Research Activities
in
NTT Basic Research Laboratories

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June 2005

NTT Basic Research Laboratories,

Nippon Telegraph and Telephone Corporation (NTT)

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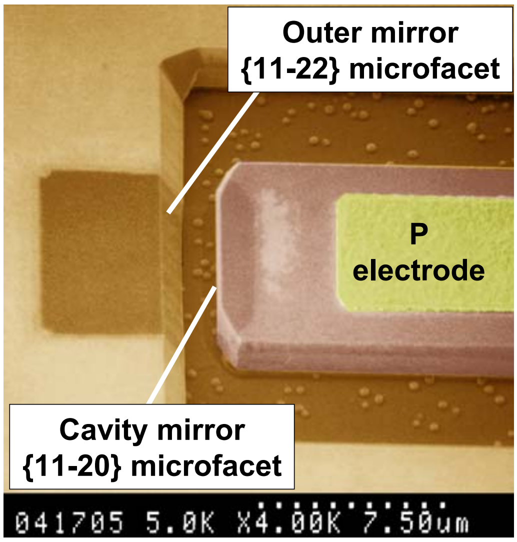
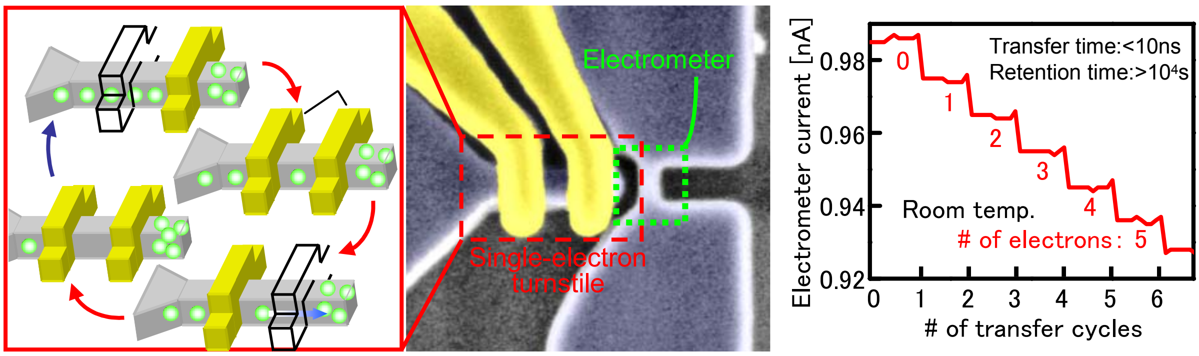


InGaN-based horizontal cavity surface emitting laser diode

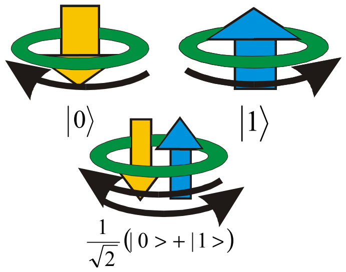
An SEM bird's-eye-view photograph of an InGaN-based horizontal cavity surface emitting laser diode (HCSELD). A Fabry-Perot cavity mirror and an outer micromirror are a vertical {11-20} microfacet and an inclined {11-22} microfacet of the regrown Mg-doped GaN layers, respectively. The {11-20} Fabry-Perot cavity mirror of the HCSELD is vertical to a SiC substrate. The angle between the inclined {11-22} outer micromirror and the SiC substrate surface is 58 degrees. Therefore, geometrically, laser beams are emitted at an angle of 64 degrees to the substrate surface. The InGaN-based HCSELDs lase at room temperature by current injection. (page 1 8)

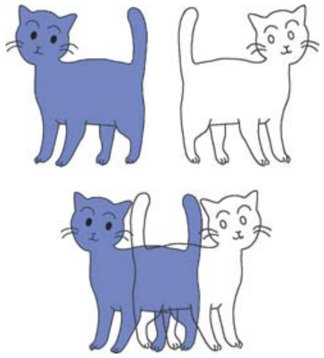


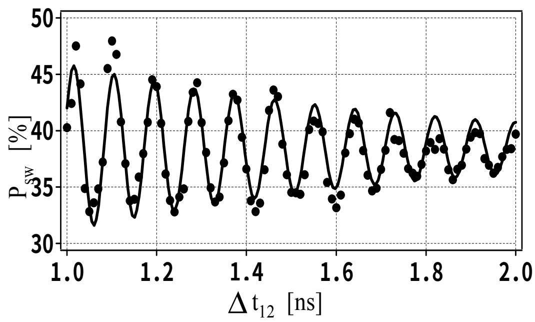
Single-electron turnstile　　Electron microscope image　　Single-electron transfer and detection

Room-temperature single-electron transfer and detection with silicon nanodevices

Transfer and subsequent detection of single electrons are demonstrated at room temperature using a silicon-on-insulator nanodevice. The turnstile, which is composed of two Si-wire-FETs with a fine gate, enables us to transfer single electrons by opening and closing the two FETs alternately. The transferred individual electrons are stored in a memory node and detected by an electrometer with single-electron resolution. The size reduction and optimized operating conditions allow the room-temperature operation. The present device achieves high-speed transfer and long retention. We demonstrated that the device could serve as a multi-level single-electron memory. (page 30)







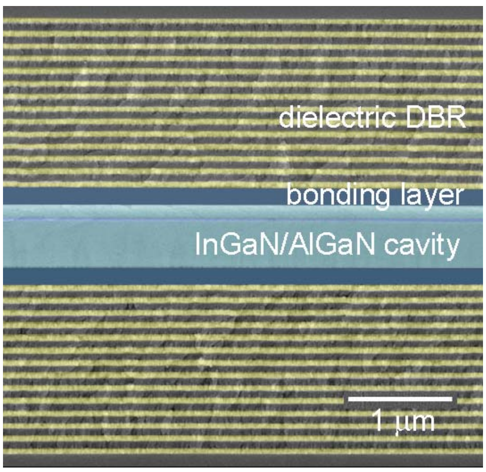
Circulating current in a qubit
Clockwise, anti-clockwise and superposition states are shown.

Schrödinger's cat
Facing left and right and these superposition are shown. Can macroscopic scale object exhibit such superposition?

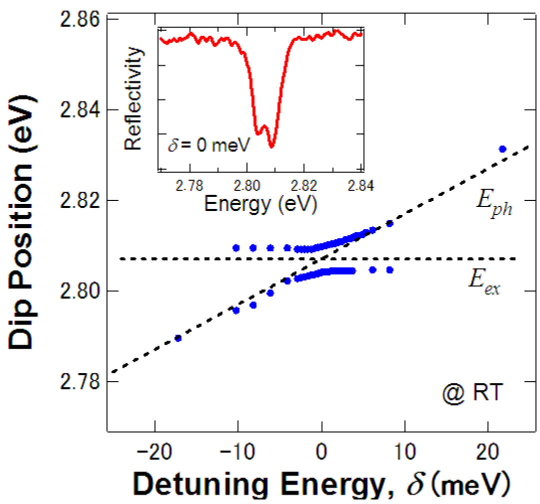
Quantum coherent oscillation
Quantum mechanical states are controlled by relative phase between two microwave pulses.

Fast control of qubit coherence with phase shift method

A superconductor ring with Josephson junctions behaves as a quantum 2-level system and is expected to be a candidate for a quantum bit (qubit), which is a key ingredient of a quantum computer. The size of the ring is about 10 μ m, which is much larger than atoms or molecules but it still shows quantum nature of the 2-level system. The quantum superposition in such a macroscopic scale object is sometimes called Schrödinger's cat. (Page 36)



Cross-sectional SEM image of microcavity



Dispersion of InGaN cavity polariton

InGaN Cavity Polaritons

Cavity polaritons are quasi-particles that are created by strong exciton-photon coupling in a semiconductor microcavity. We successfully fabricated a high quality GaN-based microcavity structure using the wafer bonding technique and formed InGaN cavity polaritons at room temperature for the first time. (Page 44)

From Science to Innovative Technology

NTT Basic Research Laboratories is extremely grateful for your interest in and support of its research activities.

The mission of NTT BRL is to: 1) discover new concepts in the field of network technology that would overcome the present limitations in speed, capacity and size, and 2) develop basic technologies that could lead to future (span of 5 to 20 years) commercial opportunities. Based on this concept it has been focusing on quantum information processing and nano-bio project.

The core research in information processing is quantum computation and quantum cryptography. Taking advantage of its rich experience and knowledge in solid-state devices, NTT BRL has been engaged in quantum bit research using superconducting device, semiconductor quantum dot and cooled atom, and achieving worldwide success. In recent years, research on quantum cryptography using novel algorithm has become another major focus. Another main research, nano-bio project, is conducted by fusing neuroscience, bio-molecular science and nanotechnology. Molecular - protein hybrid structure, for instance, could lead to novel devices in the future.

While promoting these projects, it is implementing 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 nano-tubes, and MEMS (microelectromechanical systems) related to superconductivity. It puts emphasis in having good communication between researchers and managers in order to precisely judge the potential of each research.

Innovative technology is also carried out. For instance, BRL has succeeded in operating a diamond transistor at 80GHz by developing technology to produce diamond thin films of high quality. In addition, core technologies, i.e. single-electron devices which have extremely low power consumption, photonic crystal for use as active optical circuits, and electron devices using wide-bandgap semiconductor materials, are under research and considered to solve limitations in network.

Moreover, BRL not only keeps in close touch with other NTT Laboratories, but also runs various scientific exchange programs with institutes inside and outside Japan.

It has been working on quantum dots and quantum bits together with Delft University and Stanford University, which has been producing fruitful results. Collaboration in nano-bio with University of Oxford has recently took off and is expected to achieve success.

Other activities of BRL include International Symposiums, BRL School and International Advisory Board Meetings, which play roles to disseminate its research worldwide and to encourage greater understanding of it.

June 2005

高柳英明

Dr. Hideaki Takayanagi

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Contents

II. Data

Cover photograph:

Compound semiconductor micro/nanomechanical structures

Scanning electron microscope images of various kinds of micro/nanomechanical structures fabricated from compound semiconductor heterostructures. The thickness and length of these suspended beams and cantilevers are varying from 20 to 700 nm and from 500 nm to 200 μm, respectively. These structures are characterized for studying quantum effects in the coupling of electrical and mechanical degrees of freedom, and applicable for highly sensitive force and displacement detection. (Page 32)

Member List

As of March 31, 2005
(*/ left NTT BRL in the middle of the year)

NTT Basic Research Laboratories

Director, **Dr. Hideaki Takayanagi**

Research Planning Section

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

Senior Research Scientist, Supervisor, Dr. Akira Fujiwara

Senior Research Scientist, Dr. Tadashi Nishikawa

Senior Research Scientist, Dr. Yuichi Harada

NTT R&D Fellow

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

NTT Research Professor

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

Materials Science Laboratory

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Dr. Katsuhiro Ajito

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Dr. Hideki Yamamoto	Dr. Hiroyuki Shibata	Dr. Shin-ichi Karimoto
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Dr. Haitao Ye		

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Dr. Kenichi Kanzaki	Akio Tokura	Dr. Jeong Goo-Hwan

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Dr. Hiroshi Nakashima	Touichiro Goto	Dr. Chunxi Han
Dr. Mimei Kobayashi	Dr. Tobias Nyberg	

Physical Science Laboratory

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Dr. Hiroyuki Tamura

Takeshi Karasawa

Nanodevices Research Group:

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Dr. Katsuhiko Nishiguchi, Dr. Nicolas Clement, Dr. Kazuyuki Uchida

Nanostructure Technology Research Group:

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Toru Yamaguchi, Junzo Hayashi, Dr. Hajime Okamoto
Dr. Lionel Houlet*

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Dr. Satoshi Sasaki, Dr. Akihito Taguchi, Dr. Kyoichi Suzuki
Dr. Toshiaki Hayashi, Dr. Norio Kumada, Dr. Go Yusa
Dr. Kei Takashina

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Dr. Shiro Saito, Dr. Taro Eichler, Dr. Alexander Kasper

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Dr. Tatsushi Akazaki, Dr. Yuichi Harada, Dr. Yoshiaki Sekine
Dr. Masumi Yamaguchi, Toshiyuki Kobayashi, Dr. Yiping Lin*
Dr. Yuan-Liang Zhong

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Executive Manager, **Dr. Masao Morita**

Dr. Masaie Fujino

Dr. Makoto Yamashita

Quantum Optical State Control Research Group:

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Dr. Hiroki Takesue	Dr. Fumiaki Morikoshi	Toshimori Honjo
Dr. Akira Kawaguchi		

Quantum Optical Physics Research Group:

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Dr. Takehiko Tawara	Katsuya Oguri	Dr. Atsushi Ishizawa
Dr. Takeshi Kutsuwa	Dr. Stephen Hughes	Dr. Yasuaki Okano
Dr. Nicholas Cade		

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Dr. Masaya Notomi (Group Leader)

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Dr. Hideaki Taniyama	Dr. Akihiko Shinya	Dr. Takasumi Tanabe
Dr. Satoshi Mitsugi	Dr. Tetsu Ito	

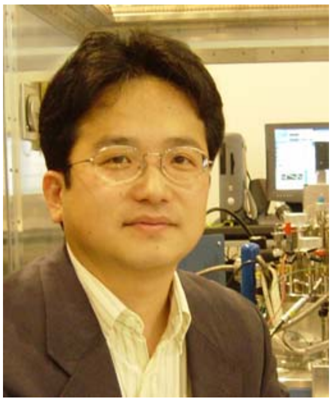
Distinguished Technical Member

Toshiki Makimoto was born in Tokyo on January 16, 1960. He received the B.E., M.S. and Ph.D. degrees in electrical engineering from the University of Tokyo in 1983, 1985 and 1993, respectively. He joined NTT Basic Research Laboratories in 1985. He was a visiting researcher in University of California, Santa Barbara, USA during 1993-1994. Since 1985, he has engaged in epitaxial growth of III-V compound semiconductors, in-situ monitoring of epitaxial growth, heterojunction bipolar transistors, and so on. His current interests are epitaxial growth of nitride semiconductors and its application to devices. He is a member of technology evaluation committee for the New Energy and Industrial Technology Development Organization (NEDO) and the Diamond Research Center in the National Institute of Advanced Industrial Science and Technology (AIST). He is an associate editor of Japan Society Applied Physics International and a member of the Japan Society of Applied Physics, and the Institute of Electronics, Information and Communication Engineers.

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*) during 2001-2004 and a member of the Japan Society of Applied Physics and the Physical Society of Japan. He was awarded the paper awards of the Japanese Society of Applied Physics in 1989 and 2004.

Distinguished Technical Member



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 received Sir Martin Wood Prize in 2003 and JSPS (Japan Society for the Promotion of Science) Award in 2005. He is a member of the Japan Society of Applied Physics, and the Physical Society of Japan.

Distinguished Technical Member

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.

Advisory Board (2004 Fiscal Year)

Name	Title Affiliation
Dr. Boris L. Altshuler	Professor Department of Physics Princeton University, U.S.A
Dr. Michel H. Devoret	Professor Department of Applied Physics Yale University, U.S.A
Dr. Serge Haroche	Professor Department de Physique De l'Ecole Normale Superieure, France
Dr. Mats Jonson	Professor Department of Applied Physics Chalmers University of Technology, Sweden
Dr. Anthony J. Leggett	Professor Department of Physics University of Illinois at Urbana-Champaign U.S.A
Dr. Johan E. Mooij	Professor Department of Applied Physics Delft University of Technology, The Netherlands
Dr. Klaus H. Ploog	Director Paul-Drude-Institut für Festkörperelektronik Germany
Dr. John F. Ryan	Professor Clarendon Laboratory University of Oxford, U.K
Dr. Klaus von Klitzing	Professor Max-Planck-Institut für Festkörperforschung Germany

Invited / Guest Scientists (2004 Fiscal Year)

Name	Affiliation Period
Dr. Hiroshi Yaguchi	Kyoto University, Japan December 03 – December 05
Dr. Tobias Nyberg	University of Tokyo, Japan January 04 – December 04
Dr. Jan Johansson	Japan Science and Technology Agency (JST), Japan February 04 – January 06
Prof. Tord Claeson	Chalmers University of Technology, Sweden February 04 – April 04
Prof. C.J.P.M. Harmans	Delft University of Technology, The Netherlands April 04 – June 04
Dr. Tobias Bergsten	Japan Science and Technology Agency (JST), Japan April 04 – March 06
Dr. Wakako Suhara	University of Tokyo, Japan June 04 – March 05
Prof. Yshai Avishai	Ben Gurion University, Israel August 04 – September 04
Dr. Victor Prinz	Russian Academy of Science, Russia October 04 – December 04
Dr. Andrei Zaikin	Forschungszentrum Karlsruhe, INT, Germany October 04 – November 04
Prof. Andreas Knorr	Technische Universität Berlin, Germany November 04
Prof. Alexander Khaetskii	Ludwig-Maximilians-Universität, Germany February 05
Dr. Michael Thorwart	Heinrich-Heine-Universität Düsseldorf, Germany February 05 – March 05

Trainees (2004 Fiscal Year)

Name	Affiliation Period
Frank Deppe	Technische Universität München, Germany May 02 – May 05
Jeff Liu	Simon Fraser University, Canada June 03 – April 04
Joyce Yat-Ling Wong	University of Toronto, Canada July 03 – June 04
Guk-Hyun Kim	KAIST (Korea Advanced Institute of Science and Technology), Korea Augut 03 – July 04
Nicolas Thillosen	Aachen University of Technology (RWTH) / Research Center Jülich, Germany November 03 – April 04
Christopher Schierholz	Universität Hamburg, Germany January 04 – July 04
Julien Duvernay	INSA (Institut National des Sciences Appliquées), France February 04 – September 04
David Deen	University of Oklahoma, U.S.A. May 04 – August 04
Kislon Voitchovsky	University of Oxford, U.K. June 04
Michael Wagenknecht	Universität Tübingen, Germany June 04 – December 04
Aravind Vijayaraghavan	Rensselaer Polytechnic Institute, U.S.A. June 04 – December 04

Christopher Margach	University of Glasgow, U.K. July 04 – January 05
Marc-Aurèle Brun	ESPCI (École Supérieure de Physique et de Chimie Industrielles), France July 04 – December 04
Olivier Crauste	ESPCI (École Supérieure de Physique et de Chimie Industrielles), France July 04 – December 04
Kasper Grove-Rasmussen	University of Copenhagen, Denmark August 04 – December 04
Simon Perraud	University of Paris 6 / CNRS, France October 04 – September 05
Eek Huisman	University of Groningen, The Netherlands November 04 – March 05
Huang-Ming Lee	National Chiao Tung University, Taiwan R.O.C. November 04 – November 05
Yueh-Chin Lin	National Chiao Tung University, Taiwan R.O.C. November 04 – May 05
Arnaud Valeille	SUPAERO (École Nationale Supérieure de L'aéronautique et de L'espace), France January 05 – August 05
Wouter Naber	Delft University of Technology, The Netherlands January 05 – June 05
Francois Chabrol	University of Newcastle Upon Tyne, U.K. February 05 – March 05
Shih-Chieh Huang	National Chiao Tung University, Taiwan R.O.C. February 05 – February 06

Vittorio Peano	Heinrich-Heine-Universität Düsseldorf, Germany February 05 – March 05
Taryl Leaton Kirk	Universität Stuttgart, Germany / Max-Planck-Institut für Festkörperforschung, Germany March 05 – April 05

Japanese Students (2004 Fiscal Year)

Name	Affiliation (Period)
Yuichi Igarashi	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Yasuaki Iwai	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Kuniaki Endo	Tokyo University of Science, Japan (May 04 – Mar. 05)
Keji Ohno	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Satoru Ohno	Keio University, Japan (Mar. 05)
Junya Ono	University of Tsukuba, Japan (Mar. 05)
Akichika Karasawa	Shonan Institute of Technology, Japan (Jun. 04 – Mar. 05)
Hiroshi Kanda	Tokyo Institute of Technology, Japan (Jul. 04-Aug. 04)
Koya Kitagawa	Tokyo University of Science, Japan (Apr. 04 – Mar. 05)
Yosuke Kitamura	University of Tokyo, Japan (Jan. 05 – Mar. 05)
Takatoshi Kido	Shonan Institute of Technology, Japan (Apr. 04 – Mar. 05)
Go Kira	Tokyo Institute of Technology, Japan (Apr. 04 – Mar. 05)
Tatsuya Kutsuzawa	Tokyo University of Science, Japan (Apr. 04 – Mar. 05)
Tetsuo Kodera	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Naofumi Kobayashi	Meiji University, Japan (Apr. 04 – Mar. 05)
Shingo Kondo	Tokai University, Japan (Apr. 04 – Mar. 05)
Daisuke Sato	University of Tsukuba, Japan (Apr. 04 – Mar. 05)
Takuya Shigetomi	Kumamoto University (Jul. 04 – Aug. 04)
Jun Sugawa	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Atsushi Sogabe	Shonan Institute of Technology, Japan (May 04 – Mar. 05)
Akio Takahashi	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Kazuyuki Tamura	Nagaoka University of Technology (Oct. 04 – Feb. 05)
Masaru Tsuchiya	Keio University, Japan (Apr. 04 – Mar. 05)

Katsuhiko Degawa	Tohoku University, Japan (Jan. 05 – Mar. 05)
Ritsuya Tomita	Tokyo Institute of Technology, Japan (Apr. 04 – Mar. 05)
Hiromasa Nakano	Tokyo University of Science, Japan (Aug. 04 – Mar. 05)
Tomohiro Nakamura	Shonan Institute of Technology, Japan (May 04 – Mar. 05)
Yoshifumi Nishi	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Masumi Noda	Tokyo University of Science, Japan (Apr. 04 – Mar. 05)
Kenichi Hidachi	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Shigeto Fukatsu	Keio University, Japan (Apr. 04 – Mar. 05)
Yusuke Furukawa	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Munekazu Horikoshi	The University of Electro-Communications, Japan (Apr. 04 – Mar. 05)
Motonari Honda	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Tetsunori Matsumoto	Tokyo University of Science, Japan (Apr. 04 – Mar. 05)
Kenji Miyakoshi	Tokyo University of Science, Japan (Apr. 04 – Mar. 05)
Takuya Mouri	Tokyo University of Science, Japan (Apr. 04 – Mar. 05)
Masakazu Morita	Tokyo Institute of Technology, Japan (Apr. 04 – Mar. 05)
Shin Yabuuchi	Keio University, Japan (Apr. 04 – Mar. 05)
Michihisa Yamamoto	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Tomoo Yokoyama	Yokohama National University, Japan (Apr. 04 – Mar. 05)
Hiroyasu Yokoyama	University of Tokyo, Japan (Apr. 04 – Mar. 05)
Hideto Yoshida	Osaka University, Japan (Nov. 04 – Dec. 04)

Ⅰ. Research Topics

Overview of Research in Laboratories

Material Science Laboratory Keiichi Torimitsu

The Materials Science Laboratory (MSL) aims at producing new functional materials and designing of advanced device based on novel materials and biological function. Controlling the configuration and coupling of atoms and molecules is our approach to accomplish these goals. Bio-nano research is set as our principle research in this laboratory.

