (Apr. 2003 – Mar. 2004)

Ⅰ. Research Topics

Overview of Device Physics Research

Yasuo Takahashi
Device Physics Laboratory

Nanotechnology will be a key role in achieving the future multimedia society. Although recent progress in information technology has been supported by the progress in Si LSI technologies, energy dissipation in small Si chips has become a critical issue because of the increasing number of transistors. For personal information tools, it is important to develop new compact hardware that operates on new principles and consumes extremely low power. The Device Physics Laboratory conducts research on single electronics, which enable us to make small and ultimately low-power devices. For nanostructure fabrication, we are working to refine lithographic techniques (top-down approach), and investigating self-assembly based on the atomic structures of the substrate (bottom-up approach). We are also examining other methods to create various 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 seeking to establish fabrication principles. SETs have special features that conventional transistors do not have. One is the capability of attaching many input gates to them, and another is their applicability to multiple-valued operation. By using these features, we have demonstrated effective arithmetic circuits operating based on multiple-valued logic and showed their rather high-speed and low-power consumption nature. We have also demonstrated multiple valued memory by using one-by-one electron transfer and a highly sensitive single-electron detection device. A key issue in making Si SETs is the oxidation reaction. To clarify their fundamental mechanisms we have conducted experimental and theoretical investigation considering atomic level processes, and performed simulations of the oxidation rate based on the newly proposed mechanisms.

The Nanostructure Technology Research Group is investigating top-down nanofabrication techniques based on electron-beam lithography. One of the important issues for nanofabrication is pattern fluctuation. We have clarified the basis of ultrafine-pattern formation by using new resist materials and have established a new supercritical-fluid drying process to make high-aspect-ratio patterns. This led to the demonstration of high-temperature operating SETs. Recently, we have expanded these two-dimensional nanofabrication technologies to three-dimensional ones by using a specially designed sample-rotation system inserted into an electron-beam lithography apparatus. As a demonstration of this new technology, we have created a nano-globe by a world map on a 60-μm sphere with 10-nm resolution. We have also succeeded in making four-point-probe nano-system for conductance measurement of small structures by using focused-ion-beam technology.

The Surface Science Research Group is investigating wafer-scale control of ordered nanostructure formation based on the bottom-up approach. We have conducted experimental and theoretical studies of the flow of surface atomic steps on the Si surface to control the self-assembled nanostructures. We have also developed the method for the real time observation of the atomic reformation on the surface by using low energy electron microscopy (LEEM). Our research on carbon nanotubes has led to a new low temperature growth technique. We have succeeded in controlling the diameter of the grown nanotubes and established the method to evaluate the electrical states and structures of nanotubes by using Raman spectroscopy, photoluminescence, and photoelectron spectroscopy. We have also succeeded the vertically aligned InP nanowire growth by using the vapor-liquid-solid mechanism with gold nanoparticles as a catalyst.

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

Effect of the Si/ SiO_2 Interface on Si diffusion in SiO_2

Masashi Uematsu, Hiroyuki Kageshima, and Yasuo Takahashi
Device Physics Laboratory

With the scaling-down of Si devices, the bulk materials of interest are closer to material interfaces. Therefore, even phenomena in bulk materials, such as diffusion, are more likely to be affected by interfaces, such as the Si/SiO_2 interface. In this report, we investigated the effect of the interface on Si self-diffusion in SiO_2 by using isotopically enriched Si.

An isotopically enriched ^{28}Si single crystal epi-layer was thermally oxidized to form $^{28}SiO_2$ of thicknesses of 200, 300, and 650 nm. The samples were implanted with ^{30}Si and diffusion-annealed at temperatures between 1150 and 1250 ºC. Si self-diffusion in SiO_2 was investigated using the implanted ^{30}Si as makers. As shown in Fig. 1, we found that the Si self-diffusivity increases with decreasing $^{28}SiO_2$ thickness, i.e., the distance between the diffusing ^{30}Si species and $^{28}Si/^{28}SiO_2$ interface [1]. In order to explain this thickness dependence, we constructed a model in which SiO molecules generated at the interface via Si + SiO_2 → 2SiO and diffusing into SiO_2 enhance Si self-diffusion in SiO_2 [2]. The thickness dependence arises because the SiO diffusion is so slow that the ^{28}SiO concentration at the ^{30}Si region critically depends on the distance from the interface, where the SiO is generated, as shown in Fig. 2. We propose a mechanism of Si self-diffusion in SiO_2 enhanced by the existence of SiO via the reaction such that $^{30}Si(s) + ^{28}SiO(i) \Leftrightarrow ^{28}Si(s) + ^{30}SiO(i)$, where substituted (s) Si atoms diffuse via the kick-out reaction with diffusing interstitial (i) SiO molecules. Based on this mechanism, we simulated and fitted the diffusion profiles of ^{30}Si (simulation in Fig. 1).

Furthermore, the simulation predicts that the self-diffusivity would increase for a longer annealing time because more SiO molecules should be arriving from the interface. As predicted, the time-dependent diffusivity was experimentally observed, and this confirms our diffusion model. The diffusion length of SiO estimated from the present results is 0.4 nm for 10-second annealing at 1100 ˚C. The present study suggests that the effect of the Si/SiO_2 interface may arise during silicon processes when the material thickness is down to 1 nm.

[1] S. Fukatsu et al., Appl. Phys. Lett. **83** (2003) 3897.
[2] M. Uematsu et al., Appl. Phys. Lett. **84** (2004) 876.

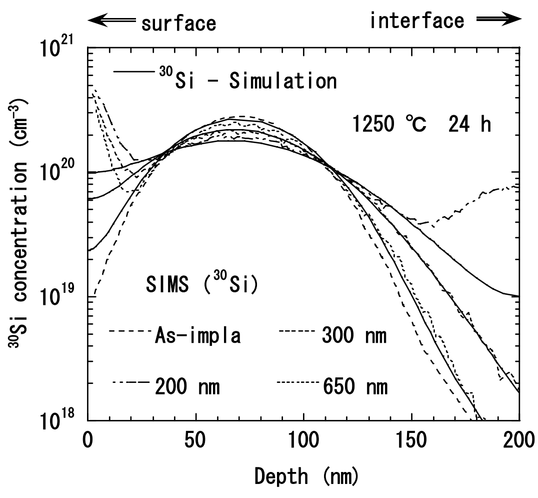


Fig. 1. Dependence of $^{28}SiO_2$ thickness on ^{30}Si diffusion in $^{28}SiO_2$.

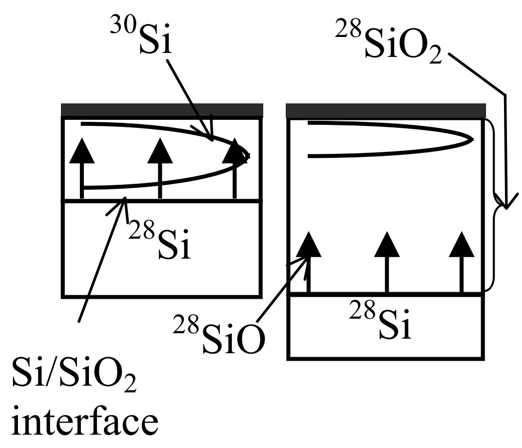


Fig. 2. Model.

World's Smallest Globe (Nano-Globe) made using electron beam

Kenji Yamazaki and Hideo Namatsu
Device Physics Laboratory

We have devised a new electron-beam (EB) lithography system for three-dimensional nanofabrication (3D-NANO) with a 10-nm resolution. As a demonstration of 3D nanopatterning using this system, we made the world's smallest globe (nano-globe) by writing the world map on a sphere sample. This technology promises to become a new important basis of many fields of nanotechnology.

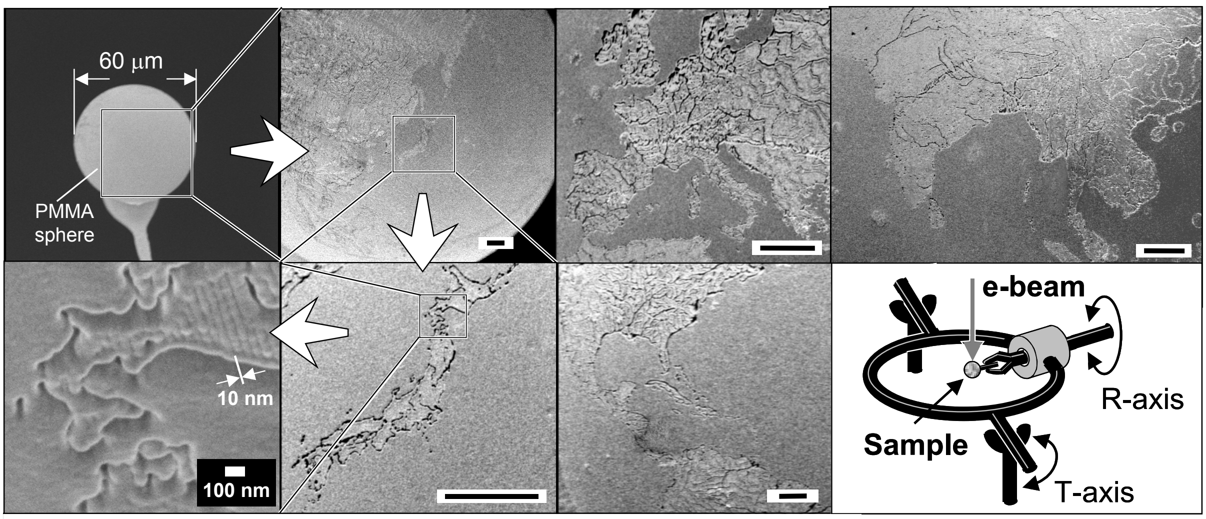
Electron beam lithography has been used for two-dimensional patterning in LSI manufacturing, and now has a resolution on the order of 5 nm. On the other hand, the resolution or fabrication speed of conventional 3D fabrication methods is too low or too slow for 3D nanotechnology. That is, methods using an optical or X-ray beam have micron-order resolutions, and deposition using an ion beam cannot accomplish fabrication at a reasonable speed. Our 3D-NANO technique using EB lithography solves these problems.

Our technique features a two-axis-of-rotation drive that works in the EB lithography apparatus. With this drive any surface of a 3D sample can be exposed to an EB [1]. Since an EB has a much larger depth of focus as well as a higher resolution than an optical or X-ray beam, an EB is convenient for writing three-dimensionally on a sample. 3D-NANO was achieved by the additional development of 3D positioning techniques for written patterns [2].

On the nano-globe, which is made of polymethylmethacrylate, the minimum size of the patterns is 10 nm. This is several ten times as small as than that for conventional methods using an optical or X-ray beam. The exposure time for the whole world map was only about 2 min. This means that the technique can be applied to fast fabrication with large-scale complicated structures. Our 3D-NANO will enable us to make novel nanodevices and will open up new fields in nanotechnology.

[1] K. Yamazaki and H. Namatsu, Microelectron. Eng., *in printing*.

[2] K. Yamazaki and H. Namatsu, Proc. IEEE MEMS 2004, 609.



Electron microscope images of the nano-globe. Unlabeled scale bars indicate 3 μm.

Illustration showing how a sample rotates.

Nano-four-point-probe systems

Masao Nagase
Device Physics Laboratory

We have developed nanotools for measuring the electrical properties of nanomaterials. The conventional probe used in scanning probe microscopy (SPM) has only one tip on the single cantilever. If we can integrate a functional device on a SPM cantilever, it will be a powerful and useful nanoelectromechanical system or nanotool for evaluating the properties of nanomaterials. However, it is very difficult to integrate the fabrication process of the functional device and that of the SPM cantilever. The recent advancement in ion optics of focused ion beam (FIB) technology has enabled us to fabricate micro- and nano-order structures. Measurement systems are integrated on a Si cantilever of SPM using newly developed fabrication methods based on nanopatterning technology. In this section, we introduce two kinds of nano-probe systems.

