3. RESEARCH ACTIVITIES
Targets and achievements of the Information Devices Division

The main aim of the information devices division is to create new materials and devices for next generation communication technology.

To accomplish the goals of this division, we have the following 6 sub-divisions with different research fields. Furthermore, we also have a partnership with atomically controlled processing research section in the Laboratory for Nanoelectronics and Spintronics.

1. Nano-Photoelectronics
2. Quantum-Optical Information Technology
3. Solid State Electronics
4. Dielectric Nano-Devices
5. Materials Functionality Design
6. Magnetic Devices (Visitor Section)

The target and the summary of achievements of the each sub-division in 2009 are described in the following pages. In addition, about the summary of achievement of the atomically controlled processing research section will be written in the chapter of the Laboratory for Nanoelectronics and Spintronics.
Nanophotoelectronics
Exploring optical and electronic properties of nanometer-sized structures and their applications in photoelectronic devices

[Research Target and Activities]

Our main interest lies in studying the physical and chemical phenomena that take place in nanometer-scale regions and their applications in nanophotoelectronic devices. We investigate the material properties of nanostructures through their optical responses to the local excitation induced by electrons from the tip of a scanning tunneling microscope (STM), as illustrated in Fig. 1. In this year, we have successfully determined *local electronic density of states* of Ag(110) (2x1) O and *local dielectric functions* of Ni(110) (2x1) O by analyzing their STM light emission (STM-LE) spectra. A new finding is obtained concerning electron tunneling between the tip and a Au film covered by a self-assembled monolayer of thiol molecules. In order to activate various functions of each molecule at solid surfaces, its electronic isolation from the substrates is of importance. NaCl films with a monolayer thickness was successfully synthesized on Au(111) for this purpose, and their dynamics was investigated by STM. We are also interested in developing novel methods for measuring nanometer-scale surface properties. We have developed the new method that makes it possible to determine phonon energies (i.e., vibarational energies of solids) with the spatial resolution of STM. STM-LE is fundamentally weak. Hence, in STM-LE measurements one is frequently confronted with a difficulty arising from this weakness. We have found that a prism-coupled STM-LE geometry enhances tenfold the STM-LE intensities. The Finite-Differential-Time-Domain analysis, which is a numerical method for solving the Maxwell equations, was successfully applied to STM-LE spectra.

[Staff]
Professor UEHARA, Yoichi Dr.
Assistant Professor KATANO, Satoshi Dr.

[Profile]
Dr. Yoichi Uehara obtained his D. Eng. degree from the Department of Engineering, University of Osaka prefecture in 1986, after which, he was initially appointed as an Assistant Professor at the Research Institute of Electrical Communication, Tohoku University. He eventually became a Full Professor at the institute in 2005. Dr. Uehara has worked on three main surface physics problems at Tohoku University: (1) light emission from metal-insulator-metal and metal-oxide-semiconductor (MOS) tunnel junctions, (2) low-energy electron spectroscopy, and (3) light emission spectroscopy of STM.

[Papers]
Quantum Optical Information Technology

Development of optoelectronic devices for quantum information and communication technology

[Research Target and Activities]

Current information and communication technology utilizes macroscopic and classical physical quantities, such as voltage or frequency of electric fields. The classical technology will reach the limit of information density and speed in the near future. The quantum-mechanical counterpart, “quantum information processing and communication technology”, in which information is carried by microscopic and quantum-mechanical quantities, is expected to overcome the difficulty.

Our goal is to develop the quantum information devices utilizing quantum interaction between electrons and photons in semiconductor nanostructures, to get further understanding of their physics, and to apply them to practical quantum information technologies. We are particularly working toward the development of future quantum information devices utilizing entangled photon pairs and electron spins in semiconductor nanostructures.

In 2009, we have achieved (1) development of novel entangled photon sources and up-conversion photon detectors using quasi-phase matched devices, (2) measurement of ultra-low-light-level optical nonlinearity in a Si wire waveguide, and (3) quantum media conversion from photons to electron spins in semiconductor quantum structures.

[Staff]

Professor: EDAMATSU, Keiichi Dr.
Associate professor: KOSAKA, Hideo Dr.
Assistant professor: MITSUMORI, Yasuyoshi Dr.

[Profile]

Keiichi Edamatsu received B.S., M.S., and D.S. degrees in Physics from Tohoku University. He was a Research Associate in Faculty of Engineering, Tohoku University, a Visiting Associate in California Institute of Technology, and an Associate Professor in Graduate School of Engineering Science, Osaka University.

[Papers]

[Research Target and Activities]
To realize the ubiquitous (or ambient intelligence) society, in which sensors and their networks are embedded in our ambience to support our daily life, a marriage between non-Si technologies suitable for environmental sensing and the Si technology suitable for signal processings is indispensable. To this goal, we investigate formation of ultrathin silicon-carbide (SiC) films on Si substrates, hoping to use them as a common interface between the two technologies. SiC is a group-IV compound that contains a pair of elements representative of both electronics (Si) and biology (C). It also bridges the gap between Si and other II-VI or III-V compounds. It is a widegap semiconductor that enables high-temperature operations. High enough strength and hardness of SiC make this material suitable for use in MEMS structures. We are developing gas-sensors, graphene-based ultrahigh-speed devices, LEDs, biosensors, MEMS structures, non-volatile memories, and photovoltaic cells based on the SiC/Si structures. What lies behind these applications is our original technology of SiC gas-source molecular-beam epitaxy (MBE) using organo-silane, which enables a high-quality, low-temperature SiC epitaxy on Si substrates. One of our most striking achievements in this field is the realization of the graphene-on-silicon structure, in which graphene, a most promising semiconducting material to be used in the next generation devices, is formed by use of surface modification of SiC/Si. Our research also covers the surface chemistry of Si-related surfaces, targeted to the control of nanostructure formation on Si and SiC surfaces. Fabrication of non-equilibrium Si structures such as amorphous-, microcrystalline-, and poly-Si thin films is also within our interests, and is being intensively investigated using atmospheric-pressure plasma-enhanced chemical vapor deposition (AP-PECVD).

[Staff]
Professor: SUEMITSU, Maki Dr.
Assistant Professor: FUKIDOME, Hirokazu Dr.
Technical Assistant: MIURA, Akemi
Postdoctoral Fellow: ALGUNO, Arnold Café Dr.

[Profile of Professor SUEMITSU]
Prof. Maki Suemitsu obtained bachelor degree on electronic engineering (1975), Ph.D on electronic engineering (1980). He started his service at Research Institute of Electrical Communication (RIEC) as research associate (1980), and became associate professor (1990). He then became professor at Center for Interdisciplinary Research (2003). Since 2008, he has been professor at RIEC. He has been engaged mainly on surfaces of semiconductor thin films. He was awarded the 30th Kumagai prize of the best paper from the Vacuum Society of Japan.

[Papers]
Dielectric Nano-Devices
Research on Dielectric Nano Science and Technology

[Research Target and Activities]

Our main area of interest is evaluation and development of dielectric materials, including ferroelectric and piezoelectric materials and their application to communication devices and ferroelectric data storage systems. Our major contributions to advancement in these fields are the invention and the development of “Scanning Nonlinear Dielectric Microscope” (SNDM) which is the first successful purely electrical method for observing the ferroelectric polarization distribution without the influence of the shielding effect by free charges and it has already been put into practical use. The resolution of the microscope has been improved up to atomic scale-order. Therefore, it has a great potential for realizing the ultra-high density ferroelectric recording system.

Major achievements of studies in 2009 are as follows: (1) Surfaces of various material (cf. silicon, titanium dioxide, strontium titanate) were observed with atomic resolution using non-contact SNDM. (2) Ferroelectric discrete track media were proposed as a novel recording method, which is expected to have improved retention characteristics. Additionally, high-accuracy and high-speed methods for ultrahigh-density ferroelectric data storage were also developed. (3) Dopant profiling method using SNDM was developed for analysis of semiconductor devices.

[Staff]
Professor : CHO, Yasuo Dr. Research Fellow : KOBAYASHI, Shinichiro Dr.
Assistant Professor : HIRANAGA, Yoshiomi Dr. Research Fellow : OKAZAKI, Noriaki Dr.
Assistant Professor : KIN, Nobuhiro Technical Official : WAGATSUMA, Yasuo

[Profile of Professor Cho]

Yasu Cho graduated in 1980 from Tohoku University in electrical engineering department. In 1985 he became a research associate at Research Institute of Electrical Communication Tohoku University. In 1990, he received an associate professorship from Yamaguchi University. He then became an associate professor in 1997 and a full professor in 2001 at Research Institute of Electrical Communication Tohoku University. During this time, his main research interests included nonlinear phenomena in ferroelectric materials and their applications, research on the scanning nonlinear dielectric microscope, and research on using the nonlinear dielectric microscope in next-generation ultrahigh density ferroelectric data storage (SNDM ferroelectric probe memory).

[Papers]

Fig.1 Digital bit data written on ferroelectric single crystal with the areal recording density of 4 Tbit/inch².
Computational Design of Functional Materials for Spintorns Devices

[Research Target and Activities]
Our research targets are as follows: (1) theoretical analyses of quantum phenomena which appear in materials and nanostructures for advanced information devices, (2) computational design of materials and nanostructures which possess new functionalities for improvement of device performance, and (3) development of new design procedures based on large-scale computational simulation techniques.

Our research activities in FY 2009 include computational materials design for spintorns as follows:
(1) Giant magnetoresistive devices using half-metallic Heusler alloys
We investigate the spin-dependent transport properties in Co$_2$MnSi/NM/Co$_2$MnSi (001) (NM = Au, Ag, Al, Cr, V) spin-valve structures theoretically on the basis of first-principles density-functional calculations. The compatibility of the Fermi surface projected onto the in-plane wave vector $k//$ plays an important role in determining the interface resistance of each spin-valve. The resistance-area product in Co$_2$MnSi/Cr/Co$_2$MnSi (001) is larger of about 13 m$\Omega$μm$^2$ than that in Co$_2$MnSi/Au/Co$_2$MnSi (001), which is in good agreement with recent experimental observations.

(2) New ordered alloy FeNi with perpendicular magnetic anisotropy
We investigate the magnetic anisotropy energy (MAE) of an L1$_0$-ordered alloy FeNi theoretically on the basis of first-principles density-functional calculations. The magnetization of FeNi prefers the [001] direction. While the MAE is almost unaltered against the contraction of the in-plane lattice constant, the MAE decreases remarkably with increasing the in-plane lattice constant (Fig. 1). The compressive stress arising from the lattice mismatch with buffer layers is favorable for achieving larger MAE in FeNi thin films.

[Staff]
Professor : SHIRAI, Masafumi Dr.
Assistant Professor : MIURA, Yoshio Dr.
Assistant Professor : ABE, Kazutaka Dr.

[Profile]
Masafumi Shirai was received the Doctor of Engineering degree from Osaka University in 1989. From 1988 to 1996, he was a Research Associate, and then an Associate Professor at Osaka University. From 2002 to the present, he has been a Professor at Tohoku University. Now his research interest is focused on computational design of functional materials and device structures in spintronics.

[Papers]
Broadband Engineering Division: Research Target and Results

In order to establish the future broadband communication systems and novel devices that are flexibly applied to the future ubiquitous ultra-large capacity information communication, research and development are carrying out over the wide bands of microwaves, millimeter/submillimeter waves, terahertz waves, and lightwaves with regard to the information generation, transmission, processing, storage, and semiconductor spintronics technologies.

(1) Wireless Information Technology

Research and development in wireless information technology are progressing toward Dependable Air for the next decade's wireless systems. To realize the Dependable Air, we are interested in developing the hybrid single-carrier and multi-carrier technique and LSI development of frequency domain equalization (FDE).

We are also actively engaged in work on following technologies for broadband, low-power consumption and small-size terminals: RF-CMOS power amplifier and synthesizer devices for millimeter-wave-band wireless modems, and GHz-band film bulk acoustic resonator (FBAR) filter and oscillator.

(2) Ultra-Broadband Signal Processing

We are developing novel, integrated electron devices and circuit systems operating in the terahertz region. One of our major concerns is a new material called "graphene," a single-layered honeycomb-lattice carbon crystal. We have fabricated a graphene-channel FET utilizing heteroepitaxial graphene-on-silicon (GOS) material (provided by the group of Prof. Maki Suemitsu in RIEC) and demonstrated excellent electron drift mobility 20 times as high as that in Si MOSFETs.

We also succeeded in observation of amplified stimulated terahertz emission from femtosecond infrared laser-pumped GOS material. The results reflect the occurrence of the negative dynamic conductivity that has been theoretically predicted by our group, leading to realization of a new type of terahertz lasers.

(3) Ultrahigh-Speed Optical Communication

To achieve a global high-capacity optical network, we have been engaged in the research on ultrahigh-speed Optical Time-Division Multiplexing (OTDM) transmission and highly spectral-efficient coherent Quadrature Amplitude Modulation (QAM) transmission.

As regards the ultrahigh-speed transmission, 640 Gbit/s/channel DPSK signal was successfully transmitted over 525 km in a single polarization by using a novel ultrafast time-domain optical Fourier transformation technique. In coherent optical transmission,
we successfully achieved a QAM multiplicity as high as 256, and demonstrated a 64 Gbit/s transmission over 160 km with an optical bandwidth of 5.4 GHz. This indicates the possibility of a spectral efficiency exceeding 11 bit/s/Hz.

(4) Applied Quantum Optics

Novel functional semiconductor photonic devices are investigated to explore new generation photonic network systems. Ultra-broadband coherent terahertz (THz) wave radiation, called as “Tera-Photonics,” is also studied.

Ultra-high-speed operation of semiconductor photonic active devices is being investigated. It is confirmed that the bandwidth can be broadened drastically to some tens of GHz by a novel passive feedback laser diode with an external cavity. Novel THz biosensors using surface plasmon resonance are also studied to achieve sensitive detection of biomolecules and THz imaging with sub-wavelength spatial resolution. High-quality THz resonators are successfully realized by using novel fabrication process.

(5) Information Storage Systems

Amount of digital information is rapidly growing year by year in this decade. High density magnetic recording technology to store the tremendous information is crucial to meet this strong demand. System technology to process data access to/from the disks plays another significant role.