We have three research groups covering from inorganic materials, such as semiconductors, to organic materials, 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.

We set up European laboratory in UK for bio-nano research, our principal research, in October and started collaboration with University of Oxford.

Physical Science Laboratory Yoshiro Hirayama

We are studying solid-state quantum systems and nanodevices, which will have revolutionary impact on communication and information technologies in the 21st century. In particular, we are making firm and steady progress in the pursuit for solid-state qubits, and related physics and technology for future quantum information processing. We maintain an open-door policy and engage in collaborations with many outside organizations to enhance our basic research into fundamental issues.

The five groups in our laboratory are working in the following areas: quantum coherent control of semiconductor and superconductor systems, carrier interactions in semiconductor hetero- and nanostructures, spintronics manipulating both electron and nuclear spins, precise and dynamical control of single electrons, nanodevices operating at ultimately low power consumption, atom traps/optics, and novel nanomechanics based on compound semiconductors. These studies are supported by cutting-edge nanolithography techniques, well-controlled nanofabrication processes, high-quality crystal growth, and theoretical studies including first-principle calculations.

Optical Science Laboratory Masao Morita

This laboratory started April 2004, and aims the development of core-technologies that will innovate on optical communications and optical signal processing, and seek fundamental scientific progress.

The three groups in our laboratory are working for the quantum state control of light, the quantum state control of materials using light, the analysis of high speed phenomena using very short pulse laser, the optical properties of nano-structure semiconductor like quantum dot, very small optical integrated circuit, and so on.

In this year, we realized the high speed and long distance quantum cryptography, the polariton laser based on nitride semiconductor, and the optical bistable switch composed of high Q-value photonic crystal resonator.

Fabrication of Josephson junctions using MgB_2

Kenji Ueda, and Toshiki Makimoto
Materials Science Laboratory

The superconducting transition temperature (T_c) of magnesium diboride (MgB_2) is 39K, the highest among metallic compounds [1]. The mechanism of superconductivity of MgB_2 has been determined to be multi-gap superconductivity, and much research on MgB_2 is investigating superconducting electronic applications.

Superconducting tunnel junctions (Josephson tunnel junctions) are the key components of devices for superconducting electronic applications such as high-sensitive magnetic sensors (SQUID) and electromagnetic wave detectors. Nb (T_c=9K) tunnel junctions are mainly used in these superconducting devices, but cooling down devices using Nb requires liquid helium. MgB_2, on the other hand, has higher T_c and superconducting devices using MgB_2 tunnel junctions can work without using liquid helium. There have been many attempts to fabricate Josephson tunnel junctions that work above liquid nitrogen temperature (77 K) using high-T_c superconductors (HTS). However, Josephson tunnel junctions using HTS have not been fabricated yet, although it has been almost twenty years since the discovery of HTS. Therefore, MgB_2 is expected for materials fabricating Josephson tunnel junctions.

We have succeeded in fabricating Josephson tunnel junctions ($MgB_2/AlO_x/MgB_2$) using as-grown MgB_2 films fabricated by molecular beam epitaxy (MBE) [2] and observed, for the first time, supercurrent at 20 K [3]. This temperature is the highest among artificially fabricated tunnel junctions and can be easily reached by using compact commercial cryocoolers.

Even though the properties of our tunnel junctions still have to be improved further, we believe that these results will enlarge the area of the superconducting electronic applications.

[1] J. Nagamatsu et al., Nature **410** (2000) 63.
[2] K. Ueda, M. Naito, Appl. Phys. Lett. **79** (2001) 2046.
[3] K. Ueda, S. Saito, K. Semba, T. Makimoto, and M. Naito, Appl. Phys. Lett. **86** (2005) 172502.

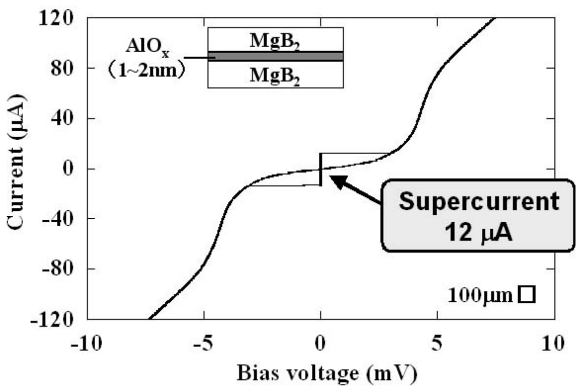


Fig. 1 : Typical current-voltage characteristics of the MgB_2 tunnel junction measured at 4.2 K.

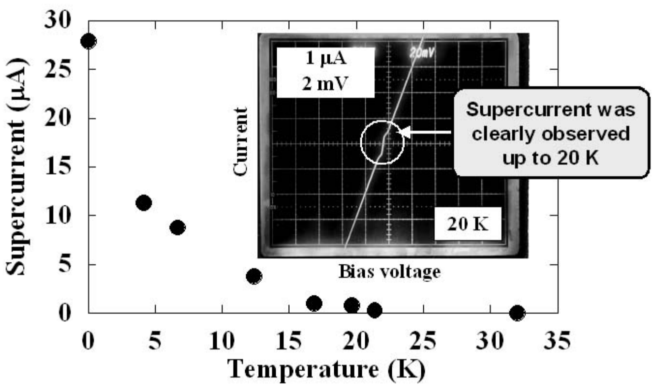


Fig. 2 : Temperature dependence of supercurrent of the MgB_2 tunnel junction. The inset shows current-voltage characteristics measured at 20K.

InGaN quantum wells with high luminescent efficiency

Tetsuya Akasaka, Hideki Gotoh, Hidetoshi Nakano, and Toshiki Makimoto
Materials Science Laboratory

InGaN quantum wells (QWs) have been widely used as the active layers of light emitting diodes and laser diodes that emit light in the visible-to-ultraviolet region. Nevertheless, the performance of these devices has been limited, in part by the emission efficiency of InGaN QWs. The emission efficiency of InGaN QWs is governed by various factors, such as spatial fluctuation of the InN composition and nonradiative recombination centers (NRCs). In this study, InGaN QWs were grown on InGaN under-lying layers (ULs) which function to reduce the NRCs and spatial fluctuation of the InN composition. These InGaN QWs on InGaN ULs have the highest luminescent efficiency at room temperature (RT) ever reported [1, 2]. Time-resolved photoluminescence (TRPL) revealed that adding indium atoms to the UL is effective in eliminating the NRCs of InGaN QWs.

Figure 1 shows Arrhenius plots of integrated PL intensity for InGaN QWs on an InGaN UL. The integrated PL intensity remains almost constant at 14-150 K and then falls gradually with a further increase of temperature. Even at RT, however, it is 71 % of that at 14 K. This value is the highest ever reported for the wavelength region of about 400 nm. PL lifetimes measured by TRPL, τ_{PL}, are plotted as a function of temperature in Fig. 2. The τ_{PL} values for a conventional InGaN QWs rapidly decrease with increasing temperature because of the thermally activated NRCs. For the InGaN UL, τ_{PL} values stay almost constant at 0.9 ns below 100 K, reflecting the behavior of localized excitons. This means that the tail states originated from the fluctuation of the InN composition is fairly shallow. From 100 to 250 K, τ_{PL} linearly increases with temperature, which is characteristic of 2D-excitons in QWs. This linear increase in τ_{PL} was clearly observed up to 250 K because of fewer NRCs. These results indicate that the InGaN UL can effectively eliminate the NRCs and also decrease the spatial fluctuation of the InN composition.

InGaN QWs on an InGaN UL are very promising for realizing novel optoelectronic devices, such as polariton lasers and single photon emitters, which require extremely high luminescent efficiency at RT.

[1] T. Akasaka et al., Appl. Phys. Lett. **85** (2004) 3089-3091.
[2] T. Akasaka et al., Appl. Phys. Lett. (accepted).

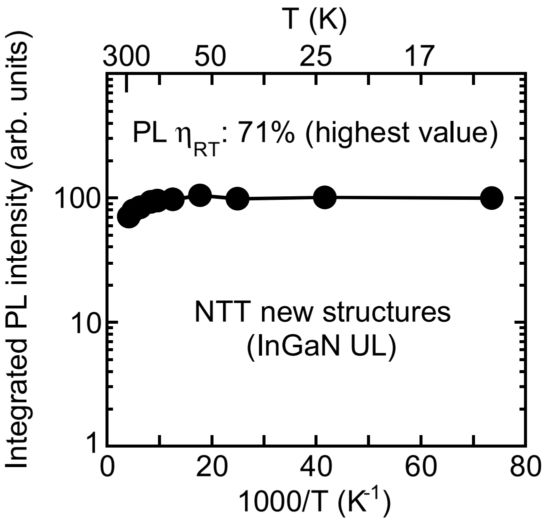


Fig. 1. Arrhenius plots of integrated PL intensity for InGaN QWs on an InGaN UL

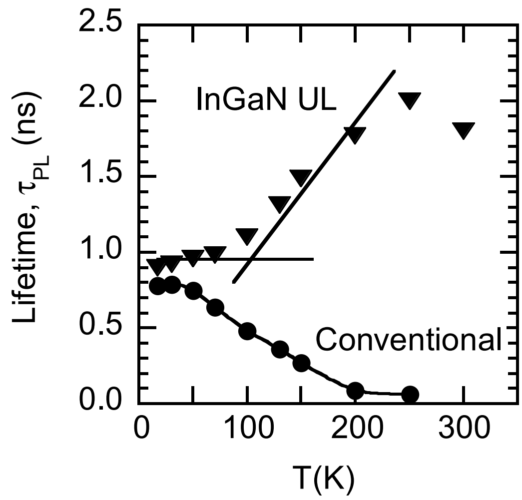


Fig. 2. Temperature dependence of PL lifetime, τ_{PL}

An InGaN-based horizontal cavity surface emitting laser diode

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Group III-nitrides, such as AlN, GaN, InN, and their alloys, are attractive for application to optoelectronic devices in the visible and UV ranges, because these semiconductors have wide and direct bandgaps. The mirror facets of group III-nitride-based lasers have been fabricated by either cleaving or dry-etching. Selectively grown microfacets are better choices for fabricating mirror facets. In this work, we fabricated an InGaN-based horizontal cavity surface emitting laser diode (HCSELD) [1]. It is a Fabry-Perot laser diode that has a pair of cavity mirrors consisting of selectively grown vertical {11-20} microfacets and a pair of outer micromirrors consisting of the selectively grown inclined {11-22} microfacets. The outer micromirrors direct the laser beam upward. Successful room-temperature lasing of the InGaN-based HCSELDs has been achieved by current injection.

Figure 1 shows an SEM bird's-eye-view photograph of an InGaN-based HCSELD. It can be seen that a Fabry-Perot cavity mirror and an outer micromirror are a vertical {11-20} microfacet and an inclined {11-22} microfacet of the regrown Mg-doped GaN layers, respectively. The {11-20} Fabry-Perot cavity mirror of the HCSELD is vertical to a SiC substrate. The angle between the inclined {11-22} outer micromirror and the SiC substrate surface is 58 degrees. Therefore, geometrically, laser beams are emitted at an angle of 64 degrees to the substrate surface. The InGaN-based HCSELDs lase at room temperature (RT) by current injection. Spectra obtained below and above the lasing threshold are shown in Fig. 2. The narrowing of the spectrum can be seen at current density above the lasing threshold. The lasing wavelength is approximately 400 nm. We also observed the nonlinear change in the current-light output relationship at the lasing threshold. This is the first current-injection lasing of the nitride-based surface emitting laser diode.

[1] T. Akasaka et al., Appl. Phys. Lett. **84** (2004) 4104-4106.

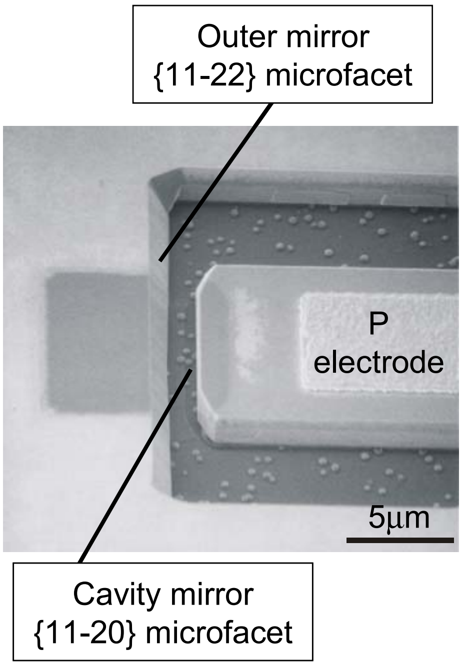

Fig. 1. Bird's-eye-view SEM photograph of an InGaN-based HCSELD.

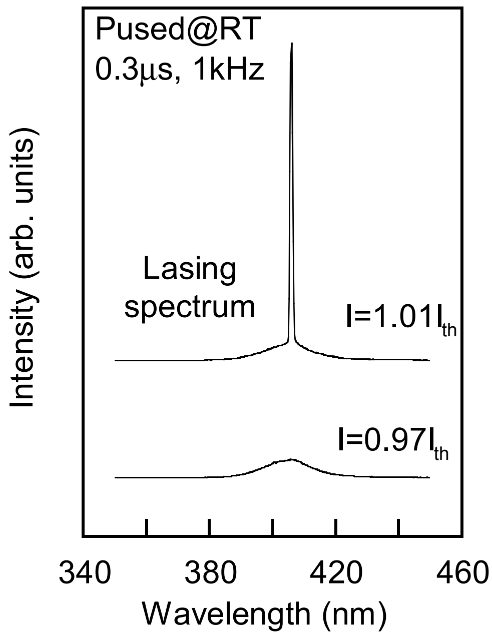

Fig. 2. Emission spectra obtained from an InGaN-based HCSELD below and above the lasing threshold.

Growth of High-Quality GaN Using Novel Buffer Layer

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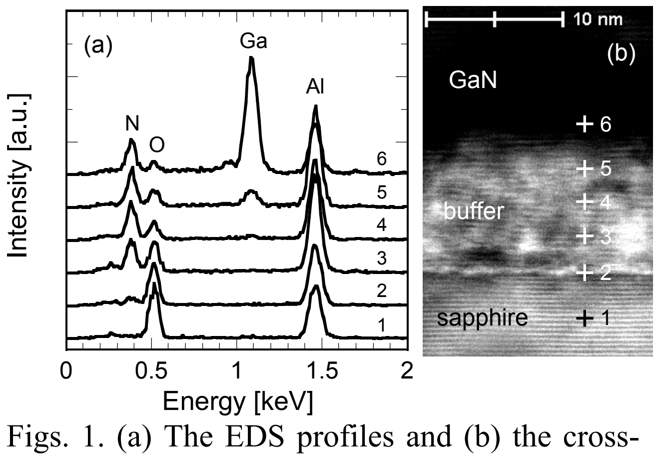
Materials Science Laboratory, *NTT Photonics Laboratories

The quality of a GaN layer grown on sapphire substrates by metalorganic vapor phase epitaxy (MOVPE) has been improved by the use of low-temperature AlN or GaN buffer layers. Since the low-temperature deposited layer is unstable, it is well-known that variously shaped islands were formed as temperature increased. Therefore, it is difficult to grow the GaN layer with sufficient quality or reproducibility, which is a quite severe problem from the commercial point of view. Thus, it is important to find a new buffer layer for GaN growth on sapphire substrates.

Electron cyclotron resonance (ECR) plasma sputtering can easily deposit a minute, uniform, and stable oxide or nitride layer on large area at room temperature. An Al_2O_3 and an AlN can also be easily deposited by ECR plasma sputtering at room temperature, and have very high melting points above 2000 °C, indicating that these materials could be used as a buffer layer with good thermal stability. Therefore, we have proposed and demonstrated the GaN growth on sapphire substrates with the ECR plasma sputtered layer of Al_2O_3/graded-AlON/AlN/Al_2O_3 as a buffer layer instead of low-temperature AlN or GaN layer.

We formed the buffer layers on c-face sapphire substrates by ECR plasma sputtering at room temperature and used them as the growth substrates. The total thickness of the buffer layers was 20 nm. We directly grew GaN on these substrates at 1000 °C. Figures 1 (a) and (b) show the energy dispersion x-ray spectroscopy (EDS) profiles and the cross-sectional transmission electron microscope (TEM) image at the interface between the sapphire substrate and the GaN layer, respectively. The peak intensities from nitrogen (N) increased gradually from the sapphire substrate to GaN layer, and those from oxygen (O) decreased gradually, as shown in Fig. 1 (a). These results indicate that we can easily form the nitride layer by gradually changing the composition from the oxide layer.

The cross-sectional bright-field TEM image showed that the dislocations were bended at the initial stage of the growth as shown in Fig. 2, which indicated the enhancement of the lateral growth, resulting in the decrease of dislocation density to be 6.0×10^8 cm^{-2} in the GaN layer. The mobility of the GaN layer was 540 cm^2/V·s at the electron concentration of 2×10^{17} cm^{-3}. These results indicate that the quality of the GaN layer grown using the ECR plasma sputtered buffer was comparable or superior to the conventional grown GaN using the low temperature buffer layer.



Figs. 1. (a) The EDS profiles and (b) the cross-sectional TEM image at the interface between the sapphire substrate and the GaN layer, respectively.

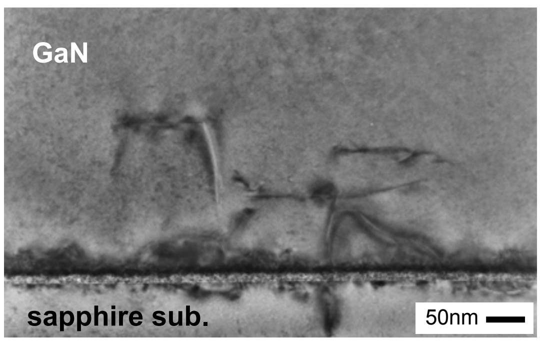


Fig. 2. Cross-sectional TEM image of the interface between the sapphire substrate and GaN layer.

AlN field emission display

Y. Taniyasu, M Kasu, and T. Makimoto
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Aluminum nitride (AlN) is a wide-band-gap (6.2 eV) semiconductor. Its electron affinity is nearly zero. Therefore, AlN is a promising material for field emitters because electrons in materials with nearly zero electron affinity can be easily extracted from the surface to vacuum. However, for AlN, the reported field emission current is too low and the turn-on electric field too high for device application. The reason is that the electron concentration in the AlN samples is so low that the electrons necessary for field emission can not be efficiently supplied to the surface.

Recently, we have achieved n-type conductive Si-doped AlN [1]. In addition, we found that heavy Si doping is very effective in improving the field emission properties of AlN [2]. This study demonstrates a triode-type field emission display (FED) and presents the field emission properties of the heavily Si-doped AlN in an actual device structure [3].

The display has a vertical triode structure consisting of the heavily Si-doped AlN cathode, mesh grid, and phosphor coated anode screen as shown in Fig. 1. The electrons are emitted by applying grid voltage and then accelerated by the anode voltage. The phosphor is excited by the electrons and emits luminescence. The cathode current (field emission current), I_C, was detected at an electric field strength of E_G = 11 V/μm. Above this turn-on electric field, the I_C increased exponentially with increasing electric field strength and reached 16 μA at E_G = 23 V/μm. We measured the stability of the cathode current against time under the DC mode without a feedback circuit. The display showed a low current fluctuation of 5.5 %. The high stability originates from the strong Al-N bond strength.

Figure 2 shows photographs of the display during operation. The luminescence area is almost the same as the opening area of the mesh grid. We observed uniform luminescence with the brightness of 300 cd/m^2, which is intense enough for display application. During operation, the uniform and bright luminescence was maintained over the entire field emission area. These results prove that the heavily Si-doped AlN field emitter is very promising for vacuum microelectronic devices.

[1] Y. Taniyasu, M. Kasu, and T. Makimoto, Appl. Phys. Lett. **85** (2004) 4672.
[2] M. Kasu and N. Kobayashi, Appl. Phys. Lett. **79** (2001) 3642.
[3] Y. Taniyasu, M. Kasu, and T. Makimoto, Appl. Phys. Lett. **84** (2004) 2115.

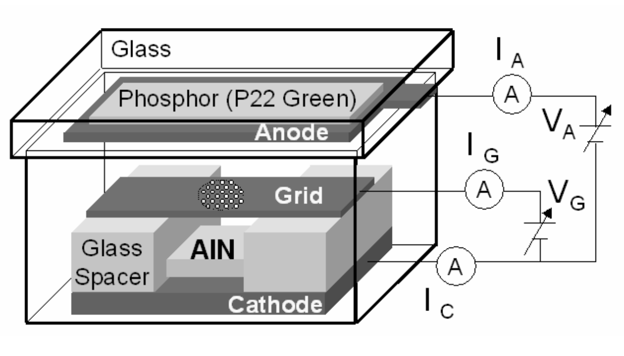

Fig. 1. Schematic diagram of display structure using heavily Si–doped AlN.

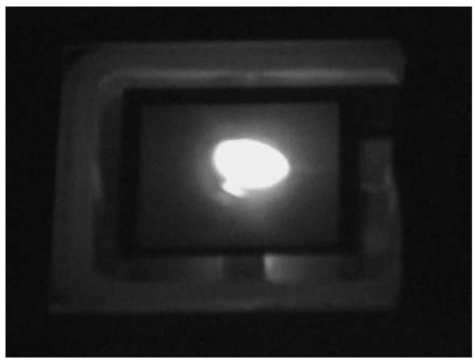

Fig. 2. The photograph of the display during operation.

Real-time Observation of Nanowire Formation by Means of GISAXS

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Nanowires composed of several semiconductor materials have recently been attracting many interests due to their promising potential for nano-technology applications such as photonics, quantum computing and bio / medical engineering. Several nanowires have been grown using the vapor-liquid-solid (VLS) mechanism in a gaseous environment and evaluated after the growth, using electron-based microscopic techniques, such as SEM and TEM. Since electron-based techniques are limited in vacuum, usual monitoring tool, for example, RHEED and LEED can not be applied to observe nanowire growth, and details of the growth is still unclear. In contrast with the electrons, x-ray has larger permeability with the materials, and is often used for monitoring crystal growth in solid, liquid and gases.