Measurement of electrical resistivity using a four-point-probe is a fundamental technology of electronic devices. However, the distance between the probes of an existing four-point-probe is a few micrometers. It is too large for evaluation of nano-order electrical properties of nanomaterials, such as CNT and DNA. We try to fabricate nano-four point probes for SPM using FIB technology. Fig. 1 shows a micrograph of the nano-four-point probes fabricated by FIB milling [1]. The thin Pt film deposited on the tip of the lever is divided into 4 parts using ion beam milling. The pitch of the probes is about 500 nm. The width is about 200 nm. To miniaturize the probes, nano-four-point probes are fabricated by electron beam nanolithography. Fig. 2(a) shows Si nanoprobes with 60-nm-pitch and 20-nm-width on a silicon-on-insulator substrate. This nanodevice is cut out from the substrate by FIB milling and is transferred to the tip of a Si cantilever with four Al electrodes. W interconnections deposited by FIB deposition (FIB-W) are formed between the Si electrodes and the Al electrodes. As a result, a nanodevice system is realized on an SPM microcantilever as shown in Fig. 2(b) [2]. FIB technology brings us a new solution for assembling nanodevices. The abilities of FIB, milling and handling of micro-scale structures and direct wiring of metal electrodes are very useful for nano- and micro-electromechanical systems.

With further miniaturization of the nanoprobe, the SPM cantilever system fabricated by FIB technology will become a useful evaluation tool for nanodevices and molecular science.

[1] M. Nagase et. al., Jpn. J. Appl. Phys. **42** (2003) 4856.
[2] M. Nagase and H. Namatsu, Jpn. J. Appl. Phys. **43** (2004), to be published.

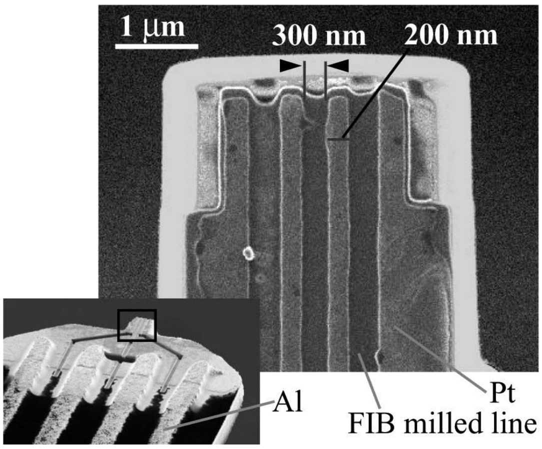


Fig. 1. Nano-four-point-probe fabricated by FIB milling.

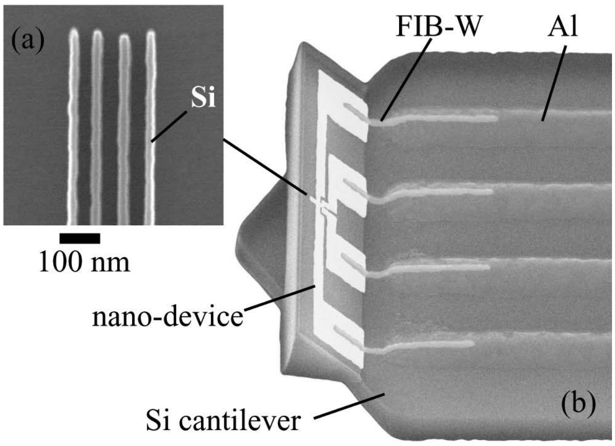


Fig. 2. Nano-four-point-probe assembled by FIB technology.

Semiconductor Nanowires

Yoshio Watanabe, Satyaban Bhunia, and Tomoaki Kawamura
Device Physics Laboratory

One-dimensional nanomaterials are expected to play a key role in fabricating nanoscale devices of the next generation. However, miniaturization in electronic and optoelectronic devices through improvements in conventional “top-down” technologies is approaching the limits of lithographic and etching processes. In contrast, bottom-up approaches to nanodevices, where the nanomaterials are assembled from basic building blocks, such as semiconductor nanowires and carbon nanotubes, have the potential to go far beyond their limits. Recently, we have successfully grown the surface mounted and vertically aligned InP nanowires by metal organic vapor phase epitaxy [1]. The nanowires were grown by the vapor-liquid-solid mechanism with Au nanoparticles acting as the catalyst. The Au nanoparticles were used as the seed to control the nanowire diameter in the nanoscale range. Figure 1 shows a typical scanning electron microscopic (SEM) picture of the nanowires grown on InP(111)B taken at an oblique angle of 40^{o}. Both scanning and transmission electron microscopic studies showed highly dense nanowires with homogeneous diameter along their length axis, and had zinc-blende structure with <111> growth direction, and most of them had diameter in the range of 20 – 25 nm. Photoluminescence measurements at room temperature showed significant blueshift in the peak position compared to bulk InP due to the quantum confinement of the carriers in the nanowires. Furthermore, heteroepitaxial InP nanowires were also successfully grown on GaP(111)B substrates [2]. Figure 2 shows a typical SEM picture of the nanowires grown on GaP(111)B. Highly dense, vertically aligned nanowires with uniform diameters along the vertical axis are visible. Very recently, the site-controlled InP nanowires were successfully grown at the positions where Au nanoparticles have been arranged through liquid Au migration and followed Au nanoparticle formation at a particular position on the patterned Si substarte [3].

[1] S. Bhunia, T. Kawamura, Y. Watanabe, S. Fujikawa, and K. Tokushima, Appl. Phys. Lett. **83** (2003) 3371.
[2] Y. Watanabe, et al., Proceedings of the Twelfth International Workshop on the Physics of Semiconductor Devices (IWPSD-2003), Chennai India, December 2003.
[3] Y. Watanabe, et al., Proceedings of Fifth International Workshop on Epitaxial Semiconductors on Patterned Substrates and Novel Index Surfaces (ESPS-NIS), Stuttgart Germany, October 2003.

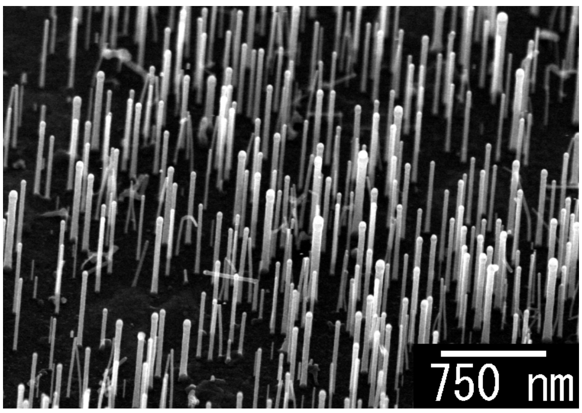


Fig. 1. SEM image of the InP nanowires grown on InP(111)B.

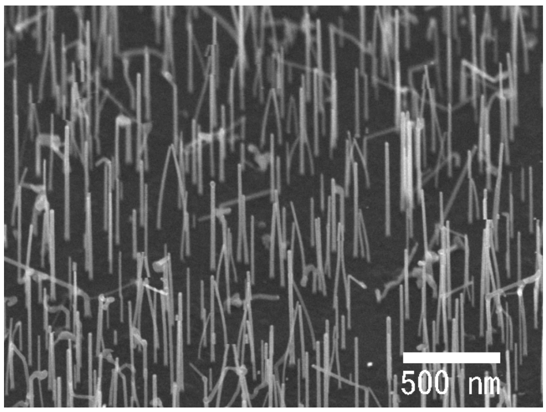


Fig. 2. SEM image of the InP nanowires grown on GaP(111)B.

Overview of Material Science Research

Masao Morita
Materials Science Laboratory

The Materials Science Laboratory (MSL) aims at producing new materials by controlling arrangement of atoms and bonding of molecular for new functions using quantum phenomena and so on. To accomplish these goals from different perspectives the following four MSL groups are formed and are studying many kinds of 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 2003.

1. The carrier transport and injection properties of conductive organic polymer with different dimensions and configurations were studied, and it was found that the carrier injection is dominated by the tunneling process at the nano-gap electrode.
2. Non-doped superconductors in lanthanum based copper oxide were discovered, though it has been believed that the non-doped parent materials of high-T_c superconductors are Mott insulators.
3. Multiphoton transitions between the superposition states in the superconducting flux qubit were observed. The microwave power dependences of the half width at half maxima of the resonant dips were well reproduced by Bloch equations based on a dressed-atom description. From this analysis, the qubit coherence time is estimated to be 5 ns.
4. The magnetization processes of micro-structured ferromagnetic rings were investigated using the local Hall effect device and it was found that the magnetic transition strongly depends on the inner diameter of the ring.

Carrier Injection and Transport of Conductive Polymer-Based Devices

Kazuaki Furukawa, Wenping Hu, Hiroshi Nakashima, Yoshiaki Kashimura, Katsuhiro Ajito, and Keiichi Torimitsu
Materials Science Laboratory

Organic molecules attract much interest recently as electronic materials. Research and development for flexible display and thin-film-transistor applications are vital today. In addition, molecular scale device, the device comprising single or small number of molecules, is considered for future organic electronic devices, not only because it has advantage in size but also it is expected to show novel phenomenon originated from single molecule. In this study, we prepared and observed carrier transport properties of organic electronic devices with different electrode sizes and configurations [1].

Figure 1 shows device structures. Nanogap electrodes (gap ~100 nm) and conventional sandwich type thin film device (with 2mm × 2mm area) were fabricated. The material is poly(*p*-phenyleneethynylene) derivative (TA-PPE, Fig.1) [2], which is know as a rigid π-conjugated polymer.

The remarkable difference between two types of devices was observed for the temperature dependence of current density-voltage (J-V) curves. Although the well known Arrhenius type temperature dependence was observed for the sandwich device, temperature dependence was not clearly observed for the nanogap device. Moreover, after the treatment of the nanogap device exposed in THF vapor, which is a good solvent for TA-PPE, the temperature dependence almost disappeared (Fig. 2). This result suggests that the carrier injection and transport is dominated by the tunneling process. During the exposure of the nanogap device in the vapor of its good solvent, TA-PPE became somewhat fluid, and thus the nanostructure of TA-PPE changed. The increase of the number of bonds between TA-PPE ends and Au electrodes at the interface made the tunneling process through Au-S bond superior.

The present results indicated that the molecular conformations as well as configurations contribute to the characteristics of molecular scale devices. The device design involving the control of molecular conformations is currently under consideration.

[1] W. P. Hu, et al., Phy. Rev. B (accepted).
[2] H. Nakashima, et al., Polym. Prepr. **44**(1) (2003) 482.

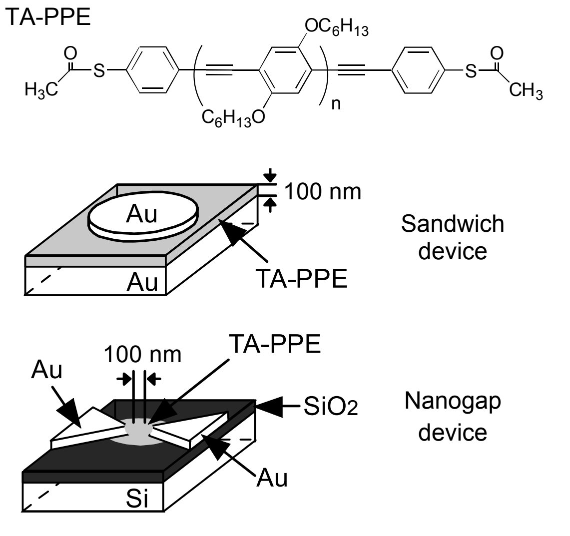


Fig. 1. Molecular structure of TA-PPE and sandwich and nanogap device structures.

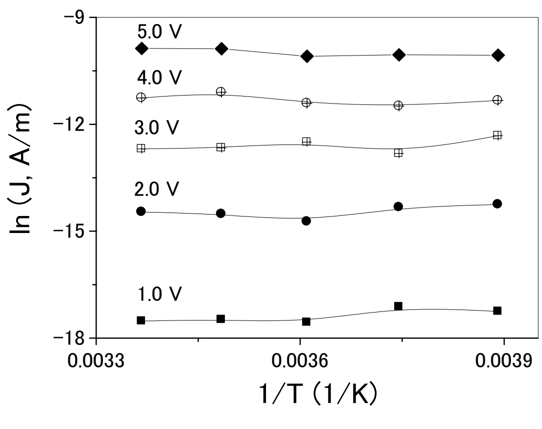


Fig. 2. ln(J) plotted vs. 1/T at different applied voltage for TA-PPE nanogap device after exposed in THF vapor.

Discovery of non-doped superconductors in lanthanum based copper oxide

Akio Tsukada, Hideki Yamamoto, and Michio Naito*
Materials Science Laboratory
*Tokyo University of Agriculture and Technology

It has been believed that the non-doped parent materials of high-T_c superconductors are Mott insulators, and superconductivity emerges only after *n*-type or *p*-type doping. Against this belief, we found that superconductivity is achieved in non-doped La_2CuO_4 with Nd_2CuO_4 (T') structure by substitution of La^{3+} by "isovalent" rare earth ions (RE^{3+}) having a small ionic radius. This substitution is intended mainly to stabilized the T' phase of La_2CuO_4 instead of T (K_2NiF_4) phase [1], so it is presumed not to cause effective doping. Therefore, our observation appears to contradict the general belief.