For a high areal density of 2 Tbits/inch², a computer simulation based on LLG equation and experimental studies for high density read/write performance of perpendicular magnetic recording have been carried out. The areal density was examined with perpendicular bit patterned media. A novel storage architecture to reduce power consumption was developed and evaluated for petabyte-class large-capacity systems.

(6) Basic Technology for Broadband Communication (Mizuno Lab.)

Development of measurement instruments using the millimeter- and terahertz-wave region of the electromagnetic spectrum is the research object of this laboratory.

Passive millimeter wave imaging devices are being developed for security and medical applications. A prototype of 77 GHz PMMW imaging device was tested in-site at the Narita International Airport to demonstrate its usefulness for security applications in the fall of 2009.

(7) Basic Technology for Broadband Communication (Inutake Lab.)

Synthetic aperture radars (SAR) are useful for all-weather surveillance and rescue. In this fiscal year we have started to develop a real-time image, air-borne SAR under the research contract with Ministry of Land, Infrastructure, Transport and Tourism.
Conceptual design of a spotlight-mode SAR system has been done, targeting at a high resolution (10 cm), small size and light weight (30-50 kg) at Ku-band, and development of a waveform synthesizer with a precise setting of delay-time has been done successfully. Scientists and engineers of universities and industries collaborate on the program.

(8) Laboratory for Nanoelectronics and Spintronics: Semiconductor Spintronics

The nanoscience and nanotechnology to control the quantum states in semiconductors, especially the spin-states and optical transitions, are investigated to realized new functional devices, such as memories and logic devices using spin states as well as quantum cascade lasers (QCL) with THz emission.

We performed direct magnetometry of electric-field effect on (Ga,Mn)As film, which showed the modulation of the Curie temperature as well as spontaneous magnetization, and elucidated the doping concentration dependence of the spin Hall conductivity of semiconductors quantitatively by systematic studies of the spin Hall effect. We also succeeded in lasing of THz-GaAs-based quantum cascade laser with a metal-metal waveguide structure, which is expected to reduce the threshold current density and raise the operation temperature.

(9) Laboratory for Nanoelectronics and Spintronics: Nano-Spin Memories

Technologies to realize advanced spin memory and logic devices using magnetic tunnel junctions (MTJs) consisting of ferromagnetic metal electrodes and insulating barriers are developing.

The TMR ratios of 78% at RT were realized in MgO-based MTJs with perpendicular anisotropy CoFe/Pd multilayers and CoFeB or Fe insertion. The TMR ratio of 122% at RT with $RA = 1.0 \Omega \mu m^2$ were obtained in CoFeB/MgO/CoFeB MTJs. Operations of the world's first 32Mb SPRAM chip, ternary content-addressable memory, Lookup-Table employing the spin-transfer torque MTJs were verified.
Research Area of Ultrahigh-Speed Optical Communication

Advanced optical communication technologies approaching the Shannon limit

[Research Target and Activities]

With the vast growth of traffic on the Internet from simple text data to high quality voice, images, and real-time video, it has become increasingly important to realize a high-capacity and high-speed network to support the daily needs of modern communications. Ultrahigh-speed optical communication is the key technology for building such an interconnected world.

This laboratory aims to achieve a global ultrahigh-speed optical network in the 21 century by engaging in the research of ultrashort pulse generation and transmission.

As regards ultrahigh-speed transmission, we successfully demonstrated 640 Gbit/s/channel single-polarization DPSK transmission over 525 km, in which a time-domain optical Fourier transformation (OFT) technique was adopted for improving the system tolerance to transmission impairments due to higher-order PMD. The OFT was successfully applied to a 640 Gbit/s DPSK signal, in which the strong chirp required for the OFT of a subpicosecond pulse is realized with a phase modulator operated in a round-trip configuration. As regards multilevel coherent transmission, 256 QAM coherent optical transmission was realized for the first time with a frequency-stabilized fiber laser and an optical PLL technique (Fig. 1). In this scheme, 64 Gbit/s (polarization-multiplexed 4 Gsymbol/s, 256 QAM) data were transmitted over 160 km with an optical bandwidth of 5.4 GHz, which corresponds to a spectral efficiency of more than 11 bit/s/Hz in a single channel.

[Staff]

Distinguished Professor: NAKAZAWA, Masataka Dr.
Associate Professor: HIROOKA, Toshihiko Dr.
Assistant Professor: YOSHIDA, Masato Dr.
JSPS Fellow: KASAI, Keisuke Dr.

[Profile of Professor Nakazawa]

Prof. Nakazawa received a Ph. D. degree from the Tokyo Institute of Technology in 1980. In 1980, he joined the Ibaraki Electrical Communication Laboratory, Nippon Telegraph & Telephone Public Corporation. He was a visiting scientist at Massachusetts Institute of Technology in 1984-1985. In 2001, he moved to the Research Institute of Electrical Communication, Tohoku University as a professor, where he has been engaged in research on ultrahigh-speed optical communication including soliton transmission, nonlinear effects in fibers, mode-locked lasers, and photonic crystal fibers. He is the author and coauthor of over 400 journal articles and holds more than 100 patents. He is a Fellow of IEEE, OSA, and IEICE, and has received various awards including the 2002 Daniel E. Noble Award and 2005 OSA R. W. Wood Prize.

[Papers]


Fig. 1 256 QAM transmission setup (a) and constellations before and after transmission (b) and (c), respectively.
**Applied Quantum Optics**

Research on Innovative Highly Functional Photonic Semiconductor Devices and Ultra-wide band coherent light sources, and their applications

[Research Target and Activities]

Novel functional semiconductor photonic devices including photonic integrated circuits are investigated to explore new-generation photonic network systems. We have also been studying ultra-broadband coherent terahertz (THz) wave radiation to explore novel science and technology, "tera-photonics".

Ultra-high-speed operation of semiconductor photonic active devices is being investigated. It is confirmed by means of numerical simulation that the operation speed of laser diodes can be increased by controlling them with high speed signal light. It is also confirmed that the bandwidth can be broadened drastically by a novel passive feedback laser diode with an external cavity. Novel THz biosensors using surface plasmon resonance are also studied to achieve sensitive detection of biomolecules, high-spatial-resolution THz imaging beyond diffraction limit. High-quality THz resonators for local-field enhancement are successfully realized by using novel fabrication process.

![Experimental setups for novel semiconductor photonic functional devices (left), and fabricated surface-plasmon THz-wave resonator (right)](image)

[Staff]

Professor : YASAKA, Hiroshi Dr.
Associate Professor : SHIKATA, Jun-ichi Dr.

[Profile of Professor Yasaka]

Hiroshi YASAKA received the B.S. and M.S. degrees in physics from Kyusyu University in 1983 and 1985, and Ph.D. degree in Electronics Engineering from Hokkaido University in 1993. In 1985 he joined the Atsugi Electrical Communications Laboratories, Nippon Telegraph and Telephone (NTT) Corporation. Since then, he has been engaging in research and development on semiconductor photonic devices for optical fiber communication systems. From 2008 he has been a professor of Tohoku University. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, the Japan Society of Applied Physics, the Physical Society of Japan, and IEEE/LEOS.

[Papers]


Contact to Professor Hiroshi YASAKA : yasaka@riec.tohoku.ac.jp
Wireless Info Tech

For Realizing Dependable Air

[Research Target and Activities]
Research and development are progressing toward Dependable Air in the 21st century's wireless information technology. The Dependable Air immediately provides any information for everyone at anytime and anywhere.

For realizing the Dependable Air, we are interested in developing following wireless network; (1) next generation mobile broadband wireless access (MBWA), (2) dependable broadband wireless local area network (WLAN), and (3) ultra broadband wireless personal area network (WPAN).

In this year, we have discussed following technology for broadband, low power consumption and small size terminals; (1) RF power amplifier, synthesizer and mixer devices for millimeter wave and GHz-band wireless modems, (2) GHz-band film bulk acoustic resonator (FBAR) devices, (3) Ultra small antennas for mobile terminals, (4) Seamless interconnection technology using 3-dementional system in package (3D SiP), and (5) frequency domain equalizer (FDE) devices on application specific integrated circuit (ASIC). Moreover, we have evaluated the MBWA field trial using frequency hopping orthogonal frequency division multiple access (FH-OFDMA) system.

[Staff]
Professor: TSUBOUCHI, Kazuo, Ph. D
Assistant Professor: KAMEDA, Suguru, Ph. D

[Profile]
Prof. Tsubouchi received the Ph.D. degree in Electronics Engineering from Nagoya University in 1974. Since 1974, he has been with the Research Institute of Electrical Communication, Tohoku University. In 1982, he spent at Purdue University as a Visiting Associate Professor. He is currently the professor and the director of IT-21 Center. He received the 2005 Achievement Award from the IEICE, and “Minister of Education, Culture, Sports, Science and Technology, Award” in the Award for Persons of Merit in Industry-Academia-Government Collaboration in FY2007, et al. He is a member of the IEEE, the IEICE, the Physical Society of Japan, the Japan Society of Applied Physics, and the Institute of Electrical Engineers of Japan.

[Papers]
Information Storage System

Research on Large Capacity Information Storage System Using Perpendicular Magnetic Recording

[Research Target and Activities]
Amount of digital information is rapidly growing year by year, which is projected to exceed 1000 Exa-byte \((10^{21}\) bytes) in 2010. Extremely large storage capacity by high density magnetic recording for the information is thus required. Perpendicular magnetic recording was introduced in order to continuously develop areal density of hard disk drives beyond the conventional density limit, i.e., near future target of 1 Tbit/inch\(^2\) and even larger than 5 Tbit/inch\(^2\). Theoretical studies including a micromagnetic computer simulation in association with experimental approach are carried out for the next generation high density perpendicular recording.

As we early proposed, magnetic nano-structure of recording media is the most essential parameter to achieve high density perpendicular recording. Bit-patterned medium (Fig 1) is one of promising candidates. An areal density of 2 Tbit/inch\(^2\) was clarified to be feasible under the condition of good geographical and magnetic uniformity of the patterned dots and a writing head resolution. A shingled writing recording with a wide track write head was also studied, which brought density increase by 50%. (Fig. 2)

In addition to the studies on magnetic recording, a novel low-power consumption architecture for the data centers in the internet was developed based on tiered operation of hard disk drives. The power reduction of 50% was confirmed from our simulation works.

[Staff]
Hiroaki MURAOKA, Professor (since 2000)
Simon J. GREAVES, Associate Professor (since 2003)
Kenji MIURA, Assistant Professor (since 2003)
Sachiko KOBAYASHI, Secretary

[Profile]
In 1991, Professor Muraoka joined Tohoku University. Since then, he has been engaged in research on high-density magnetic recording devices, systems and recording theories, mainly for perpendicular magnetic recording. He received PhD degree in 1981. He is a Fellow of IEEE.

[Papers]
Ultra-broadband Signal Processing

Novel Millimeter-wave and Terahertz Integrated Electron Devices and Systems

[Research Target and Activities]

We are developing novel, integrated electron devices and circuit systems operating in the terahertz (THz) region. We are pursuing new materials called “graphene,” a single-layered carbon-atomic honeycomb lattice crystal featuring extraordinary carrier transport properties. We have theoretically predicted the occurrence of negative dynamic conductivity in the THz range for optically pumped graphene. Very recently we have succeeded in observation of amplified stimulated THz emission from femtosecond infrared-laser pumped heteroepitaxial graphene on Si (developed by Prof. Maki Suemitsu in RIEC). This will be the first big step ahead to a new principle THz laser. We have also succeeded in transistor operation by introducing graphene as a channel material in a Si-based FETs, demonstrating an excellent electron drift mobility by 20 times higher than that for Si MOS-FETs. The other theme includes the development of plasmon-resonant-based new type of THz emitter/detector devices.

[Staff]
Professor: OTSUJI, Taiichi Dr.
Associate Professor: SUEMITSU, Tetsuya Dr.
CREST Researcher: TAKABAYASHI, Masaru Dr.
JSPS Research Fellow: BOUBANGA TOMBET, Stephane Albon Ph.D. Secretary: UENO, Kayo

[Profile]
Prof. Taiichi Otsuji received the B.S. and M.S. degrees in electronic engineering from Kyushu Institute of Technology (Kyutech), Fukuoka, Japan, in 1982 and 1984, and the Ph.D. degree from Tokyo Institute of Technology, Tokyo, Japan, in 1994. After working for NTT Laboratories, Japan, since 1984, he joined Kyutech in 1999, as an associate professor, being a professor from 2002. Since 2005, he has been a professor at RIEC, Tohoku University, Japan. He is the recipient of the Outstanding Paper Award of the 1997 IEEE GaAs IC Symposium. He is a member of IEEE, OSA, IEICE, and JSAP.

[Papers]
Basic Technology for Broadband Communication
Development of Measurement Instrumentation by the Millimeter and THz Wave

[Research Target and Activities]
Development of measurement instruments using the millimeter- and terahertz- wave region of the electromagnetic spectrum is the research target of this Division. Since the wavelength of this region is larger than that of the infrared and optical region, scattering by cloud, dust, flame, fabrics, skin, etc. is much smaller and since photon energy of this region is much smaller than thermal energy kT at the room temperature, non-invasive measurement for materials is possible. In this Division passive millimeter wave imaging systems are now being developed for security and medical applications.

A prototype of 77 GHz PMMW imaging device was tested in-site at the Narita International Airport to demonstrate its usefulness for security applications in the fall of 2009.

[Staff]
Visiting Professor: MIZUNO, Koji Dr

[Profile]
Koji Mizuno was graduated from the Department of Electronic Engineering, Tohoku University, Sendai, in 1963 and was appointed Professor at the University in 1984. He was a visiting researcher at the University of London in 1972, and at California Institute of Technology in 1990. In 2004 he was appointed Professor Emeritus of Tohoku University and also Research Professor of RIEC. He is recipient of the IEEE Fellow grade in 1993, the Kenneth J. Button Medal in 1998, the Minister Award of MEXT (Ministry of Education, Culture, Sports, Science and Technology, Japan) in 2003, and IEEE MTT-Society Distinguished Educator Award in 2005.

[Paper & Book]
Basic Technology for Broadband Communication

High Resolution Synthetic Aperture Radar for Civilian Applications

[Research Objectives and Activities]
We are developing air-borne synthetic aperture radars (SAR) for civilian applications. The SAR is useful for all-weather surveillance and rescue in disastrous fires and smokes. Scientists and engineers from both universities and industries collaborate on this research project.