In this work, we evaluated nanowire growth with using GISAXS (Grazing Incidence Small Angle X-ray Scattering) since this technique can be applied fro evaluating nano-structures in a gaseous and liquid environment. Figure 1 shows the experimental layout for GISAXS measurement. X-rays were impinged at the grazing condition and scatterings from the nanowires were observed with the digital x-ray CCD camera every several seconds. Figure 2 shows the GISAXS image obtained just after the nanowire growth. Obviously, clear scatterings along qy and qz direction were observed, suggesting dense nanowires on the substrate. Theoretical calculations with using DWBA (Distorted Wave Born Approximation), shown in Fig. 3 (a) and (b), suggests x-rays were scattered mainly by the hexagonal objects than hemispheres. This was consistent with the results of SEM observation which clearly showed vertical nanowires with hexagonal cross-section.

[1] T. Kawamura, et al., Proc. of XTOP 2004, Prague, September 2004.
[2] S. Bhunia, et al., Appl. Phys. Lett. **83** (2003) 3371.

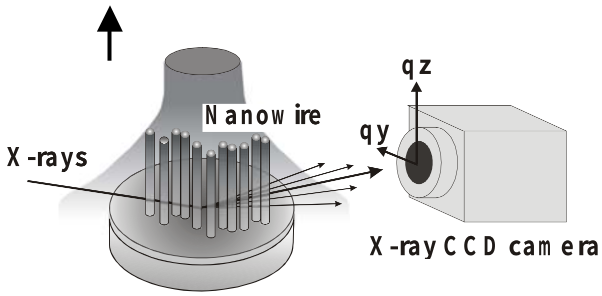

Fig.1 Experimental layout of GISAXS.

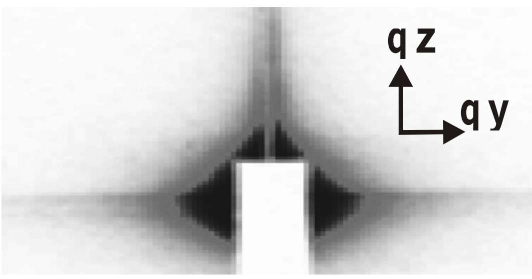

Fig.2 GISAXS image after nanowires formation (Ts=400℃)

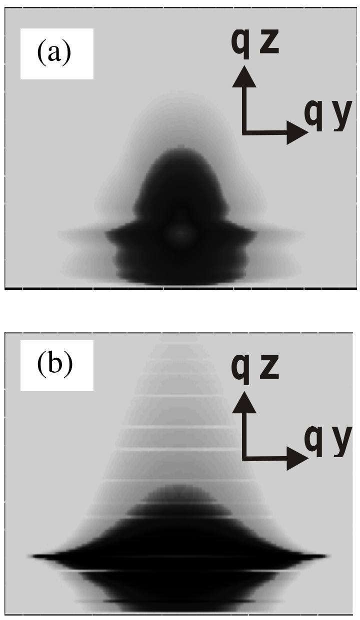

Fig.3 Calculated GISAXS image by DWBA approximation. (a) hemisphere, (b) hexagonal pillar.

Synthesis of Functionalized Carbon Nanotubes using DNA and Gold Nanoparticles

Goo-Hwan Jeong, Satoru Suzuki and Yoshihiro Kobayashi
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Due to the outstanding physical, chemical and electrical properties of carbon nanotubes (CNT), a number of applications in various fields are expected. Especially, extensive researches related with CNT-functionalization using foreign atom or molecules have been performed to control electronic property of CNT because diameter- or chirality-controlled growth has not been realized yet, which is determining factor of electronic property. Here, we introduce our CNT-functionalization study for the application of CNT-based nanoelectronics or biosensor. DNA and Au nanoparticles (NP) are selected among various materials to functionalize CNT [1] owing to their specific assembling and strong coupling properties.

Ferritin covered with protein shell and contains Fe clusters in its 6-nm diameter inner space was used to synthesize diameter-controlled single-walled carbon nanotubes (SWNTs). A Co-ferritin, Fe is replaced by Co, was also used. By controlled methane CVD experiments at 900ºC, suspended SWNTs are successfully synthesized on Si or SiO_2 pillar-structured substrates using not only ferritin but also Co-ferritin, which is the first report [2]. A scanning electron microscope (SEM) image [Fig. 1(a)] and Raman spectrum [Fig. 1(b)] of the suspended SWNTs grown using Co-ferritin catalyst are presented.

SWNTs-functionalization was performed by covalent coupling between carboxyl and amine groups produced by acid and aminopropyltriethoxysilane (APTES) treatment, respectively. DNA/Au hybrids were made by simple mixing of thiolated-DNA and Au NP (5nm diameter). Finally, SWNTs are modified by Au NP or DNA/Au hybrids.

Figure 2 shows SEM images obtained from SWNTs/Au [Fig. 2(a) and (b)] and SWNTs/DNA/Au hybrids [Fig. 2(c)]. The density of Au NP attached along the suspended SWNTs was controlled by changing treatment time and Au-colloid concentration. In addition, the change of Raman spectra was also observed from the SWNTs/DNA/Au hybrid [3], which implies the different electronic or optical properties are expected. These results show functionalized CNT can be developed to electronic and optical applications.

[1] M. Zheng et al., Science **302** (2003) 1545-1548.
[2] G.-H. Jeong et al., J. Am. Chem. Soc., submitted 2005.
[3] G.-H. Jeong et al., MRS 2005 Spring Meeting, San Francisco, March 2005.

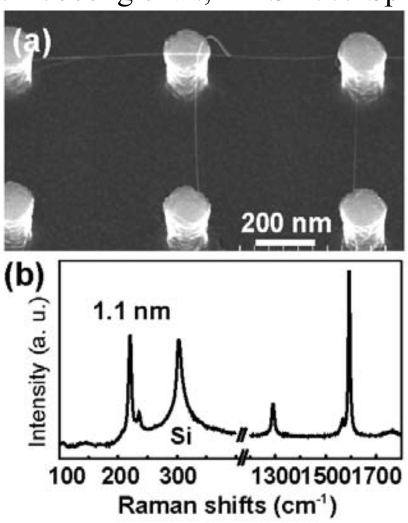

Fig. 1. Suspended SWNTs from Co-ferritin. (a) SEM image and (b) Raman result.

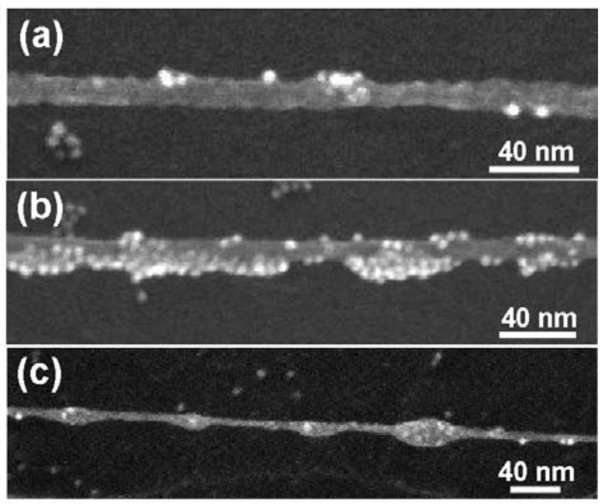

Fig. 2. SEM images of CNT/Au hybrids [(a),(b)] and CNT/DNA/Au hybrid (c).

Spatially Selective Removal of Carbon Nanotubes

Satoru Suzuki, and Yoshihiro Kobayashi
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Carbon nanotubes are one of the most promising materials for future nanoelectronics, because of the nanometer-scale structure and the unique electronic properties. Actually, a nanotube-based field effect transistor and single electron transistor have been demonstrated to overcome a Si device. For fabricating a nanotube-based integrated circuit, it is necessary to place nanotubes only at specified positions. However, high-density nanotube growth almost always results in the growth of unnecessary nanotubes at unspecified positions, which would cause short circuits, because controlling the growth direction of individual nanotubes is still impossible. Thus, selective removal of carbon nanotubes from a nanotube network is a crucial issue for fabricating an integrated circuit.

Recently, we found that low-acceleration-voltage electron irradiation induces significant damage in single-walled carbon nanotubes (SWNTs). Moreover, we developed a simple method for removing unnecessary nantoubes selectively utilizing the low-acceleration-voltage electron irradiation damage.

Raman spectra of SWNTs before and after electron beam irradiation is shown in Fig. 1. The acceleration voltage was 1 kV. The electron irradiation drastically decreased the radial breathing modes (RBM) intensity, which is characteristic in the quasi-one-dimensional structure of SWNTs, indicating that the irradiation caused structural damage in the SWNTs [1]. This damage was found to be extensively caused at around 1 kV. Although SWNTs are chemically highly stable, the electron irradiation significantly reduces the chemical stability. This enables us to simply remove the damaged SWNTs selectively. A typical example of suspended SWNTs after the selective removal procedure is shown in Fig. 2. The SWNTs were grown on Si pillars having diameters of 200 nm. The electron beam was scanned along the dashed line, and then, the sample was annealed in air. In spite of the very simple procedure, the SWNTs initially crossing the line were successfully removed. This technique would make it possible to fabricate various kinds of nanotube circuits.

[1] S. Suzuki et al., Jpn. J. Appl. Phys. **43** (2004) L1118.
[2] S. Suzuki et al., Jpn. J. Appl. Phys. **44** (2005) L133.

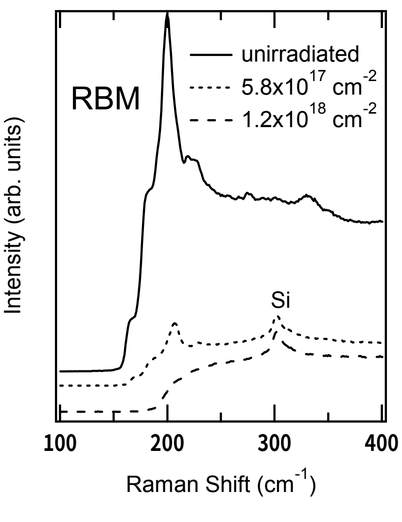

Fig. 1. Raman spectra of SWNTs before and after electron irradiation.

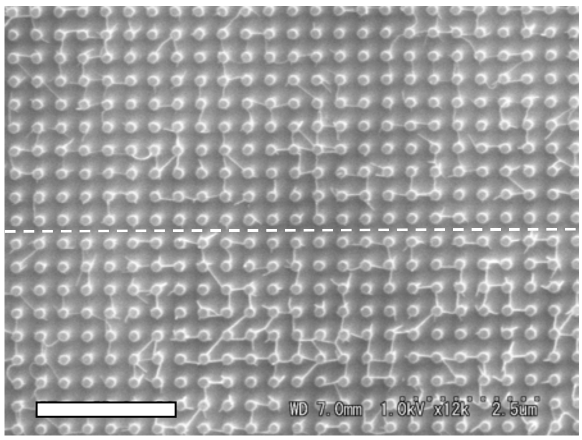

Fig. 2. SEM image of the suspended SWNT network after the selective removal procedure. The electron beam was scanned along the dashed line. Scale bar: 2.5 μm.

Arrangement of Au-Si alloy islands at atomic steps

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Approaches to fabricating semiconductor nanostructures can be roughly classified into "top-down" lithography and "bottom-up" self-assembly. Self-assembly has potential advantages of low cost, large scale, high quality, and so on, but there still remain lots of problems to be solved, especially in the controllability of the size and position of nanostructures. Our group has developed novel self-organized nanostructure fabrication methods through atomic scale control of semiconductor surface structures. Here, we demonstrate that Au-Si alloy islands are self-assembled in a controlled manner using an atomic step array on Si(111) as templates.

We formed three-dimensional (3D) islands on Si(111) by Au deposition at high (~700°C) and then at low (~400°C) temperatures. Figure 1 shows an atomic force microscopy (AFM) image of the islands and their height distribution. 3D islands with a relative deviation of 10% are arranged at atomic steps. Real-time observations of the island formation using low-energy electron microscopy (LEEM) revealed that the islands formed within a narrow Au coverage window, resulting in the narrow size distribution. The islands were allowed to coarsen by interrupting the Au deposition. When the Au deposition was resumed, the islands moved into upper terraces leaving trenches behind. This indicates that the islands are Au-Si alloy droplets. Additionally, the islands moved on the terraces almost at constant velocities, but when they approached the upper-side steps, they jumped to the steps (Fig. 2). The atomic steps provide stable positions for Au-Si alloy islands, which helps them to arrange at the steps.

We showed that the position and size of Au-Si alloy islands can be controlled by using atomic steps as templates for island formation. Our method is very simple because it does not include any lithographic techniques, and it is useful for preparing substrates for semiconductor nanowire growth and attaching functional molecules.

*Present address: NTT advanced technology Corporation

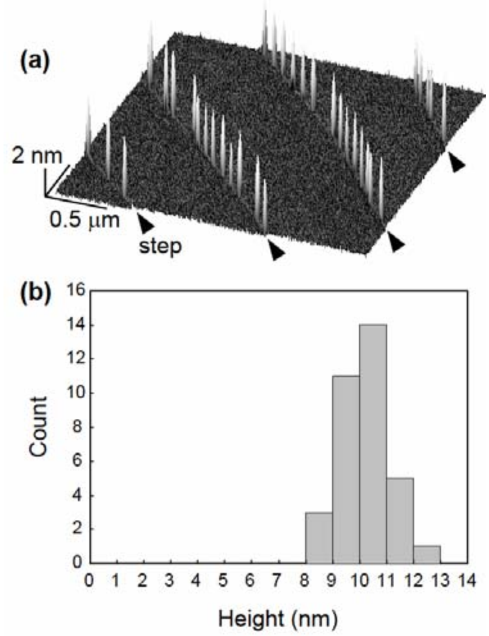


Fig. 1. AFM image of 3D islands and their height distribution.

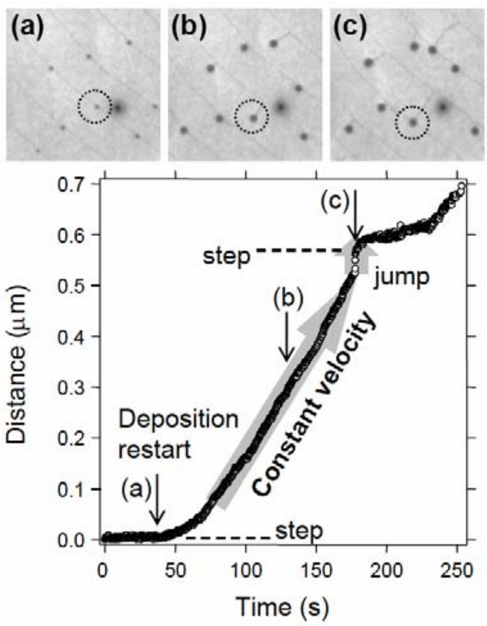


Fig. 2. The moving distance of the island indicated by the dotted circle in LEEM images (a)-(c) as a function of time.

Development of a conducting polymer electrode and measurements of neural activity with a microelectrode array

Akiyoshi Shimada, Tobias Nyberg, Nahoko Kasai and Keiichi Torimitsu
Materials Science Laboratory

The brain processes information related to perception, consciousness and behavior by using two types of electrical signals: localized graded potentials and action potentials. However, it is less well understood how information is coded by these electrical signals or how neural networks develop.

To answer these questions, we recorded the activity from dissociated cultures of rat or mouse cerebral cortical neurons with a microelectrode array (MEA). MEA-based recording is an effective way to study the relationship between the electrical activities of individual neurons and the neural network that they compose.

However, the extracellular signals produced by neurons are generally small. This has led to the need for a conducting polymer electrode with a low signal-to-noise ratio. Figure 1 shows the structure of a conducting polymer electrode with low impedance. The impedance of this electrode was about 5 kΩ at 1 kHz [1], which is one-twentieth that of a conventional platinized electrode [2]. We confirmed that this polymer electrode could measure the action potentials of cortical neurons for more than 1 month.

In addition, there are two types of neurons (excitatory and inhibitory) in a neural network, and it is difficult to identify the neuron type in living tissue. So we have employed a recently developed glutamic acid decarboxylase-green fluorescence protein (GAD67-GFP) knock-in mouse to allow us to observe the distribution of GABAergic neurons, which constitute the majority of inhibitory neurons, as shown in Fig. 2. Developmental changes in the spontaneous activity suggested that GABAergic neurons became active earlier than non-GABAergic neurons.

We are now investigating the interaction between excitatory and inhibitory neurons in relation to information processing with this polymer electrode.

[1] T. Nyberg et al., Neuro2004 Sept 21-23, Osaka, Japan (2004).
[2] Y. Jimbo et al., IEEE Trans. Biomed. Eng., **50**, 2 (2003) 241.

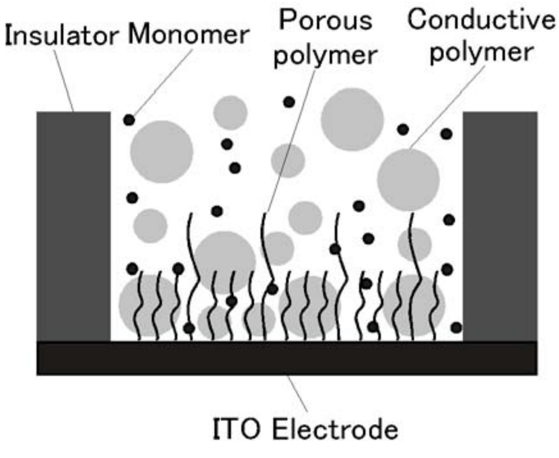


Fig. 1 Structure of a polymer electrode

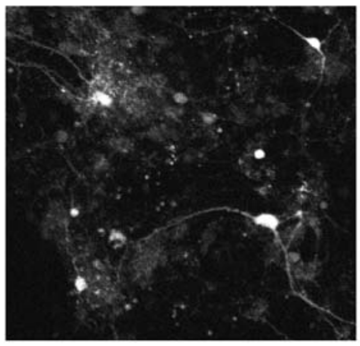


Fig. 2 Inhibitory neurons marked with GFP

AFM observation of purified IP_3 receptor protein

[1]Wakako Suhara, [1]Ichiro Fujimoto, [1,2]Katsuhiko Mikoshiba, [1,3]Mime Kobayashi
[1,3]Touichiro Goto, and [1,3]Keiichi Torimitsu
[1]The Division of Neural Signal Information, NTT-IMSUT
[2]The Institute of Medical Science, University of Tokyo, [3]Materials Science Laboratory

Mikoshiba's group identified an abundant glycoprotein that exists in Purkinje cells of cerebellum as an inositol 1,4,5-trisphosphate receptor (IP_3R) in 1989. IP_3R has shown to play pivotal roles in neuronal transmission and other functions that relate to morphological and physiological processes in living organisms. Those functions include fertilization, activation of an egg, axon extension of a neuron, and cerebral nerve plasticity.

Previous analysis of numerous negatively stained images of fixed samples has indicated that the receptor changes its morphology depending on intracellular Ca^{2+} concentrations. The receptor was square-shape in un-liganded state and windmill-shape in the presence of Ca^{2+}. In this study, we attempted to observe unfixed samples of a single IP_3R protein by atomic force microscopy (AFM).

The same samples used for the previous electron microscopic studies were used. Single IP_3R tetramers on mica were successfully observed in imaging buffer without detergent (Fig. 1A). The square-like structure with a width of about 25 nm closely resembles the model proposed in previous studies. We expect that individual IP_3R molecules assemble in a certain direction resulting from the electrostatic interaction between IP_3R and the mica surface. After imaging IP_3R in standard imaging buffer without Ca^{2+}, buffer was changed to the one with Ca^{2+}. We found several types of structures in the presence of Ca^{2+}. Most notably, we found IP_3R tetramer with a dent in the center (Fig. 1C). While the height decreased slightly, the width clearly increased. The structure resembles the windmill-like configuration reported in a previous electron microscope study. The IP_3R appeared to be inclining slightly backwards, and two wing-like structures that were higher than others could be distinguished. Section analysis along these two higher structures showed a width of 30 nm.

We believe that our study is an important stepping-stone for the application of AFM to biological samples. Further improvements in AFM will make it possible to reveal the structural changes of other membrane proteins in a natural environment.

[1] W. Suhara et al., 34^{th} annual meeting of Society for Neuroscience, San Diego, USA (2004)
[2] I. Fujimoto et al., 9^{th} Linz winter workshop, Linz, Austria (2005).

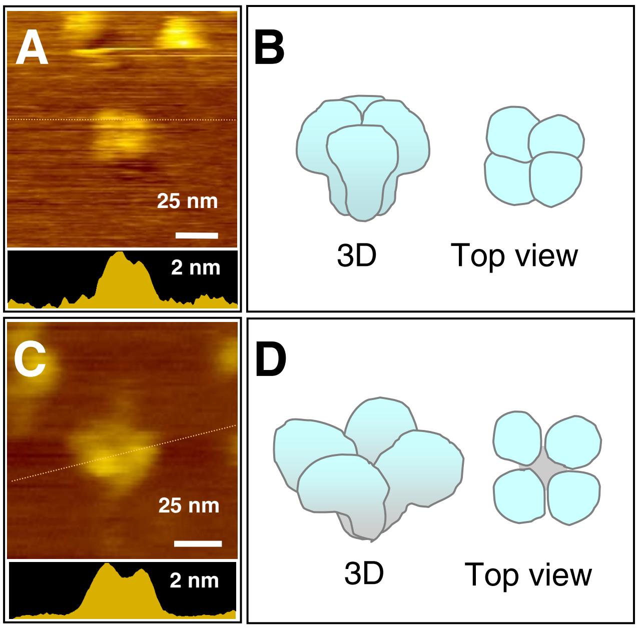


Fig. 1. AFM topographs of IP_3R. Single IP_3R imaged without (A) or with (C) Ca^{2+} in buffer. Section analyses along dotted lines are shown in bottom insets. Three-dimensional reconstructed models are shown in (B) and (D).