The new superconductors T'-$La^{3+}_{2-x}RE^{3+}_xCuO_4$ (RE^{3+} = Sm^{3+}, Eu^{3+}, Gd^{3+}, Tb^{3+}, Lu^{3+}, Y^{3+}) were prepared by molecular beam epitaxy (MBE) and showed superconducting transition at ~ 21 K [2]. Figure 1 shows the temperature (T) dependence of resistivity (ρ) for the films of $La_{2-x}Y_xCuO_4$ with various x. Superconductivity appears at x = 0.09 and 0.15 with T_c ~ 20 K. Superconductivity was also observed in other *RE* substitution except for Pr and Nd substitution. Figure 2 summarizes the *RE* concentration dependence of T_c in T'-$La_{2-x}RE_xCuO_4$. Regarding the origin of superconducting carriers in T'-$La_{2-x}RE_xCuO_4$, one can think of two possible scenarios. One is that the oxygen deficiencies are a source of effective electron carriers. The other is that the T'-La_2CuO_4 is not a Mott insulator, and has intrinsic carriers, as predicted by the band calculation for Nd_2CuO_4. If the latter scenario is well-established, it will urge a reexamination of the early controversy on the "doped Mott-insulator scenario", which is now widely accepted as a starting viewpoint for high-T_c superconductivity.

[1] A. Tsukada, et al., Phys. Rev. B **66** (2002) 184545.
[2] A. Tsukada, et al., Physica C, in press.

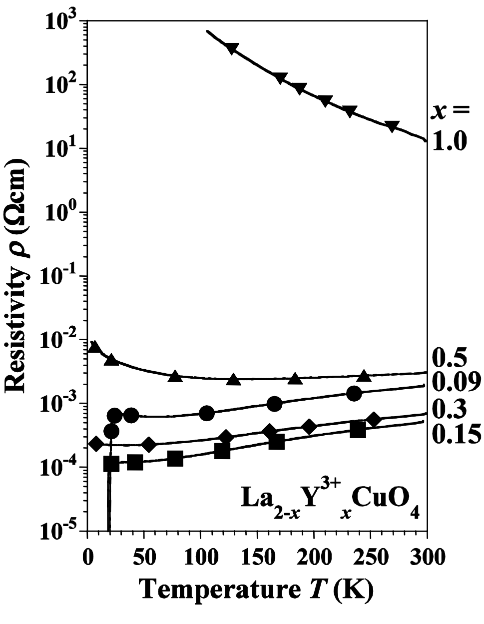


Fig. 1. ρ-T curves for $La_{2-x}Y_xCuO_4$.

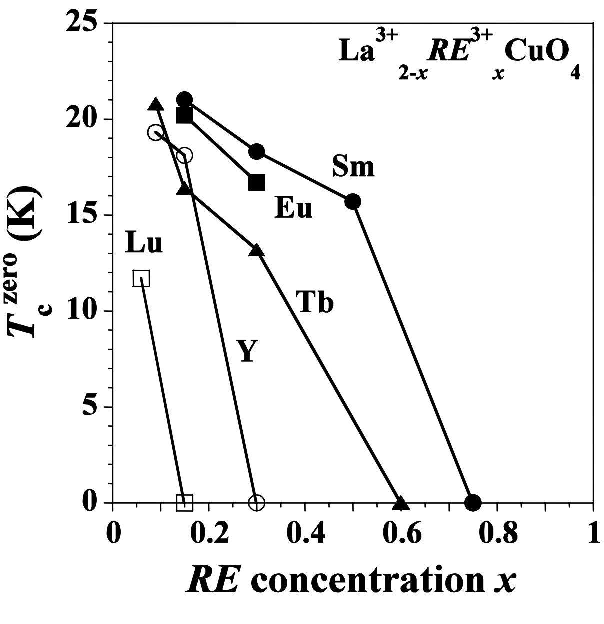


Fig. 2. T_c for $La_{2-x}RE_xCuO_4$.

Multiphoton absorption observed in a superconducting flux qubit

Shiro Saito, Michael Thorwart[1], Hirotaka Tanaka, Hayato Nakano, Kouichi Semba,
Masahito Ueda[2], and Hideaki Takayanagi
Materials Science Laboratory, Heinrich-Heine-Universität Düsseldorf[1],
NTT Research Professor and Tokyo Institute of Technology[2]

Of the recently realized solid-state quantum bits (qubits), the superconducting flux qubit has advantages because its scalability and long coherence time. The qubit consists of a superconducting loop with three Josephson junctions (see Fig. 1). The two states of the qubit correspond to clockwise $|0\rangle$ and counterclockwise $|1\rangle$ superconducting current in the loop. The current involves millions of Cooper pairs, which means that the two states are macroscopically distinct. Hence, this system can realize a superposition between two such macroscopic states. For the first time, we observed multiphoton transitions between the superposition states in the superconducting flux qubit [1].

Figure 2(a) shows the magnetic flux dependence of the qubit energy levels, where Φ_{qubit} is the flux through the qubit loop and Φ_0 $(=h/2e)$ is the flux quantum. The arrows in the figure represent a microwave with an energy of 9.1 GHz. The qubit can be excited from the ground state to the first excited state by absorbing multiple photons. We remark that the existence of the energy gap at the degeneracy point $\Phi_{\mathrm{qubit}}/\Phi_0 = 1.5$ is strong evidence for the superposition between the macroscopically distinct states.

The qubit was read out by measuring the switching current of a superconducting quantum interference device (dc-SQUID) (see Fig. 1). Figure 2(b) shows the change dI_{sw} in the switching current as a function of the magnetic flux under the microwave irradiation. The dc-SQUID detected the change in the qubit state from $|0\rangle$ to $|1\rangle$ induced by magnetic flux. Furthermore, resonant peaks and dips were observed at the expected operating points in Fig. 2(a). The microwave power dependences of the half width at half maxima of the resonant dips were well reproduced by Bloch equations based on a dressed-atom description (see Fig. 3). From this analysis, we found the qubit coherence time to be 5 ns, which is consistent with that obtained from another experiment using a microwave pulse.

[1] S. Saito, et al., cond-mat/0403425.

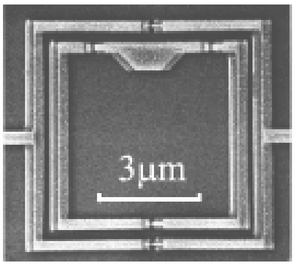


Fig. 1. Superconducting flux qubit (inner loop) and dc-SQUID for readout (outer loop)

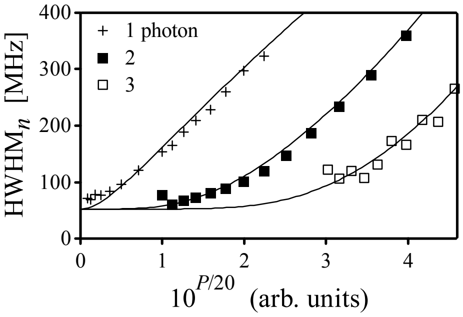


Fig. 3. Microwave power dependence of HWHM of resonant dips. Solid curves represent theoretical simulations.

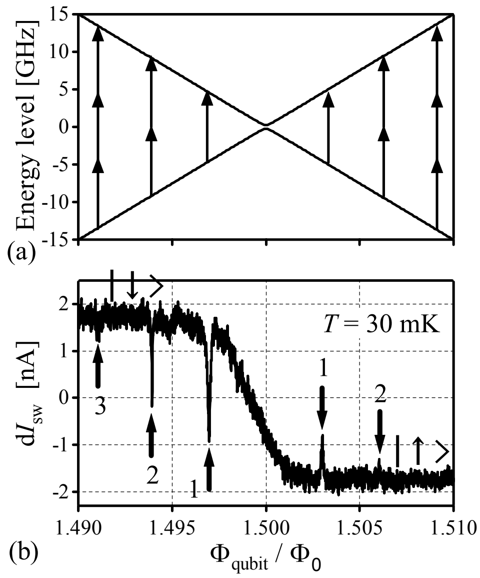


Fig. 2. (a) Energy diagram of qubit.
(b) Magnetic field dependence of qubit readout.

Control of magnetization states in micro-structured ferromagnetic rings

Marcus Steiner and Junsaku Nitta
Materials Science Laboratory

It is difficult to detect the magnetization of a single micro-magnet even by using a high sensitive susceptibility-meter; therefore, ensemble averaged magnetization processes is measured in an array including several thousand micro-structured magnets. We have shown that a fringe-field-induced local Hall effect (LHE) device can detect the magnetization process of a single micro-structured magnet [1]. It has been predicted that a flux closure state (vortex state) is stable in ferromagnetic small ring structures. In the vortex state, almost no stray field is generated, that offers a potential application for high integration of the magnetoresistive random access memory (MRAM). We have investigated the magnetization processes of micro-structured ferromagnetic rings using the LHE device and have found that the magnetic transition strongly depends on the inner diameter of the ring.

The inset of Fig. 1 shows an SEM image of a fabricated sample. A cross-shape is a semiconductor Hall device. A NiFe micro-structured ferromagnetic ring is placed near the Hall cross to detect a fringe field. An external magnetic field is applied in parallel to the semiconductor two-dimensional electron gas in order that it does not affect the Hall resistance. Figure 1 shows hysteresis loops of the Hall resistance. The outer diameter of the rings is fixed to 2.0 μm, and the inner diameter is varied from 0 (Disk) to 1.6 μm in steps of 0.4 μm. We observed a systematic change in the hysteresis loops by increasing the inner diameter. For narrow rings, sharp transitions from the so-called “onion” state to the “vortex” state were observed. In rings with smaller inner diameter, the transitions are broad and more complex [2]. A comparison between the hysteresis loop of the Hall resistance of a 0.4 μm-diameter ring and numerical calculation is shown in Fig. 2. Starting from the onion state (i), the ring reversibly enters a wave-like state (ii). The global vortex state (iii) is then irreversibly reached and forms a stable configuration that produces a plateau in the hysteresis. Via an irreversible transition into a single local vortex state (iv), the saturation configuration is reached again. The measured Hall resistance loop is well reproduced by the numerical simulation.

These results indicate that the transition field to the vortex state can be controlled by the inner diameter.

[1] J. Nitta, et al. Jpn. J. Appl. Phys. **41** (2002) 2479.
[2] M. Steiner and J. Nitta, Appl. Phys. Lett. **84** (2004) 939.

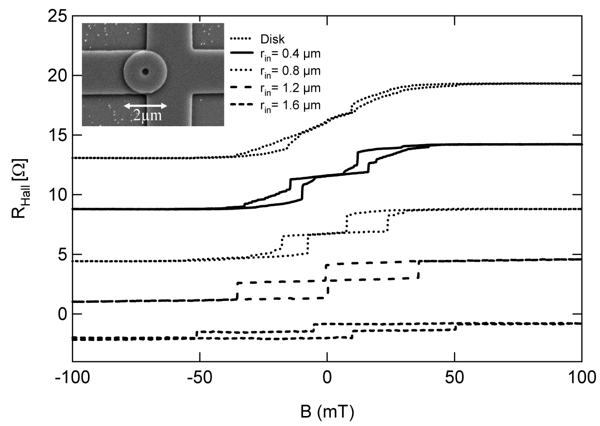


Fig. 1. Local Hall resistance measurements.

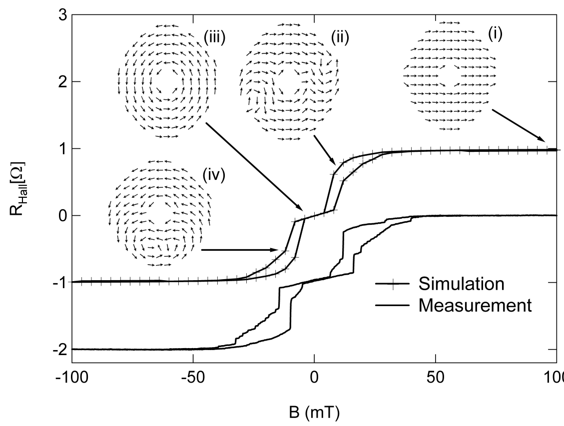


Fig. 2. Measured and simulated hysteresis loops.