Development of a high resolution (10cm), small size and light weight (30kg) SAR at Ku-band has been started in this year under the contract of Ministry of Land, Infrastructure, Transport and Tourism. Conceptual design of a real-time image-formation SAR system has been done, as shown above.

[Staff]
Visiting Professor : INUTAKE, Masaaki Dr.

[Profile]
1966: Bachelor of Engineering, University of Tokyo.
1972: Doctor of Engineering, University of Tokyo.
1972-1974: Research Fellow, Institute of Space and Aeronautical Science, University of Tokyo.
1974-1980: Assistant Professor, Institute of Plasma Physics, Nagoya University
1980-1994: Associate Professor, Graduate School of Applied Physics, University of Tsukuba.
1994-2007: Professor, Graduate School of Engineering, Tohoku University.
2007-present: Visiting Professor, Research Institute of Electrical Communication, Tohoku University.
Researches: Microwave / laser-aided plasma diagnostics. Alfven wave physics and its applications to the wave heating of a fusion plasma and the acceleration of supersonic plasma flows in a magnetic nozzle for an advanced space propulsion. Prizes for Science & Technology (Research Category), Commendation for Science & Technology by the Minister of Education, Culture, Sports, Science and Technology, (April, 2008).

[Papers]
Aims and Achievements of Human Information Systems Division

Understanding the mechanisms of human information processing and realizing appropriate information communication environments are necessary for advanced information communication systems.

The aim of this division is to develop elementary and system technologies for the next generation of information communication systems that are in harmony with human and the environment. For the aim, Achievements of Human Information Systems Division covers the research fields of information creation of biological systems, information communication environments optimization and human information processing.

To achieve the aim, the division consists of the following four laboratories: Electromagnetic Bioinformation Engineering, Advanced Acoustic Information Systems, Visual Cognition and Systems, Interdisciplinary Field for Informatics, and Ubiquitous Communications System.

(1) Electromagnetic Bioinformation Engineering

(Aims) The aim of our division are to obtain the high accuracy sensor system for the signals from the human body or electric devices and to obtain the system for approaching action to the human body, by using the nano-scale controlled magnetic materials and by the development of the devices under the functions of the magnetics.

(Achievements) We proposed an extraordinary high sensitivity of the magnetic field sensor and the strain sensor by the technique of optimizing the anisotropy of the magnetic thin films. The manipulating technique for controlling the coagulation and the dispersion of the magnetic small particles, which will be used in the human body, was proposed. In addition, 3D position detecting system using magnetic markers was studied to improve its position accuracy. The study about the magnetic actuator driven by external magnetic field was carried out for micro-pump, micro-cantilevered actuator, and so on. The system supporting the medical operation under the endoscopes was studied accompanied with the medical doctors.

(2) Advanced Acoustic Information Systems

(Aims) To realize future high-definition communication systems with rich and natural sense of presence, acoustic information processing technologies based on good knowledge of human auditory system as well as multimodal perception relating to hearing are studied.

(Achievements) In 2009, we deepen the understanding human spatiotemporal perceptual processes of audio-visual and audio-vestibular information. This is particularly important to realize future multi-modal information processing and communication systems.

We clearly demonstrated that the alternation of sound location induces illusory visual motion when vision cannot provide accurate spatial information (sound-induced visual motion: SIVM). We continued to develop methods, such as virtual auditory displays based on our accumulated knowledge of human auditory space perception, new auralization method for concert hall based on sound field simulation and sound reproduction method based on ambisonics techniques, and high-precision...
analyzing method using a surrounding microphone array, to realize 3D immersive sound fields. They are keenly required to realize super-definition audio-visual communications in near future. Furthermore, we developed new signal processing algorithms of multiple description method for realizing high secrecy in voice over internet protocols (VoIP), advanced digital hearing aids, and high-performance binaural speech enhancement providing proper spatial information.

(3) Visual Cognition and Systems
(Aims) To understand the vision-related brain functions in order to apply the knowledge to realize human oriented information communication systems.
(Achievements) We achieved results in the fields of visual attention, motion perception and color perception. Firstly, we succeeded to measure distribution of visual attention while people tracking a moving object, and the measurements showed that the visual system has difficulty to pay attention to different location other than the object tracked. This knowledge is useful to model the function of visual attention. Secondly, we showed that only slow motion detectors contribute to detection of global motion and also that it is different from the attention-based motion system. Since slow motion signals have been paid little attention both in vision and image processing, the result provided new view of role of motion signals in visual processing. Thirdly, we have clarified that color information in human visual cortex is not coded by the combinations of red-green and blue-yellow components through functional brain-imaging technique and its analysis by image-classification technique.

(4) Interdisciplinary Field for Informatics
(Aims) The interdisciplinary field of research combining nanobiotechnology and information technology attracts our exceeding interests. These studies stand on the development of new materials created by self-assembly of functional molecules and nanomaterials, leading to new classes of biosensing devices.
(Achievements) Ag nanosheet composed of AgMy is sensitive to photocatalytic reaction and changes the color from yellow to gray when the decomposition of myristate cappings and the fusion of silver cores take place. By use of Ag nanosheet as a marker, we found TiO2 nanotube anatase crystals synthesized by anodic oxidation exhibit extremely high remote photocatalytic activity. UV spectra and SEM images confirmed that only 10-20% of TiO2 nanotubes on surface decomposes the entire surface of AgNPs nanosheet. This lateral remote reaction was observed only for TiO2 nanotubes but not for commercial TiO2 powders.

(5) Ubiquitous Communications System
(Aims) The goal of ubiquitous communications is to realize communications environments in that everybody can communicate with anybody, anywhere and anytime through the research and developments on radio propagation characteristics, antennas and radio equipment with which customers can communicate universally. Towards this goal, the core technologies to realize Super Broad Band Indoor Wireless Communications, millimeter wave beam forming antenna and CMOS RF amplifier for portable terminals have been studied. Also, it is included to contribute or to lead
IEEE standardization based on "Japanese technologies."
(Achievements) Millimeter wave beam forming antennas and RFCMOS amplifiers together with propagation characteristics have been studied and have yielded following:

1) As results of beam forming antenna with 4-elements employing discrete phase control (90 degree step), following have been clarified by computer simulations:
   i. Antenna gain variation is as small and practical as 0.9 dB,
   ii. Slot-type antenna has shown the best gain/beam performance among of the candidates studied so far,
   iii. The antenna beam can be controlled well by 11 combinations of the discrete phases for four antenna elements.

2) Based on the computer simulation results together with fixed phase shifters, a prototype slot-type antenna was fabricated and measured. The results on antenna gain and beams show good agreements with the design.

3) CMOS 60 GHz amplifiers have been challenged by Class-B operation and the computer simulations showed about 20% power added efficiency and fabricated RFIC indicated high possibility of achieving 20 % power added efficiency as well.

4) Moreover, a simulator based on ray-tracing to find out the positions and sizes of artificial reflectors to enhance communications probability has been developed.

By leading COMPA (Consortium for Millimeter wave Practical Applications, Chair: Shuzo Kato) and integrating other 17 overseas Partners (17 organizations in all) who have agreed to COMPA’s proposal, the millimeter wave standardization (IEEE802.15.3c) was completed in September, 2009. It is the first successful IEEE 802 Standardization carried out from the very beginning up to the end, managed and negotiated with many others by Japanese organizations to promote the Japanese technologies. This will be a good success example for Japanese industry to learn for the future standardization.
Electromagnetic Bioinformation Engineering

Communication with human body

[Research Target and Activities]

Fig.1 Sensitive magnetic field sensor         Fig. 2 Magnetic actuator for capsule-endoscope

The magnetic field sensor with very high sensitivity was produced. In this work, new processes for controlling the anisotropy of the magnetic thin films were approached and a huge change of the impedance of the sensor was obtained. On the work of wireless magnetic motion capture systems, the factors in the detection accuracy were quantitatively clarified. The magnetic actuators such as the micro-pump, and the cantilevered actuator with the magnetostrictive thin films were studied. The work for the magnetic actuator for the capsule-endoscope was carried out with a company of the medical equipments.

[Staff]
Professor: ISHIYAMA, Kazushi Dr.
Assistant Professor: HASHI, Shuichiro Dr.

[Profile of Professor ISHIYAMA]
He received his MS and PhD degrees in Electrical Engineering from Tohoku University in 1986 and 1993, respectively. He is currently working as a professor in Research Institute of Electrical Communication, Tohoku University. His research interests are in the area of magnetics and magnetic applications.

[Papers]
Advanced Acoustic Information Systems

Development of next generation communication systems

[Research Target and Activities]
The main interest of this laboratory is a study of the information processing in the human auditory system. We are, at the same time, aiming at the realization of a 'comfortable' sound environment exploiting digital signal processing techniques. Three-dimensional sound image control by high-definition virtual auditory displays based on simulating transfer functions of sound paths from sound sources to listeners' external ears, and a sound field simulator based on precise sound field analysis and control are two examples. These systems are expected to provide a high-quality 3D virtual sound space, which is keenly required to realize in the multimedia communications, cyberspace systems and super-definition audio-visual display systems. Moreover, in 2009, we put a lot of efforts to investigate the spatiotemporal integration process of multisensory information processing. Furthermore, in 2009, we developed new signal processing algorithms of digital watermarking, advanced digital hearing aids, and high-performance two-stage binaural speech enhancement.

[Staff]
Professor: SUZUKI, Yōiti Dr.
Associate Professor: IWAYA, Yukio Dr.
Assistant Professor: SAKAMOTO, Shuichi Dr
Technical Official: SAITO, Fumitaka
Research Fellow: CUI, Zheng Lie Dr., KOBAYASHI, Maori Dr., OKAMOTO, Takuma Dr., OTANI, Makoto Dr. and TERAMOTO, Wataru Dr.

[Profile of Professor SUZUKI Yōiti]
SUZUKI Yōiti graduated from Tōhoku University in 1976 and received his Ph. D. degree in electrical and communication engineering in 1981. His research interests include psychoacoustics, high-definition auditory display and digital signal processing of acoustic signals. He received the Awaysa Kiyoshi Award and Sato Prize from the Acoustical Society of Japan. He served as a president of the Acoustical Society of Japan from 2005 to 2007. He is a fellow of the Acoustical Society of America.

[Papers]

Fig. 1 Application for training spatial cognition based on high-definition virtual auditory display
Visual Cognition and Systems

Vision sciences for visual communication

[Research Target and Activities]
In order to realize human oriented information communication systems and visual environments gentle to humans, it is necessary to understand the functions of the human visual system. The aims of visual cognition and systems laboratories are to investigate on vision functions in the human brain and to apply the knowledge to human factors and image sciences.

1. 3D motion mechanisms
There are several processes for perception of motion in depth. We revealed the importance of interocular velocity differences. We have been studying the properties of the interocular velocity differences. We found that the specificity of spatial frequency in the 3D motion-in-depth process is different from that in the 2D motion process. This suggests that the 3D motion process is independent of spatial scale on the retina.

2. Measurement of the shift of visual attention using steady state brain wave
In order that visual attention shifts independently of gaze, we need devised ways for the measurement of the shift of visual attention. Although the property of the shift of visual attention has been examined in detail by psychophysical studies, those methods are very complicated and limited in temporal resolution. Previous studies have not been success in the measurement of the shift of visual attention. We succeeded the measurement of the shift of visual attention using the steady state visual evoked potential (SSVEP) in which brain wave is induced by a flicker stimulus consisting of temporally sinusoidal wave. We found that our method can discern the difference between transient attention and sustained attention.

[Staff]
Professor : SHIOIRI, Satoshi
Associate Professor : KURIKI, Ichiro
Assistant Professor : MATSUMIYA, Kazumichi
Postdoctoral fellow : OGIYA, Mitsuharu MATSUBARA, Kazuya

[Profile]
Professor Shioiri graduated Tokyo Institute of Technology and received Dr. Eng in 1986. He was a postdoctoral researcher at University of Montreal from 1986 to 1989. From June of 1989 to April of 1990, he was a research fellow at Auditory and Visual Perception Laboratories of Advanced Telecommunications Research Institute. He moved to Chiba University at May of 1990, where he spent 15 years as an assistant professor, an associate professor, and a professor of Department of Image Sciences Department of Image, Information Sciences and Department of Medical Systems. In 2005, he moved to Tohoku University. Since then, he has been a professor of Research Institute of Electrical Communication of Tohoku University. His research interests cover early, middle and high level vision, including motion perception, depth perception, color vision, visual attention, eye movements, modeling of visual functions and comparison of the conscious and unconscious vision processes.


Interdisciplinary field for informatics
Fabrication and Application of Plasmonic Ag Nanosheet

[Research Target and Activities]

The interdisciplinary field of research combining nanobiotechnology and information technology attracts our exceeding interests. These studies stand on the development of new materials created by self-assembly of functional molecules and nanomaterials, leading to new classes of biosensing devices. The plasmons, especially the combination of surface plasmons propagating along the metal-organic interface and local surface plasmons on metal nanoparticles is crucial to control and manipulate localized light in nanoscale for nanosensing.

Our main topic, “plasmonic silver nanosheet”, obtained one remarkable success in its application this year. Ag nanosheet composed of AgMy is sensitive to photocatalytic reaction and changes the color from yellow to gray when the decomposition of myristate cappings and the fusion of silver cores take place. By use of Ag nanosheet as a marker, we found TiO2 nanotube anatase crystals synthesized by anodic oxidation exhibit extremely high remote photocatalytic activity [3]. UV spectra and SEM images confirmed that only 10-20% of TiO2 nanotubes on surface decomposes the entire surface of AgNPs nanosheet (Fig. 1). This lateral remote reaction was found only for TiO2 nanotubes but not for commercial TiO2 powders(∼ m). This difference in remote photocatalytic activity between the TiO2 nanotubes and powders is probably correlate to the different life time of produced radicals produced on each surface, although a further investigation is necessary.

[Staff]
Professor TAMADA Kaoru Dr. (from Oct. 2007)

[Profile]

[Papers]
Ubiquitous Communications System
Research and Development on Super Broadband Wireless Communications

[Research Target and Activities]

[Target]

The goal of ubiquitous communications is to realize communications environments in that everybody can communicate with anybody, anywhere and anytime through the research and developments on radio propagation characteristics, antennas and radio equipment with which customers can communicate universally.