Photoresponse Behavior of Conjugated Polymer-Based Nano Device

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

Molecular-scale device, comprising single or small number of organic molecules, has experienced extensive attention and rapid development recently. Bottom-up process using organic molecules enables us to fabricate high-dense and fine-tuned devices due to the advantages in size and design of the molecules. Conjugated polymers exhibit remarkable carrier transport and photo absorption/emission properties based on electrically conjugated polymer chain, and are thus expected to apply nano-scale electronic and photonic device components. Recently, we have synthesized a rigid π-conjugated poly(*p*-phenylene-ethynylene) derivative including thiol end groups (TA-PPE, Fig.1) [1]. By utilizing a selective chemisorption property of thiol end groups onto Au surface, it is possible to fabricate a self-assembled TA-PPE nanojunction between Au nanogap electrodes, Au/TA-PPE/Au (gap ~40 nm). We successfully observed a remarkable photocurrent switching behavior of the nanojunction [2].

Figure 2 shows the photocurrent response behavior of the nanojunction under light irradiation. With light on or off, the nanojunction exhibits switching between a low-current state in dark conditions and a high-current state in light conditions as a nanometer-scale photoswitch (the voltage between two nanoelectrodes is kept constant at 0.5 V). In the “off” state, the resistance is as high as $\sim 10^{15}$ Ω. In the “on” state, the resistance is $\sim 10^{12}$ Ω, the switching ratio is as high as 1000. The switching in those two states is reversible and fast. Under illumination, the photon-generated excitons are dissociated into free electrons and holes, some of them possessing sufficient energy to jump over or tunnel through the Au-S barrier, resulting in high current (“on” state) of the nanojunction. In addition, with intensity of the incident light changing, the current of the nanojunction device changed, exhibiting significant light intensity dependence. This phenomenon is understandable in terms of the changing of photon density in the incident light.

In the future, we are aiming at the fabrication of novel molecular-scale composite devices integrating the nanojunction with other optoelectrically functionalized organic/bio molecules.

[1] H. Nakashima, et al., Langmuir **21** (2005) 511.
[2] W. Hu, et al., J. Am. Chem. Soc. **127** (2005) 2804.

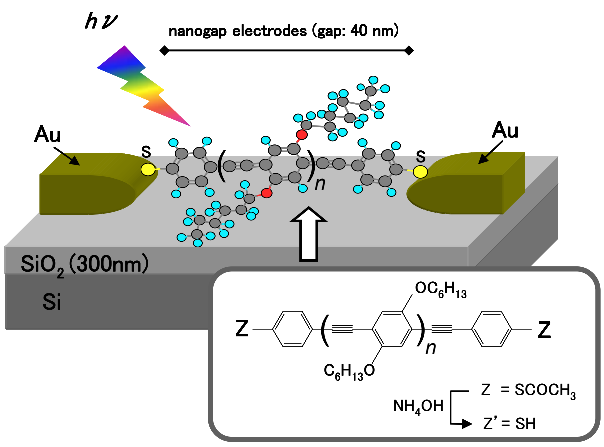


Fig. 1. Molecular structure of TA-PPE and nanodevice structure

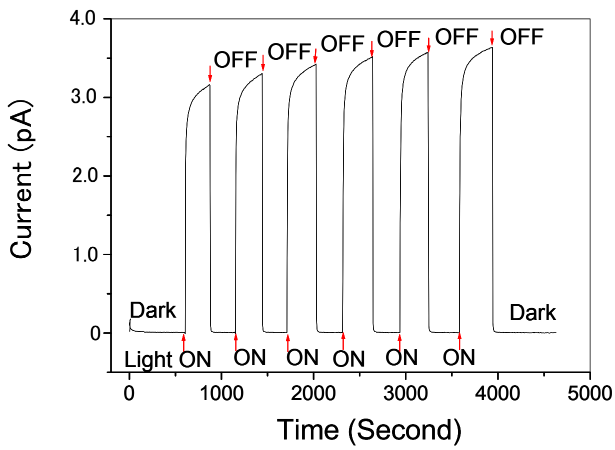


Fig. 2. Photoresponse characteristics of the nanojunction device (white light, 52 mW)

Organotypic culture techniques and study of neural toxicity

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

Organotypic slice culture technique of rat hippocampus is very important tool to study the physiological and pharmacological properties of neuron and neuronal circuits. Because the slices retain the cytoarchitecture and neuronal circuits of the tissue and because they are relatively easy to prepare, it is one of the best materials to study long-term studies of neuronal network. In epileptic animal models and human temporal lobe epilepsy, many studies have reported that the CA1 and CA3 sectors of the hippocampus are susceptible to neuronal cell death. However, little attention has been paid to neuronal cell death in CA2 sector.

In this study, we applied the rat hippocampal slice culture technique to test whether the CA2 sector is more resistant than other sectors to chronic stimulation with bicuculline (BiC), a $GABA_A$ receptor antagonist [1][2]. The results indicated that selective neuronal cell death in the CA2 sector is induced by exposure to BiC for 12 h (Fig. 1A). After 24 h, cell death was observed in an extended area, predominantly in the CA3 sector. We investigated the type of voltage dependent calcium channel (VDCC) involved in the cell death. It was revealed that the neuronal cell death process involves a Ca^{2+} influx (Fig. 1B) via P/Q-type VDCC [1].

[1] C. Han, N. Kasai, K. Torimitsu, Neuroreport **16** (2005) 333-336.
[2] C. Han, N. Kasai, K. Torimitsu, Bul. JSN. **42** (2003) 238.

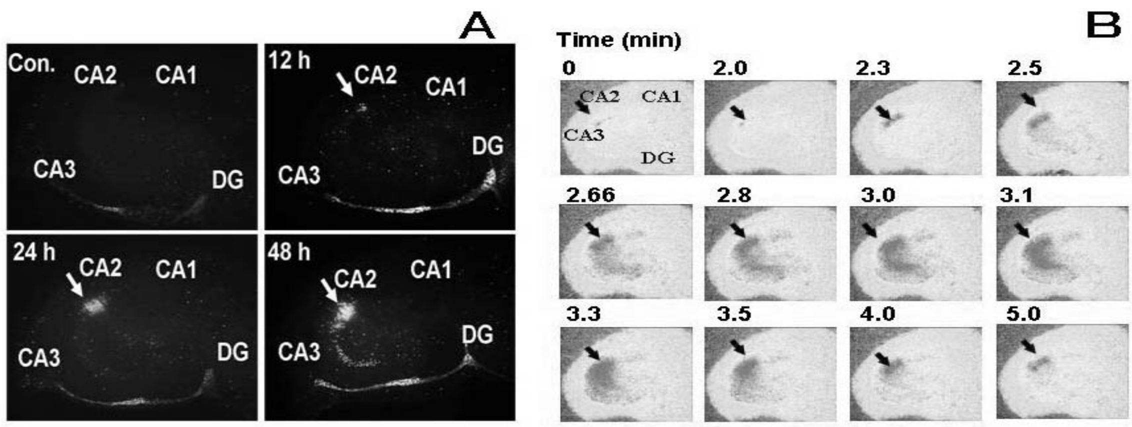


Fig. 1. Time- and region-dependent neuronal cell death (A) and Ca^{2+} influx (B) were induced by exposing the hippocampal slice cultures to BiC.

First-principles Study of Interfacial Reaction Mechanism during Silicon Thermal Oxidation Process

Hiroyuki Kageshima and Masashi Uematsu
Physical Science Laboratory

Silicon thermal oxide films are essential elements in fabricating silicon-based devices as well as even in future silicon devices. We have been studying the unified understanding on the mechanism of the silicon thermal oxidation process so as to control the process precisely in the atomic scale.

The oxidation process is generally thought to consist of two sequential processes; the oxygen diffusion process through the covering oxide films and the oxygen reaction process with the silicon substrate at the interface. However, we think the oxygen reaction process should be further classified in two processes; oxygen incorporating process with the substrate and the strain releasing process by the structural transformation. Our picture is supported by recent isotope experimental results, which show the back flow of some reduction species from the interface into the oxide [1].

For the oxygen incorporation process, first principles studies have revealed that there are not so high reaction barriers as expected by the general understandings (Fig. 1) [2]. Thus, this process does not necessarily govern the interfacial reaction speed. This is because the bonds of the oxygen molecule and of the Si substrate do not completely break through the incorporation process.

For the strain releasing process, first principles studies have revealed that the high-density oxide regions with oxygen vacancies (Fig. 2) formed at the interface play important roles [3]. Even though these regions accompany the oxygen vacancy, there is no broken dangling bond but only the covalent bonds, being consistent with experimental quite low densities of electric and magnetic defects. These regions can be regarded as regions with interstitial SiO molecules, being consistent with the isotope experiments mentioned above.

[1] S. Fukatsu et al., Appl. Phys. Lett. **83** (2003) 3897.
[2] T. Akiyama and H. Kageshima, Surf. Sci. 576 (2005) L65.
[3] H. Kageshima et al., Jpn. J. Appl. Phys. **43** (2004) 8223.

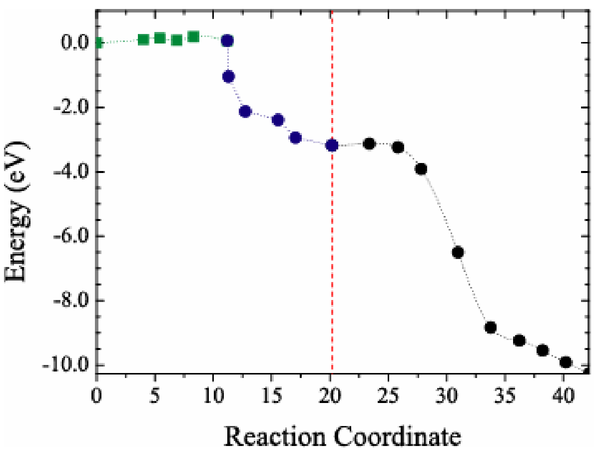


Fig. 1. Energy profile in the oxygen incorporation process into the substrate

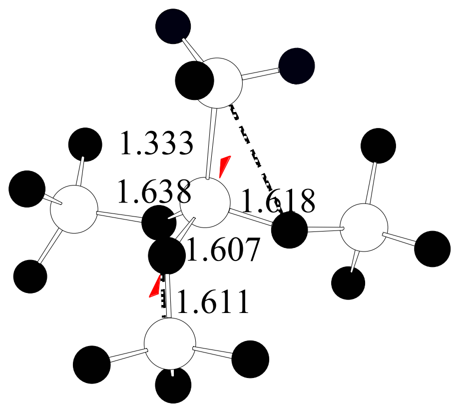


Fig. 2. Structure of high-density oxide regions with oxygen vacancies

Room-temperature single-electron transfer and detection with silicon nanodevics

Katsuhiko Nishiguchi, Akira Fujiwara, Yukinori Ono, Hiroshi Inokawa, and *Yasuo Takahashi
Physical Science Laboratory, *Present address: Hokkaido university

Single-electron devices (SEDs) have great attention because of their ultra-low power consumption. The single-electron turnstile, which transfers electrons one by one, is a member of the SED family and is a promising device for an architecture which treats one electron. This architecture requires precise control of electron movement and accurate detection of single electrons. Although various studies demonstrated these two key points, the operation temperature has remained quite low because the devices were not small enough to prevent thermal energy disturbing electron movement and to gain sufficient sensitivity for single-electron detection.

We thus proposed the silicon nanodevices which can transfer and detect single electrons and fabricated them on a silicon-on-insulator (SOI) (Fig. 1) [1]. The single-electron turnstile is composed of two wire-FETs. A single-electron box (SEB) is electrically defined between FETs. By turning on FET1 and FET2 alternately, the single electron is transferred to the memory node (MN) through the SEB (the inset of Fig. 2). One transfer cycle for injecting the single electron in the MN is composed of four steps shown in the inset of Fig. 2 [2]. By repeating the transfer cycles, the electrons are transferred one by one. The single electrons transferred into the MN are detected by an electrometer capacitively coupled to the MN. The electrometer is carefully positioned close to the MN so that the sensitivity of the electrometer is high enough to detect single electrons in the MN [3].

Figure 2 shows changes in the electrometer current when transfer cycle was repeated. Current change per transfer cycle was caused by one electron transfer. The size reduction of the SEB and optimized operating conditions allowed the single-electron transfer and detection at room temperature. The present device using FETs for the electron transfer and storage achieves high-speed transfer (<10ns) and long retention (>10^4s). We also demonstrated that the present device could serve as a multi-level (5 bit) single-electron memory [1].

[1] K. Nishiguchi, et al., International Electron Devices Meeting (IEDM) (2004) 199.
[2] A. Fujiwara, et al., Appl. Phys. Lett. **84** (2004) 1323.
[3] K. Nishiguchi, et al., Appl. Phys. Lett. **85** (2004) 1277.

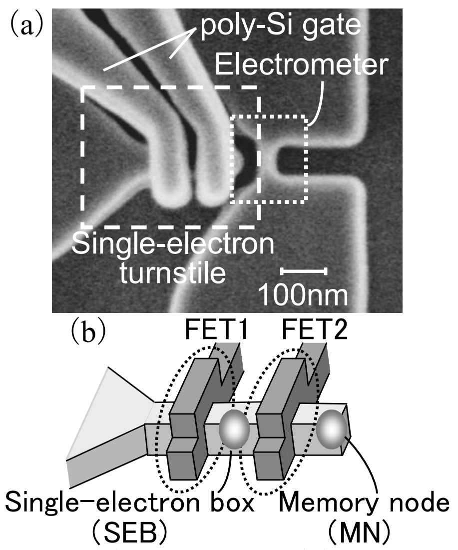


Fig. 1. (a) SEM image. (b) Schematic view of the single-electron turnstile.

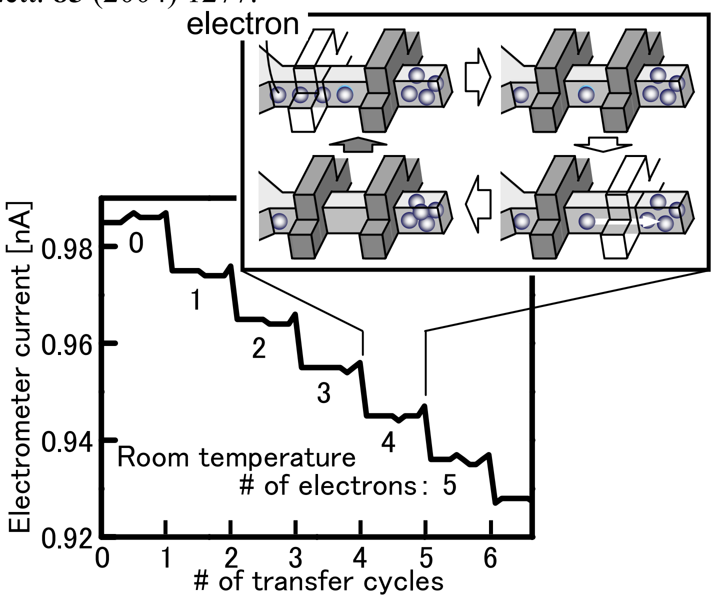


Fig.2. Single-electron transfer and detection

Integrated carbon multi-probe with nano-spring on Si cantilever

Masao Nagase
Physical Science Laboratory

Multi-probe systems based on scanning probe technology are expected to become a powerful tool for measuring electrical properties in high resolution. We have demonstrated a feasibility of a new multi-probe system. Four carbon probes with nano-springs have been integrated on a silicon cantilever with aluminum electrodes by using focused-ion-beam chemical-vapor-deposition (FIB-CVD) technique. Diamond like carbon (DLC) deposited by FIB-CVD is known to be stiff and conductive. These properties are suitable for electrical probes. Recently, Matsui et al. have demonstrated the fabrication of the coil spring structure using FIB-CVD technique. [1] The nano-springs are expected to compensate for the height difference between the probes which are not adjustable in conventional probe systems. [2]

Figure 1 is a schematic and microphotographs of four carbon probes on a Si cantilever. The three-dimensional FIB-CVD structures are fabricated by SMI2050 (SII-NT) in Univ. of Hyogo. [1] The height of the probe with nano-spring is about 10μm. The diameter of the probe is 110 nm. The coil diameter of the nano-spring is 380 nm. Figure 2 shows the electrical contact characteristics between the conductive sample and one of the probes. The origin of the displacement axis is the set point for AFM imaging in contact mode. The triangle mark (contact height) indicates that this probe establishes electrical contact with the sample at 580 nm. Since the displacement of the Si cantilever is about 200 nm at the set point, the nanospring is shortened by about 400 nm. Every probe contacts the sample surface even if the heights of probes are different, because the probe can shorten freely. Therefore, the nano-springs compensate for any height differences. The mechanical characteristics are also confirmed in a tensile test of the nano-spring grown on a conventional Si cantilever. The shear modulus of the nanospring is estimated to be almost the same as that of the conventional steel spring. Since no deformation of the FIB-CVD probes is observed after imaging by atomic force microscopy (AFM) in contact mode, the stiffness of the probes is sufficiently high.

Combining scanning probe technology and focused ion beam technology will open a new area of micro- and nano-electromechanical systems.

[1] S. Matsui et al., J. Vac. Sci. & Technol. B 18 (2000) 3181.
[2] M. Nagase et al., Jpn. J. Appl. Phys. 42 (2003) 4856.

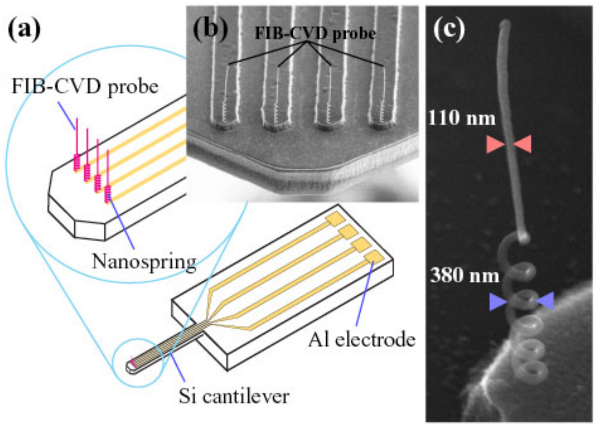


Fig. 1. (a) Schematic of four-point -probe on Si cantilever. (b) SEM micrograph of integrated FIB-CVD multi-probe. (c) Magnified image of carbon probe with nano-spring on Al electrode.

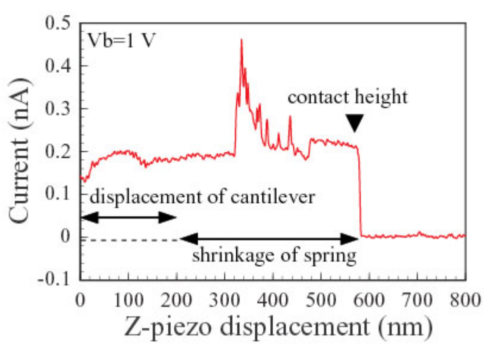


Fig. 2. Displacement dependence of probe current. Voltage of the sample (Au film) is 1V.

Force/Displacement Detection Using Electron Interference

Hiroshi Yamaguchi and Yoshiro Hirayama
Physical Science Laboratory

Ultra-small force and displacement have been detected using a small bar, clamped at one end like a diving board, known as a cantilever. It is already used in practical systems, such as in the pickups for analog disks, atomic force microscopes, and the accelerometers of automobile airbag systems. Especially, the micron-scale cantilevers play essential roles in the technology using microelectromechanical systems (MEMS), which has made rapid advances in the last few years. For detecting the cantilever deflection, both optical and electrical methods are widely used. Optical methods, such as optical levers and laser interferometers, offer higher detection sensitivity than electrical ones. They have been recently used even for the detection of single spins [1]. In contrast, electrical methods are advantageous for downscaling and integration. In addition, we could strongly enhance the detection sensitivity in piezoresistive cantilevers, which is one of the most important electrical methods, using the quantum effects in semiconductor low-dimensional structures.

At low temperatures, electrons exhibit wave-like behavior, so they can be used for highly accurate sensing just like the photons in a laser interferometer. We have succeeded in detecting the displacement of a micromechanical cantilever by using electron interference [2]. The device used was an InAs/AlGaSb pieozoresistive cantilever with the thicknesses of conductive InAs and insulating AlGaSb films of 15 nm and 285 nm, respectively. A scanning electron microscope image of a typical fabricated device is shown in Fig. 1. The resistance change induced by the cantilever deflection was measured under a magnetic field (Fig.2). The magnetic field was used to adjust the phase differences among different electron paths in the InAs films. The resistance change, i.e. the cantilever deflection sensitivity, has a strong and aperiodic *B* dependence, which was reproducible in repeated measurements. At 6.9 T, the resistence change had a maximum value, which was nearly one order of magnitude larger than that at zero magnetic field. This clearly demonstrates the possibility of highly sensitive quantum mechanical displacement sensing, which is promising for future micromechanical cantielver applications.

[1] D. Ruger et al., Nature **430** (2004) 329.
[2] H. Yamaguchi et al, Phys. Rev. Lett. **93** (2004) 036603.

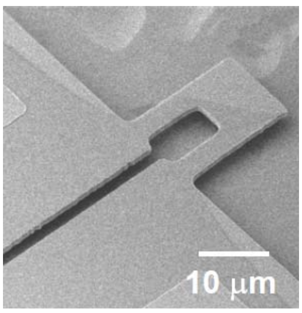


Fig. 1 SEM image of a fabricated piezoresistive cantilever.

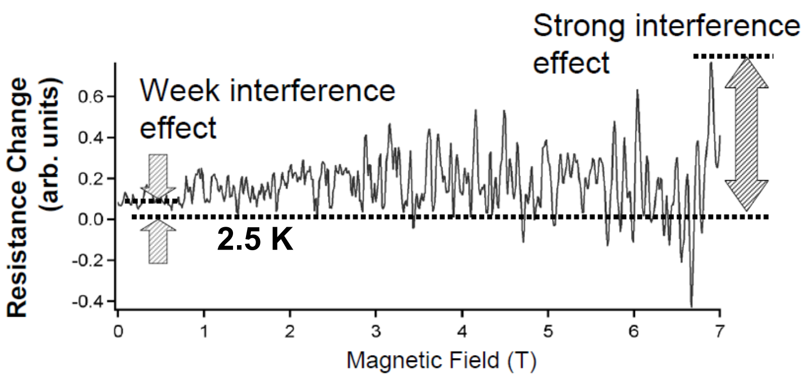


Fig. 2 Measured resistance change as a function of magnetic field.