Overview of Quantum Physics and Electronics Research

Yoshiro Hirayama
Physical Science Laboratory

Our research in the fields of quantum physics and electronics, which is based on semiconductor nano-structures fabricated by high-quality semiconductor crystal growth and advanced device fabrication techniques, focuses on quantum coherent control, carrier interactions and wide-bandgap semiconductor physics. Our aim is the development of innovative semiconductor devices. 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 semiconductor heterostructures (carrier interractions in bilayer systems, interactions between nuclear-spin and conduction electrons).
(2) Quantum electronic state control in quantum dot systems (spin/charge control, carrier dynamics of quantum nanostructures, 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) High-quality diamond epitaxial growth and its application to electronics devices.
(5) Developing new semiconductor materials such as InN.

Major results obtained this fiscal year 2003 are reported in the following pages.

We have successfully applied electrical pump and probe technique to control a single electron motion in a coupled quantum dot coherently. We have demonstrated one qubit operation, i.e. arbitrary rotation on the Bloch sphere, for the semiconductor charge qubit. This is the first step towards physical realization of electrically-controlled semiconductor quantum computer.

In a high magnetic field, electron interactions in the two-dimensional electron gases result in the fractional quantum Hall effects. In this regime, two different electron spin states energetically degenerate in a certain condition. We have found that a novel interaction between electron and nuclear spins occurs in such condition and this interaction is very sensitive to the electron spin state. We have also shown a possibility to control nuclear spin polarization in a mesoscopic scale.

By using high-quality diamond films grown by MOCVD, we have fabricated a diamond field-effect transistor (FET) in collaboration with Ulm University. The fabricated FET exhibited the highest cut-off frequencies among diamond FETs and showed the first amplification in the millimeter-wave range (30～300 GHz).

We have also successfully fabricated an npn-type GaN/InGaN heterojunction bipolar transistor (HBT) using the base regrowth technique. The fabricated HBTs show high current gains and super-high-power density of 230,000 W/cm^2.

Semiconductor Charge Qubit

Toshiaki Hayashi and Toshimasa Fujisawa
Physical Science Laboratory

The study of quantum computing has attracted great attention because it is more efficient at some specific calculations than classical computing. The elementary unit of quantum computing (qubit) has two quantum states which are taken as a set of basis states (|0> and |1>). Unlike a classical bit, any state of a qubit which represents quantum information can be described as a linear combination of the two basis states. Quantum information processing devices are required to perform universal unitary gate operations within the decoherence time of the qubits. Although much effort has been invested, the experimental realization of quantum computing is still challenging.

We have studied a charge qubit in a semiconductor double quantum dot (QD) because all parameters we need for unitary gate operations can be controlled electrically [1]. The double QD consists of two QDs coupled to each other via a tunnel barrier and electrons can flip back and forth between the two QDs. For simplicity, we consider that we have one electron in the double QD. The two states of the charge qubit are the states in which the electron occupies one of the two QDs.

We employed a lateral double QD fabricated from a GaAs / AlGaAs heterostructure, as shown in Fig. 1. A voltage pulse is applied to the drain electrode to modify the electronic state of the double QD abruptly. This non-adiabatic transition allows us to perform initialization, coherent manipulation, and read-out operations of the qubit state. We have also demonstrated rotation gate operation [1] and phase-shift gate operation [2] on the charge qubit at 20 mK.

Figure 2 shows the normalized current through the device, which can roughly be taken as the averaged number of electrons in the right QD at measurement operation. This shows an oscillating behavior as a function of pulse length, which corresponds to rotation gate operation. We also showed that it was possible to change the oscillation frequency, which is related to the coupling energy between the two QDs, by changing the gate voltages.

The present result is the first step towards physical realization of quantum computing.

[1] T. Hayashi et al., Phys. Rev. Lett. **91** (2003) 226804.
[2] T. Fujisawa et al., Physica E, in press.

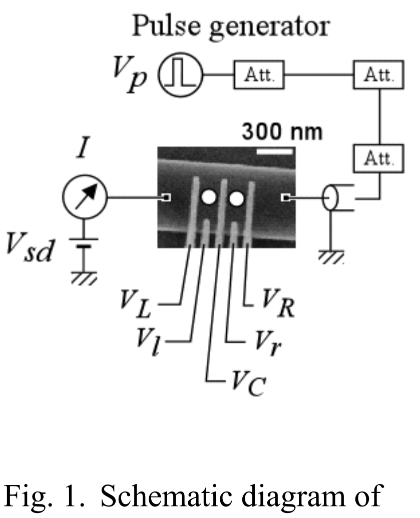


Fig. 1. Schematic diagram of double QD sample.

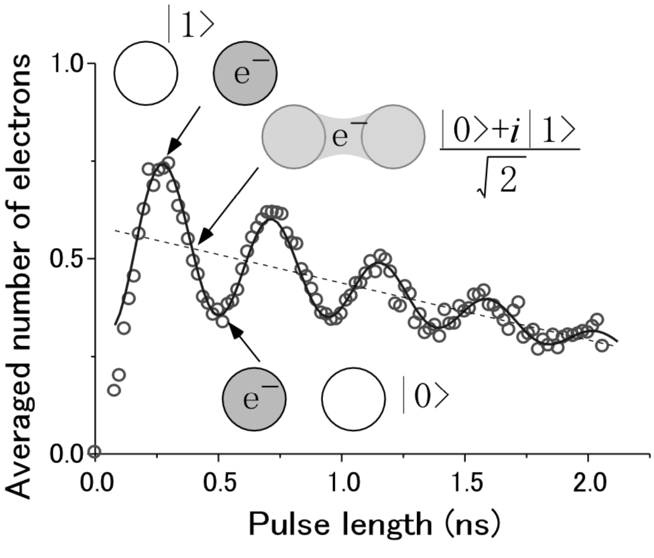


Fig. 2. Averaged number of electrons as a function of pulse length.

Microwave Performance of Diamond Field-Effect Transistor

Makoto Kasu
Physical Science Laboratory

At present the data transfer rate in communications is increasing very rapidly. Therefore, electronic devices that can operate at higher frequencies with higher output power are eagerly needed. Diamond has the highest thermal conductivity among materials and therefore offers the highest heat dissipation efficiency during high-power operation. Diamond exhibits a very high breakdown electric field, which means diamond devices can operate at extremely high voltage. These properties are important for high-output-power devices. In addition, the carriers in diamond have a high mobility and a high saturation drift velocity, which make high-frequency and high-speed operation possible. In fact, from device figures of merit calculated from the physical properties of high-frequency high-power devices diamond is the best among semiconductors and can therefore be called “ultimate semiconductor.” However, until now, the growth of high-quality diamond thin film had been impossible because of the formation of numerous crystalline defects and impurities during growth.

We have developed a CVD growth technology for high-quality diamond thin films with a low density of defects and impurities [1] and, using those thin films, have, in collaboration with the University of Ulm, Germany, fabricated diamond field-effect transistors (FET) [2], as shown in Fig. 1. In the FET, a quasi two-dimensional hole channel formed as a result of hydrogen surface termination, and we formed a 0.2 μm-long short gate contact using electron-beam lithography and self-aligned technology. As shown in the frequency dependence of power gains (Fig. 2), the FET exhibited the transition frequency (f_T) for $|h_{21}|^2$ of 25 GHz, and the maximum oscillation frequency (f_{MAX}) for the maximum available gain (MAG) and unilateral power gain (U) of 63 and 81 GHz, respectively. These values are the highest ever for diamond, and show the first amplification in the millimeter-wave range.

The power characteristics of the diamond FET for A-class operation at 1 GHz showed a linear power gain of 14 dB for a wide input power range, and the maximum output power (P_{MAX}) of 0.35 W/mm. The P_{MAX} is the highest ever for diamond, and will be increased by one order by optimizing the device structure. The microwave noise measurements of the FET showed that the minimum noise figure (F_{min}) was only 0.72 dB at 3 GHz. This F_{min} is better than that of Si MOSFET and comparable with those of p-GaAs HEMT and n-GaN HEMT with the same gate length. This means that a diamond FET is very promising for microwave receivers as well as transmitters.

[1] M. Kasu, M. Kubovic, et al., Diamond and Related Materials **13** (2004) 226.
[2] M. Kubovic, M. Kasu, et al., to be published in Diamond and Related Materials (2004).

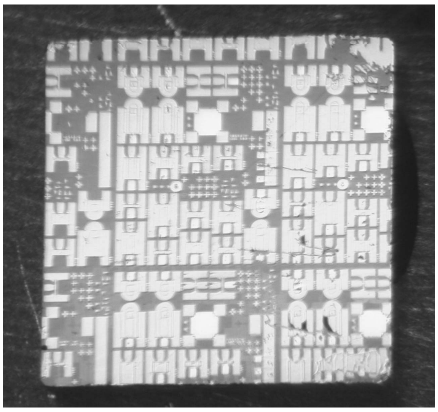


Fig. 1. Overview of diamond FETs.

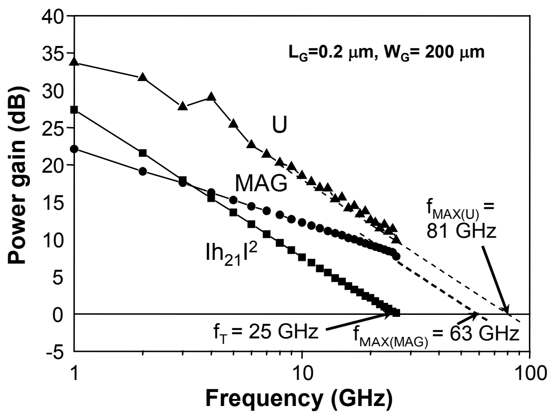


Fig. 2. Frequency dependence of power gains.

Nitride Heterojunction Bipolar Transistors for High-Power Applications

Toshiki Makimoto, Yoshiharu Yamauchi and Kazuhide Kumakura
Physical Science Laboratory

Compared with Si and GaAs, nitride semiconductors have high breakdown voltage because of their wide bandgap. On the other hand, one of the characteristics of a heterojunction bipolar transistor (HBT) is high current density. Therefore, a nitride HBT is a promising electronic device in terms of both materials and device types. However, there are two issues for the nitride HBT. One is a relatively low current gain and the other is a high offset voltage in the common-emitter current-voltage (I-V) characteristics. As a result, high-power characteristics of a nitride HBT have not been reported, though they are theoretically expected.

We have developed a GaN/InGaN HBT. Our GaN/InGaN HBT uses a low-resistivity p-InGaN layer as a base layer instead of the conventional p-GaN [1] and has a double heterostructure for a high breakdown voltage [2]. To improve current gain and reduce the offset voltage, we used a base regrowth technique. The current gain increased 100 fold and the offset voltage was reduced to 1/10 compared with the previous record [3]. This time, we have investigated the high-power characteristics of these GaN/InGaN HBTs.

The base-collector junction is reverse-biased and the HBT power increases with increasing reverse voltage. Figure 1 shows typical I-V characteristics of a base-collector diode. The leakage current is small even at the reverse bias voltage of –50 V because of the wide bandgap of the GaN collector. On the other hand, the output power depends on the collector current in the common-emitter I-V characteristics. Figure 2 shows the maximum collector current as a function of the emitter size. As shown in this figure, the maximum collector current is proportional to the emitter size. Since the breakdown voltage is independent of the emitter size, the output power is proportional to the emitter size. Up to now, we have obtained a maximum output power exceeding 10 W for a 90 μm x 50 μm emitter. The maximum power density is as high as 270,000 W/cm^2 [4]. This is the first demonstration of high-power characteristics in a nitride HBT.

[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., Appl. Phys. Lett. **83** (2003) 1035.
[4] T. Makimoto et al., Appl. Phys. Lett. **84** (2004) 1964.

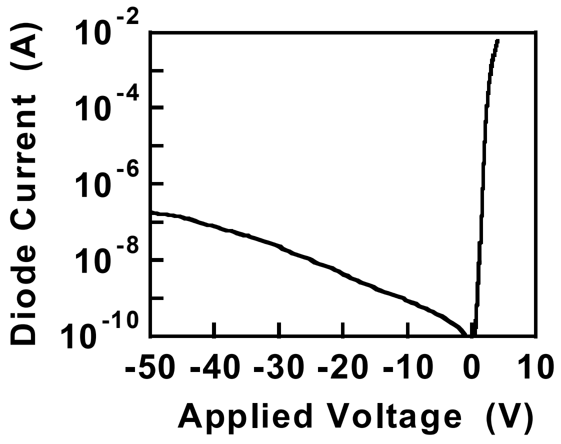


Fig. 1. Typical I-V characteristics of a base-collector diode.