[Activities]

Millimeter wave beam forming antennas and RFCMOS amplifiers together with propagation characteristics have been studied and have yielded following:

1) Based on the computer simulation results together with fixed phase shifters, a prototype slot-type antenna was fabricated and measured. The results on antenna gain and beams show good agreements with the design.

2) CMOS 60 GHz amplifiers have been challenged by Class-B operation and the computer simulations showed about 20% power added efficiency and fabricated RFIC indicated high possibility of achieving 20% power added efficiency as well.

By leading COMPA (Consortium for Millimeter wave Practical Applications, Chair: Shuzo Kato) and integrating with other 17 overseas Partners (17 organizations in all) who have agreed to COMPA’s proposal, the millimeter wave standardization (IEEE802.15.3c) was completed in September, 2009. It is the first successful IEEE 802 Standardization carried out from the very beginning up to the end, managed and negotiated with many others by Japanese organizations.

[Staff]

Professor: KATO, Shuzo Ph.D.
Associate Professor: NAKASE, Hiroyuki Ph. D.
Assistant Professor: SAWADA, Hirokazu Ph. D.

[Profile of Professor Shuzo Kato]

Prof. Shuzo Kato received his Ph. D degree in electrical and communications engineering from Tohoku University, Sendai Japan in 1977. From 1977 to 1995, he worked at NTT (Nippon Telegraph and Telephone) Research Laboratories in Japan, specializing personal and satellite communications systems R&D. He founded Pacific Communications Research Corp., focusing on ASIC, SW and system design for PCS in 1995, at the same time he served as Senior Executive Vice President, and later as President of Uniden Corporation. From January 1999 to July 2001, he served as Executive Vice President, Mitsubishi Wireless Communications Inc (MWCI) in USA, as well as President, Mobile Communications Technology Center of MWCI in San Diego, CA responsible for mobile phone technology development up to real/sellable and high yield cell phones with all certificates (FCC, CTIA and inter-operability). From 2002 to 2005, he served as Executive Vice President of Teradyne Japan responsible for P/L, Engineering, Production and Global Marketing as well as President and CEO of Omni Wireless Inc., in California, USA. He currently is Professor, Research Institute of Electrical Communications, Tohoku University, Japan, Program Coordinator, Ubiquitous Mobile Communications at NICT (National Institute of Information and Communications Technology) working on wireless communications systems R&D focusing on millimeter wave communications systems. He has been serving as Vice-chair of IEEE802.15.3c Task Group working on millimeter wave systems standardization and Chair of COMPA (Consortium of Millimeter Wave Systems Practical Applications) promoting millimeter wave systems globally. He has published over 200 technical papers, held over 75 patents (including a patent which became DOD (Department of Defense, USA) standard in 1998), co-founded International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC). He is a Fellow of the IEEE and IEICE Japan and served as an Editor of IEEE Transaction on Communications, Chairman of Satellite and Space Communications Committee, COMSOC IEEE, a Board Member of IEICE Japan.

[Papers]

Research Targets and Activities of Systems & Software Division

The goal of System & Software Division is to realize Ubiquitous environment. In an ideal ubiquitous environment, everyone can communicate with anybody, anywhere, with any kind of information, at any time, freely and in real time. Our division has the following five research fields related to such high-level system, software and contents by integrating computer and communication:

- Software Construction: Reliable and high-level software.
- Communication Network: Symbiotic computing.
- Information Content: Network-oriented contents management and utilization technology.
- Structure of Information Society (Visitor Section).

An overview of research results from Apr. 2009 to Mar. 2010 of these fields except the visitor section is described in this section.

(1) Software Construction

We have been researching on theoretical foundations for flexible yet reliable programming languages, and have been conducting a development project of SML#, a new programming language in the ML family, that embodies some of our research results such as more flexible static typing and high-degree of inter-operability with existing languages and databases. The major results of 2009 academic year include the following. (1) A type theoretical foundations for foreign function interface. We developed a type theory for functional languages that can inter-operate with polymorphic and higher-order functions defined in the C language, and developed a compilation algorithm for such a functional language based on the type theory. (2) Development of the SML# Compiler. The last year's development includes a compiler back-end that produces an x86 object file in the standard format compatible with C and other languages.

(2) Computing Information Theory

Aiming at combining program transformation methods and automated theorem proving methods, we continued to pursue the possibility of program transformation by second-order templates based on term rewriting. We proposed a second-order generalization algorithm and based on this, we implemented a method to extract second-order templates from concrete program transformations. Although many automated termination provers have been proposed recently, little work is reported on automated confluence provers. We developed an automated confluence prover ACP for term rewriting systems based on several divide-and-conquer methods such as direct sum decomposition and commutative decomposition. Applying decreasing diagram technique and incremental extension technique, we developed new methods for proving confluence of term rewriting systems. Other research results of this year include a new termination proof of simply typed S-expression rewriting.
systems and a new procedure for disproving head normalization of infinity term rewriting systems.

(3) Communication Network

We have studied new management schemes for next generation ubiquitous networks (SCOPE project, 2007-2009, Ministry of Internal Affairs and Communications) and promoted standardization activities for “Network Mobility Management Information Base (NEMO-MIB)” in IETF WG. As an outcome of this work, we have succeeded in international standardization of NEMO-MIB on 14th April, 2009 (RFC 5488). We have also issued a press release on this standardization on 23rd July, 2009, which had attracted wide press coverage. In the field of “Symbiotic computing”, we have refined the details of its model and architecture, and have developed some prototype systems, such as supervisory support system for elderly people (uEyes) and real/cyber integrated space (SymbioZone). We have published six papers in international journals, including one invited paper. Moreover, we had also demonstrated our systems in Forum on Information Technology (FIT2009) and RIEC open house which had attracted people from academic and industrial fields.

(4) Information Content

We have been developing creation technologies, retrieval technologies and distribution technologies for information content. We are developing DMD (Digital Movie Director), which makes it possible to generate 3DCG animation content only by text (scenario) input, and automatic human-pose estimation technology for cloth fitting room. Besides we are studying a high-performance video shot boundary detection technology, automatic video metadata generation technology and so forth. Furthermore, we are proposing a new cyclic broadcasting method and an overlay multicast technology for low-cost & high-performance video distribution.
Software Construction

Foundations for Developing High-level and Reliable Programming Languages

[Research Target and Activities]

Today’s software systems are becoming more and more complicated due to the need of integrating various computation resources available in the Internet. A key to control the complexity and to enhance the reliability of such a system is to develop a high-level programming language that can directly represent various resources and automatically detect potential inconsistencies among the components in a system. Based on this general observation, our research aims at establishing both firm theoretical basis and implementation method for flexible yet reliable programming languages for advanced applications. Research topics on theoretical foundations include: logical foundations for compilation, verification of low-level code, and type-directed compilation for polymorphic languages. We are also developing a new practical ML-style programming language, SML#, which embodies some of our recent results such as record polymorphism, rank1 polymorphism, and high-degree of inter-operability with existing languages and databases.

The major results of 2009 academic year include the following. (1) A type theoretical foundations for foreign function interface with C. One major weakness of functional languages is the lack of inter-operability with C and other languages. To overcome this weakness, in this research, we investigated type theoretical properties of inter-operability between an ML style polymorphic language and the C language, and developed a type system for an ML-style polymorphic functional language with powerful foreign function interface. The developed type system allows an ML programmer to call C functions seamlessly without writing complicated and error-prone stab functions. The target C functions can even be polymorphic and higher-order ones. These results solve the long standing problem of the lack of inter-operability in ML-style functional languages. (2) Development of the SML# Compiler. In the last year, we developed the following methods and components. (i) A compilation method that enables SML# object files to be statically link with C library. (ii) A compiler back-end that produces x86 object files in the standard object file format so that they can be statically linked with C object files using an ordinary linker. (iii) A prototype module for seamless inter-operation with an SQL database system. The module first type-checks SQL expressions based on record polymorphism and compiles them to code that interact with an SQL database server.

[Staff]

Professor OHORI, Atsushi (2005-)
Assistant Professor UENO, Katsuhiro (2009-)

[Profile]

Professor Atsushi Ohori was born in 1957. He received his BA degree in Philosophy from University of Tokyo, 1981; received his MSE degree in Computer and Information Science from University of Pennsylvania, 1986; and received his Ph.D. degree in Computer and Information Science from University of Pennsylvania, 1989. He worked for Oki Electric Industry as a programmer, a researcher and a senior researcher from 1981 until 1993. From 1989 until 1990, he spent one year in University of Glasgow as a postdoctoral research fellow funded by Royal Society Research Fellowship. In 1993, he joined Research Institute for Mathematical Sciences, Kyoto University as an Associate Professor. In 2000, he joined Japan Advanced Institute of Science and Technology as a Professor. In 2005, he moved to RIEC, Tohoku University as a Professor.

[Papers]


Computing Information Theory
Towards a New Software Paradigm Arising from Computation and Proof

[Research Target and Activities]
We are working on the development of a new software paradigm that arises from computation and proof. For this, we focus on a rewriting formalism which offers both flexible and effective reasoning with equations. In the rewriting formalism, proofs by equational reasoning and computations by rewriting systems can be combined in a unified framework (see the figure above). We aim at applying our new paradigm to the development of formal techniques for construction and verification of reliable software. We are currently working on rewriting theories for termination, confluence, program transformation, and program verification. Recent research activities include higher-order rewriting systems, automated inductive theorem proving, combination of functional-logic languages and automated theorem proving systems.

[Staff]
Professor : TOYAMA, Yoshihito Dr
Associate Professor : AOTO, Takahito Dr
Assistant Professor : KIKUCHI, Kentaro Dr

[Profile of Professor TOYAMA]
Yoshihito Toyama was born in 1952. He received his B.E. from Niigata University in 1975, and his M.E. and D.E. from Tohoku University in 1977 and 1990. He worked as a Research Scientist at NTT Laboratories from 1977 to 1993, and as a Professor at the Japan Advanced Institute of Science and Technology (JAIST) from 1993 to 2000. Since April 2000, he has been a professor at the Research Institute of Electrical Communication (RIEC) of Tohoku University. His research interests include term rewriting systems, program theory, and automated theorem proving.

[Papers]
Communication Network Systems
Information Communication Systems based on Symbiotic Computing

[Research Target and Activities]
Aiming towards the next generation ubiquitous stage we are pursuing a research on information and communication paradigm, called “Symbiotic computing”. The purpose of this work is to establish a method comprising of flexible information and telecommunication system with the co-existence of human and IT environment. This computing paradigm operates with stability while satisfying user and system provider’s criteria. We have been promoting both theoretical and practical researches of Symbiotic computing based on the concept of flexible information network where human and IT environment co-exist. Our focus also includes performance evaluation of super-high-speed network and its efficient management.

1) Symbiotic computing: Theory and application.
2) Symbiotic society and health-care/watch-over support/real-cyber space integration

In 2009, for Symbiotic computing research, we have studied model and architecture of Symbiotic computing in detail. We had also demonstrated our systems in Forum on Information Technology (FIT2009) and RIEC open house. For network management research, we have investigated IPv6 network mobility support and designed a MIB specialized in network mobility. We also promoted standardization activities in IETF Working Group. As an outcome of this work, we have succeeded in international standardization of NEMO-MIB on 14th April, 2009 (RFC 5488). We have also issued a press release on this standardization on 23rd July, 2009, which had attracted wide press coverage.

[Staff]
Professor: SHIRATORI, Norio Dr.
Associate Professor: SUGANUMA, Takuo Dr.
Visiting Associate Professor: CHAKRABORTY Debasis Dr.
Secretary: Kaori Moriya

[Profile]
Prof. Shiratori was born in 1946 in Miyagi Prefecture. He received his doctoral degree from Tohoku University in 1977. He is currently a Professor at RIEC. Before moving to RIEC in 1993, he was the Professor of Information Engineering at Tohoku University from 1990 to 1993. Prior to that, he served as an Associate Professor and Research Associate at RIEC. He received IEEE Fellow in 1998, IPSJ Fellow in 2000 and IEICE Fellow in 2002. He is the recipient of many awards including, IPSJ Memorial Prize Wining Paper Award in 1985, IPSJ Best Paper Award in 1996, IPSJ Contribution Award in 2007, IEICE Achievement Award in 2001, IEICE Best Paper Award, IEEE ICOIN-11 Best Paper Award in 1997, IEEE ICOIN-12 Best Paper Award in 1998, IEEE ICPADS Best Paper Award in 2000, IEEE 5-th WMSCI Best Paper Award in 2001, UIC-07 Outstanding Paper Award in 2007, Telecommunication Advancement Foundation Incorporation Award in 1991, Tohoku Bureau of Telecommunications Award in 2002, The Commendation for Science and Technology by the MEXT, in 2009, etc. He was the vice president of IPSJ in 2002, IFIP representative from Japan in 2002, an associate member of Science Council of Japan in 2007, and president of IPSJ in 2009. He is working on methodology and technology for symbiosis of human and IT environment.

[Papers]
Information Contents

Creation, Understanding, Distribution and Consumption of Next-generation Digital Content

[Research Target and Activities]
In our laboratory, we developed new technologies this fiscal year.
1. Automatic Character Positioning Method in DMD
   We developed automatic character positioning method in DMD (Digital Movie Director), which is innovative and useful because user does not have to think of three dimensional CG space.
2. A Cyclic Broadcasting Method for NVoD for IPTV era
   We developed a new broadcast scheduling method for end user to distribute their video content with their PC and network resources. The features of this method is to own network-error resilience.
3. An Intuitive Character Motion Creation System
   In general, character motion creation is difficult to generate for most of CG creators. We developed a new system based on arrow-input interface. CG creators can generate new motions more and more easily by this system.
4. High-performance Video shot Boundary Detection Technology
   Existing shot boundary detection methods are difficult to detect all of shot boundaries exactly. This is why we proposed a new approach to handle numerous video features based on multivariate statistics. This method showed our proposal to detect most of shot boundaries which existing methods are difficult to detect.