Landau-level hybridization and the quantum Hall effect in InAs/GaSb electron-hole systems

Kyoichi Suzuki, Kei Takashina, and Yoshiro Hirayama
Physical Science Laboratory

In InAs/GaSb heterostructures, the conduction band in InAs and the valence band in GaSb overlap. Consequently, a two-dimensional electron gas (2DEG) in the InAs and a two-dimensional hole gas (2DHG) in the GaSb can coexist in close proximity. A unique quantum Hall effect (QHE) has been known to occur in these structures where the Hall resistance is quantized by the difference between2DEG and 2DHG Landau-level (LL) filling-factors (ν_e, ν_h). Its mechanism had yet to be clarified, and had been thought to be a complex combination of QHE arising in both 2DEG and 2DHG.

We clarified the mechanism using back-gated structures (Fig. 1) and detailed magneto-transport measurements. The samples consisted of an InAs 2DEG layer on the surface side and a GaSb 2DHG layer on the substrate side. We succeeded in controlling the 2DHG density with the gate voltage, while keeping the 2DEG density constant by the surface potential. Changing the thickness of the inserted AlSb layer between the InAs and GaSb layers, which works as a potential barrier for both 2DEG and 2DHG, the hybridization strength between 2DEG and 2DHG wavefunctions can be controlled. Under magnetic field, in samples without wavefunction hybridization, the electron and hole energy levels split into LLs shown as the dashed lines in Fig. 2. In samples where wavefunction hybridization is allowed, however, LLs also hybridize (solid lines) and a new energy structure is formed, in which the region of ν_e=ν_h becomes effectively the band gap. Net carriers (difference of 2DEG and 2DHG densities) fill the hybridized LLs above the band gap. Therefore, conventional 2DEG-like QHE occurs, according to the net carrier density.

We believe our results will become useful for realizing new physics phenomena reflecting electron-hole interactions and correlations, such as Bose-Einstein condensation of the dipole excitons, and contribute to the development of mid-infrared device applications using inter-subband transitions and inter-layer tunneling.

[1] K. Suzuki et al., Phys. Rev. Lett. 93 (2004) 016803.

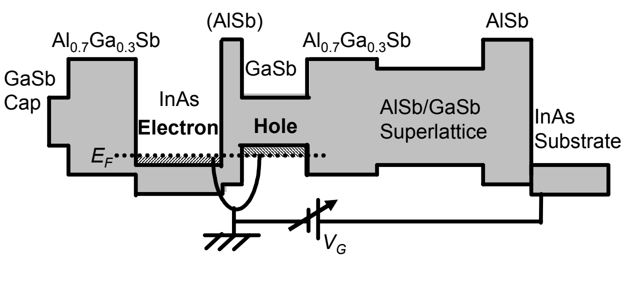


Fig. 1. Sample potential profile

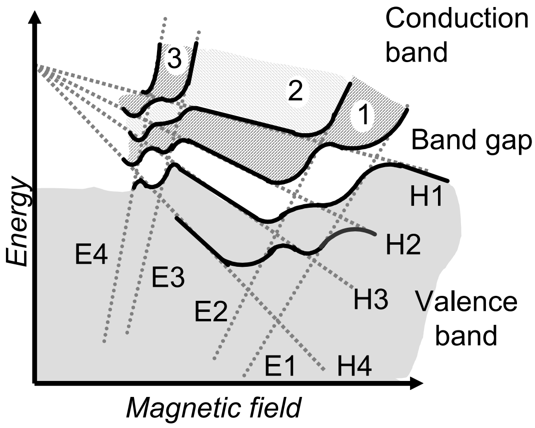


Fig. 2. Landau-level hybridization
Dashed lines: Electron and hole Landau -levels without hybridization.
Solid lines: Hybridized Landau-levels.

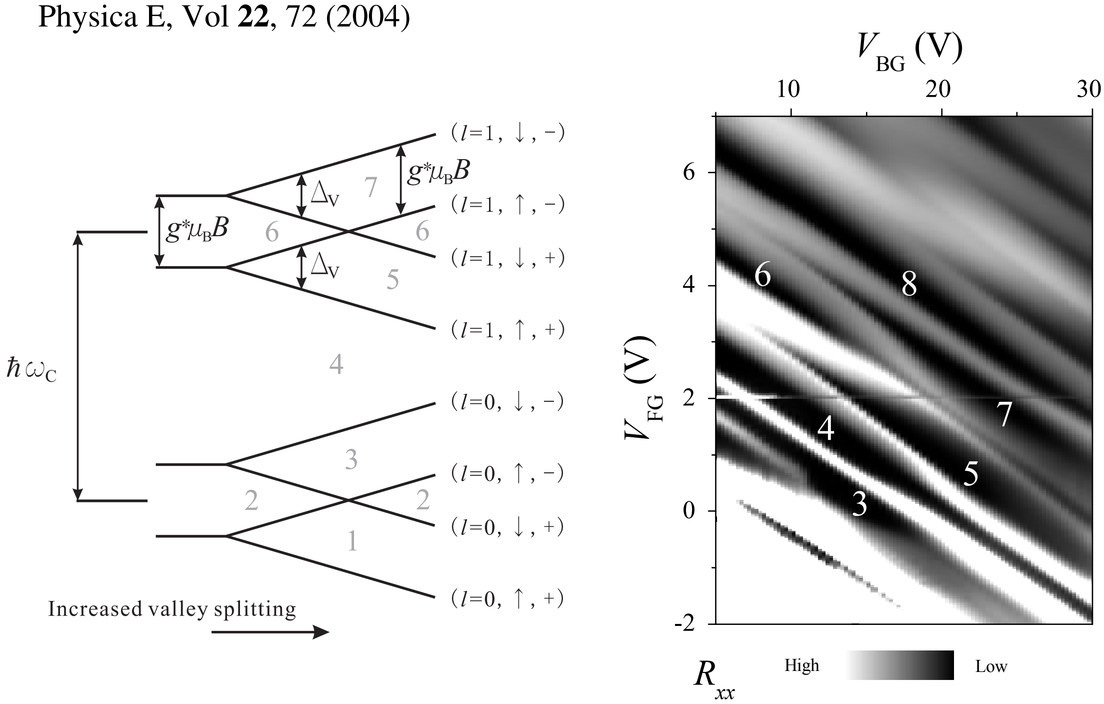
Controlled Valley Splitting in $SiO_2/Si/SiO_2$ Quantum Wells

Kei Takashina, Akira Fujiwara and Yoshiro Hirayama
Physical Science Laboratory

Besides being of immense technological importance, electrons in silicon offer a number of unique possibilities for exploring new physical conditions and new phenomena. One of these arises due to their bulk dispersion relation where there are six, energetically degenerate conduction band valleys. In (100) Si-MOSFETs where electrons are two-dimensionally confined, this six-fold degeneracy is lifted, due to anisotropic effective mass, to leave only two low lying valleys available for occupation. 2-D electrons in such structures consequently have freedom as to how they occupy these degenerate valleys giving them a valley degree of freedom on top of in-plane motion and spin.

In the present study, we have been able to show that valley-splitting, which lifts this remaining two-fold valley degeneracy can be controlled over an unprecedented extent using SOI (Silicon-On-Insulator) MOSFETs. These structures consist of silicon sandwitched between layers of SiO_2 forming $SiO_2/Si/SiO_2$ quantum wells. Since there are two Si-SiO_2 interfaces present in such structures, by using interfaces with different properties, electronic properties can be readily tuned by shifting the wavefunction between them. Here, we have used SIMOX (Separation by IMplantation of OXygen) MOSFETs where we find the valley-splitting to be strongly enhanced at the Si-buried oxide interface. The valley splitting can therefore be tuned, simply by adjusting front and back gate voltages to shift the wavefunction between the interfaces with small and large valley splitting [1,2].

[1] T. Ouisse, D.K. Maude, S. Horiguchi, Y. Ono, Y. Takahashi, K. Murase and S. Christoleanu, Physica B, **249-251**, 731 (1998)
[2] K. Takashina, A. Fujiwara, S. Horiguchi, Y. Takahashi, Y. Hirayama, Phys. Rev. B, 69, 161304(R), (2004), K. Takashina, Y. Hirayama, A. Fujiwara, S. Horiguchi, Y. Takahashi, Physica E, Vol **22**, 72 (2004)



Left: A schematic diagram of Landau levels with increased valley-splitting.
Right: Longitudinal resistance at 11T. Numbers indicate filling factors associated with quantized Hall states.

Single-Electron Counting of Electrical Current

Toshimasa Fujisawa
Physical Science Laboratory

Electrical current is widely used in various electronic systems, and is one of the fundamental measurement for electron transport phenomena. However, the minimum detectable current is remained at around 10^5 – 10^6 electrons/sec. Recent development in nanotechnology research enables us to manipulate single electron in a small conductive island (quantum dot). More recent activities are devoted to some applications, such as single-electron transistors and memories, as well as physical interests on electronic states in quantum dots. In this study, we have succeeded in observation of each electron tunneling events through a quantum dot in real time scale, which is expected to be applied to extremely sensitive ampere meter that counts how many electrons has passed through a device.

In this work, we prepare two quantum dots (the upper one and the lower one) coupled electrostatically, and the current through the upper dot can be detected with a change in the current through the lower dot [1]. Electron counting can be realized since the current through the lower dot decreases (increases) when an electron enters (leaves) the upper quantum dot. The device used in this study is shown in the SEM picture of Fig. 1. Two quantum dots (denoted by circles) embedded in isolated two electrical channels is fabricated in AlGaAs/GaAs modulation-doped heterostructure by etching process (dark regions) and fine Schottkey gates (bright vertical lines). We feed a small current through the upper quantum dot, and tunneling events can be measured with the conductance through the lower dot. In order to improve the frequency band width, high-frequency carrier signal (660 MHz) is introduced, and the transmitted signal is amplified with LC resonator and detected with a mixer. The output voltage, V_{det}, is proportional to the conductance of the lower dot.

Figure 2(a) shows typical time dependent signal V_{det}, when the upper quantum dot is adjusted at the Coulomb blockade (CB) condition and at the single-electron tunneling (SET) condition. Binary switching signal is appeared in the SET condition, and double peak feature is observed in the histogram of V_{det} taken with a loger period (shown in Fig. 2(b)). Therefore, we are able to determine when an electron enter the upper dot (denoted by white circles in Fig. 2(a)) and when an electron escape to the electrode (solid circles). In this case, there are five tunneling events within the 10 ms period, corresponding to 0.08 fA of current. We expect to develop an electron counting device for either current direction in future.

[1] T. Fujisawa et al., Appl. Phys. Lett. 84, 2343 (2004).

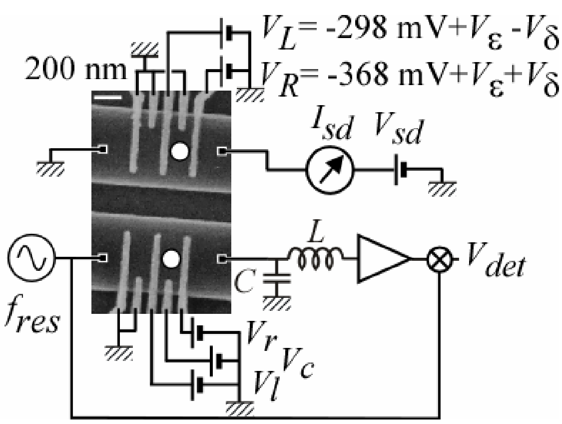


Fig. 1. Measurement system and an electron counting device.

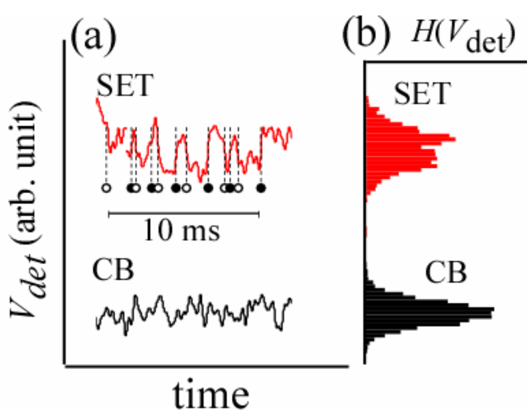


Fig. 2. Single-electron counting (SET) and background noise (CB)

Fast control of qubit coherence with phase shift method

Hirotaka Tanaka, Tatsuya Kutsuzawa, Shiro Saito
Physical Science Research Laboratory

A superconductor ring with Josephson junctions behaves as quantum 2-level system and is expected to be a candidate for a quantum bit (qubit), which is a key ingredient of quantum computer(Fig. 1). We controlled and measured the quantum coherence of this ring using two sequential microwave pulses with phase shifted. This ring has two different states of opposite directions of current flowing in clockwise and anti-clockwise and shows the quantum superposition of these states. The size of the ring is about 10 μm, which is much larger than that of atoms or molecules but it still shows quantum nature of 2-level system. We experimentally confirmed that the ring shows quantum superposition between |0> and |1> states. The quantum superposition in a macroscopic scale object is sometimes called Schrödinger's cat.

We utilized phase shift method, which uses simultaneous phase-pulse modulation of microwave pulses. Two sequential microwave pulses are applied to the ring with frequency of 11.4 GHz and duration of 5 ns. The phase of the pulses is continuously shifted. The first pulse makes the state of the ring superposition of |0> and |1>. (The point on the equator in the sphere in Fig. 2) The state of the ring has its phase coherence depending on the phase of the first pulse. Then second pulse transforms the state of the ring depending on the phase of the second pulse. (The point on the equator, north and south pole in the sphere in Fig. 2)

We experimentally showed the fast and effective quantum coherent control with the phase shift method[1]. It can be applied also to Hadamard gate, which is an important gate operation in quantum computation. In addition, the phase shift method allows us to choose optimum pulse sequences in a 2-qubit system for fast and effective operations.

[1] T. Kutsuzawa, et al., Appl. Phys. Lett. **87**, (2005): (accepted). ArXiv : cond-mat/0501592.

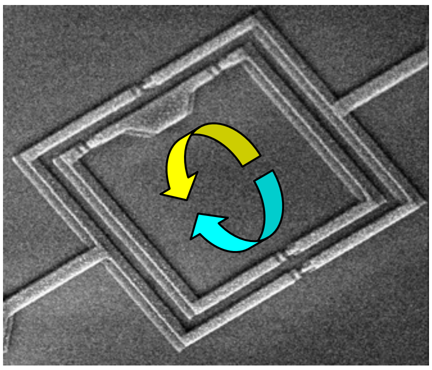


Fig. 1 Scanning electron microscope picture of superconductor qubit. Inner squared loop is a qubit and outer is a DC-SQUID(Superconducting quantum interference device) for readout.

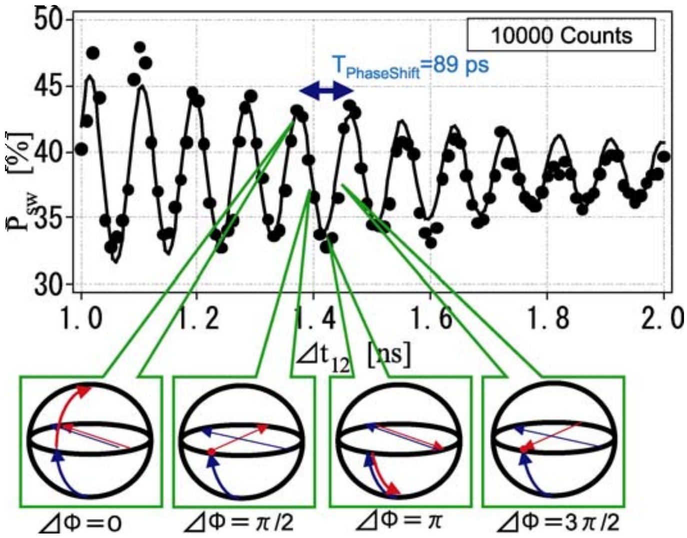


Fig. 2 Qubit state measurement with two pulses applied. The state is oscillating by the relative phase of the microwave pulses.

Quantum Computation with Neutral Atoms

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Physical Science Laboratory
*NTT Research Professor and University of Electro-Communications

Neutral atoms are promising candidate to realize quantum gates. The advantage of using neutral atoms for quantum computation is as follows. 1) We can make arbitrary amplitude distribution among internal states with laser light. Therefore, single-qubit operations are easy and accurate. 2) Two qubits operations are possible with atom-atom interactions or indirectly via an auxiliary quantum system. 3) Disturbance from external fields to neutral atoms is relatively weak, and decoherence time is very long. 4) All atoms are identical and we can expand number of qubits without taking care of the characteristics of individual qubits. 5) We can fill qubit locations with few defects from Bose-Einstein Condensate (BEC). However, the progress of neutral-atom quantum computer is slow because implementation of all necessary functions in a system is not easy.

Recent progress in laser cooling of atoms enables us to cool down atomic samples to a temperature below one micro-Kelvin and to make 2- or 3-dimensional array of neutral atoms. Employing high-quality micro-fabrication technology and our experiences in laser and efficient evaporative cooling for making BEC [1], we are trying to develop a model quantum computation system with ultra-cold neutral atoms.

In the first project we plan to use 2-dimensional magnetic trap arrays. It consists of micro-fabricated Z-shaped wires on a silicon surface. To realize an array of single atoms in the ground vibrational state and to ensure atom-atom interaction we have to reduce the distance between atoms and surface. This short distance introduces extra potential noises and short decoherence time. We are trying to overcome this problem with super-conducting wires on silicon substrate (Atom Chips).

In the second project we use an optical lattice. We have proposed a scheme to realize a scalable quantum computer with double optical lattices [2]. Employing this scheme we can compose an universal quantum computer with complete scalability and we hope to achieve a practical quantum computer with more than 1000 qubits operating together. We are trying to implement the double optical lattices scheme to a real system.

[1] T. Mukai and M. Yamashita, Physical Review A **70** (2004) 013615.
[2] F. Shimizu, Japanese Journal of Applied Physics **43** (2004) 8376.

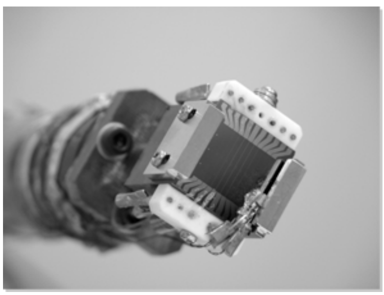


Fig. 1. Sample Atom Chips

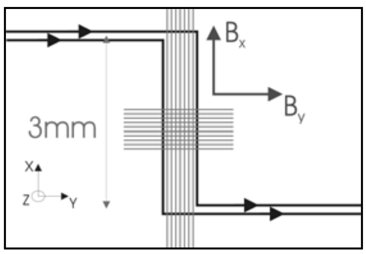


Fig. 2. Pattern of wire

Fig.3. Double Optical Lattice

Spin Interferometer by the Rashba Spin-Orbit Interaction

Y. Sekine[1], T. Koga[1,2,*], and J. Nitta[1,3,‡]
Physical Science Laboratory[1], PRESTO JST[2], CREST JST[3]

Experimental demonstration of an electric-field-controllable spin interferometer is reported. In this study, we focused on the spin degree of freedom rather than the charge degree of freedom used in conventional semiconductor devices. The electron spin is usually controlled by a magnetic field; however, it has been demonstrated that the electron spin precession can be controlled by an electric field. These results are the first step towards new functional devices that utilize the spin degrees of freedom of electron.

A key to controlling electron spin in a semiconductor is the Rashba spin-orbit interaction, which makes it possible to control the spin precession by an electric field. Figure 1(a) shows a scanning electron microscope (SEM) image of the semiconductor spin interferometers. An array of square loops was fabricated by the electron beam lithography and a dry etching technique. The lighter region contains the electron path, and a typical path is outlined by the black square. Figure 1(b) shows a schematic view of the sample. The entire sample is covered with a voltage-gate electrode, which makes it possible to control the spin precession due to the Rashba spin-orbit interaction. The Al'tshuler-Aronov-Spivak (AAS) oscillations were observed to investigate the angle of the spin precession. Two partial electron waves that travel along the four sides of the square in the clockwise and the counter-clockwise directions interfere each other. Due to the Rashba spin-orbit interaction, the spin precession occurs as these waves pass through the square loop. The interference depends on the difference of the angle of the spin precession. The gate voltage, V_g, dependence of the AAS oscillation amplitude is shown in Fig. 2. With increasing V_g, the sign of the conductivity, σ_{xx}, without a magnetic field, B, changes from minus to plus. These results show that the electron spin interference is realized by the electric-field-controllable spin precession.

[1] T. Koga, J. Nitta, M. van Veenhuizen, Phy. Rev. B **70**, 161302(R) (2004).
Present Address: Graduate School of Information Science and Technology, Hokkaido University*, Graduate School of Engineering, Tohoku University‡.

Fig. 1
(a)
(b)

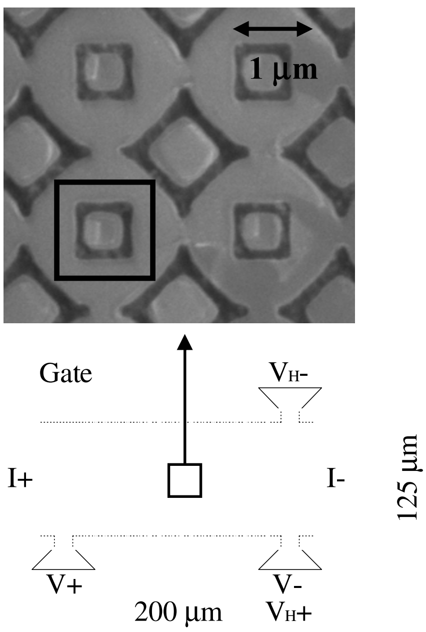


Fig. 2

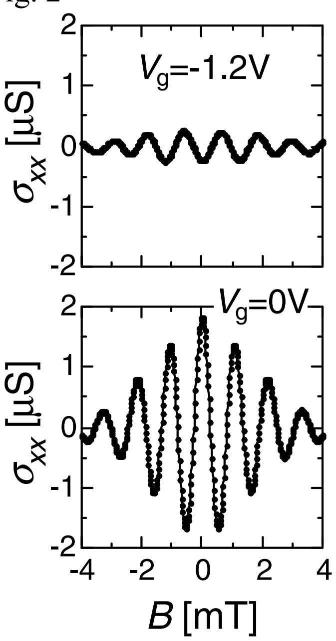


Fig. 1. (a) A SEM picture of the spin interferometers. The black square represents a typical electron path. (b) A schematic view of the sample. The entire sample is covered with a voltage-gate electrode.

Fig. 2. The gate voltage dependence of the AAS oscillations. The sign of σ_{xx} at B=0 changes from minus to plus. The electric-field-controllable spin precession results in the modulation of the spin interference.