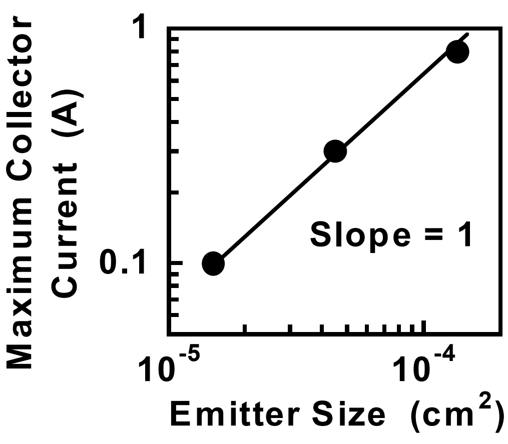


Fig. 2. Maximum collector current as a function of the emitter size.

Overview of Quantum Optics and Optical Materials Research

Yoshiro Hirayama
Physical Science Laboratory

In the fields of quantum optics and optical materials we pursue our studies for the development of core-technologies that will innovate optical communications and optical signal processing as well as for the scientific progress of the field. Optical State Control Research Group, Ultrafast Optical Physics Research Group, Optical Device Physics Research Group and Photonic Nanostructure Research Group are engaged in the subjects listed below.

Quantum State Control Research Group

(1) Experimental and theoretical studies for quantum cryptography/computing/protocols.
(2) Quantum transport theory and electron/spin entanglement.

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) Coherent control of excitonic and spin states in quantum dots & wires.
(2) Optical properties in nitride-semiconductors and their device applications.
(3) Single/entangled photon emitters and detectors.

Photonic Nanostructure Research Group

(1) Two-dimensional photonic crystal optical circuits (ultra-low loss waveguide, resonator, filter)
(2) Interaction between photonic nanostructures and materials (negative refraction, extremely-large group velocity dispersion, photonic quasicrystal laser).
(3) Nanoprint lithography

Major results obtained this fiscal year 2003 are reported in the following pages.

We have demonstrated a long-distance quantum key distribution by using a single photon emitter based on quantum dots. We have also proposed and demonstrated a novel quantum cryptography scheme called differential-phase-shift quantum key distribution. This scheme will provide stable and high-speed quantum cryptography.

Efficiency of water-widow x-ray pulse conversion from femtosecond laser plasma was successfully improved by using a carbon nanotube target. The result indicates that carbon nanotubes are attractive as fs-laser plasma target for realizing single-shot x-ray microscopy. Sampling measurement of femtosecond soft x-ray pulse, which is based on optical-field induced ionization dynamics, has been demonstrated.

We combined GaN quantum wells with oxide-based distributed Bragg reflectors by using a wafer bonding technique. The VCSEL (vertical cavity surface emitting laser) operation was successfully demonstrated for the fabricated structures. We also started a new project for single and entangled photon emitters and detectors in collaboration with TAO (Telecommunications Advanced Organization of Japan).

We have demonstrated ultra-low-loss photonic bandgap waveguide and developed ultra-small and high-Q filter based on SOI (silicon on insulator) photonic crystal systems. We have also fabricated photonic quasicrysytal lasers with organic dye and confirmed clear lasing action for the first time. Our experimental results indicate that lasing occurs by delocalized coherent modes inside the quasicrystal.

Differential-Phase-Shift Quantum Key Distribution

Kyo Inoue
Physical Science Laboratory

Quantum cryptography, which provides an unconditionally secured secret key based on quantum mechanics, is extensively studied. Although several schemes have been proposed, each has problems with respect to suitability for fiber transmission, or operation stability, or data rate. This study proposes and demonstrates a novel quantum cryptography scheme, called differential-phase-shift quantum key distribution, which can realize a stable high-speed system.

Fig. 1 shows the configuration of the proposed system. The transmitter (called Alice) randomly phase-modulates a coherent pulse train and sends out it with a power level of 0.1 photon/pulse. The receiver (called Bob) detects the pulses after a one-bit delayed interferometer. In the detection, DET1 clicks for 0 phase difference between two sequential pulses, and DET2 clicks for π phase difference. Here, the click occurs once in ten time-slots (Detection time is probabilistic) since the transmitted power is 0.1 photon/pulse. After the transmission, Bob discloses detection instances to Alice, who can identify, from her modulation data, which detector clicked at corresponding instances. Provided that the DET1 click represents "0" and the DET2 click "1", Alice and Bob share an identical bit string, which can be a secret key because the bit information itself has not been leaked to the outside. The system consists of a simple phase modulation scheme and a passive interferometer, and thus can realize stable operation at a high data rate.

We carried out an experiment to demonstrate the above scheme. A 0.8-μm LD light was phase-modulated, attenuated, and then was photon-detected after an open-space interferometer. The result is shown in Fig. 2. Proper correlation between Alice and Bob was obtained, which confirmed the operation.

[1] K. Inoue, E. Waks, and Y. Yamamoto, Phys. Rev. Lett. **89** (2002) 037902.
[2] K. Inoue, E. Waks, and Y. Yamamoto, Phys. Rev. A **68** (2003) 022317.

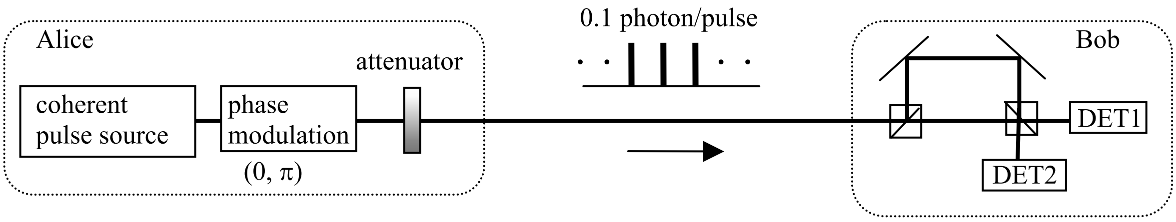
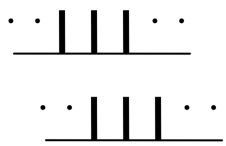


Fig. 1. Configuration.



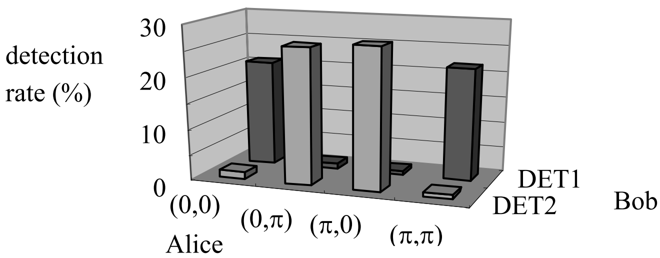


Fig. 2. Experimental result.

GaN-Based Vertical Cavity Surface Emitting Lasers

Takehiko Tawara, Hideki Gotoh, Tetsuya Akasaka, Naoki Kobayashi, and Tadashi Saitoh
Physical Science Laboratory

Optical devices based on III-nitride quantum wells (QWs) have been actively studied. However, the refractive index contrasts between III-nitride and air are relatively small compared with those in GaAs-based semiconductors and the reflectivity is about 18%. This leads to an increase in the driving current needed for optical devices [1]. With lasers, one way to reduce the lasing threshold is to use the vertical cavity surface emitting laser (VCSEL) structure. If the cavity size is of the order of the emission wavelength, the spontaneous emission rate can be controlled and the lasing threshold can be reduced.

VCSEL structures usually consist of a cavity with active layers and distributed Bragg reflectors (DBRs), which are formed by monolithic growth with the same kind of semiconductor. When a high reflectivity DBR is constituted from GaN-based semiconductors, however, the large lattice mismatch between each layer of the DBR generates surface roughening and cracking of the cavity layer.

We prepared a GaN-based cavity layer including InGaN QWs on a SiC substrate and oxide-based DBRs separately. The VCSEL structure was formed by using a wafer bonding technique after removing the SiC substrate by selective dry etching. We realized high quality VCSEL structures without cracking or surface roughening (Fig. 1). The spectral linewidth of the cavity mode at the InGaN emission wavelength of 400 nm was less than 1 nm, and this indicates that we realized a microcavity with low optical loss. Moreover, we measured the luminescence intensity from the fabricated VCSELs for different optical excitation powers at room temperature (Fig. 2). A clear nonlinear characteristic was observed, and this shows that the VCSEL is lasing. Furthermore, the spontaneous emission factor (the coupling efficiency of the spontaneous emissions to the lasing mode) was about 0.01, and this is 1000 times more efficient than in a typical edge-emitting laser [2].

In such a structure, there is an advantage in that the reflectivity and the stopband width of the DBR can be chosen freely while maintaining the crystal quality of the cavity layers. Moreover, the realization of strong exciton-photon coupling at room temperature will be possible by using such high quality microcavities, because the exciton oscillator strength and binding energy of III-nitride semiconductors are large compared with GaAs-based semiconductors.

[1] H. Wang, et al., Appl. Phys. Lett. **81** (2002) 4703.
[2] T. Tawara, et al., Appl. Phys. Lett. **83** (2003) 830.

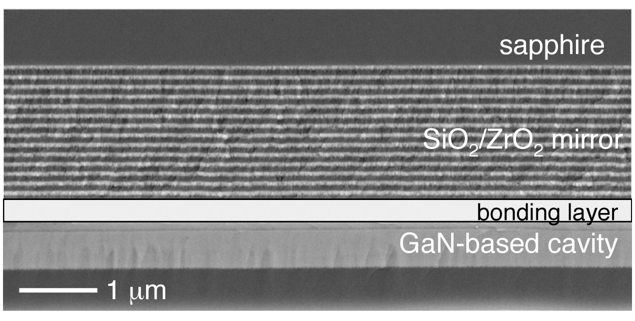


Fig. 1. Cross-sectional image of the VCSEL.

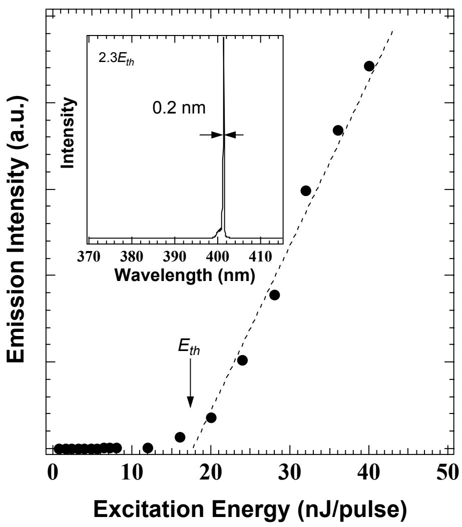


Fig. 2. Lasing characteristics.

Penrose-lattice Photonic Quasicrystal Laser

Masaya Notomi[1], Hiroyuki Suzuki[2], Toshiaki Tamamura[3], and Keiichi Edagawa[4]
Physical Science Laboratory[1], NTT Photonics Labs. [2], NTT Electronics[3], Univ. of Tokyo[4]

Crystals have periodicity and translational symmetry. But there exist a certain class of structures called q*uasicrystals* that do not posses periodicity nor translational symmetry, but have long-range order and rotational symmetry. Quasicrystals have bandgap and density of states in a similar way to crystals, but some important concepts such as band structures, Bloch theorem, Brillouin zone cannot be defined. Concerning crystals, it has been known that lasing action is possible in photonic crystals having optical gain because of some standing wave formation at the photonic band edges. Then, what happens if we introduce gain into photonic quasicrystals that do not have periodicity? Is coherent lasing possible?

From these backgrounds, we have fabricated photonic quasicrystal lasers with organic dye for the first time. [1] Our quasicrystals have so-called Penrose lattice (shown in Fig. 1(left)) exhibiting 10-fold rotational symmetry which is inhibited in periodic crystals. By optical pumping, we observed clear lasing action, and peculiar 10-fold rotationally symmetric spot patterns shown in Fig. 1(right). Both of lasing wavelengths and spot patterns sensitively depend on the quasilattice constant, indicating that lasing is due to the quasiperiodicity. Sharp spot patterns also indicate that lasing occurs by delocalized coherent modes inside the quasicrystal.