[Staff]
Professor : NUMAZAWA, Junji Dr.
Associate Professor : AOKI, Terumasa Dr.
Secretary : MUTO, Nobuko

[Profile of Professor Numazawa, Junji]
Junji Numazawa received the M.E., and Ph.D degrees in electronics engineering from Hokkaido University, Sapporo, Japan, in 1971, and 1994, respectively. He joined NHK (Japan Broadcasting Corp.) in 1971. He was Director of the Science and Technical Research Laboratories of NHK in June 1996, Director of Engineering Administration Department of NHK in June 1999, Executive Research Engineer of Science and Technical Research Laboratories of NHK in June 2002. Since 2004, he has been a Professor at the RIEC and GSIS of Tohoku University. He received “Suzuki Memorial Incentive Awards” and “Fujio Frontier Awards” of The Institute of Image Information and Television Engineers (ITE) in 1980 and 1995 respectively, “Distinguished Invited Paper Awards” of IUMRS·ICAM-93 in 1993, “Person Who Has Rendered Distinguished Service Awards” of Tokyo Metropolitan Government in 2003. Dr. Numazawa is a Fellow of the Institute of Image Information and Television Engineers (ITE).

[Papers]
Laboratory for Nanoelectronics and Spintronics

The Laboratory for Nanoelectronics and Spintronics of the Research Institute of Electrical Communication was established in 2004. Its purpose is to develop and establish the science and technology of nanoelectronics and spintronics for information technology, utilizing the facilities installed in the Nanoelectronics-and-Spintronics building having 1300 m$^2$ of cleanroom area. The Laboratory for Nanoelectronics and Spintronics consists of four Sections:

- Atomically Controlled Processing (Junichi Murota, Professor)
- Semiconductor Spintronics (Hideo Ohno, Professor)
- Nano-Molecular Devices (Michio Niwano, Professor)
- Nano-Spin Memory (Shoji Ikeda, Associate Professor)

These Sections cooperatively carry out the research aimed at establishing nanoelectronics and spintronics, together with the groups of Intelligent Nano-Integration System (Koji Nakajima, Professor), Quantum-optical Information Technology (Keiichi Edamatsu, Professor), and Ultra-Broadband Signal Processing (Taiichi Otsuji, Professor) and with the research groups of the Institute, the Graduate School of Engineering, the Graduate School of Information Science, Tohoku University, and nation-wide cooperative research projects in the field.
Highlights of Research Activities in 2009:

Atomically Controlled Processing [Murota Laboratory]

In order to create atomically controlled processing for nanometer-order artificial heterostructures of group IV semiconductors, following experimental results have been obtained: (1) In the research on P atomic-layer doping, low-temperature Si epitaxial growth by reaction of Si$_3$H$_6$ as a higher reactivity gas enables higher P concentration. (2) By heavy C atomic-layer doping at heterointerface between a Si cap layer and a Si$_{0.55}$Ge$_{0.45}$ layer in Si/Si$_{0.55}$Ge$_{0.45}$/Si(100) heterostructure, the intermixing between Si and Ge at heterointerface is effectively suppressed. (3) In the research on B atomic-layer doping in Si by using a plasma CVD without substrate heating, it is clarified that lowering of the plasma energy effectively suppresses a plasma induced lattice damage and a surface B reduction, and it becomes quite important to achieve heavy B atomic-layer doping in a nanometer-order ultrathin Si film.

Semiconductor Spintronics [Ohno Laboratory]

Our research activities focus on the establishment of the fundamental technologies for future spintronic devices. The outcomes in the last fiscal year are following. (1) We performed the direct magnetometry of electric-field effect on (Ga,Mn)As thin film and observed the modulation of the Curie temperature as well as spontaneous magnetization. (2) Doping concentration dependence of the spin Hall conductivity of semiconductors was quantitatively obtained by systematic studies of the spin Hall effect using scanning Kerr microscope. (3) We demonstrated GaAs THz quantum cascade laser emission with threshold current density of 0.8 kA/cm$^2$ and maximum operation temperature of 146 K.

Nano-Molecular Devices [Niwano Laboratory]

(1) We have fabricated P3HT organic transistors using an ionic liquid to observe its high operating current as compared to the conventional organic field effect transistors. We monitored in-situ the chemical state of the P3HT active layer during FET operation using infrared absorption spectroscopy, and found that the ionic-liquid-based P3HT transistors are operated by electrochemical doping. (2) We have succeeded in fabricating a thin film of TiO$_2$ nanotubes on a glass substrate by anodizing a metal titanium film deposited on the substrate in an NH$_4$F-based organic electrolyte. (3) Planar bilayer lipid membranes (BLMs) were formed in microfabricated apertures in Si chips. We have succeeded in preparing BLMs which are stable enough for repetitive solution exchanges and electric stress, and demonstrated that electric noise was suppressed by coating the chip surface with dielectric layers. (4) BLMs with channel proteins were formed in nanoholes of an anodic porous alumina film. We demonstrated that these BLMs exhibited improved mechanical and electric stability compared to BLMs formed in the conventional Teflon films.

Intelligent Nano-Integration System [Nakajima Laboratory]
(1) We proposed a discrete-type inverse function delayed neural network with high-order synapse connections and demonstrated its usability for combinatorial optimization problems by stability analysis on solution states. Moreover, we expanded our new analysis on nonlinear dynamics to a coupled nonlinear system, and burst firing dynamics was successfully generated by using a coupled BVP model. (2) We analyzed the resonant activation property of a Bi-2212 intrinsic Josephson junction and found possible reasons for degradation of the quality factor Q. In order to gain a better Q factor, we designed a filter circuit for suppressing high frequency noise in bias lines and a line for feeding microwave. (3) To improve the performance of high-speed operation for the single flux-quantum fast Fourier transform, a carry look-ahead adder was fabricated using Nb integrated circuits. The high-speed operation of the adder circuit was successfully demonstrated up to 30GHz. A neural network using superconducting quantum interference devices for solving a combinatorial optimization problem was proposed and numerically demonstrated.

Quantum-Optical Information Technology [Edamatsu Laboratory]

1. We have demonstrated that quantum state is transferred from photons to electron spins in a semiconductor. This demonstration opens up an avenue to quantum media conversion between multiple quantum media such as superconducting qubit, nuclear spin qubit, and ion qubit.

2. We have developed the technique of heterodyne Kerr rotation spectroscopy for ultra-high sensitivity measurement of the spin state in semiconductor quantum structures. We have demonstrated the measurement of Kerr rotation induced by an exciton in a single quantum dot.

Nanospin Memory [Ikeda Laboratory]

We are developing technologies to realize advanced spin memory and logic devices using magnetic tunnel junctions (MTJs) consisting of ferromagnetic metal electrodes and insulating barriers. In our group, the following results were obtained: 1) The TMR ratios of 78% at RT were realized in MgO-based MTJs with perpendicular anisotropy CoFe/Pd multilayer electrodes and bottom CoFeB and top Fe insertion layers. 2) For the CoFeB/MgO/CoFeB pseudo spin valve MTJs with in-situ annealing, high TMR ratios were observed in the lower resistance area product ($RA$) range. The TMR ratio of 122% at RT with $RA=1.0 \Omega \mu m^2$ were obtained. 3) Operations of the world's first 32Mb non-volatile random access memory (SPRAM) chip, ternary content-addressable memory (TCAM), Lookup-Table employing the spin-transfer torque MTJs with synthetic ferrimagnetic free layer were verified.

Ultra-Broadband Signal Processing [Otsuji Laboratory]

The goal of our research is to explore the terahertz frequency range by means of novel electron devices and systems. Graphene has mass-less carriers and their peculiar characteristics are expected to be useful as a candidate to realize such systems. We have
theoretically predicted the occurrence of negative dynamic conductivity in the THz range for optically pumped graphene. Using an epitaxial graphene formed on silicon substrates provided by Prof. Suemitsu's group, we have succeeded in observation of amplified stimulated THz emission from femtosecond infrared-laser pumped graphene. We have also achieved the transistor operation in graphene-channel FETs that demonstrate an electron drift mobility by 20 times higher than that for Si MOSFETs. We have also developed a terahertz spectroscopy system using 2D-plasmon resonant terahertz-wave emitters based on compound semiconductor heterostructures.

**Wireless Info Tech [Tsubouchi Laboratory]**

For realizing radio frequency (RF) filter and oscillator of 5-GHz-band broadband wireless terminal, we have developed bulk acoustic wave (BAW) device. Film AlN was manufactured using metalorganic chemical vapor deposition (MO-CVD) method. Using the manufactured AlN, film bulk acoustic resonator (FBAR) was developed. We have evaluated characteristics of FBAR using computer simulation.

**Electromagnetic Bioinformation Engineering [Ishiyama Laboratory]**

We have studied successively about a high accuracy strain sensor for detecting the bio-information. In the year 2009, to obtain the higher accuracy, the optimum fabricating conditions of sensor elements for controlling the internal residual stress of the magnetic thin films were examined. In addition, the magnetic domain observation, the magnetization properties, and the impedance properties of the strain sensors were studied in detail. As the result, the strain sensor elements exhibiting the accuracy of 18,000 were successfully realized in result.

**Solid State Physics [Takahashi Laboratory]**

For low power consumption MRAM (Magnetic Random Access Memory) and high density HDD (Hard Disk Drive), high-efficiency of current induced magnetization switching (CIMS) and high stabilization of magnetization in a pinned layer in tunnel magnetoresistance devices are indispensable. For high-efficiency of the CIMS, in this study, combination of normal- and inverse-CIMS has been demonstrated. As a result, the inverse-CIMS is obtained in the magnetic tunnel junction with Fe₄N layer. And negative anisotropic magnetoresistance (AMR) which arises from -1.5 % to -4% with temperature in a stepwise fashion near 50 K is observed in the Fe₄N single layer. For high stabilization of magnetization, systematic change of the composition of the pinned-ferromagnetic (FM) layer has revealed that body-centered cubic FM layers were more likely to induce stronger exchange anisotropy than face-centered cubic FM layers.

**Electromagnetic Theory [Yamaguchi Laboratory]**

Magnetically soft amorphous particles and Ni-Fe films have been investigated as seeds of
new materials with high performance in the RF (GHz range) applications. As for the particles, their advantages are their high saturation magnetization and submicron size. In addition to the original synthesizing process, particle precipitation in a magnetic field is studied. In the process of precipitation in the magnetic field the particles are bonded into long chains leading to an appreciable reduction of the demagnetizing field that has generally been an obstacle to the high-permeability performance of soft magnetic particles. The microstructures, magnetic softness of the chains, and significant enhancement of the permeability in the frequency range 0.05~10 GHz are demonstrated.

As for Ni-Fe films, the damping constant ($\alpha$) of 100-nm-thick Ni$_x$Fe$_{1-x}$ films with various Ni compositions ($x$) was estimated using a coplanar waveguide (CPW)-FMR system. While $\alpha$ increases from 0.0092 to 0.0099 in the range of $x$ between 0.67-0.76, it tends to decrease from 0.010 to 0.0079 and again increase to 0.011 as $x$ is varied from 0.76 to 0.86, resulting in the minimum $\alpha$ for $x=0.78$. All these $\alpha$ are larger than that of bulk-Ni-Fe (0.007).

**Microelectronics [Sahashi Laboratory]**

The microwave oscillation generated by spin transfer torque (STO), which relates to the damping parameter ($\alpha$) of ferromagnetic material have been studied. In this study, an appropriate electrode structures for the measurement of STO were investigated. We have designed several masks of coplanar wave guide (CPW) electrode structure, which the high frequency can transmit. The CPW transmission line and attenuation characteristics are evaluated by S11 parameter of network analyzer. The CPW transmission line is found to show good noise attenuation characteristics. The magnitude of the reflected signal increases progressively with increasing cross section area. The study on STO including the estimation of $\alpha$ for ferromagnetic thin films will be continued by using the most suitable pattern of electrode for higher frequency of microwave transmission.

**Solid State Electronics [Itoh Laboratory]**

High-performance TFTs with pseudo-single-crystal silicon has been investigated. A novel laser optical system was introduced to our laser crystallization apparatus, and large elongated silicon grain with the length of over 100 $\mu$m was formed. This laser annealing technology was also applied to ferroelectric thin film on glass substrate, and its low temperature annealing method was obtained. As a novel device structure, nanograting MOSFET has been suggested. This device structure was applied to Poly-Si TFT, and its current drivability was enhanced. For RF integrated circuits, above CMOS inductor technology was suggested. Methods for parameter tuning were shown and discussed.

**Basic Plasma Engineering [Hatakeyama Laboratory]**

Single-walled carbon nanotubes have successfully been grown from nonmagnetic catalysts by plasma chemical vapor deposition (CVD) for the first time. Based on the systematical
investigation for the combination of catalyst type (magnetic or nonmagnetic) and CVD method (plasma CVD or thermal CVD), it is found that a low concentration of hydrogen species during nanotubes growth is the critical factor to realize the SWNTs growth from a nonmagnetic catalyst by the plasma CVD method. This can be explained by the different binding energy between hydrocarbon and catalyst surface. Nano particle fabrication is carried out under the novel reaction phase, where plasma and liquid interface is directly contacted. It is revealed that there is a close correlation between plasma parameters and size distribution of nano particles.

**Optical Physics Engineering [Yamada Laboratory]**

Our research focus on silicon photonic-wire waveguides, with silicon (Si) core and silica (SiO$_2$) cladding, with the objective of realizing integrated optical circuits. In this year, we studied an optical input/output interface and an integration method of LDs on Si waveguides. Both, the numerical calculations and the experimental results, showed good properties. In addition, we found an abnormally localized optical mode in 1-D photonic crystals.

**Spin Electronics [Ando Laboratory at Department of Applied Physics]**

Magnetic tunnel junctions (MTJs) with a half-metallic Co$_2$MnSi Heusler alloy electrode and a high-quality MgO tunneling barrier have been developed. We have succeeded to observe a very large tunnel magnetoresistance (TMR) ratio of 217% at RT and 753% at 2K. The observed large TMR ratio results from both half-metallicity of Co$_2$MnSi and coherent tunneling through the crystalline MgO barrier. In addition, we succeeded to suppress temperature and bias voltage dependence of TMR ratio by inserting a very thin CoFeB layer into the Co$_2$MnSi/MgO interface.

**Superstructured Thin Film Chemistry [Kawasaki Laboratory at Institute for Materials Research]**

One of oxide heterointerfaces, MgZnO/ZnO, can provide an interesting arena for investigation of quantum transport properties with high-mobility two-dimensional electron gas (2DEG). Electron mobility in the 2DEG reaches 180,000 cm$^2$/Vs by optimization of fabrication conditions. We have also fabricated an FET device with a dielectric layer by atomic layer deposition method and precisely modulate the charge carrier density in the 2DEG. As a result, we firstly observed a fractional quantum Hall effect in oxide heterostructure. The improved controllability will lead to higher performance of transparent field effect transistor.