Electron-Spin Control based on RKKY Interaction

Hiroyuki Tamura
Physical Science Laboratory

We theoretically proposed a method to control electron-spin state electrically by tuning a magnetic interaction between local spins confined in quantum dots and conduction electrons in semiconductors [1]. When quantum dots confining electrons are coupled to conducting semiconductors, the conduction electron can jump into and out of the quantum dot and interact with the confined electron in it. This process induces an antiferromagnetic interaction between the confined electron and the conduction electron. When two quantum dots are coupled to the conducting semiconductor as shown in Figure, the conduction electron can go back and forth between two dots. If the distance of two dots is much smaller than the Fermi wavelength, the conduction electron can travel without losing spin orientation and the localized spins in dots are aligned in the same direction, which results in a ferromagnetic interaction known as Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction. Since the degradation of spin orientation depends on the electron density in the conduction region, one can tune the spin state both in parallel and anti-parallel way by changing gate voltages.

The key for electric control of spins is the artificial magnetic impurities formed in the quantum dots and the tunable electron-density in semiconducting materials. These features make it possible to realize a new type of spintronics device.

By utilizing the RKKY interaction, one can expect to achieve ferromagnetism in an array of semiconducting quantum dots where all the spins are aligned in the same direction. Experimental search for detecting the RKKY interaction between dots has already started [2], which will help to prove our theoretical prediction.

[1] H. Tamura, K. Shiraishi, and H. Takayanagi, Japan Journal of Applied Physics **43** (2004) L691-693.
[2] N. J. Craig, J. M. Taylor, E. A. Lester, C. M. Marcus, M. P. Hanson, and A. C. Gossard, Science **304** (2004) 565-567.

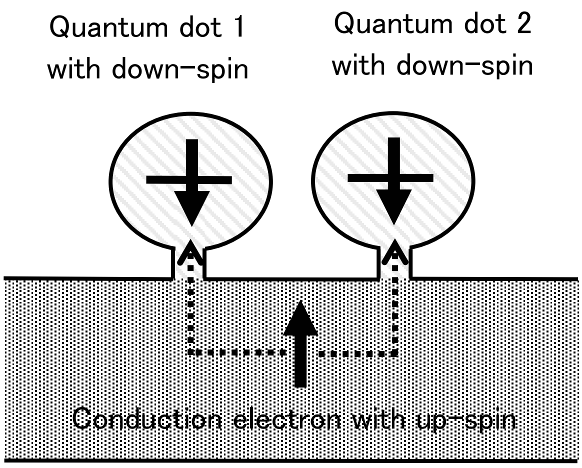


Figure: Two quantum dots coupled to the conduction electron system. Electron spins in two dots are aligned in the downward direction when the conduction electron with opposite (up) spin jumps back and forth between two dots.

Generation of telecom-band polarization entangled photon pairs using spontaneous four-wave mixing in dispersion-shifted fiber

Hiroki Takesue
Optical Science Laboratory

Generation of entangled photon pairs in the 1.5 μm band is one of the important technological challenges for realizing quantum communication over optical fiber networks. We have succeeded in generating polarization entangled photons in the wavelength band, by using spontaneous four-wave mixing (SFWM) in a loop formed with a polarization beamsplitter (PBS) and a dispersion-shifted fiber (DSF).

Fig. 1 shows the configuration. A pump pulse with a 45 ° linear polarization is input into the loop. The PBS divides the pump into horizontal (H) and vertical (V) polarization components. The H and V components generate signal-idler photon pairs $|H\rangle_s|H\rangle_i$ and $|V\rangle_s|V\rangle_i$ through a SFWM process while propagating in the loop in the counter-clockwise and clockwise directions, respectively. These two product states are superposed at the PBS output, the pump is then suppressed, and a polarization entangled state $(|H\rangle_s|H\rangle_i + |V\rangle_s|V\rangle_i)/\sqrt{2}$ is obtained. The loop configuration makes it possible to stabilize the relative phase between two product states without any feedback control, and so our system is both simple and stable.

We confirmed the feasibility of our method experimentally. We used fiber-Bragg gratings (FBG), an arrayed waveguide grating (AWG) and bandpass filters (BPF) to suppress the pump and separate the signal and idler photons. The signal and idler photons were polarization-controlled and input into polarizers, and detected using avalanche photo diodes (APD). We undertook two-photon interference experiments, and obtained coincidence fringes with >90 % visibilities, which is shown in Fig. 2. We then observed a violation of Bell's inequality by seven standard deviations. We also confirmed the preservation of the quantum correlation between the photons even after they had been separated by 20 km optical fiber.

This result is an important step toward highly sophisticated quantum communication networks over optical fiber.

[1] H. Takesue and K. Inoue, Phys. Rev. A, 70, 031802(R) (2004).

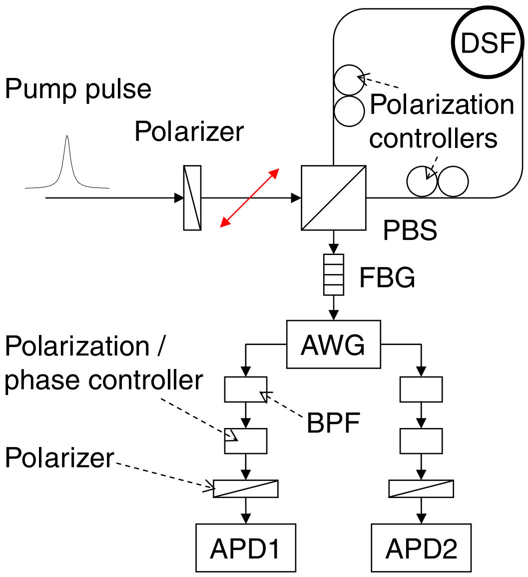


Fig. 1. Configuration

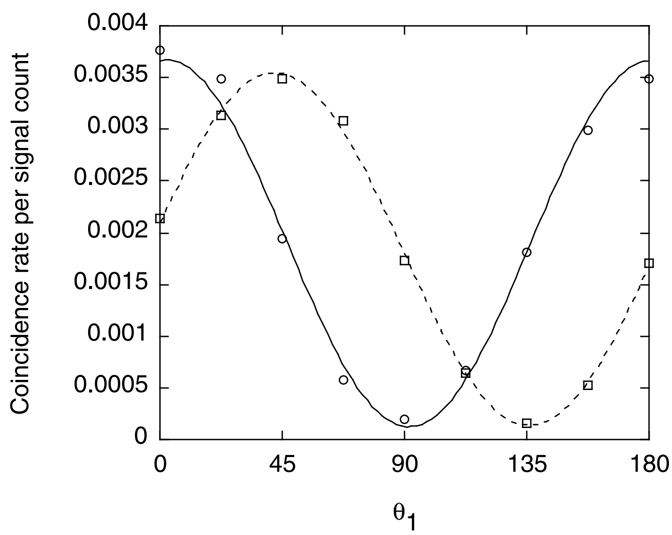


Fig. 2. Coincidence fringes

Differential-phase-shift quantum key distribution experiment

Toshimori Honjo and Kyo Inoue
Optical Science Laboratory

Quantum key distribution (QKD) has been studied as a way to realize unconditionally secure communications. We proposed a new QKD scheme called a differential-phase-shift QKD (DPS-QKD). This scheme has several advantages including suitability for fiber transmission. This study demonstrates a feasibility of DPS-QKD by using a glass waveguide interferometer.

Fig. 1 shows the experimental setup. The signal source was an external-cavity laser diode(λ=1551 nm). Cw light from the laser was converted into a pulse stream by an intensity modulator, and then was randomly phase-modulated for each pulse by $\{0, \pi\}$. The pulse width was 125 ps and the repetition rate was 1GHz. The light power was attenuated to be 0.1 photons per pulse. After 20-km fiber transmission (4.46-dB propagation loss), the light passed through a glass waveguide Mach-Zehnder interferometer packaged with fiber ports. The path-length difference was 20 cm, which introduced one-bit delay of 1 ns at 1 Gbit/s. The waveguide is made of silica glass by using PLC (planar lightwave circuit) technology, and the excess loss of the interferometer was only 2.64dB. The polarization dependence was small, such that the extinction ratio of the interferometer ranged from 0.27% to 0.46% when the input polarization state was changed. The two outputs from the interferometer were received by APDs gated at 5 MHz. After the photon transmission, Bob told Alice the photon arriving time, from which a key was created. Since APDs had time jitter, the arrival time of photons vacillated and errors could be induced. To reduce this timing error, Bob took data within a time window, at the expense of the key generation rate. Fig. 2 shows the raw key generation rate and quantum bit error rate (QBER) for several time windows, where the polarization state was set to give the worst QBER. A sufficient QBER was obtained to create a secret key after error correction and privacy amplification.

In summary, a differential-phase-shift QKD experiment was carried out using a glass waveguide Mach-Zehnder interferometer. Stable polarization-insensitive operation was demonstrated in 20-km fiber transmission. The key creation rate was 3076bit/s with a 5.0% QBER.

[1] K. Inoue, E. Waks and Y. Yamamoto, Phys. Rev. A **67,** (2003) 022317.
[2] T. Honjo, K. Inoue and H. Takahashi, Opt. Lett. **29**, (2004) 2797.

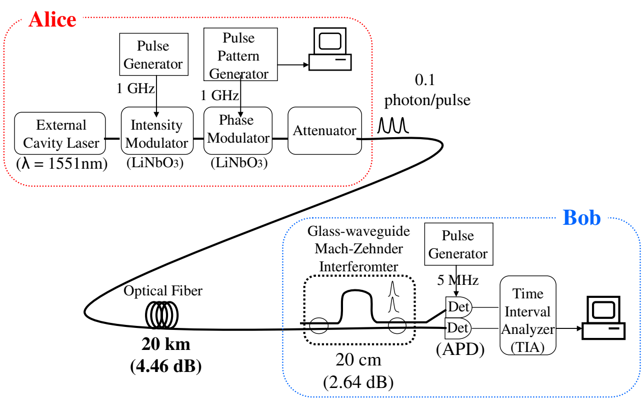


Fig. 1. Experimental setup

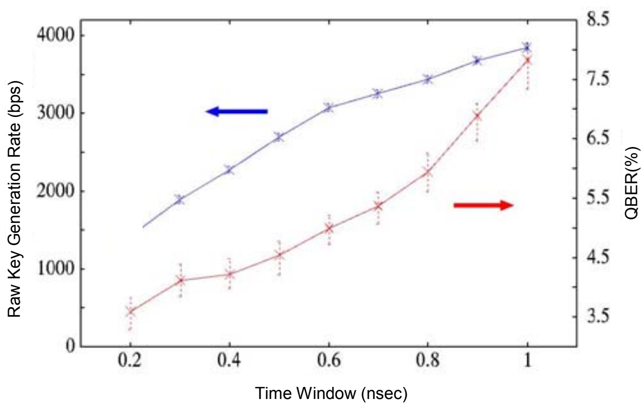


Fig. 2. Experimental results

Time-resolved EXAFS

Katsuya Oguri, Yasuaki Okano, Tadashi Nishikawa and Hidetoshi Nakano
Optical Science Laboratory

The recent development of various ultrashort x-ray-pulse sources based on high-power femtosecond lasers has stimulated progress on ultrafast time-resolved x-ray probing techniques with femtosecond or picosecond resolution. In particular, the time-resolved extended x-ray absorption fine structure (EXAFS) approach is expected to become a powerful technique for probing ultrafast structural dynamics, because EXAFS provides such structural properties as bond distance and coordination number for various materials including amorphous materials and liquids [1]. Here, we present a time-resolved EXAFS technique with picosecond resolution that employs a soft x-ray pulse emitted from femtosecond laser-produced plasma. By employing this technique, we successfully observed the time evolution of an ultrafast melted Si L-edge EXAFS induced by femtosecond laser irradiation [2].

We constructed an experimental laser-pump and x-ray probe setup based on a 100-fs Ti:sapphire laser system. Figure 1 shows an example of the absorption spectrum of Si foil. We clearly observed the $L_{II,III}$ edge at 99 eV, the L_I edge at 150 eV, and the damped oscillation, which corresponds to EXAFS, in the region of 150 – 270 eV. Figure 2 shows the time evolution of the EXAFS spectrum at various time delays, which was extracted from each absorption spectrum. We can clearly see that the oscillation amplitude decreases with a small peak shift to a lower wave number at a time delay of 0 ps while there is no great difference between the EXAFS spectra of the pumped and unpumped samples at a time delay of -330 ps. The small peak shift indicates that the oscillation period becomes shorter than that of the unpumped Si and this strongly suggests that the Si-Si atomic distance was broadened slightly by the laser excitation. We obtained a Si-Si atomic distance of 2.43 Å, which is clearly larger than the value of 2.32 Å for solid Si obtained by Fourier transformation of the data. This expansion of the atomic distance can be explained in terms of the ultrafast production of liquid Si. At a time delay of +1670 ps, the EXAFS becomes too weak for us to analyze its oscillation structure. The disappearance of the oscillation indicates the further structural disordering of Si due to the onset of evaporation from the liquid phase to the gas-like phase. This result is the first step towards establishing ultrafast time-resolved EXAFS technique.

[1] T. Lee et al., Chem. Phys. **299** (2004) 233.
[2] K. Oguri et al., Appl. Phys. Lett.**87**(2005)011503

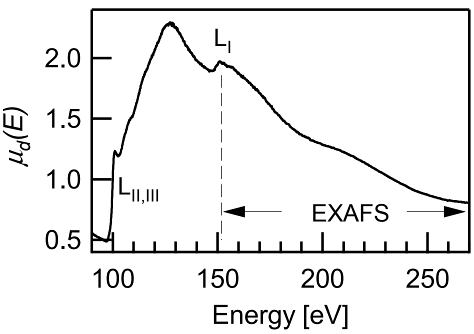


Fig. 1. Example of Si-absorption spectrum.

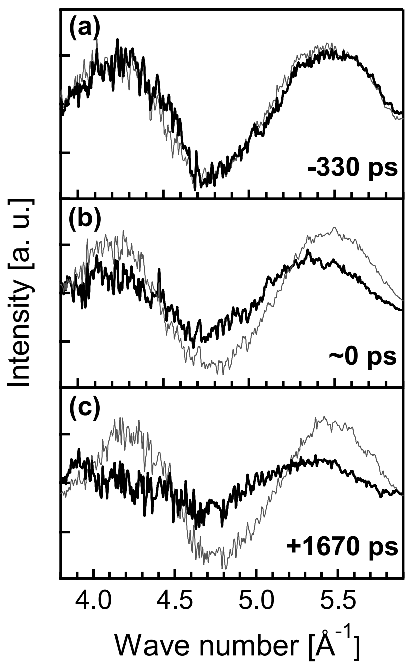


Fig. 2. Transient EXAFS spectra with (thin black line) and without (thick gray line) laser irradiation.

Exciton and Biexciton Coherent Effects in Quantum Dots

Hideki Gotoh and Hidehiko Kamada
Optical Science Laboratory

Semiconductor quantum dots have discrete density of states and exhibit strong interaction effects with light. Moreover, optically created excitons and biexcitons exist stably in quantum dots because of confinement effects from all spatial directions. These features promise possible future applications of quantum dots for quantum information processes. In quantum dots, there may be coherent interactions between excitons and biexcitons and the effects of these interactions have not yet been clearly observed. These effects provide a source of quantum correlations by exciton-biexciton interactions and a principle of optical functions by quantum interference effects.

We examined the photo-absorption properties of excitons and biexcitons in a single InGaAs quantum dot. The coherent effects may appear in these absorption properties. We employed a micro-photoluminescence (PL) method. Figure 1 shows measured absorption spectra of exciton (X) and biexciton (XX) for two excitation conditions. At a low excitation, we obtained usual peak shaped absorption spectra. However, these spectra change greatly with a high excitation. The XX spectrum has a broadened peak. In contrast, the X spectrum has an unusual dip-shaped structure. Figure 2 reveals the physical origin of the unusual spectrum. The figure shows the energy level structure for the measurement result. The energy structure is a coherently interacting three-level system with ground, exciton and biexciton states. This structure varies greatly with excitation. With a high excitation, the exciton and biexciton states split due to Rabi oscillation between the exciton and biexciton states. This causes the exciton state to vanish resulting in the dip-shaped exciton absorption. This Rabi oscillation is a coherent effect and our result confirms that there is a strong coherent effect in the exciton and biexciton states.

Our results are an important step towards achieving a quantum two-bit gate with an exciton and a biexciton. Moreover, this provide a possible way to demonstrate optical device functions with quantum interference effects.

[1] H.Gotoh, et al., Appl. Phys. Lett. **85** (2004) 3480.
[2] H.Gotoh, et al., Phys. Rev. **B** in press

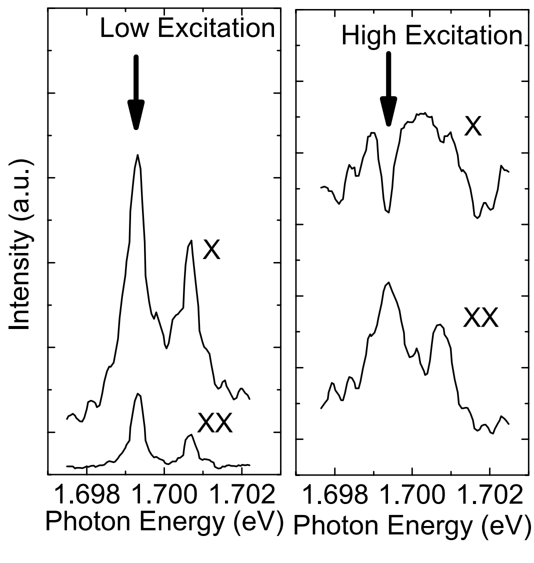


Fig. 1. Exciton and biexciton absorption.

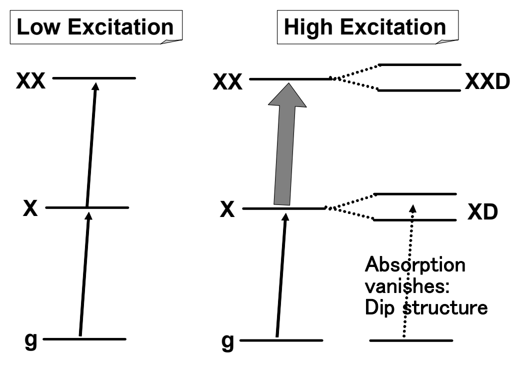


Fig. 2. Energy level structure

InGaN Cavity Polaritons

Takehiko Tawara[1], Hideki Gotoh[1], Tetsuya Akasaka[2] and Toshiki Makimoto[2]
[1]Optical Science Laboratory, [2]Materials Science Laboratory

Cavity polaritons are quasi-particles that are created by strong exciton-photon coupling in a semiconductor quantum well (QW) microcavity. In recent years, much attention has been directed to the behavior of these cavity polaritons as composite bosons at sufficiently small densities. One area of interest relates to polariton devices that employ bosonic behavior, such as the threshold-less “polariton” laser. To achieve these devices and room temperature operation, we have to choose materials that have large oscillator strength and a large exciton binding energy.

GaN-based semiconductors have a large exciton binding energy, and this energy allows excitons to exist even at room temperature. Moreover, the oscillator strength of this system will be larger than that of typical III-V semiconductors owing to the large effective mass of nitrides. Therefore, we can expect very strong exciton-photon coupling in GaN-based QW microcavities that will enable us to achieve polariton devices that operate above room temperature.

We used smooth and crack-free InGaN QW microcavities to realize strong coupling. The microcavities were fabricated using a wafer bonding technique with an InGaN/AlGaN QW layer and dielectric DBRs (Fig. 1). We observed a lasing action in the fabricated microcavity as shown in Fig. 2 [1]. Figure 3 shows the reflection spectra of the QW microcavities for various degrees of cavity detuning (δ). We observed the appearance and disappearance of splitting and these positions varied with δ. This behavior is evidence of cavity polariton formation, and the vacuum-field Rabi splitting which reflects the strength of the exciton-photon coupling is about 6 meV. We deduced from these results that the oscillator strength of InGaN QW excitons is one order of magnitude larger than that of GaAs QW excitons. These results indicate that GaN-based semiconductors are advantageous for studying the polaritonic effect and its device applications.

[1] T. Tawara, et al., Appl. Phys. Lett. **83** (2003) 830.
[2] T. Tawara, et al., Phys. Rev. Lett. **92** (2004) 256402.

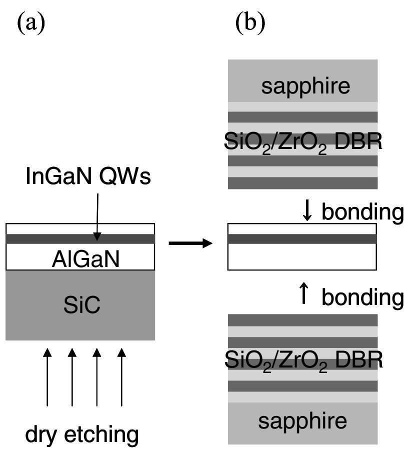


Fig. 1. Fabrication.

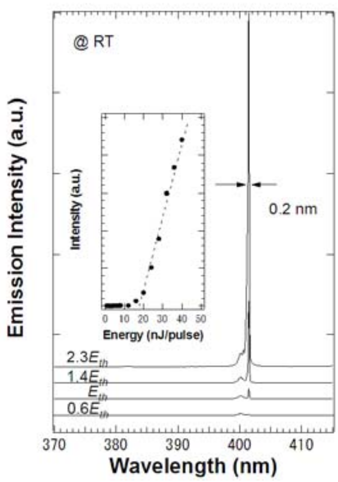


Fig. 2. Lasing by optical pumping.

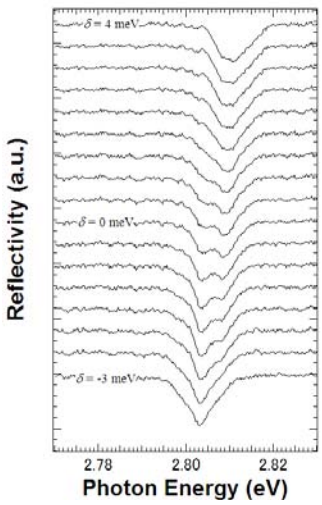


Fig. 3. Formation of cavity polariton.

Fabrication and Physics of Low-Loss Photonic Crystal Slab Waveguides

Eiichi Kuramochi, Stephen Hughes, and Masaya Notomi
Optical Science Laboratory

Recently, the two-dimensional photonic crystal slab (PCS) has attracted great interest because it has led to the development of high quality-factor photonic nanocavities and low-loss waveguides [1]. It has been revealed that a guided mode induced by a line defect in ideal PCS is theoretically lossless when it is designed to be inside the photonic band gap and under the light line. However, current nanolithography technology allows nanometer-order disorder and it is believed that such disorder causes a considerable loss increase due to out-of-plane scattering.