Since we cannot use conventional band theory for quasicrystal, we instead used their reciprocal lattice to analyze the lasing action, and successfully explained the observed lasing wavelengths and spot patterns quantitatively. The reciprocal lattice of quasicrystals are very unique comparing to crystals one. The reciprocal lattice of crystals have a Brillouin zone and any points outside it are equivalent to some points inside it. In the case for quasicrystals, all of them are basically non-equivalent, and thus a wide variety of lasing modes can exist. This uniqueness of the reciprocal lattice is most distinguishable feature of quasicrystal lasers. In fact, lasing action in periodic photonic crystals is restricted from the limitation of periodicity, but quasicrystal lasers are free from those restrictions.

[1] M. Notomi, H. Suzuki, T. Tamamura, K. Edagawa, Phys. Rev. Lett. **92** (2004) 123906.

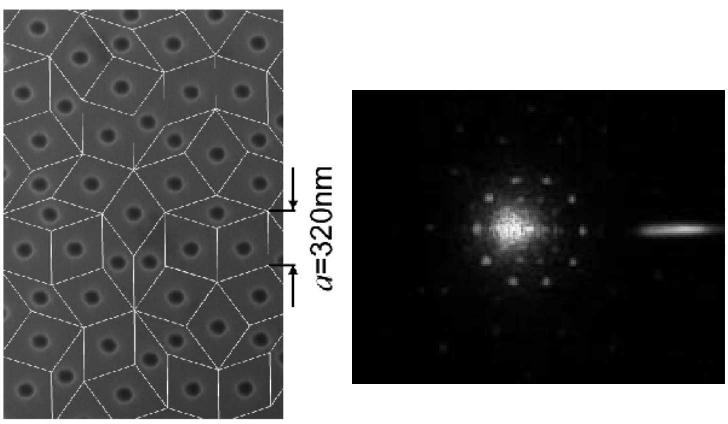


Fig. 1. Electron microscope image of the Penrose-lattice photonic quasicrystals (left). The observed 10-fold rotationally symmetric spot pattern for photonic quasicrystal lasers (right).

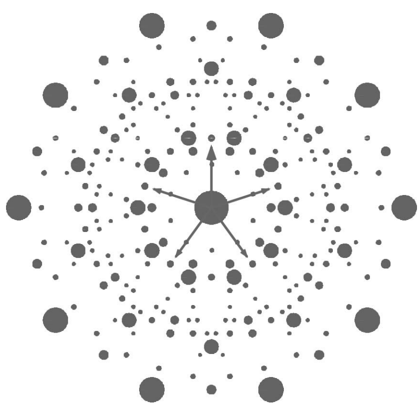


Fig. 2. Reciprocal lattice of the fabricated Penrose-lattice photonic quasicrystals (calculation).

Ⅱ. Data

International Symposium on Mesoscopic Superconductivity and Spintronics --- In the light of Quantum Computation ---

The symposium MS+S2004 was held during March 1-4, 2004, at NTT Atsugi R&D Center in collaboration with Core Research for Evolutional Science and Technology - Japan Science and Technology Agency (CREST-JST), Research and Development Association for Future Electron Devices (FED), NTT Basic Research Laboratories, and NTT Communication Science Research Laboratories.

Recently, mesoscopic superconductivity and spintronics have attracted much interest because of their potential ability to produce novel and revolutionary devices, such as scalable solid-state quantum computer. In this symposium, setting a key-word as “quantum computation”, we NTT Basic Research Laboratories together with NTT Communication Science Research Laboratories have invited the leading scientists in these fields and have promoted active discussions including up-to-date topics. This biannual symposium was first held in the year of 2000, and this is the third symposium.

On the 1st day, after the opening and welcome address by Dr. Hideaki Takayanagi, R&D Fellow and the Director of NTT Basic research Laboratories, Dr. John. Martinis (NIST Fellow) gave a plenary lecture with the title “Coherence in Josephson Phase Qubits”. Including a lecture about superconducting flux qubit by prof. J. E. Mooij (Delft Univ.), there were 11 oral presentations concerning qubit. After a short laboratory tour to SOR facility and qubit facilities, the 45 posters were presented in the evening session.

On the 2nd day, the 5 oral presentations discussed on quantum information theory and quantum algorithm including an exciting lecture by prof. Seth Lloyd (MIT). There were 5 oral presentations discussed on spintronics The first demonstration of gate control of electron spin was shown by NTT. The tunable magnetism in quantum dot device was also proposed by NTT. In the evening session, the 40 posters were presented.

On the 3rd day, in the morning session, there were 6 oral presentations on spintronics. In the afternoon, the excursion to Lake Ashi in Hakone was carried out and the banquet party was held in Gotenba.

On the 4th day, Chalmers Univ., NTT-BRL, Kansas Univ., D-Wave Systems, CNRS Grenoble, RIKEN-NEC, CEA-Saclay group presented quantum oscillations and coherent control of superconducting qubit. There were 14 oral presentations.

The total number of participants was 203 (133 from outside of NTT). During the conference, participants were strongly impressed by high-quality presentations and stimulating discussions.

International Symposium on Functional Semiconductor Nanosystems (FSNS2003)

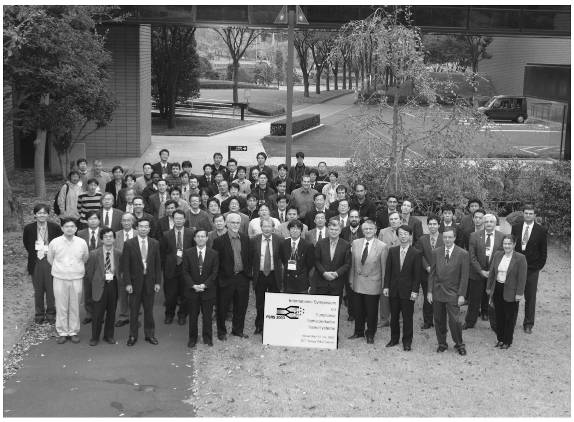
The International Symposium on Functional Semiconductor Nanosystems (FSNS2003) was held from 12 (Wed.) through 14 (Fri.) of November, 2003, at the NTT Atsugi R&D Center in collaboration with New Energy and Industrial Technology Development Organization (NEDO) and Japan Science and Technology Corporation (JST).

Ultra-small “nano-scale” materials with semiconducting properties have been attracting a lot of attention for many years. Recently, the field has been largely advanced by coupling, interconnecting and integrating novel structures such as nanotubes, nanowires, and molecules, and by introducing new properties such as mechanics, elasticity and magnetism. These novel “nanosystems” are expected to lead to new functionality that cannot be provided by conventional structures in semiconductor science and technology.

The purpose of FSNS2003 was to provide an international forum dedicated to the latest progress related to these novel kinds of nanostructures. The symposium covered all aspects of fabrication and characterization of semiconductor nanosystems - including growth and processing, and optical, electrical, elastic, structural, and mechanical properties - and their applications and dealt with all kinds of semiconductors, carbon nanotubes, and organic materials. Papers were solicited on a wide variety of topics.

The opening and welcoming remarks were given by Dr. Hideki Takayanagi, Director of NTT Basic Research Laboratories. On the second day, in his plenary talk, Prof. von Klitsing, Max-Planck Institute, reviewed about the distinctive features of the quantum transport that occurs in two-dimensional systems of high mobility electrons under microwave radiation. There were 27 oral presentations, including 17 invited talks, and 43 poster presentations. Totally, there were 71 presentations, which were categorized into three areas: transport and mechanical properties in nanostructures, advancement in the research of the carbon nanotube, and self-organization of nanostrucutres and their characterization.

The participants were totally 164 people. All participants thoroughly enjoyed the high-quality presentations and discussions. They especially enjoyed the opportunity to talk with researchers from different areas, which certainly led to many valuable suggestions and insights. By organizing these interdisciplinary areas under the banner “semiconductor nanosystems” and hosting conference like FSNS, we hope to advance the discussion of nano-science and thereby accelerate the development of nanotechnology.



Science Plaza 2003

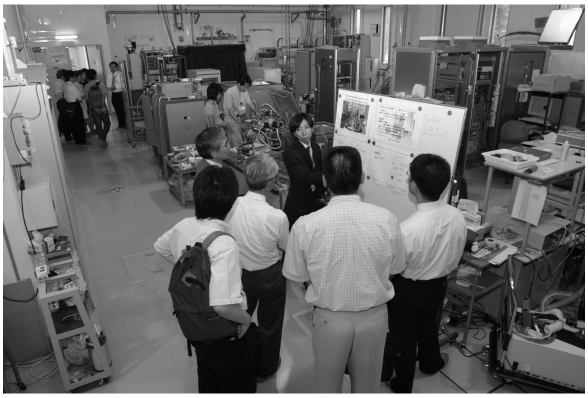
Science Plaza 2003, the annual open house event of NTT Basic Research Laboratories, was held on August 22, 2003 at the NTT Atsugi R&D Center. The purpose of Science Plaza 2003 was to introduce the latest research results both inside and outside of NTT Basic Research Laboratories and obtain feedback and opinions through discussions.

After opening remarks by Dr. Hideaki Takayanagi, Director of NTT Basic Research Laboratories, the symposium session began. The symposium featured three talks, “Silicon Single Electron Devices and Their Application”, “Nanobioscience – Fusion of a Nerve Function and Nanotechnology” and “New Materials Changing Optical Technology – Photonic Crystal”, which were selected from the fields of device physics, materials science, and physical science, respectively. In the afternoon session, Prof. Reiko Kuroda, Professor of the Graduate School of Arts and Science at the University of Tokyo, gave a special lecture entitled “Chiromorphology”, in which she spoke about molecule morphology and the recognition and invention of chirality.

The Poster Session, featured thirty-one of the latest research developments and provided forum for lively debate among the participants. In addition, major research findings were presented as a movie in the Video Theatre. We also conducted Lab tours. The tours gave participants an opportunity to see the equipment used in NTT Basic Research Laboratories, where are normally not open to the public. After the program was completed, a social gathering was held in the evening in the dining room, where participants could continue their productive discussion.

Approximately 300 people from the research departments of universities, business organizations, and NTT groups attended Science Plaza 2003, which was an increase from last year’s event. The symposium was a huge success, and we sincerely thank all those who participated.

Symposium session



Laboratory tour

Award Winner's List (Fiscal 2003)

Award on Superconductivity Science and Technology, Forum of Superconductivity Science and Technology	H. Takayanagi	"Suggestion and demonstration of a concept for devices with control of superconductivity coherence"	June 24, 2003
Japanese Journal of Applied Physics Paper Award	A. Fujiwara Y. Takahashi	"Mechanism of Single-Charge Detection using Electron-Hole System in Si-wire Transistors"	Aug. 30, 2003
The 5th Sir Martin Wood prize	T. Fujisawa	"Study of single-electron dynamics in quantum dot"	Nov. 26, 2003

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

NTT R&D Award	K. Inoue	"Quantum Cryptography using Single Photon Sources"	Feb. 12, 2003
NTT R&D Award	M. Kasu	"Diamond Semiconductors"	Feb. 12, 2003
Award for Achievements by Director of Basic Research Laboratories	H. Inokawa	"Pioneering Study for Single-electron Multiple-valued Logic Devices"	Mar. 22, 2004
Award for Achievements by Director of Basic Research Laboratories	T. Koga Y. Sekine J. Nitta	"Spin Control in Semiconductors with Gate Electrodes"	Mar. 22, 2004
Award for Achievements by Director of Basic Research Laboratories	M. Kasu	"Study for High-frequency Diamond FETs"	Mar. 22, 2004
Award for Distinguished Services by Director of Basic Research Laboratories	K. Igeta Y. Harada	Renewal of He Liquefaction System	Mar. 22, 2004
Award for Excellent Papers by Director of Basic Research Laboratories	T. Hayashi	"Coherent Manipulation of Electronic States in a Double Quantum Dot" Phys. Rev. Lett. Vol. 91, 226804 (2003)	Mar. 22, 2004
Award for Excellent Papers by Director of Basic Research Laboratories	T. Makimoto	"High current gain (> 2000) of GaN/InGaN double heterojunction bipolar transistor using base regrowth of p-InGaN" Appl. Phys. Lett. Vol. 83, 1035 (2003)	Mar. 22, 2004

List of Visitor's Talks (Fiscal 2003)