Co-doped TiO$_2$ is one of room temperature ferromagnetic oxide semiconductor. In this study, we fabricated electric double layer transistors on Co-doped TiO$_2$ films, which can modulate high charge carrier density as high as $10^{14}$ cm$^{-2}$ by a gate electric field. The device shows paramagnetic to ferromagnetic switching by applying external gate bias at room temperature. We will extend this study to device applications in spintronics area.
Materials Quantum Science [Nitta Laboratory at Department of Materials Science]

We have investigated the spin orbit interaction (SOI) in semiconductor heterostructures. (1) We investigated magneto-transport properties in gate fitted narrow wire structures based on InGaAs/InAlAs two dimensional electron gas. Spin relaxation length was enhanced more than 10 times larger than that in the Hall bar structure. From the theoretical analysis, origin of the enhanced spin relaxation length is due to both the one dimensional confinement effect and the Persistent Spin Helix condition, where the strength of Rashba SOI is close to that of Dresselhaus SOI. (2) We investigated the size dependence of spin interference effect in mesoscopic ring structures. With propagating length of electron waves, resistance oscillations observed as Aharanov-Casher effect are systematically changed, which reveals that electrical spin manipulation depends on the diameter of the ring structures.

Nanoscale magnetism and devices [Kitakami Laboratory at Institute of Multidisciplinary Research for Advanced Materials]

Research project on development of high-$K_u$ materials and understanding of magnetization behavior of nanoscale magnets are being carried out, aiming to achieve ultra-high density magnetic memory. Magnetization process under a short pulse field is one of the key issues to increase the operation frequency of magnetic device. Magnetization process of a nanoscale Co/Pt multilayer dot was investigated by detecting anomalous Hall effect of a single dot. It is revealed that the magnetization reversal is initiated by the nucleation process within sub-nanoseconds time scale followed by its growth in nanoseconds.

Medical Nanosystem Engineering [Tanaka Lab at Graduate School of Biomedical Engineering]

The novel SPRAM-based 3-dimensional reconfigurable spin processor has been proposed. This year, two main results below were obtained. As a SPICE model of MTJ was successfully made, it became possible to simulate logic circuit operation including MTJ using SPICE. This leads to a highly efficient analysis of SPRAM circuits. The SPRAM-based reconfigurable logic block circuit is composed of the SRAM for LUT and the SPRAM for configuration data. As the write circuit design of reconfigurable logic block was improved, 2.4% faster SRAM read-back circuit speed was successfully achieved.

New Paradigm VLSI System [Hanyuu Laboratory]

Our research group has fabricated a nonvolatile LUT (Lookup-Table) circuit in FPGA (Field-Programmable Gate Array) using a MTJ (Magnetic Tunnel Junction) device-based logic technology. The proposed LUT circuit fabricated by a 0.14um CMOS/MTJ-hybrid process achieves area reduction by 2/3 compared to a conventional SRAM-based one, and complete elimination of standby power dissipation. The MOS-transistor part is fabricated by Hitachi Co., Ltd. and the MTJ-device part is fabricated by Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University. This is the collaboration of Prof. H. Ohno’s, Prof. S. Ikeda’s and our laboratories.
Technology Development Division Storage Technology Group [Fujimoto Laboratory]

A cooperative research project between industry, academia and government: Development of super high-speed mass storage HDD systems started in August 2007 under the collaborations between RIEC including IT21 storage technology group, major Japanese HDD manufacturers and other laboratories researching related technologies within Tohoku University. Developments of high density patterned media and high sensitivity sensor are research subjects in this project, and we fabricated fine dot arrays of Co based alloy films and spin accumulation devices and studied fundamental properties. We started experimental analysis of magnetization reversal for dot arrays of high-Ku perpendicular films with the dot diameter of 10~15 nm. Moreover, a preliminary study of read/write properties for bit-patterned media (60 nm in dot diameter) using a static tester revealed that the writing margin was 70% to the bit length.

Solid State Electronics [Suemitsu Laboratory]

We have this year made progresses on the establishment of graphene-based field effect transistor (G-FET) and the evaluation of device characteristics of G-FET. As a result, we could have succeeded in fabricating and evaluating of G-FET, which can in principle overwhelm Si-based MOS-FET. Further we have tackled one of the big problems in the application of G-FET, the adequate adoption of the materials for insulator. We have then succeeded in using organic thin films as insulators for the ultra high-speed G-FET.

Researching Section [Endoh Lab at Center for Interdisciplinary Research]

To develop a novel Spin device technology for the Magnetic Tunneling Junction (MTJ) combined with the Si-CMOS circuit, we have systematically studied the Spin device technology, the integration process technology, the circuit design and the measurement.

We fabricated the MTJs on via metal with surface roughness of 0.30nm with 0.14μm CMOS process and 60×180nm² MTJ process. The fabricated MTJ on CMOS logic circuit plane achieves a large change in a resistance of 3.63kΩ (anti-parallel) with the TMR ratio of 138% at room temperature. Furthermore, we have successfully demonstrated the DC and AC operation of this MTJ with write transistor. As a result, our MTJ achieves high enough write/read performance with transistors for realizing MTJ-based logic circuits. This is the collaboration of Prof. H. Ohno’s, Prof. S. Ikeda’s and our laboratories.

Intelligent Nano-Process [Samukawa Laboratory]

We work on the development of quantum dot solar cell and quantum dot laser with ultra-low damage neutral beam etching and sub-10nm bio-template. In the last fiscal year, the outcomes are as follows. (1) We succeeded in controlling the band gap energy (1.4 to 2.2eV) of high density (>7x10¹¹ cm⁻²) 2-dimensional Si-nanodisk (2D Si-ND) array by changing the Si-ND thickness (12-2nm). This characteristic of Si-ND shows great potential to realize all-Si tandem solar cell. PL peak at approximately 630nm was also observed in 2D Si-ND at 100K. (2) Vertical etching profile of GaAs/AlGaAs quantum well (QW) was realized using neutral
beam etching. There is almost no lattice defect on the etched side-wall of GaAs and roughness of etched surface is the same as bare GaAs wafer. The PL intensity of etched GaAs/AlGaAs QW is comparable to unetched one. The result means that ultra low damage etching of GaAs/AlGaAs is realized.

**Applied Quantum Optics [Yasaka Laboratory]**

Highly functional semiconductor photonic devices and ultra-broadband coherent terahertz (THz) wave sources have been studied to explore new-generation photonic network systems as well as novel science and technology. Novel THz biosensors using surface plasmon resonance were studied to achieve sensitive detection of biomolecules, high-spatial-resolution THz imaging beyond diffraction limit. High-quality THz resonators for local-field enhancement were successfully fabricated on silicon wafers by introducing novel fabrication process using SU-8.
Atomically Controlled Processing

Creation of Atomically Controlled Processing of Group IV Semiconductor and Application to Nano Heterodevices

[Research Target and Activities]

Development of atomically controlled processing technology in deposition and etching is quite important to fabricate future higher-performance ultralarge-scale integrated circuits (ULSIs) as well as quantum devices for new functions and to create new materials with novel properties which are different from that of conventional bulk materials. To overcome the limits of Si material properties and device miniaturization and to achieve on-chip integration of ultimate charge control into Si ULSIs, this laboratory aims to establish atomically controlled processing for nanometer-order artificial heterostructures of group IV semiconductors with atomically controlled surface and interfaces and nanometer-order three-dimensional patterning with molecular control to fabricate nanometer-order heterostructure devices. (Fig. 1)

In this year, following experimental results have been obtained: (1) In the research on P atomic-layer doping, low-temperature Si epitaxial growth by reaction of Si$\text{H}_6$ as a higher reactivity gas enables higher P concentration. (2) By heavy C atomic-layer doping at heterointerface between a Si cap layer and a Si$_{0.55}$Ge$_{0.45}$ layer in Si/Si$_{0.55}$Ge$_{0.45}$/Si(100) heterostructure, the intermixing between Si and Ge at heterointerface is effectively suppressed. (3) In the research on B atomic-layer doping in Si by using a plasma CVD without substrate heating, it is clarified that lowering of the plasma energy effectively suppresses a plasma induced lattice damage and a surface B reduction, and it becomes quite important to achieve heavy B atomic-layer doping in a nanometer-order ultrathin Si film.

[Staff]

Professor: MUROTA, Junichi Dr.
Associate Prof.: SAKURABA, Masao Dr.

[Profile of Prof. J. Murota]

Prof. J. Murota was born in 1948. He received the B.E., M.E. and Ph.D degrees in electronic engineering from Hokkaido University in 1970, 1972 and 1985, respectively. He joined the Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation (NTT) in 1972. In 1983, he moved to the Atsugi Electrical Communication Laboratory, NTT. In 1985 he became an Associate Professor in the Research Institute of Electrical Communication, Tohoku University and in 1995 became a Professor. He is actively involved in researches on atomically controlled processing of group IV semiconductors. He was awarded the 3rd (2003) Yamazaki-Teiichi Prize and the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology for 2010: The Prizes for Science and Technology in Research Category.

[Papers]


Fig. 1. 10 nm-scale quantum nanodevices with strain controlled nano-scale patterned heterostructure of group IV semiconductors.
Semiconductor Spintronics

Nanoscience and Nanotechnology for Spintronics and THz Lasers

[Research Target and Activities]

We are working on the nanoscience and nanotechnology to control the quantum states in semiconductors, especially the spin states and optical transitions in the mid-infrared to THz.

Materials of interest include GaAs/AlAs, InAs/(Al,Ga)Sb, GaN, and ZnO, with and without doping of magnetic elements, all grown by molecular beam epitaxy. We are investigating electrical, optical, magnetic, and conductive properties of these materials and their application to new functional devices, such as memories and logic devices using spin states as well as quantum cascade lasers (QCL) with THz emission.

The outcomes in the last fiscal year are (1) Direct magnetometry of electric-field control of magnetism in a (Ga,Mn)As thin film. (2) Determination of spin Hall conductivity in n-type GaAs and its theoretical description (3) Demonstration of GaAs THz quantum cascade laser emission with threshold current density of 0.8 kA/cm² and maximum operation temperature of 146 K.

[Staff]
Professor : OHNO, Hideo
Associate Professor : OHNO, Yuzo
Associate Professor : MATSUURA, Fumihiro
Assistant Professor : OHTANI, Keita

[Profile of Professor Hideo Ohno]
Hideo Ohno received Ph. D. degree from the University of Tokyo in 1982. He was with the Faculty of Engineering, Hokkaido University as a Lecturer (1982) and then as an Associate Professor (1983). He moved to Tohoku University in 1994 as a Professor. He received the IBM Japan Science Prize (1998), the IUPAP Magnetism Prize (2003), the Japan Academy Prize (2005), and the 2005 Agilent Technologies Europhysics Prize. He is Institute of Physics (IOP) Fellow (2004), Honorable Professor at Institute of Semiconductors, Chinese Academy of Sciences, and JSPS fellow (2007), Distinguished Professor at Tohoku University (2008), and IEEE Magnetic Society Distinguished Lecturer for 2009. He is a member of JSAP, JPS, JACG, IEICE, APS, IOP, IEEE, and AVS.

[Papers]

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Nano-Molecular Devices

Control of surface and interface of molecular informational devices and development of novel nano-molecular devices

[Research Target and Activities]

Our research aims at application of the Si technology to organic semiconductor devices or many kinds of biosensors. We have investigated development of 1) an organic transistor using an ionic liquid, 2) an ion channel sensor using a Si technology, and 3) a nanofabrication method using electrochemical processes such as anodization of valve metals. Especially, we have applied TiO$_2$ nanotubes formed by anodization to dye-sensitized solar cells (DSC).

1) Fabrication and characterization of an organic transistor using an ionic liquid

We have fabricated P3HT organic transistors using an ionic liquid to observe its high operating current as compared to the conventional organic field effect transistors. We monitored in-situ the chemical state of the P3HT active layer during FET operation using infrared absorption spectroscopy, and found that the ionic-liquid-based P3HT transistors are operated by electrochemical doping.

2) Development of planar bilayer lipid membranes

Planar bilayer lipid membranes (BLMs) were formed in microfabricated apertures in Si chips. We have succeeded in preparing BLMs which are stable enough for repetitive solution exchanges and electric stress, and demonstrated that electric noise was suppressed by coating the chip surface with dielectric layers. BLMs with channel proteins were also formed in nanoholes of an anodic porous alumina films.

3) Direct formation of a titanium oxide nanotube film on a substrate using anodization

A titanium oxide nanotube film was directly formed on a substrate by anodization of a metal titanium film deposited on it in an ammonium fluoride based organic electrolyte.

[Staff]

Professor : NIWANO, Michio Dr.
Assistant professor : KIMURA, Yasuo Dr.

[Profile of Professor NIWANO, Michio]

1998 - present RIEC, Tohoku University, Japan, Professor
Memberships: Electrochemical Society (ECS), Material Research Society (MRS), American Vacuum Society (AVS)
Education: March, 1980 Tohoku University, Japan, Doctorate of Science

[Papers]


Nanob-Spin Memory
Research of spin based device and memory

[Research Target and Activities]
We are developing technologies to realize advanced spin memory and logic devices using magnetic tunnel junctions (MTJs) consisting of ferromagnetic metal electrodes and insulating barriers. In our group, the following results were obtained.

1) TMR properties and film structures of perpendicular MTJs with CoFe/Pd multilayer and different insertion layers such as CoFeB and Fe were investigated. The insertion of 1.8 nm-thick CoFeB layers between CoFe/Pd multilayers and MgO barrier resulted in an increase of TMR ratio from a few percent to up to 43%. By applying combination of bottom CoFeB and top Fe insertion layers, the TMR ratio reached 67%. For the MTJs with in situ annealing the TMR ratio of 78% was observed. 2) Operation of a prototype of the world’s first 32Mbit non-volatile random access memory (SPRAM) chip employing the spin-transfer torque MTJs with synthetic ferrimagnetic free layer was verified.

[Staff]
Associate Professor: IKEDA, Shoji Ph.D., Visiting Professor: HASEGAWA, Haruhiro Ph.D., Research Fellow: GAN, Huadong Ph.D., Research Fellow: YAMAMOTO, Hiroki, Research Fellow: MIURA, Katsuya Ph.D., Research Fellow: YAMAMOTO, Hiroki.