One aim of our research is to demonstrate that waveguide loss can be reduced by reducing fabrication disorder. We patterned PCSs by using a precise electron beam lithography system with 1-nm position accuracy and 100-kV acceleration, where we paid great effort to minimizing the proximity effect. We observed the fabricated Si PCS with scanning electron microscopes and found that disorder (σ, RMS) was about 3 nm (Fig. 1). We measured the propagation loss of PCS waveguides by the cut-back method. The minimum loss measured was 5dB/cm (Fig. 2), which is record loss for photonic crystal waveguides [2].

Another aim of our research is to reveal the physics of PCS waveguide loss. We applied the photon Green function tensor (GFT) formalism [3] to disorder-related scattering in the guided mode. We derived the loss formula as a simple product of the disorder and local density of states of light between the initial state and final state. We calculated the loss assuming σ of 3nm, and the result showed surprisingly good agreement with the experimental data (Fig. 2). This loss calculation by our GFT method is the most detailed ever achieved. We investigated the scattering-loss mechanism in detail by theory and experiment. We revealed for the first time that the loss characteristics of PCS waveguides are unique and complex because the loss mechanisms (out-of-plane scattering, intermode scattering, and backward scattering) are tightly bound with photonic band structure.

In conclusion, by experiment and theory, we successfully revealed the detailed physics of scattering loss in PCS waveguides caused by fabrication disorder.

[1] M. Notomi et al., Optics Express **12**, 1551 (2004).
[2] E. Kuramochi et al., LEOS2004, WF6 (2004).
[3] S. Hughes et al., Phys. Rev. Lett. **94**, 033903 (2005).

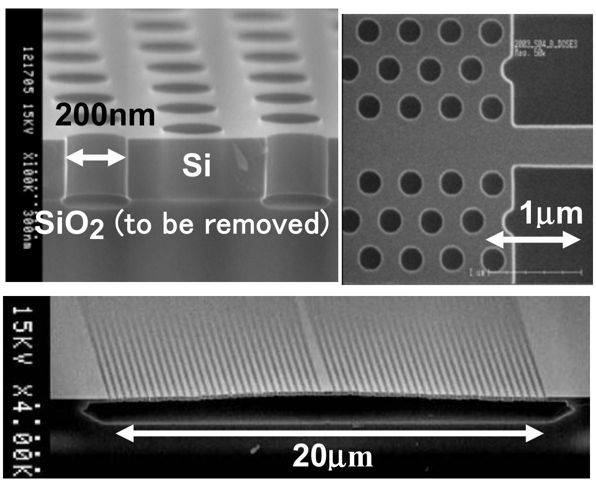


Fig. 1. SEM images of Si PCSs fabricated in this study.

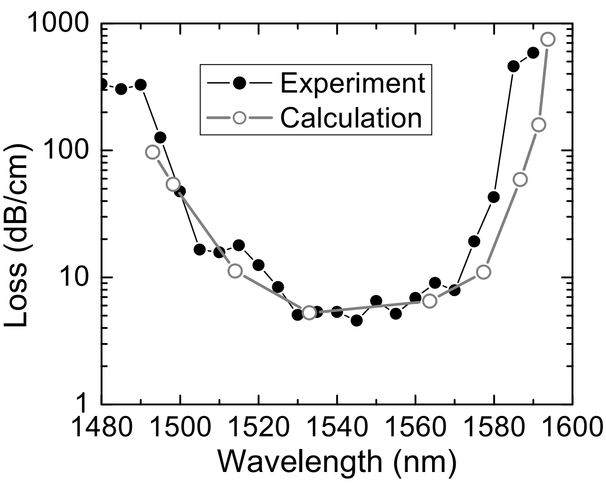


Fig. 2. Measured and calculated loss spectra of PCS waveguides.

All-optical switches based on photonic crystal nanocavities

Takasumi Tanabe, Akihiko Shinya, and Masaya Notomi
Optical Science Laboratory

Small cavities with strong light confinement (high-Q) can be fabricated by employing photonic crystals (PhCs) [1], whose dielectric is periodically modulated. In such small high-Q optical cavities, efficient all-optical modulation based on the light-matter interaction is expected because the photon density inside the cavity becomes extremely high. Silicon-based integrated optical circuits are regarded to have very high potential, due to the possibility of fusion with existing electrical devices. However, there has been some doubt as to whether active all-optical devices can satisfy certain requirements, such as low operation energy, high-speed operation, high switching contrast, and small device size. We will also have to be able to cascade them on-chip. No device meeting these requirements has been fabricated on silicon yet. Here, we demonstrated low operation energy and high-speed all-optical switching on silicon-chip based on a PhC high-Q nanocavity [Fig. 1 (top)].

The resonant transmission spectrum of a fabricated device under the linear operation condition is shown in Fig. 1 (bottom). When the optical energy of the near-infrared light is converted to thermal energy through the two-photon absorption process, the center of the transmission spectrum of the nanocavity shifts because the refractive index is modulated. By utilizing this phenomena, ultra-low-energy switching operation of a few pJ (pico=10^{-12}) is performed [2]. By utilizing refractive index modulation due to the carrier-plasma effect, further operation energy reduction and switching speed enhancement are expected. As shown on Fig. 2, the all-optical switching operation based on the carrier-plasma effect is demonstrated at few ten fJ (femto=10^{-15}) effective energy with a speed higher than 100 ps [3]. In the case shown in the graph, continues-wave signal light whose wavelength is slightly detuned to shorter wavelength from Mode-S resonance is modulated with pulsed control light, which is Mode-C resonant. This energy value and the device size are the smallest yet reported for fast silicon all-optical active devices, and these are achieved owing to the high-Q and efficient coupling with waveguides that are simultaneously attained in our PhC nanocavities [2].

The present result opens the way to *silicon photonics*; namely, the possibility of practical high-speed, low-power, and high-density all-optical logic gate on-chip applications on a silicon PhC platform.

[1] M. Notomi et al., Opt. Express **12** (2004) 1551.
[2] M. Notomi et al., Opt. Express **13** (2005) 2678.
[3] T. Tanabe et al., CLEO/QELS2005,QDPA5, Baltimore (2005).

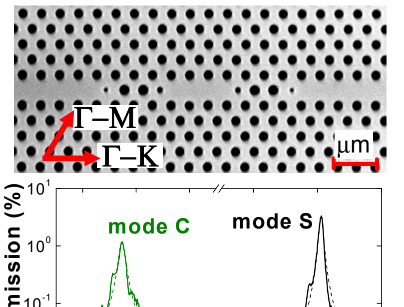


Fig. 1. Electron microscope image of the silicon PhC nanocavity (top). Linear transmission spectrum (bottom).

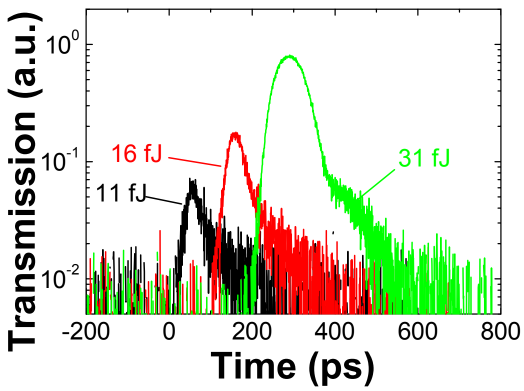


Fig. 2. Recorded switching operation of the signal waveform as a function of the control pulse energy.

Nanoelectrode lithography

Atsushi Yokoo
Optical Science Laboratory

Recently, nanoprint-nanoimprint technologies or scanning probe microscope (SPM) lithography is attracting attentions for the fabrication of nanostructures used in electronic or optical devices. Compared to conventional "projection-type" lithography, these "contact-type" lithographies have advantages in size and ease of operation. However, because the basic concept involves transferring the surface shape of a mold, the pattern cannot be modified in nanoprint-nanoimprint technologies. SPM lithography, in which an electrochemical reaction is induced by a conductive probe tip, can provide pattern flexibility. However, the throughput is still low. We are trying to develop a lithography technique that can provide good throughput and flexibility simultaneously.

Figure 1 shows the principle of nanoelectrode lithography. A nanoelectrode surface consists of a conductive area and an insulating area. The nanoelectrode makes contact with the surface of a target. When a voltage is applied, current flows between the nanoelectrode and the target material. Then, an electrochemical reaction occurs on the target surface. For example, anodic oxidation of the semiconductor, Si or GaAs, transfers the pattern to the target [1, 2]. Figure 2 shows an example of Si substrate patterning by nanoelectrode lithography. In Fig. 2, a nanoelectrode with a 300-nm-pitch dot pattern was used. The fabricated oxide pattern worked well as a mask for wet and dry etching, which means that resist-less patterning is possible. In addition, nanoelectrode lithography does not deform the surface of the target during the patterning process. Therefore, it will enable us to overwrite a pattern to fabricate a more complex pattern. Figure 3 shows checked pattern fabricated by repeating the process with a line-and-space (L/S) pattern [3].

As shown here, nanoelectrode lithography has some advantages, such as direct fabrication of the etching mask and modification of fabricated patterns by combining this approach with another lithographic technique. In addition, the lithography process can directly fabricate patterns defined by chemical characteristics such as hydrophilic or hydrophobic properties. These pattern may be used as templates for selective growth of semiconductors. We will apply nanoelectrode lithography for patterning of metal layers or resist layers on a substrate to prove the generality of the technique.

[1] A. Yokoo, Jpn., J. Appl., Phys., 42, L92 (2003)
[2] A. Yokoo, S. Sasaki, Jpn., J. Appl., Phys., 44, 1119 (2005)
[3] A. Yokoo, J. Vac. Sci. Technol. B, 21, 2966 (2003)

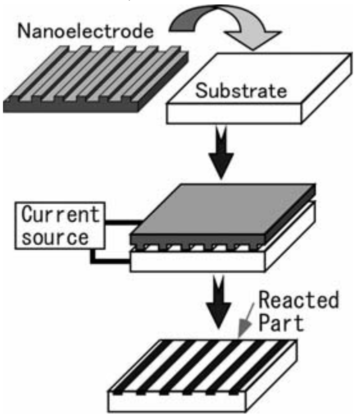


Fig. 1 Nanoelectrode lithography

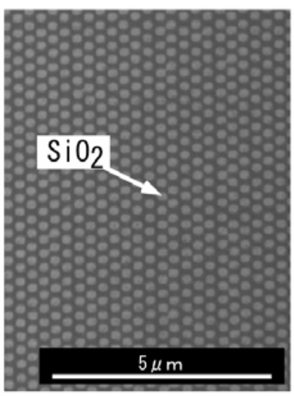


Fig. 2 Fabricated pattern on Si

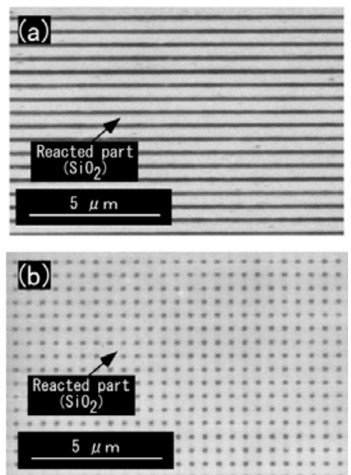


Fig. 3 Multiple patterning
(a) after 1st procedure
(b) after 2nd procedure

Ⅱ. Data

Second NTT- Basic Research Laboratories School

Second NTT BRL School, under the theme of "Transport Properties in Quantum Nanostructure", was held during the period of October 8th to 14th, 2004 at Fuji Seminar House (Fujiyoshida city, Yamanashi prefecture) and NTT Atsugi R&D Center. The purpose was to 1) foster young researchers in physics field and 2) improve visibility in international society.

Lectures were given by prestigious professors throughout the world: "Coulomb Blockade in Quantum Dots" by Prof. L. Glazman (University of Minnesota, USA), "Electronic Properties of Semiconductor Nanostructures" by Prof. S. Tarucha (University of Tokyo, Japan), "Quantum Dynamics of Superconducting Nanocircuits" by Prof. R. Fazio (Scuola Normale Superiore, Italy), "Carbon Nanotubes (theory)" by Prof. C. Schönenberger (University of Basel, Switzerland), and "Carbon Nanotubes (experiment)" by Prof. T. Ando (Tokyo Institute of Technology, Japan). Thirty two participants, mainly Ph.D. students, gathered from diverse countries which counted up to 17.

Following the lectures, each student introduced his/her research overview in a poster style. Director, managers and research group leaders of NTT BRL joined this session as well. In response to the students' detailed explanation of their research, vigorous discussion took place among students, and between students and professors/NTT researchers, which continued until the middle of the night.

Besides above mentioned schedule, the director presented overview of NTT BRL together with its mission and system on the first day. On the last day, managers gave detailed introduction of research activities at each laboratory, Materials Science Laboratory, Physical Science Laboratory and Optical Science Laboratory, followed by a laboratory tour to a clean room, low temperature laboratory, optical-materials evaluation equipment, and superconducting thin-film crystal-growth equipment.

At the end of the school, students were asked to fill out a questionnaire for overall evaluation. The answers included: "extremely satisfying and highly concentrated lectures," "became acquainted with the activities of NTT BRL and was impressed with its research environment," "became interested in working at NTT BRL in the future." These favorable responses indicate that the school provided great success in appealing quality of research activities at NTT BRL and contributed to its visibility improvement. NTT BRL continuously holds a school this year and will ongoingly engage in making further progress in raising its profile among young researchers abroad.

Science Plaza 2005

Science Plaza 2005, the annual open house event of NTT Basic Research Laboratories, was held on January 24, 2005, at the NTT Atsugi R&D Center. Science Plaza 2005 was aimed not only to introduce our latest research results to people inside and outside of NTT Basic Research Laboratories, but also to provide us feedback and opinions through discussion.

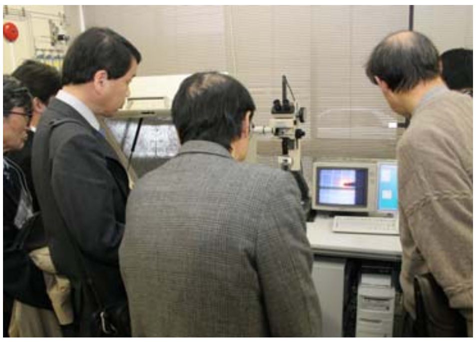
During the Plaza, overviews of research activities in the fields of materials science, physical science, and optical science were presented in morning lectures. In the afternoon, Dr. Mats Jonson, Professor of Physics at Chalmers University of Technology and Göteborg University in Sweden, and a member of the Nobel Prize committee in Physics, presented a special lecture entitled "The Nobel Prize in Physics, past, present and future", reviewing the history of the Nobel Prize, the recent awards, and the outlook for the future.

In the Poster Session, we presented thirty of our latest research developments, which generated lively debates and meaningful discussions among the participants. In addition, a movie highlighting our major research findings was shown in the video theatre. We performed three Lab tours, which gave participants an opportunity to see the facilities used in NTT Basic Research Laboratories, including the Low-Temperature Experiments Building, and learn how our research is performed. After the program, we had a social gathering in the evening in the dining room, where participants could continue with their productive discussions.

Approximately, a total of 200 people from the research departments of universities, business organizations, and the NTT groups attended our Science Plaza 2005. The symposium was a huge success. We would like to take this opportunity to sincerely thank all those who participated in Science Plaza 2005.

Special lecture


Poster session


Lab tour: carbon nanotubes

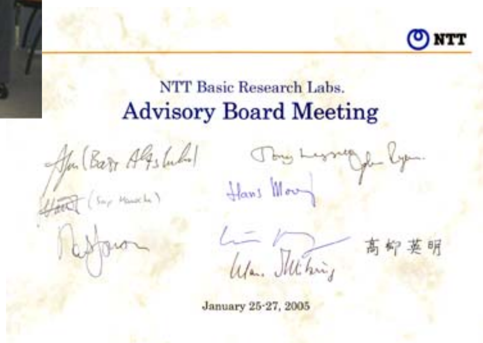

Lab tour: low-temperature physical-property experiments

The 3rd Advisory Board Meeting

The advisory board, an external evaluation committee for NTT Basic Research Laboratories (BRL), convened for three days, January 25, 26, and 27, 2005. The advisory board started in 2001 as a way to evaluate research plans and activities objectively so that NTT BRL can adopt strategic management in a timely manner. This was the third board meeting, and this time we reorganized the board to welcome five new members.

During the meeting, the board gave us many valuable suggestions and comments on our research activities and management. Members commented that the research level is generally high on a world scale, which strengthened our commitment to keep our research at the top level and communicate our results and ideas to the world. They also pointed out several issues regarding human resources, inheritance of technology, and internal and external collaboration. We will work to improve our management and circumstances based on their valuable suggestions.

At this meeting, there were many opportunities for young researchers to communicate with the board members. We had a lunch party and also conducted laboratory tours with young researchers as attendants. The board members and young researchers enjoyed these chances to interact. The next board meeting will convene in a year and half.



Board members	Affiliation	Research field
Prof. Altshuler	Princeton U	Condensed matter
Prof. Devoret	Yale U	Mesoscopic physics
Prof. Haroche	Ecole Normale	Quantum optics
Prof. Jonson	Chalmers UT	Condensed matter
Prof. Leggett	U Illinois	Quantum physics
Prof. Mooij	Delft UT	Quantum computers
Prof. Ploog	Paul-Drude-Inst.	Nanostructures
Prof. Ryan	U Oxford	Nano-bio technology
Prof. von Klitzing	Max-Planck-Inst.	Semiconductor physics

International Conference on Nanoelectronics, Nanostructures and Carrier Interactions

The conference was held from January 31 to February 2, 2005, at the NTT Atsugi R&D Center in collaboration with *Solution Oriented Research for Science and Technology* (SORST) sponsored by the *Japan Science and Technology Agency* (JST).

Ultra-small "nano-scale" structures and the behavior of carriers in these structures have been the focus of much attention for many years. Recently, the field has been advanced significantly through the introduction of additional degrees of freedom, such as electron and nuclear spins, magnetism, and mechanical motion. In addition, novel quantum mechanical concepts like quantum computing and quantum cryptography are attracting a great deal of interest. With the aim of further advancing these studies, this conference aspired to gather leading scientists and provide forum for discussing the most recent topics in nanoelectronics, nanostructures, and carrier interactions. The conference was organized by Dr. Yoshiro Hirayama and Dr. Hiroshi Yamaguchi of NTT Basic Research Laboratories which have led these fields.

On January 31st, after the opening and welcoming remarks by Dr. Hideaki Takayanagi, Director of NTT Basic Research Laboratories, the technical session was opened with the invited talk "Superconducting Flux Qubits" by Prof. J. E. Mooij from Delft University of Technology. There were 11 oral presentations on superconducting q-bits, nanoprobes, and mesoscopic/spin phenomena, and 28 poster presentations. On February 1st, the 12 oral presentations discussed micro/nanomechanical systems, quantum information processing, and mesoscopic and spin phenomena. On the 2nd, there were 9 oral presentations on nuclear spin and related phenomena and advanced heterostructures, and 28 poster presentations. The final talk was given by Prof. K. Ploog from Paul Drude Institute on "Unexpected Gems in the Search for Optimized Spin-Injector Materials". We believe that we provided a very nice opportunity for mutual communication within and among the related research fields.

The participants were totally 149 people [including 67 from NTT]. All participants well enjoyed the high-quality presentations and discussions on nanoelectronics, nanostructures, and carrier interactions.