I. Device Physics

Date		Speaker	Affiliation "Topic"
May	5	Prof. F. Rosei	Universite du Quebec, Canada "Organic Molecules on a Metal Surface: Fundamentals and Applications"
May	29	Prof. S. Masuda	University of Tokyo "Local electronic states at a solid surface and chemical reactions studied by metastable atom electron spectroscopy"
June	16	Prof. M. Watanabe	Tokyo Institute of Technology "Present status and future prospects of surface studies by LEEM and PEEM"
July	15	Dr. V. Tonchev	Bulgarian Academy of Science, Bulgaria "Models of Step Bunching: "Classical" and New Results"
Sept.	9	Prof. S. Stoyanov	Institute of Physical Chemistry, Bulgaria "Electromigration induced bunching of steps - a key to understanding the processes at the Si crystal surface"
Sept.	19	Dr. V. Tonchev	Bulgarian Academy of Science, Bulgaria "Step Bunching on Vicinal Crystal Surfaces: From Models to Experiments and Back"

II. Materials Science

Date		Speaker	Affiliation "Topic"
April	9	Prof. T. Martin	Universite de la Mediterranee, France "Bell inequalities and entanglement in normal-superconductor junctions and in carbon nanotubes" "Electron spin teleportation with a quantum dot array"

July	3	Dr. M. Thorwart	Delft University of Technology, Netherlands “Decoherence in superconducting flux qubits coupled to a SQUID detector”
July	22	Prof. J. Kono	Rice University, USA “Ultrafast Optical Control of Band Structure and Ferromagnetism in Semiconductors”
July	23	Dr. M. Thorwart	Delft University of Technology, Netherlands “Multi-photon transitions in superconducting flux qubits”
July	25	Dr. M. C. Geisler	Max-Planck-Institute for Physics, Germany “Experimental Evidence for a Landau Level Coupling Induced Rearrangement of the Hofstadter Butterfly”
July	30	Prof. E. Mendez	State University of New York at Sony Brook, USA “An Overview of Recent Research in Stony Brook's Qunatum Structure Group”
Nov.	18	Prof. J. E. Mooij	Delft University of Technology, Netherlands “Measurements on Flux Qubits”
Dec.	22	Prof. S.-IK Lee	Pohang University of Science and Technology, Korea “Is electron doped infinite layer superconductivity similar to hole doped cuprate superconductivity?”
Feb.	25	Prof. G. Falci	Universit a di Catania, Italy “Interaction of Josephson qubits with strong QED cavity modes:dynamical entanglement transfer and navigation”
Feb.	26	Prof. W. Peiheng	Nanjing University, China “Intrinsic Josephson Junctions in High Temperature Superconductors and their Possible Electronic Applications”
Mar.	8	Prof. A.D. Zaikin	Forschungszentrum Karlsruhe, Germany “Transport of interacting electrons in metallic quantum dots and diffusive wires”
Mar.	10	Dr. F. Pistolesi	LPMMC-CNRS Grenoble, France “Energy dependence of current noise in superconducting/normal metal structures”
Mar.	15	Prof. D. B. Haviland	The Royal Institute of Technology, Sweden “Quantum Josephson Junctions at KTH”
Mar.	15	Prof. F. W. J. Hekking	LPMMC-CNRS Grenoble, France “Coherent oscillations in a current-biased dc-SQUID”

III. Quantum Electron Physics

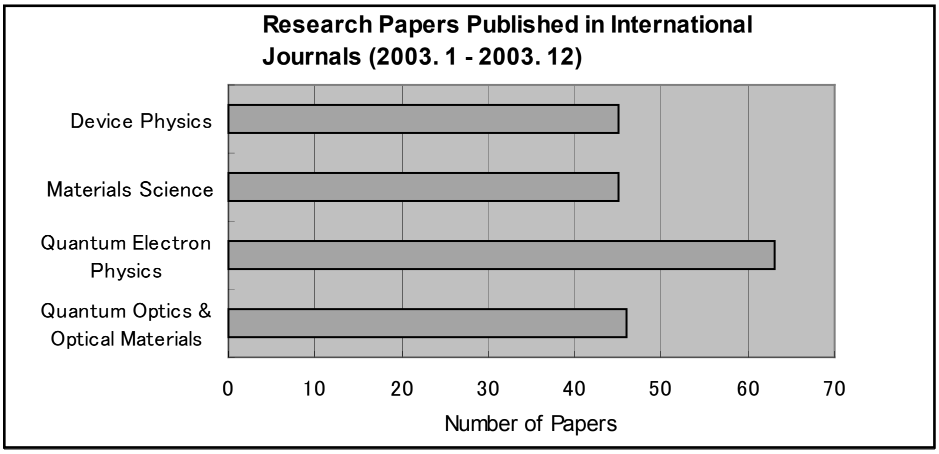
Date		Speaker	Affiliation "Topic"
June	4	Prof. V. P.-Solorzano	University of Stuttgart, Germany “Comparison of the material properties of GaInN structures grown with ammonia and DMHy as nitrogen precursors”
June	4	Prof. F. Habel	University of Ulm, Germany “Determination of dislocation density in epitaxially grown GaN using an HCl etching process”
July	23	Mr. Y. Kato	University of California, Santa Barbara, USA “Gigahertz electron spin manipulation using G-tensor modulation resonance”
July	24	Dr. T. D. Mishima	University of Oklahoma, USA “TEM Study of InSb Reconstructed Surfaces/Quantum Wells and InGaAs Quantum Dots & SDR Study of Si/SiO2 Interface Defects”
Nov.	18	Prof. P. Lindelof	University of Copenhagen, Denmark “Electronic Transport through Carbon Nanotubes”
Nov.	26	Prof. C. Manfredotti	University of Torino, Italy “Blue light sensitization of CVD diamond detectors”
Nov.	27	Prof. R. Nicholas	University of Oxford, UK “Quantum box superlattice transport in InAs/GaSb superlattices” “Optical properties of carbon nanotubes”
Mar.	9	Prof. E. Munoz	University Politecnica de Madrid, Spain “Photodetectors and HEMT devices based on nitrides”
Mar.	25	Dr. D. J. Reilly	University of New South Wales, Australia “The 0.7 Conductance Feature above the Kondo Temperature” “Phosphorus in Silicon Quantum Computation”
Mar.	25	Dr. A. Denisenko Dr. E. Kohn	University of Ulm, Germany “Theoretical study of a projected RF-performance of sub-μm lateral field emitting structures based on carbon nanotubes”

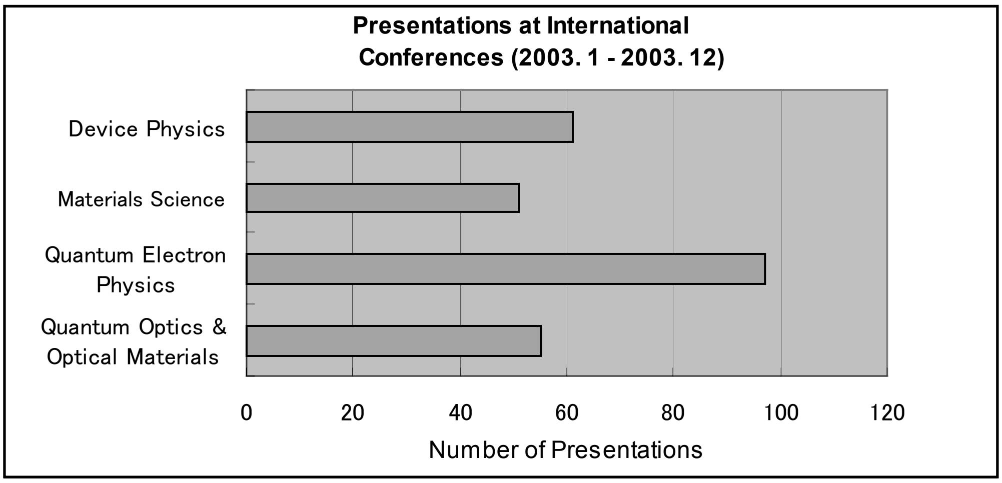
IV. Quantum Optics & Optical Materials

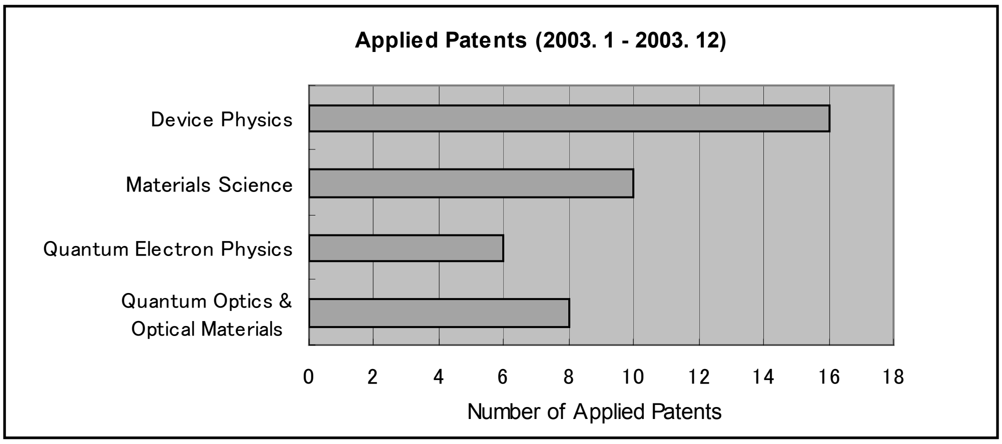
Date		Speaker	Affiliation "Topic"
April	25	Dr. M. Ono	University of Tokyo “Gigantic optical nonlinearity in one-dimensional strongly-correlated electron systems”
July	10	Dr. T. Yamashita	Georgia Institue of Technology, USA “Active and Emissive Photonic Crystal Nano-Architectures”
July	14	Prof. K. Yamauchi	University of Tokyo “Control of Molecules in Intense Laser Fields”
Aug.	19	Prof. J. H. Wolter	Eindohoven University of Technology, Netherlands “Photonic Integration: Challemges for Material Research”
Oct.	21	Prof. J. Limpouch	Czech Technical University in Prague, Czech Republic “Simulations of femtosecond K-alpha emission from short-pulse laser-target interactions”
Nov.	14	Prof. M. Mitsunaga	Kumamoto University “Quantum Interference Effects: Principles and Applications”
Dec.	12	Prof. J. Zi	Fudan University, China “Liquid surface waves and negative refraction”
Jan.	19	Prof. R. Morandotti	Universite du Quebec, Canada “Optical discrete solitons”
Mar.	16	Prof. M. Kristensen	Technical University of Denmark, Denmark “Planar PBG Pipes at COM”

Research Activities of Basic Research Laboratories in 2003

The numbers of research papers, presentations at the international conferences and applied patents amounted to 190, 264, and 40 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	(IF2002)*	Numbers
Nature	(30.432)	2

Specialized Journals

Name	(IF2002)*	Numbers
Japanese Journal of Applied Physics	(1.280)	20
Applied Physics Letters	(4.207)	14
Physical Review B	(3.327)	14
Journal of Applied Physics	(2.281)	8
Physica E	(1.107)	8
Physical Review A	(2.986)	7
Physical Review Letters	(7.323)	5
Surface Science	(2.140)	4
Macromolecules	(3.751)	2
Review of Modern Physics	(23.672)	1
Account of Chemical Research	(15.901)	1
Advanced Materials	(6.801)	1
Nano Letters	(5.033)	1

*IF2002: Impact factor 2002（Journal Citation Reports, 2002）

The average impact factor for individual research papers from all NTT Basic Research Laboratories is 2.87.

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

Conferences	Numbers
International Symposium on Functional Semiconductor Nanosystems (FSNS 2003)	22
Carrier Interactions and Spintronics in Nanostructures (CISN 2003)	15
7th International Conference on Atomically Controlled Surface and Inerfaces and Nanostructures (ACSIN-7)	13
5th International Conference on Nitride Semiconductors (ICNS-5)	11
The 15th International Conference on Electronic Properties of Two-Dimensional System (EP2DS-15)	9
2003 Material Research Society Meeting	8
The 2003 International Conference on Solid State Devices and Materials	6
The 16th International Symposium on Superconductivity (ISS)	5
Conference on Laser and Electro-Optics/Quantum Electronics and Laser Science Conference	4
The 5th Laser Cooling Workshop	4

List of Invited Talks at International Conferences (2003)

I. Device Physics

(1) Y. Takahashi, Y. Ono, S. Fujiwara, and H. Inokawa, "Development of silicon single-electron devices", The 4th International Symposium on Nanostructures and Mesoscopic Systems (NanoMES2003), Tempe, USA (Feb. 2003).

(2) Y. Homma, "In situ observations using ultrahigh vacuum scanning electron microscopy", Microscopy and Microanalysis, San Antonio, USA (Aug. 2003).