[Papers]


Development of perpendicular MTJs with CoFe/Pd multilayer and different insertion layers such as CoFeB and Fe.

VLSI Circuits 2009

32M Spin-Transfer Torque RAM (SPRAM) chip employing the spin-transfer torque MTJs with a synthetic ferrimagnetic CoFeB/MgO/CoFeB free layer.
Laboratory for Brainware Systems
Research Targets and Activities of Laboratory for Brainware Systems

The Laboratory for Brainware Systems of the Research Institute of Electrical Communication was established in 2004. Its purpose is to contribute to the research and development of advanced information science and technology for Brainware systems which realize a seamless fusion of the changeable and complex real world and the cyber space.

We aim at establishing scientific and technological foundations for Real-World Computing (section), New Paradigm VLSI System (section), Intelligent Nano-Integration System (section), Microarchitecture (section), Cyber Robotics (planned section), and Next-Generation Human Interface (planned section). The Laboratory for Brainware Systems consists of the above six sections which cooperatively carry out the research. At the same time they serve as a laboratory for nation-wide cooperative research in the field of Brainware systems.

The technology developed in the Laboratory is expected to enhance the research carried out in the four Divisions of the Institute, and the research conducted in the Divisions, in turn, is expected to provide scientific basis for the information technology developed in the Laboratory.

[Research Target]

Real-World Computing Section: Our main aim is to understand highly harmonic and autonomous biological-information systems, and to propose principles for designing new systems. For carrying out any purpose or any function, the biological system must solve inverse problems in the real-world. Since the inverse problem is an ill-posed one, the system has to create an appropriate constraint for solving the ill-posedness by itself, and autonomously satisfies the created constraint in real time. Clarifying logic and basic mechanisms of “Constraint Self-Emergence and Self-Satisfaction”, we create artificial systems for pattern recognitions and motion controls that work well in the real-world.

New Paradigm VLSI System Section: Performance degradation of SoCs due to wiring complexity, power dissipation and characteristic variation of materials/devices is increasingly getting a serious problem in recent era. Our research activity is to solve the above problem by the following two ways: the use of logic-in-memory architecture based on nonvolatile logic, and the use of asynchronous data-transfer scheme based on multiple-valued current-mode logic, which would open up a novel VLSI chip paradigm, called a “new-paradigm VLSI system.”

Intelligent Nano-Integration System Section: Our research activities cover the fields of architectures of Brain computing systems, characterization and application of artificial neural networks, computer aided designs and fabrications of intelligent integrated circuits, and exploitation of new devices for neural circuits. At present research is focused on the large scale integration of Brain computing system and exploitations of new neural devices proposing a neuromorphic quantum computation.
Microarchitecture Section: The research activities in microarchitecture lab. include architecture and circuit design of mixed-signal SoC applicable to sensor network system to explore brain activity research along with mixed-signal toptdown design methodology.

[Research Activities]

Real-World Computing Section (Yano Laboratory): We obtained the following three main results. First, we proposed a computational algorithm for odor information representation using time dimension, and clarified how to implement it into a neurobiologically plausible network model. The model accounted for essential features of odor responses of biological networks and emergence of olfactory cognitive functions. Second, concerning arm reaching movement, we computationally demonstrated that the posture and motion of arm can be controlled in autonomous decentralized manner by using "mobility measure" of each joint calculated from its kinematical and dynamical information in real time. We also found that the resulted arm movements of our model have a global optimality with respect to energy consumption during motion. Furthermore, we psychophysically clarified that executing various motion under unpredictable environment would enhance the adaptability of motion control to environmental changes. Third, we examined the psychophysical effects of formant peak and spectral-slope on vowel perception, and found that the vowel perception can be generally accounted for by two acoustic features, slope and prominence of band-limited spectrum.

New Paradigm VLSI System Section (Hanyu Laboratory): As this-year research results in the nonvolatile logic-in-memory circuit technology, we have succeeded the chip fabrication of an MOS/MTJ-hybrid Lookup-Table (LUT) circuit for a nonvolatile Field-Programmable Gate Array (FPGA) and confirmed its "immediate wake-up" behavior without reloading the configuration data from external nonvolatile devices. We have also succeeded the fine-grained power-gating scheme of the nonvolatile ternary content-addressable memory (TCAM) proposed last year, which results in great reduction of wasted power dissipation in the TCAM. Moreover, we have succeeded the chip fabrication of the single-wire multiple-valued single-track test chip under a 0.13um CMOS process, and confirmed its energy-efficient asynchronous data transmission on the wire length of 5mm.

Intelligent Nano-Integration System Section (Nakajima-Sato Laboratory): (1) We proposed a discrete-type inverse function delayed neural network with high-order synapse connections and demonstrated its usability for combinatorial optimization problems by stability analysis on solution states. Moreover, we expanded our new analysis on nonlinear dynamics to a coupled nonlinear system, and burst firing dynamics was successfully generated by using a coupled BVP model. (2) We analyzed the resonant activation property of a Bi-2212 intrinsic Josephson junction and found possible reasons for degradation of the quality factor Q. In order to gain a better Q factor, we designed a filter circuit for suppressing high frequency noise in bias lines and a line for feeding microwave. (3) To improve the performance of high-speed operation for the single flux-quantum fast Fourier transform, a carry look-ahead adder was fabricated using Nb integrated circuits. The high-speed operation of the adder circuit was successfully demonstrated up to 30GHz. A neural network using superconducting quantum interference devices for solving a combinatorial optimization problem was proposed and numerically demonstrated.

Microarchitecture Section (Masui Laboratory): We have been investigating architecture and circuit techniques for low-power and low-cost CMOS transceiver ICs applicable to wireless sensor network, and high-speed A/D converter applicable to vision sensing. We have been explored a low-power fractional-N PLL synthesizer design with high-speed setup circuit, and a low-power/low-cost bandpass filter implemented with active gm-RC scheme. We start to investigate the hardware optimization technique for time-interleaved A/D converters to achieve one tenth of power consumption and one fifth of area compared with conventional pipeline A/D converters. In terms of design productivity enhancements, we have established a gm/Id lookup table design optimization methodology for low-power OTA (operational transconduction amplifier), and have successfully implemented an optimization flow including a detailed settling time analysis.
Real-world computing
Odor Representation Algorithm: Invariance, Similarity, and Speed-Accuracy Trade-off.

[Research Target and Activities]
Time is a key dimension for sensory information coding in biological networks. In olfactory systems (Fig. 1), an odor-evoked spatial pattern of glomerular activation is transformed into first dense, then sparse spatiotemporal patterns of spikes at Primary olfactory and higher center networks, respectively. Although these spatiotemporal neural representations seem to be useful for concentration invariant odor identification and classification, computational strategy and mechanisms underlying these transformation are still unclear.

We proposed a two-stage algorithm for odor representation that causally and logically relates the neurobiological representations from a computational point of view, and that satisfies computational criteria for usefulness in odor identification and classification. Odor concentration change significantly alters the evoked glomerular activation pattern, but would not affect a ranking of glomeruli in order of their relative response intensity. Implementing the algorithm, a model first extracts the glomerular ranking as a temporal sequence of spike bursts, but its detailed temporal structure still concentration-dependent. In the second-stage, the model evaluates exclusively the activity sequence in the first-stage representation, and acquires the concentration-invariant representation as a sparsely distributed spike sequence (Fig. 2). The represented odor information can predict how odors are grouped. Introduction of plastic connections into the second-stage network enables the system to store odor information as a weighting of network connectivity. The model accounts for essential features of odor responses of biological networks and the emergence of olfactory cognitive functions. The temporal sequence representation predicted by the proposed algorithm is a tool for pattern recognition that warrants further investigation in biological systems and for designing flexible information and communication systems.

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Assistant professors: MAKINO, Yoshinari Dr., SAKANOTO, Kazuhiro Dr.
Research associate: TOMITA, Nozomi Dr.

[Profile of Professor Yano]
1992: Professor, Research Institute of Electrical Communication, Tohoku University.
2007: Director, Research Institute of Electrical Communication, Tohoku University.

[Papers]
Intelligent Nano-Integration System
Basic Technology of Integrated System for Intelligent Processing

[Research Target and Activities]
Our research activities cover the fields of architectures of Brain computing systems, characterization and application of artificial neural networks, computer aided designs and fabrications of intelligent integrated circuits, and exploitation of new devices for neural circuits.

We have constructed a stochastic artificial neural network with one million synaptic units, analyzed the dynamic behaviour of neural networks aiming at a time-dependent data processing, succeeded to propose a system where we are able to get off successfully from any local minima fallen into on the way of data processing in neural networks, and fabricated its prototype hardware system on the silicon microchip by using the CMOS technology. We have also presented an FFT and a neural system operated by using a flux quantum logic in superconducting integrated circuits.

At present research is focused on the large scale integration of Brain computing system and exploitations of new neural devices proposing a neuromorphic quantum computation.

Research Activities in 2009
(1) We proposed a discrete-type inverse function delayed neural network with high-order synapse connections and demonstrated its usability for combinatorial optimization problems by stability analysis on solution states. Moreover, we expanded our new analysis on nonlinear dynamics to a coupled nonlinear system, and burst firing dynamics was successfully generated by using a coupled BVP model.
(2) We analyzed the resonant activation property of a Bi-2212 intrinsic Josephson junction and found possible reasons for degradation of the quality factor Q. In order to gain a better Q factor, we designed a filter circuit for suppressing high frequency noise in bias lines and a line for feeding microwave.
(3) To improve the performance of high-speed operation for the single flux-quantum fast Fourier transform, a carry look-ahead adder was fabricated using Nb integrated circuits. The high-speed operation of the adder circuit was successfully demonstrated up to 30GHz. A neural network using superconducting quantum interference devices for solving a combinatorial optimization problem was proposed and numerically demonstrated.

[Staff]
NAKAJIMA, Koji Professor
SONOMI, Takeshi Assistant Professor
SATO, Shigeo Associate Professor

[Profile]
K. Nakajima was received his B.E. M.E. and Dr. Eng. from Tohoku University, Sendai, Japan, in 1972, 1975, and 1978, respectively. Since 1978, he has been working at the Research Institute of Electrical Communication, Tohoku University, except for a ten month period in 1983 when he was a Visiting Assistant Research Engineer at the University of California, Berkeley. He is a professor at the Research Institute of Electrical Communication, Tohoku Univ., and is currently engaged in the study of VLSI implementation of neural network, and Josephson junction devices for digital applications.

[Papers]

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Ubiquitous society has been established by the deployment of various wireless systems ICs, and it demands advances in mixed-signal (analog and digital) design technique as well as higher integration through SoC (System on a Chip). Our research activities include architecture and circuit design of mixed-signal SoC applicable to sensor network systems for the investigation of brain activities researches as well as design automation of RF/analog circuit. We propose a mixed-signal platform to maximize the design creativity by utilizing IP-based digital design methodology to various RF/analog and mixed-signal circuits. Moreover, we have been researching on the development of RF/analog design optimization flows by using gm/Id based lookup table methodology.

[Staff]
Professor: MASUI Shoichi Dr.

[Profile]
Shoichi Masui received the B. S. and M. S. degrees from Nagoya University, Nagoya, Japan in 1982, and 1984, respectively, and received the Ph. D. degree from Tokyo Institute of Technology in 2006. From 1990 to 1992, he was a Visiting Scholar at Stanford University, Stanford CA, and in 2001, he was a Visiting Scholar at University of Toronto, Toronto ON, Canada. Since 2007, he is a professor in Research Institute of Electrical Communication, Tohoku University. He was the recipient of a commendation by the Minister of Education, Culture, Sports, Science, and Technology, Japan, in 2004 for his research achievements on FeRAM.

[Papers]
New Paradigm VLSI System Research Group

Realization of a New-paradigm VLSI System

[Research Target and Activities]
Rapid progress in recent deep submicron regime has led the capability to realize giga-scaled embedded systems on a chip (SoC), while performance degradation of SoCs due to wiring complexity, power dissipation and device-characteristic variation is increasingly getting a serious problem in the recent VLSI chip. Our research activity is to solve the above problem primarily by the following two ways: the use of logic-in-memory architecture based on nonvolatile logic, and the use of asynchronous data-transfer scheme based on multiple-valued current-mode logic, which would open up a novel VLSI chip paradigm, called a “new-paradigm VLSI system.”

As a this-year research result in nonvolatile-logic area, we have succeeded the chip fabrication of MTJ (Magnetic Tunnel Junction)-based basic logic component, a nonvolatile LUT (look-up table) circuit chip (Fig.1). We have also designed and fabricated a high-throughput asynchronous multiple-valued single-track data-transfer test chip (Fig.3), whose performance is evaluated to be 1.5-times faster than that of a conventional implementation with maintaining less wire counts. Furthermore, we have proposed nonvolatile TCAM based on a fine-grained power-gating scheme which enables to greatly reduce standby power in the TCAM (Fig.2).

[Staffs]
Professor HANYU, Takahiro Dr.,
Assistant Professor NATSUI, Masanori Dr., MATSUMOTO, Atsushi Dr.
Research Fellow MATSUNAGA, Shoun Dr., ONIZAWA, Naoya Dr., SUZUKI, Daisuke Dr.

[Profile]
Takahiro Hanyu received the B.E., M.E. and D.E. degrees in Electronic engineering from Tohoku University, Sendai, Japan, in 1984, 1986, 1989, respectively. He is currently a Professor in the Research Institute of Electrical Communication, Tohoku University. His general research interests include multiple-valued current-mode logic and its application to high performance and low-power arithmetic VLSIs.

[Papers]

Contact to Professor Takahiro HANYU : hanyu@rieclaboratory.tohoku.ac.jp
IT-21 center

Research and Development of the IT-Based Practical Technology
by the Industry-Academia-Government Collaboration

[Research Target and Activities]

The purpose of the IT-21 center is development of practical technologies for IT based on the advanced technologies of RIEC with the partnership among Industry, Government and University. The term of development is limited less than 5 years. The projects are planned on matching with both basic technologies in the University and application in the Industry. Combination of the technologies of the University and Industry makes practical technologies with availability for the commercial products. The center actively accelerates to obtain the intellectual properties generated from the development of practical technology to the Industry. From 2007, the new 2 projects were started.