Award Winner's List (Fiscal 2004)

Japanese Journal of Applied Physics Research Paper Presentation Awards	S. Saito	"Multiphoton Absorption Observed in a Superconducting Flux Qubit"	May 17, 2004
The 33rd IEEE International Symposium on Multiple-Valued Logic Distinctive Contributed Paper Award	H.Inokawa Y.Takahasi	"Experimental and Simulation Studies of Single-Electron-Transistor-Based Multiple-Valued Logic"	May 21, 2004
The Society of Non-Traditional Technology Award for Superconductor science and technology	M. Naito	"Development of Molecular Beam Epitaxy for High Tc Superconducting Materials"	June 21, 2004
Japanese Journal of Applied Physics Paper Award	V. Seleznev H. Yamaguchi Y. Hirayama V. Y. Prinz	"Single. Turn GaAs/InAs Nanotubes Fabricated Using the Supercritical CO_2 Drying Technique"	Sep. 1, 2004
Japanese Journal of Applied Physics Paper Award	T. Nishikawa K. Oguri T. Suzuki Y. Watanabe H. Nakano	"Enhanced Water-Window X-Ray Pulse Generation from Femtosecond Laser Produced Plasma with a Carbon Nanotube Target"	Sep. 1, 2004
Fellow of The Institute of Physics (IOP)	Y. Hirayama	"Contribution to the institute as a member of an Editorial Board"	Sep. 1, 2004

The Ericsson Young Scientist Award	Go Yusa	"Trapping of photogenerated carriers by InAs quantum dots and persistent photoconductivity in novel GaAs/n-AlGaAs field-effect transistor"	Nov. 22, 2004
Physical Society of Japan JPSJ Editor's Choice Paper	M. Kawamura H. Yaguchi N. Kikugawa Y. Maeno H. Takayanagi	"Tunneling Properties at the Interface between Super-conducting Sr_2RuO_4 and a Ru Microinclusion"	Feb. 1, 2005
Japan Society for the Promotion of Science Prize	T. Fujisawa	"Research on Quantum-state Control of Semiconductor Quantum Dots"	Mar. 22, 2005

In-house Award Winner's List (Fiscal 2004)

NTT R&D Award	T. Hayashi T. Fujisawa	"Electronically Controlled Semi-conductor Qbits"	Dec. 8, 2004
NTT R&D Award	K. Yamazaki H. Namatsu	"Nano-Globe"	Dec. 8, 2004
Award for Achievements by Director of Basic Research Laboratories	H. Yamaguchi	"Pioneering in Quantum Nano-mechanics"	Mar. 15, 2005
Award for Achievements by Director of Basic Research Laboratories	H. Tanaka S. Saito M. Ueda H. Nakano K. Semba	"Coherent Control on Superconducting Flux Qbits"	Mar. 15, 2005
Award for Achievements by Director of Basic Research Laboratories	T. Honjo H. Takesue K. Inoue Y. Tokura	"Quantum Key Distribution and Entangled Photon Generation with Optical Fibers"	Mar. 15, 2005
Award for Excellent Papers by Director of Basic Research Laboratories	K. Takashina	"Valley splitting control in $SiO_2/Si/SiO_2$ quantum wells in the quantum Hall regime" Phys. Rev. B Vol. 69, 161304(R) (2004)	Mar. 15, 2005
Award for Excellent Papers by Director of Basic Research Laboratories	T. Akasaka	"An InGaN-based horizontal cavity surface emitting laser diode" Appl. Phys. Lett. Vol. 84, 4104 (2004)	Mar. 15, 2005

Special Award by Director of Basic Research Laboratories	H. Namatsu	"Distinctive Contribution on Patent Application"	Mar. 15, 2005
Award for Achievements by Director of Photonics Laboratories	H.Yokoyama M. Hiroki H. Sugiyama K. Kumakura N. Watanabe	"Development of Fabrication Techniques for High Quality GaN/AlGaN HEMT Epitaxial Wafers on Sapphire Templates"	Mar. 16, 2005

List of Visitor's Talks (Fiscal 2004)

I. Materials Science

Date	Speaker	Affiliation "Topic"
May 17	Mr. Atsushi Nishikawa	The University of Tokyo "Fabrication of GaInNAsQuantum Dots by MBE and Its Optical Characterization"
June 1	Prof. I.S.T. Tsong	Arizona State University, USA "Nucleation and growth of epitaxial ZrB2(0001) on Si(111) for III-nitride applications"
June 11	Dr. Jingyue Liu	Monsanto Company, USA "Electron Microscopy of Atoms and Clusters"
June 18	Dr. Jun Nakamura	The University of Electrto-Communications "Dielectric characteristic evaluation of ultra-thin film by first-principle calculation"
July 6	Dr. Sonia A. Contera	University of Oxford, UK "Pulling an alpha-helix peptide out of a lipid bilayer with an AFM"
Nov. 15	Prof. Daoben Zhu	Chinese Academy of Sciences, China "Recent Advance on Molecular Materials in the Organic Solid Laboratory"
Nov. 15	Prof. Wenping Hu	Chinese Academy of Sciences, China "Self Assembly Devices"
Nov. 22	Prof. Esko I. Kauppinen	Helsinki University of Techology, Finland "Nanoparticle Technology Center for New Materials (CNM)"
Feb. 17	Prof. Clive Bramham	University of Bergen, Norway "Molecular mechanisms of synaptic plasticity in vivo: BDNF as a trigger for synaptic consolidation"
Feb. 22	Prof. Mervyn Miles	University of Bristol, UK "Real-time imaging of materials using fast scan AFM"
Feb. 22	Prof. Daniel Robert	University of Bristol, UK "Mechano receptor involvement in nanoscale sensing capability of insect antennae"
Mar. 10	Prof. Kenshi Hayashi	Kyushu University "Multi-purpose electrochemical sensor detecting molecular adsorption"

II. Physical Science

Date	Speaker	Affiliation "Topic"
Apr. 7	Prof. T. Claeson	Chalmers University of Technology, Sweden “Transport in single molecules: influence of distinctly different charged states of the conjugate molecule and of the image charge in the electrodes”
Apr. 15	Prof. Yosuke Kayanuma	Osaka Prefecture University “Nonadiabatic Electron Manipulation in a Quantum-Dots Array and Some Related Topics”
Apr. 28	Prof. Fujio Shimizu	University of Electro-Communications “How to pursue atomic quantum computer”
May 19	Prof. Kees Harmans	Delft University of Technology, Netherlands “Quantum dynamics of persistent current Qubits”
May 25	Dr. Gunther Lientschnig	Delft University of Technology, Netherlands “Electrical Transport through Molecules”
July 16	Dr. Cary Y. Yang	Santa Clara University, USA “Carbon Nanotubes as On-chip Interconnects”
Sep. 7	Dr. Evgeni Ilichev	Jena University, Germany “Radio-frequency method for investigation of quantum properties of superconducting structures”
Sep. 10	Dr. P. V. Santos	Paul Drude Institute, Germany “Controlling photons,electrons, and spins in GaAs using acoustic waves”
Sep. 14	Prof. R. A. Hogg	University of Sheffield, UK “Low Threshold 1.31um QD laser Diodes on GaAs”
Sep. 16	Prof. Hideo Kosaka	Tohoku University “Qbits Conversion from Polarization of Photons to Electron Spin”
Oct. 6	Prof. Susumu Sasaki	Niigata University “A new development of neuclear magnetic resonance (NMR): Coherence of neuclear spins in semiconductors”
Oct. 6	Prof. Ruldof Gross	Bavarian Academy of Sciences, Germany “Research activity in Solid state based quantum information, within the Cooperative Research Center 6317”
Oct. 14	Dr. Ch. vom Hagen	Universitat Heidelberg, Germany

		"Towards a Degenerate Fermi Gas on an Atom Chip"
Nov. 2	Prof. A.D. Zaikin	Universitat Karlsruhe, Germany "Interaction-induced low temperature decoherence of electrons in disordered conductors: Theory and Experiment"
Nov. 18	Prof. Eugene S. Polzik	Copenhagen University, Denmark "Quantum memory for light: can complementary variables be remembered?"
Nov. 19	Prof. Gerhald Abstreiter	Walter Schottky Institute, Germany "Optoelectronic control of single charge, spin and photon in semiconductor quantum dots and its possible impact on future quantum information technology"
Dec. 1	Prof. V. Y Prinz	Russian Academy of Science, Russia "Precise semiconductor nanotubes,nanofibers and nanocorrugated quantum systems"
Dec. 2	Prof. Pawel Hawrylak	National Research Council of Canada, Canada "Designing quantum systems for nano-spintronics, nano-photonics and quantum information processing"
Dec. 3	Prof. A. J. Fisher	University College London, UK "Decoherence and quantum information processing in condensed matter"
Dec. 16	Prof. Miles.P.Blencowe	Dartmouth College, USA "Mesoscopic Mechanics"
Dec. 16	Prof. K. H. Ploog	Paul Drude Institute, Germany "Nitrides seem to be good for everything"
Dec. 22	Dr. Vladimir Bubanja	Industrial Research, New Zeeland "Single Electron Metrology"
Jan. 11	Dr. Pablo Jarillo-Herrero	Delft University of Technology, Netherlands "Orbital spectroscopy and Kondo effects in carbonnanotubes"
Jan. 19	Prof. Jung-Bum Choi	Chungbuk National University, Korea "Single-Electronics: Beyond the Roadmap CMOS toward Quantum Computation"
Feb. 21	Dr. Alexander Khaetskii	Russian Academy of Science, Russia "Spin currents. Myth and reality."
Feb. 25	Prof. Tetsuya Sato	Keio University "Magnetic Properties in Surfaces of Nano Particles"
Feb. 25	Vittorio Peano Michael Thorwart	Dusseldorf University, Germany "One-Dimensional Ultracold Atom Gases in a Nanoscale Magnetic Waveguide formed by two

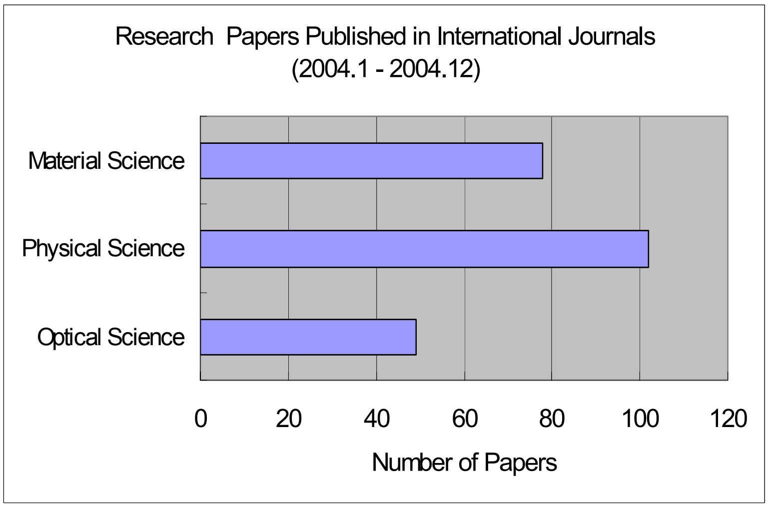
		Doubly-Clamped Suspended Carbon NanoTubes”
Mar. 15	Prof. Bernhard Kramer	Universtitaet Hamburg, Germany “Spin blockade in quantum dots”
Mar. 18	Prof. Jörg Schmiedmayer	Universität Heidelberg, Germany “Micro-manipulation of ultra cold atoms on Atom Chips”
Mar. 22	Mr. Anton Öttl	ETH Zürich, Switzerland “Observation of Single Atoms in Degenerate Quantum Gases”

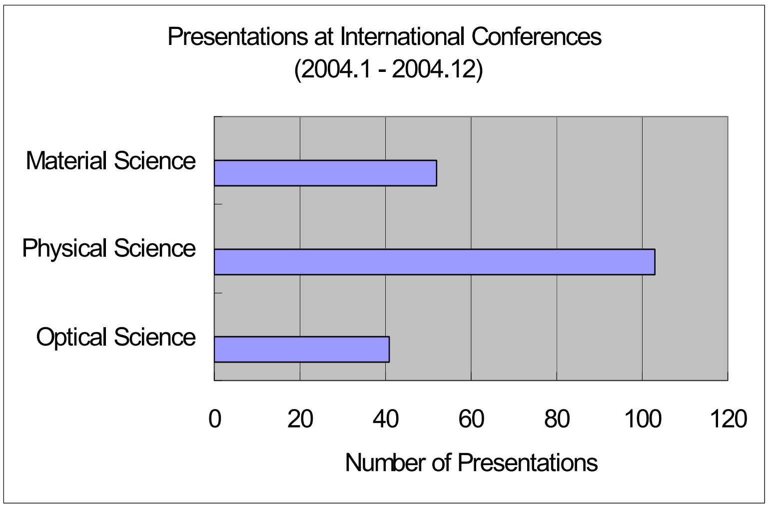
III. Optical Science

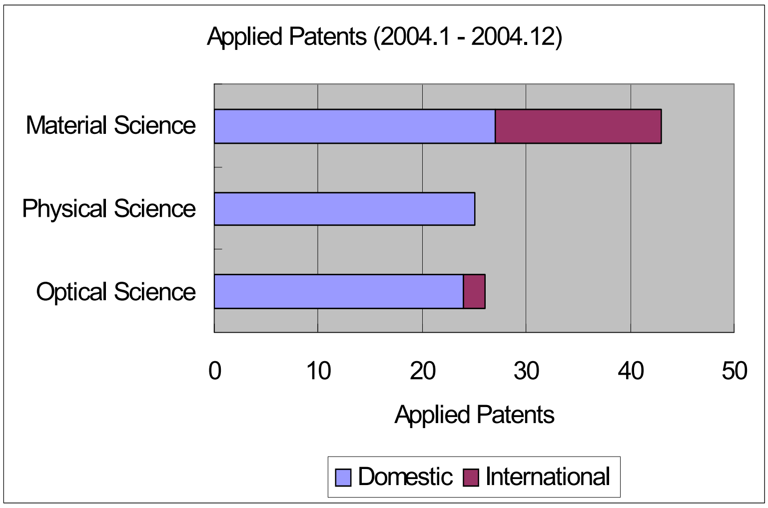
Date	Speaker	Affiliation "Topic"
Apr. 16	Prof. Keiichi Edagawa	The University of Tokyo “Properties of Quasi-crystals: Current State and Future Prospects”
July 7	Dr. Xuedong Hu	SUNY Buffalo, USA “Dynamical Nuclear Spin Polarization in a Semiconductor Double Quantum Dots”
Aug. 19	Mr. Aaron Danner	The University of Illinois, USA “Photonic Crystal VCSEL (Vertical Cavity Surface Emitting Laser)”
Sep. 22	Prof. S. G. Tikhodeev	General Physics Institute, Russia “Waveguide-plasmon polaritons in photonic crystal slabs with metal nanowires”
Nov. 11	Prof. A. Knorr	TU Berlin, Germany “Semiconductor Nano Optics: Perspective from the Theory of Light-Matter Interactions on Ultrashort Time and Length Scales”
Nov. 17	Prof. A. Knorr	TU Berlin, Germany “Ultrafast Optics of Multiple-Quantum-Well Photonic Crystals”
Jan. 7	Prof. Yshai Avishai	Ben-Gurion University, Israel “Fano effect of a strongly interacting quantum dot in contact with superconductor”
Mar. 11	Prof. Ian Walmsley	University of Oxford, UK “The Photon and the Vacuum Cleaner”

Research Activities of Basic Research Laboratories in 2004

The numbers of research papers, presentations at the international conferences and applied patents amounted to 227, 196, and 64 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	(IF2003)*	Numbers
Nature	(30.979)	1

Specialized Journals

Name	(IF2003)*	Numbers
Physica E	(0.93)	34
Japanese Journal of Applied Physics	(1.171)	32
Physical Review B	(2.962)	24
Applied Physics Letters	(4.049)	23
Physica C	(1.192)	13
Physical Review Letters	(7.035)	12
Applied Surface Science	(1.284)	7
Nano Letters	(6.144)	2
Advanced Materials	(7.305)	1
Analytical Chemistry	(5.25)	1
Biophysical Journal	(4.463)	1

*IF2003: Impact factor 2003（Journal Citation Reports, 2003）

The average impact factor for individual research papers from all NTT Basic Research Laboratories is 2.42.

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

Conferences	Numbers
27th International Conference on the Physics of Semiconductors (ICPS27)	17
International Symposium on Mesoscopic Superconductivity and Spintronics 2004	12
International Conference on Solid State Devices and Materials (SSDM)	11
Annual APS March Meeting 2004	7
MRS Meeting 2004	7
CLEO/QELS 2004	4
14th International Conference on Ultrafast Phenomena	4
17th International Symposium on Superconductivity (ISS2004)	4
2004 International Workshop on Dielectric Thin Films for Future ULSI Devices	4
International Workshop on Nitride Semiconductors	4

List of Invited Talks at International Conferences (2004)

I. Material Science Laboratory

(1) N. Kobayashi, K. Kumakura, T. Makimoto, T. Hashizume, T. Fukui, and H. Hasegawa, "Characterization of Heterojunction in High Current Gain GaN/InGaN Heterojunction Bipolar Transistors", 31st Conference on The Physics and Chemistry of Semiconductor Interfaces (PCSI-31), Hawaii, USA (Jan. 2004).

(2) T. Nishida, T. Ban, H. Saito, N. Kobayashi and T. Makimoto, "High power extraction of 340 to 350-nm UV-LEDs", Photonics West, San Jose, USA (Jan. 2004).

(2) K. Furukawa, "Single polymer science based on semiconducting polymer", International Workshop "Beam Science and Nanotechnology", Osaka, Japan (Jan. 2004).

(4) Y. Homma, Y. Kobayashi, J. Lefebvre, and P. Finnie, "Suspended Carbon Nanotube Architectures: Growth Control and Optical Properties", International Symposium on the Creation of Novel Nanomaterials (ISCNN'04)", Toyonaka, Japan (Jan. 2004)

(5) E. Kohn, A. Aleksov, M. Kubovic, A. Denisenko, and M. Kasu, "Diamond electronic devices - opportunities and obstacles", 9th International Conference on New Diamond Science and Technology, Tokyo, Japan (Mar. 2004).

(6) Y. Homma, "Standardization of SIMS depth profiling in ultra-shallow region", 1st International Symposium on Standard Materials and Metrology for Nanotecnology (SMAM-1), Tokyo, Japan (Mar. 2004)

(7) K. Torimitsu, "Nano-bio science: from molecule to nano-bio device", Chinese Chemical Society & 24th CCS Congress, Hunan, China (Apr. 2004).

(8) K. Torimitsu, N. Kasai and Y. Furukawa, "Effect of magnesium on neural ativities in cultured rat cortical and hippocampal neurons", 8th European Magnesium Conf., Romania, Italy (May, 2004).

(9) C. Han and K. Torimitsu, "Neuronal cell death and sprouting of mossy fibers are induced by kanic acid exposure in rat hippocampal slice cultures", The 3ed International Symposium on Neuroscience of Young Scholars", Guangzhou, China (Jun. 2004).

(10) Y. Homma, "Towards standardization of ultra-shallow depth profiling: Multiple delta layers

as a measure of depth scale", 16th International Vacuum Congress, Venice, Italy (Jun. 2004)

(11) K. Torimitsu, "Bioinfomatics", The 19th UK-Japan High Technology Industry Forum, Bristol, UK (Jul. 2004).

(12) K. Torimitsu, Y. Furukawa, H. Nakashima, K. Furukawa, Y. Kashimura and W. Hu, "NanoBio Science - Neural functions and molecules", ICCE-11, Hilton Head Island, USA (Aug. 2004).

(13) T. Makimoto and K. Kumakura, "Recent Development of Nitride Heterojunction Bipolar Transistors", 2004 ECS Joint Meeting in Hawaii, Honolulu, USA (Oct. 2004).

(14) Y. Watanabe, S. Suzuki, Y. Homma, S. Heun, and A. Locatelli, "SPELEEM observation of individual single-walled carbon nanotubes", 3rd Int. Workshop on Nanoscale Spectrosc. Nanotech., Maryland, USA (Dec. 2004).

II. Physical Science Laboratory

(1) T. Fujisawa "Coherent control of carrier dynamics in coupled quantum dots", 31st Conf. Phys. Chem. Semicond. Interface (PCSI-31), Kailua-Kona, USA (Jan. 2004).

(2) T. Fujisawa "Dynamics of single-electron charge in quantum dots", 20th Yokohama City University International Forum (YCUIF-20), Yokohama, Japan (Jan. 2004).

(3) T. Hayashi, T. Fujisawa, and Y. Hirayama, "Coherent charge oscillation and decoherence in a semiconductor double quantum dots", Rencontres de Moriond, La Thuile, Italy (Jan. 2004).

(4) H. Takayanagi, "Superconducting Flux Qubit as a Macroscopic Artificial Atom", 39th Recontres de Moriond, LaThuile, Italy (Jan. 2004).

(5) Y. Tokura, "Spin-Effects in a Transport Through a Point Contact", Int. Workshop on Spin-FET based Quantum Information Processing, Tsukuba, Japan (Feb. 2004).

(6) K. Inoue, "Nonlinear amplifiers and fiber processing devices," Conference on Optical Fiber Communications (OFC2004), Los Angles, USA (Feb. 2004).

(7) H. Tamura, "Tunable exchange interaction and Kondo screening in quantum dot devices", The 2nd Quantum Transport Nano-Hana International Workshop, Chiba, Japan (Mar. 2004)

(8) H. Takayanagi, "Quantum Information Processing at NTT BRL", International Symposium on

Quantum Info-Communications and Related Quantum Nanodevices, Tokyo, Japan (Mar. 2004).

(9) H. Takayanagi, “Superconducting Flux Qubit”, Quantum Technologies 2004, Vancouver, Canada (Mar. 2004).

(10) T. Fujisawa “Dynamics of single-electron charge in quantum dots”, Material Research Society (MRS) Meeting, San Fransisco, USA (Apr. 2004).

(11) K. Semba, “Superconducting qubits:Experimental forefront and challenges”, International conference : Are the DiVincenzo Criteria fulfilled 2004 ?, Osaka, Japan (May. 2004).

(12) J. Nitta, “Spin-related transport in semiconductors and semiconductor/ferromagnet hybrid structures” International Conference on “Nanospintronics Design and Realization” ICNDR, Kyoto, Japan, (May 2004)

(13) T. Fujisawa, “Dynamics of Single Electron Charge in a Double Quantum Dot”, Quantum Dots Conference (QD2004), Alberta, Canada (May, 2004).

(14) T. Fujisawa “Dynamics of single-electron charge and spin in semiconductor quantum dots”, Quantum Computation:Are the DiVincenzo criteria fulfilled in 2004?, Osaka (May 2004).

(15) Y. Hirayama, “Coupled-quantum-dot charge qubit”, Spin and Qubit, Niels Bohr Institute, Copenhagen, Denmark (May, 2004).

(16) Y. Hirayama, T. Hayashi, T. Fujisawa, “Semiconductor charge qubit”, ITAMP workshop on Mesoscopic Physics, Quantum Optics, and Quantum Information, Boston, USA (May, 2004).

(17) H. Inokawa, Y. Ono, A. Fujiwara, K. Nishiguchi, and Y. Takahashi, “Single-Electron Devices fabricated by MOS Processes,” European Materials Research Society (E-MRS) Spring Meeting, Strasbourg, France (May, 2004).

(18) H. Takayanagi, “Research Acitivities of Quantum Information Technology at NTT BRL”, Spin Qubit Symposium, Copenhagen, Denmark (May 2004)

(19) T. Fujisawa “Dynamics of single-electron charge and spin in semiconductor quantum dots”, International workshop on Macroscopic Quantum Coherence and Computing (MQC2), Napoli, Italy (Jun. 2004).

(20) S. Horiguchi, A. Fujiwara, H.Inokawa and Y. Takahashi, “Electronic States in Si

Single-Electron Transistors," IEEE Si Nanoelectronics Workshop, Honolulu, USA (Jun. 2004).

(21) Y. Takahashi, Y. Ono, A. Fujiwara, K. Nishiguchi, and H. Inokawa, "Fabrication and Application of Silicon Single-Electron Devices," Ultimate Lithography and Nanodevice Engineering Conference, Agelonde, France, (Jun. 2004).

(22) H. Takayanagi, "Superconducting Flux Qubit", Foundation of Probability and Physics-3, Växjö, Sweden (June 2004)

(23) M. Yamashita, "Magnetic properties of trapped spin-one bosons in an optical lattice", International Laser Physics Workshop (LPHYS'04), Trieste Italy (Jul. 2004).

(24) T. Fujisawa, "Single electron charge qubit in a semiconductor double quantum dot", Control of quantum coherence, BadHonnef, Germany(Jul. 2004).

(25) Y. Hirayama, "Manipulation of nuclear spin polarization and relaxation by two-dimensional electron systems", International Conference on Superlattices, Nano-structures and Nano-devices (icsnn04), Cancun, Mexico (Jul. 2004).

(26) H. Yamaguchi, S. Miyashita, Y. Tokura, and Y. Hirayama "InAs-based Micromechanical Two-dimensional Electron Gas Systems", 27th International Conference on the Physics of Semiconductors (ICPS27), Flagstaff, USA (July. 2004).

(27) M. Uematsu, "Unified simulation of diffusion in silicon and silicon dioxide," 6th international conference on diffusion in materials (DIMAT), Krakow, Poland (Jul. 2004).

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