(3) Y. Homma, "Self-assembled nanotube networks for nano-device applications", 4th International Symposium on Atomic Level Characterizations for New Materials and Devices (ALC'03), Hawaii, USA (Oct 2003).

(4) S. Suzuki, Y. Watanabe, Y. Homma, T. Ogino, S. Heun, L. Gregoratti, A. Brinov, B. Kaulich, and M. Kiakinova, "Photoemission spectromicroscopy and spectroscopy of carbon nanotubes", AVS international Symposium, Baltimore, USA (Nov 2003).

(5) Y. Takahashi, S. Fujiwara, and S. Horiguchi, "Silicon nano-wire and quantized conductance", International workshop on smart interconnects, Atami, Japan (Nov. 2003).

(6) H. Hibino, Y. Homma, C.-W. Hu, M. Uwaha, T. Ogino, and I. S. T. Tsong, "Structural and morphological changes on surface with multiple phases studied by low-energy electron microscopy", 7th International Conference on Atomically Controlled Surfaces, Interfaces and Nanostructures (ACSIN-7), Nara, Japan (Nov. 2003).

(7) Y. Takahashi, Y. Ono, S. Fujiwara, K. Nishiguchi, and H. Inokawa, "Silicon single-electron devices operating with MOSFETs", Sixth International Conference on New Phenomena, Maui, USA. (Dec. 2003).

(8) Y. Watanabe, S. Suzuki, Y. Homma, and T. Ogino, "Spectromicroscopy of carbon nanotubes", 2nd Int. Conf. on Materials for Advanced Technology, Singapore (Dec. 2003).

(9) Y. Takahashi, Y. Ono, S. Fujiwara, K. Nishiguchi, and H. Inokawa, "Silicon nano-devices and single-electron devices", 2003 International Semiconductor Device Research Symposium (ISDRS2003), Washington D.C., USA (Dec. 2003).

(10) Y. Homma, "Suspended carbon nanotube architectures: growth control and optical properties", 12th International Conference on Advanced Materials and Devices 2003, Jeju island, Korea (Dec. 2003).

(11) Y. Watanabe, B. Satyaban, T. Kawamura, S. Fujikawa, and N. Yamamoto, "Growth and Characterization of Vertically Aligned InP Nanowires on Semiconductor Substrates", 12th Int. Workshop the Physics of Semicond. Dev., Chennai, India (Dec. 2003).

(12) Y. Watanabe, “InP nanowire growth on semiconducting materials by metal organic vapor phase epitaxy”, Int. Conference on Nano Science and Technology, Kalkata, India (Dec. 2003).

II. Materials Science

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

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

(3) J. Nitta, “Rashba spin-orbit interaction and spin-interference in nano-structures”, International Workshop “Coherence in Nanosystems” Spin-related transport in semiconductors, Soul, Korea (Feb. 2003).

(4) Y. Jimbo,“ Plasticity in cultured neuronal network”, Int. Workshop on “Biology and Physics at Interfaces”, Julich, Germany (May 2003).

(5) K.Torimitsu, “Nanobioscience-molecular device and neural functions”, Workshop on nanotechnology and postgenomics, New Castle, UK (Jun. 2003).

(6) K. Torimitsu, “On Bio and Nano Technology”, International Conference on Composites Engineering, ICCE/10, New Orleans, USA (Jul. 2003).

(7) A. Matsuda, “Inhomogeneity in the electronic state of Bi-2212 - from the insulating to superconducting state -”, Self Organized Strongly Correlated Electron Systems, Santorini, Greece (Aug. 2003).

(8) K. Ajito, “Nanometer-scale Raman Spectroscopy of Neurons”, Microscopy and Microanalysis 2003, Quebec Convention Center, San Antonio, USA (Aug. 2003).

(9) K. Semba, “Single Shot Readout of the Flux-Qubit”, Hot Topics in Quantum Statistical Physics: q-Thermodynamics, q-Decoherence and q-Motors, Leiden University, Holland (Aug. 2003).

(10) J. Nitta and T. Koga, “Gate Control of Electron Spin in Semiconductor Nanostructure”, Photonics and Spintronics in Semiconductor Nanostructures toward Quantum Information Processing, Kyoto, Japan (Nov. 2003).

(11) H. Takayanagi, “ Single-shot measurement of the qu-bit state with a dc-SQUID”, The 9th Japan-US Joint seminar Quantum Correlations and Coherence, Yatsugatake, Japan (Sep. 2003).

(12) M. Naito, “Search for new high-Tc superconductors by molecular beam epitaxy”, The 8th IUMRS International Conference on Advanced Material (IUMRS-ICAM2003), Yokohama, Japan (Oct. 2003).

(13) M. Naito, "Large-area RE-123 thin films for microwave applications", The 16th International Symposium on Superconductivity (ISS2003), Tsukuba, Japan (Oct. 2003).

(14) K. Totimitsu, "Neural Functions and Nano-Bio Device", Sweden-Japan Workshop on Bionanotechnology, Kyoto, Japan (Nov. 2003).

(15) M. Naito, "MgB_2 thin films", Program committee of The European Network For Superconductivity, Spain (Nov. 2003).

III. Quantum Electron Physics

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

(2) K. Kanisawa, Y. Tokura, H. Yamaguchi, and Y. Hirayama, "Scanning tunneling spectroscopy study of zero-dimensional structures at the InAs surface", 30th Conf. on Phys. and Chem. of Semicond. Interfaces (PCSI-30), Salt Lake City, USA (Jan. 2003).

(3) H. Yamaguchi, S. Miyashita, and Y. Hirayama "Fabrication and Characterization of InAs-based Electromechanical Systems", 2003 RCIQE International Seminar on Quantum Nanoelectronics for Meme-Media-Based Information Technologies, Sapporo, Japan (Feb. 2003).

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

(5) T. Makimoto, K. Kumakura, and N. Kobayashi, "npn-Type Nitride Heterojunction Bipolar Transistors", 2003 Asia-Pacific Workshop on Fundamental and Application of Advanced Semiconductor Devices (AWAD2003), Busan, Korea (Jun. 2003).

(6) M. Kasu and N. Kobayashi, "Influence of epitaxy on the surface conduction of diamond film", 2003 European Materials Research Society Spring Meeting (E-MRS2003), Strasbourg, France (Jun. 2003).

(7) Y. Hirayama, "Quantum Hall Effects at Landau Level Crossings", Int. Symp. on Quantum Hall Effects: Past, Present, and Future, Stuttgart, Germany (Jul. 2003).

(8) T. Fujisawa, "Single electron dynamics in quantum dots", The 11th International Conference on Modulated Semiconductor Structures (MSS11), Nara, Japan (Jul. 2003).

(9) T. Nishida, T. Ban, and N. Kobayashi, "Nitride UV emitters", 30th Int. Symp. Compound Semicond. (ISCS2003), San Diego, USA (Aug. 2003).

(10) Y. Hirayama, "Electronic States and Their Control in Semiconductor Quantum Dots", Trends in Nanotechnology (TNT2003), Salamanca, Spain (Sep. 2003).

(11) T. Matsuoka, H. Takahata, T. Mitate, S. Mizuno, and T. Makimoto, "Polarity of GaN

grown on a several substrates by MOVPE", 8th Wide-Bandgap Ⅲ-Nitride Workshop, Richmond, USA (Sep. 2003).

(12) T. Matsuoka and H. Okamoto, "MOVPE Growth of InN and its Band-Gap Energy", 8th Wide-Bandgap Ⅲ-Nitride Workshop, Richmond, USA (Sep. 2003).

(13) T. Matsuoka, H. Okamoto, M. Nakao, H. Harima, H. Takahata, T. Mitate, S. Mizuno, Y. Uchiyama, and T. Makimoto: "MOVPE Growth of Wurtzite InN and its Optical Characteristics", 2003 Int. Conf. on Solid State Devices and Materials (SSDM2003), Tokyo, Japan (Sep. 2003).

(14) H. Yamaguchi, K. Kanisawa, S. Miyashita, and Y. Hirayama, "InAs/GaAs(111)A Heteroepitaxial System", 5th International Workshop on Epitaxial Semiconductors on Patterned Substrates and Novel Index Surfaces (ESPS-NIS2003), Stuttgart, Germany (Oct. 2003).

(15) T. Fujisawa, "Coherent charge oscillations in a semiconductor double quantum dot", Int. Workshop on Correlation, Decoherence and Spin Effects in Simple and Complex Quantum Dot Systems, Bad Honnef, Germany (Oct. 2003).

(16) T. Nishida, "GaN-free Transparent Structure for Ultraviolet Light Emitting Diodes", Phys. of Light-Matter Coupling in Nanostructures (PLMCN3), Sicily, Italy (Oct. 2003).

(17) Y. Hirayama and T. Fujisawa, "Carrier Dynamics and Coherent Oscillation in Quantum Dots", 6th Int. Conf. New Phenomena in Mesoscopic Structures and The 4th Int. Conf. Surface and Interfaces in Mesoscopic Devices (NPMS-6/SIMD-4), Hawaii (Nov. 2003).

(18) T. Matsuoka, H. Okamoto, M. Nakao, H. Takahata, T. Mitate, S. Mizuno, Y. Uchiyama, H. Harima, and T. Makimoto, "MOVPE Growth of Wurtzite InN and Experimental Consideration of its Optical Characteristics", ONR Indium Nitride Workshop (ONR), Fremantle, Australia (Nov. 2003).

(19) T. Fujisawa, "Dynamics of single-electron charge and spin in semiconductor quantum dots", Int. Conf. Quantum Information (ICQI), Kyoto, Japan (Dec. 2003).

(20) T. Fujisawa, "Dynamics of single electron charge and spin in semiconductor quantum dots" Solid State Quantum Information Processing Conference, Amsterdam, The Netherland (Dec. 2003).

IV. Quantum Optics & Optical Materials

(1) 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).

(2) A. Shinya, M. Notomi, E. Kuramochi, T. Shoji, T. Watanabe, T. Tsuchizawa, K. Yamada, and H. Morita, "Functional Components in SOI Photonic Crystal Slabs", SPIE Photonics West, Optoelectronics 2003, San Jose, USA (Jan. 2003).

(3) H. Kamada, H. Gotoh, H. Ando, and T. Takagahara, "Quantum dot exciton Rabi oscillation and quantum gate operation", 8th Int. Symp. on Advanced Physical Fields, (APF8), Tsukuba, Japan (Jan. 2003).

(4) H. Kamada, "Quantum Computation with Quantum Dot Excitons", Int. Conf. on Non-equilibrium Carrier Dynamics in Semicond., Modena, Italy (Jul. 2003).

(5) H. Kamada, "Quantum Computation with Quantum Dot Excitons", FST2003, Chiba, Japan (Jul. 2003).

(6) M. Yamashita, "Dynamics of evaporative cooling and growth of a Base-Einstein condensate", 12th International Laser Physics Workshop Hamburg, Germany (Aug. 2003).

(7) Y. Tokura, "Spin Structures in Quantum Dot System", Workshop on Computational Approaches Towards the Electronic Properties of Quantum Dots, Chicago, USA (Sep. 2003).

(8) H. Nakano, T. Nishikawa, and K. Oguri, "Time-resolved absorption spectroscopy using ultrashort soft x-ray pulse from femtosecond laser-produced plasma", 9th Conference on Laser Optics (LO2003), St. Petersburg, Russia (Sep. 2003).

(9) H. Nakano, T. Nishikawa, K. Oguri, and N. Uesugi, "Femtosecond laser plasma x-ray for time-resolved spectroscopy", 7th International Conference on Optics (ROMOPTO2003), Constantza, Romania (Sep. 2003).

(10) H. Nakano, "Time-resolved absorption spectroscopy using ultrashort soft x-ray pulses generated by femtosecond laser pulse", International Symposium on Ultrafast Intense Laser Science 2: Technology, Trends, Propagation and Interaction (ISUILS2), Quebec, Canada (Sep. 2003).

(11) M. Notomi, "Photonic-Band-Gap Waveguides and Resonators", Intl. Photonics Technol. Conf. 2003 (IPTC2003), Soul, Korea (Sep. 2003).

(12) M. Notomi, "Photonic-Band-Gap Waveguides and Resonators", Annual Meeting of IEEE Lasers and Electro-Optics Society (LEOS2003), Tucson, USA (Oct. 2003).

(13) M. Notomi, "Lasing action in organic photonic crystal and quasicrystal", The 5th Pacific Rim Conf. on Lasers and Electro-Optics CLEO/Pacific Rim2003), Taipei, Taiwan (Dec. 2003).

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