1. Development of Dependable Wireless System and Devices

Our new project “Development of Dependable Wireless System and Devices” was accepted in 2007 as the Japan Science and Technology Agency (JST) CREST type research program “Fundamental Technology for Dependable VLSI System.” The project has been executed by the collaborations between RIEC including IT21 mobile wireless technology group, major Japanese mobile terminal manufacturers and other universities. In this project, concept of Dependable Air, which is multi-mode and multi-band dependable wireless network, is proposed. The targets of this project are (1) all IP dependable wireless network which can realize a communication speed of 1Mbit/s~10Gbit/s, (2) all Si CMOS mixed signal LSI with frequency range of 500MHz~70GHz, (3) LSI development of frequency domain equalizer technology, and (4) scalable AD converter.

2. Development of Low Power Consumption Mass Storage HDD Systems

A new project “Development of super high-speed mass storage HDD systems” started in 2007 under the collaborations between RIEC including IT21 storage technology group, major Japanese HDD manufacturers and other laboratories within Tohoku University. The goals of this project are to develop the perpendicular recording technologies required for higher than 2 Tb/inch² recording density and, based on these technologies, to develop the system architecture for realizing large capacity, high performance and low power consumption storage systems; (1) Development of fundamental technologies for the recording densities over 2 Tb/inch²: high sensitivity sensors, high recording resolution SPT writers and high-density media including patterned media, (2) Development of a system architecture for high performance and low power consumption storage systems.

[Staff]

Director: Kazuo TSUBOUCHI, Professor
Katsumi SAGAE, Technical Official

Project Planning Division
Makoto FURUNISHI, Professor

Technology Development Division (Mobile Wireless Technology Group)
Tadashi TAKAGI, Professor
Makoto IWATA, Visiting Professor

Technology Development Division (Storage Technology Group)
Kazuhisa FUJIMOTO, Professor
Hajime AOI, Visiting Professor
Takehito SHIMATSU, Associate Professor
Kiyoshi YAMAKAWA, Visiting Associate Professor
The IT-21 Center Project Planning Division
Planning and Encouraging of R&D Projects

[Research Target and Activities]
Study on trends of science and technology policy, etc. to launch R&D projects with industries. Study on schemes to support R&D projects.

We have successfully launched two new projects since 2007FY, “the development of super high-speed mass storage HDD systems” and “the development of CMOS wireless LAN by 3D SiP”. We issued a final report on the IT Project which was entrusted by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) from 2002FY to 2007FY. Planning of a new project is underway to utilize the internationally standardized outcome of the IT Project.

We have proposed the roles that the Research Institute of Electrical Communication (RIEC) would play in the management of intellectual property rights, and have arranged a new scheme to handle intellectual property rights with industries in order to carry out the projects mentioned above.

We hold meetings with institutes with which RIEC has concluded the cooperation agreements to start R&D projects.

[Staff]
Professor : FURUNISHI, Makoto
Secretary : KAGAMITANI, Machiko

[Profile]
1986.3 got master’s degree from Department of Mechanical Engineering, Faculty of Engineering, the University of Tokyo
1986.4 joined Science and Technology Agency (Ministry of Education, Culture, Sports, Science and Technology (MEXT) at present)
2005.1- 2004.7 Director of Nuclear Fuel Cycle Regulation Division, NISA, METI
2006.8- 2009.9 Professor, IT-21 Center, RIEC, Tohoku University, 2006.11-2008.3 Special Advisor to President
2009.9- Councilor, Secretariat of Science Council of Japan
2009.12- Visiting Professor, RIEC, Tohoku University

[Article]
IT21 Center Mobile Wireless Technology Group

Development of Dependable Wireless System (DWS) Technology for Dependable Air

[Research Target and Activities]
"Development of Dependable Wireless System and Devices" project was accepted in 2007 as the Japan Science and Technology Agency (JST) CREST type research program "Fundamental Technology for Dependable VLSI System." In this project, concept of Dependable Air, which is multi-mode and multi-band dependable wireless network, has been proposed. The targets of this project are (1) all IP dependable wireless network which can realize a communication speed of 1Mbit/s-10Gbit/s, (2) all Si CMOS mixed signal LSI with frequency range of 500MHz-70GHz, (3) LSI development of frequency domain equalizer technology, and (4) scalable AD converter.

1. All Si CMOS RFIC
For realizing DWS, we have developed a 5GHz- and 60GHz-band RF circuits using 90nm Si-CMOS technology.

2. Digitally Assisted Compensation Technology
We have developed a novel frequency domain equalizer (FDE) technology implemented to an application specific integrated circuit (ASIC). We have demonstrated a transmission test under multipass fading environments. Due to the FDE, we have realized to improve bit error rate (BER) characteristics. Conventionally, FDE technology has been evaluated by simulation. Here, we have been able to realize it by experiment.

3. Adaptive and Scalable ADC/DAC (Analog-to-Digit al Converter/ Digital-to-Analog Converter)
We have devised a current mode pipeline ADC, which is suitable for process miniaturization and low supply voltage. We have designed several core circuits of the ADC and have realized static characteristics.

[Staff]
Professor: TAKAGI, Tadashi, Dr. (since 2005)
Guest Professor: IWATA, Iwata, Dr. (since 2003)

[Profile of Professor TAKAGI, Tadashi]
Professor TAKAGI Tadashi received the B.S. degree in physics from Tokyo Institute of Technology, Tokyo, Japan and Ph.D. degree in electronic engineering from Shizuoka University, Shizuoka, Japan, in 1973 and 1995, respectively. In 1973, he joined the Mitsubishi Electric Corporation, where he was engaged in development on microwave and millimeter-wave circuits technology. Since 2005, he has been with Tohoku University, where he is now a professor. Now, his main area of research interest is mobile wireless broadband communication circuits and systems technology. He is a senior member of the IEEE and a member of IEICE of Japan.

[Papers]
IT-21 center, Technology Development Division, Storage Technology Group

Development of low power consumption mass storage HDD systems

[Research Target and Activities]
A new project :Development of super high-speed mass storage HDD systems started in August 2007 under the collaborations between RIEC including IT21 storage technology group, major Japanese HDD manufacturers. The goals of this project are to develop the perpendicular recording technologies required for higher than 2 Tbits/inch\(^2\) recording density and, to develop the system architecture for realizing large capacity, high performance and low power consumption storage systems.

This year we continued fundamental studies and obtained the following achievements.

1) High density recording media\(^1\): L1\(1\)\textsuperscript{-type CoPtM (M: Fe, Ni, Cr, Mn, Pd) ordered alloy films with a large uniaxial magnetic anisotropy were fabricated using UHV sputter film deposition, and magnetic properties were examined. Moreover, we started experimental analysis of magnetization reversal for dot arrays of high\(-K_u\) perpendicular films with the dot diameter of 10~15 nm.

2) High sensitivity sensor technology\(^\text{a}\): It was experimentally shown for high sensitivity spin accumulation sensor that an introduction of MgO barrier structure resulted in an enhancement of output signal.

3) Single pole type writer with a high recording resolution\(^\text{b}\): Multiple tapered main-pole structure was further improved utilizing simulation. Preliminary study of head element fabrication was started.

4) New recording algorithm for over terabits per square inch densities\(^\text{c}\): Possibility of attaining 2Tb/in\(^2\) using hard/soft stacked structure bit patterned media (BPM) was confirmed using LLG simulation. Moreover, a preliminary study of read/write properties for bit-patterned media (60 nm in dot diameter) using a static tester revealed that the writing margin was 70% to the bit length.

5) A 64-TB testbed with “2-dimension data allocation method with an access prediction” was developed to evaluate the energy savings with minimum loss of speed and could obtain an energy-saving of 16% compared with current tiered-storage without loss of data-throughput. The energy savings in 1-PB capacity system, estimated from the measured data, corresponded to a saving of 55%.

[Staff]
Kazuhisa FUJIMOTO, Professor. Hajime AOI, Visiting Professor. Takehito SHIMATSU, Associate Professor. Kiyoshi YAMAKAWA, Visiting Associate Professor.

[Profile]
Kazuhisa Fujimoto received the Dr. of Engineering degree from Kyushu University in 1997. He joined Central Research Laboratory, Hitachi, Ltd., in 1987. He joined RIEC, Tohoku University in 2007. He has been engaged in research on storage system architectures.

[Papers]

Management Office for Safety and Health
Realizing and Maintaining a Safe and Comfortable Environment to Support Research

[Research Target and Activities]

1. Outline of the Management Office for Safety and Health
The Management Office for Health and Safety is established to maintain the health and safety of students and staff working at the institute. The use of chemicals, high-pressure gas and radiation in research activities at the institute entails many risks. The Management Office for Health and Safety provides support for health and safety management in research laboratories, experimental facilities and the Fundamental Technology Center through various activities to ensure safe and smooth research activities within the institute.

2. Activities by the Management Office for Safety and Health
For the actual management of health and safety at the office, the Health and Safety Committee first presents the basic policies of safety management at the institute, and the Management Office for Health and Safety then plans and executes activities based on them. At the institute, laboratories and other individual sections are highly independent of each other; unlike a general corporate organization, top-down safety management is not suitable and measures appropriate for independent sections need to be taken. Various considerations are also necessary for students, researchers, and other members engaged in research activities as well as faculty staff. At this institute, extremely hazardous materials and facilities are used, including chemicals, high-pressure gas, and X-ray devices. Since there is also a clean room and other special workplaces, safety management should be extended by considering them. In these circumstances, the Management Office for Health and Safety will monitor situations and characteristics in each section at the institute, plan and recommend practical management methods and improvement measures, and support their implementation for the efficient and effective management of health and safety. The main activities in this fiscal year are as follows:

- Holding safety and health seminar and high-pressure gas seminar for staff and students at the institute
- Inspection of and assistance in improving the health and safety management system and working environment within the institute
- Holding first-aid training course
- Investigation of laws related to health and safety and collection of information regarding health and safety management
- Providing advice and information to health and safety personnel in each department

[Staff]
Manager: Michio NIWANO Dr., Professor
Deputy Manager: Yoichi UEHARA Dr., Professor
Nobuyuki SATO Dr., Assistant Professor
Ayako CHIBA, Clerk

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Flexible Information System Research Center

Development of Flexible Information Systems and Management of Network

[Research Target and Activities]
The present information systems such as computers are inflexible systems, because their purpose is predefined and they provide only the fixed procedures and functions. On the other hand the flexible information system can perform the flexible information processing adapted to the human intention and situation of its environment.

Our goal is to investigate principles of the flexible information processing through the theories and experiments, and establish their system construction methodology. Moreover, we also study the flexible distributed systems for advanced organization, utilization, administration, operation and putting out scientific information. Through practical applications of above results to the real network in RIEC, we confirm effectiveness of our methods. To achieve the above goal, this year we have conducted the following researches:

1. development of distributed and scalable authentication method for large scale overlay network,
2. development of an agent based network management system (Fig.1) and
3. flexible computing mechanism in biological system.

[Staff]
(1) Steering Committee
Professor: SUZUKI Yôiti Dr., SHIRATORI Norio Dr., TOYAMA Yoshihito Dr., KINOSHITA Tetsuo Dr., SHIRAI Masafumi Dr., OHORI Atsushi Dr.
(2) FIR Committee
Professor: TOYAMA Yoshihito Dr., KINOSHITA Tetsuo Dr.
Associate Professor: AOTO Takahito Dr., AOKI Terumasa Dr., KITAGATA Gen Dr.
Assistant Professor: YOSHIDA Masato Dr., ONOMI Takeshi Dr., SASAI Kazuto Dr.
Research Fellow: OSADA Toshiaki Dr.
Technical Support Member: SUZUKI Midori, NIITSUMA Sachiko

(3) Regular Staff
Associate Professor: KITAGATA Gen Dr.
Assistant Professor: SASAI Kazuto Dr.
Research Fellow: OSADA Toshiaki Dr.
Technical Support Member: SUZUKI Midori, NIITSUMA Sachiko

[Profile]
Refer to the Advanced Acoustic Information Systems Laboratory for the profile Prof. Yôiti Suzuki.
Refer to the Computing Information Theory Laboratory for the profile Prof. Yoshihito Toyama.

[Papers]
Fundamental Technology Center
Supporting research with high-level specialized knowledge and technology

[Research Target and Activities]
The Fundamental Technology Center provides research support, closely linked with research activities at the Institute, based on its high-level specialized knowledge and technology. We must maintain and improve our organization to develop and pass on high-level knowledge and technology. Based on this philosophy, the Center provides research support through its four Divisions.

1. Machine Shop Division
The Machine Shop Division has previously pioneered a number of new machining methods, and contributed to research on high-density magnetic recording and many other types of research relating to advanced information and communications. This year, there were 129 fabrication requests from laboratories (114 from inside the Institute, 15 from outside).

2. Evaluation Division
The Evaluation Division provides the following as measurement equipment for shared use:
atomic force microscope, scanning electron microscope, X-ray diffractometer, electron spin resonance spectrometer, scanning transmission electron microscope, electron probe micro analyzer, X-ray fluorescence analyzer, fourier transform infrared spectrophotometer, infrared-visible spectroscope, liquid chromatograph, optical characteristic measurement equipment, in-air photoelectron measurement equipment, dicing saw

3. Process Division
The Process Division provides the following as measurement equipment for shared use:
Focused ion beam system, mask aligner, X-ray diffractometer for thin films, electron beam exposure equipment, sputtering equipment, scanning electron microscope, optical microscope, scanning probe microscope, spectrophotometer, digital microscope, dicing saw, UV & ozone dry stripper

4. Software Technology Division
The Software Technology Division manages, operates and develops information systems for the Institute. To support research in each field, the Division handles tasks like disseminating information on research results and providing services for gathering/organizing/utilizing academic information, such as space collaboration systems and a database of RIEC researchers.

[Staff]
Director (Professor): Michio NIWANO Dr., Assistant Professor: Nobuyuki SATO Dr.
Technical Official: Yasuo WAGATSUMA, Shigeto AGATSUMA, Koichi SHOJI, Tamotsu SUENAGA, Takeshi YAMASHITA, Maho ABE, Keisuke SATO, Kento ABE, Hiroshi WATANABE, Munetomo SUGAWARA, Yuji KONNO, Ryuji YONEZAWA, Choichi TAKUYU,