QNERC NEWSLETTER

TOKYO INSTITUTE OF TECHNOLOGY

FEBRUARY 2015 VOL. 11

QNERC Quantum Nanoelectronics Research Center

QNERC Spotlight on William Milne

As a world-renowned researcher in the field of carbon nano-electronics, William Milne is a frequent visitor to QNERC from the University of Cambridge in the UK. Milne's early career focused on developing and optimising amorphous silicon for use in solar cells and thin film transistors. Following a number of successful projects in this area he expanded his interests to carbon-based electronics. He spent some time investigating the controlled growth and characterisation of carbon nanotubes (CNTs) and, more recently, graphene and related 2-D materials.

"In 2006, my colleagues and I started up Cambridge Nanoinstruments to build systems to grow CNTs – the company was bought by Aixtron in 2008," states Milne.

As well as carbon-based work, Milne also spent several years developing miniature, ultra-low power sensors using a unique silicon-on-insulator platform. His second business venture, Cambridge CMOS Sensors, again set-up with colleagues, now markets these sensors, which can be used for monitoring both indoor and outdoor air quality. "My newest company, set up in 2014, returns to carbon-based technology once more," explains Milne. "We aim to explore the use of CNTs in X-ray systems."

William Milne

Milne's links to QNERC go back 30 years. "I went to Tokyo Institute of Technology on sabbatical in 1985 to work on thin film transistors," says Milne. "There I met Shunri Oda, who is now a senior member of QNERC. We have remained close friends and colleagues since then, investigating electronic transport in silicon-based nanocrystals and nanowires together."

Current projects at QNERC include work on quantum dots, nanowires, and terahertz devices, alongside silicon photonics. "These projects are innovative and timely and are in many instances world-leading," states Milne. "Researchers from all over the world are attracted to QNERC, including those from my own group, and it is one of the leading international research centres in this field."

Focus on gates for silicon devices

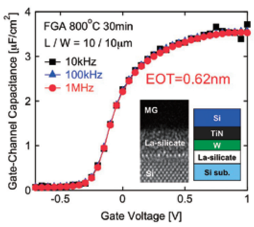
Takamasa Kawanago
Assistant Professor, QNERC

Takamasa Kawanago was appointed Assistant Professor at the Oda Laboratory, QNERC in January 2015. "During my doctorate I focused on clarifying the behavior of oxygen in lanthium-silicate (La-silicate) dielectrics," explains Kawanago. "This research is important for the fabrication of high performance silicon MOSFETs."

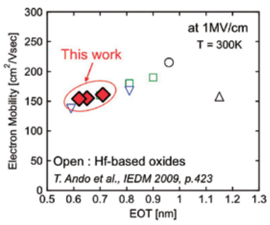
Highlights of Kawanago's research include: (1) incorporation of oxygen into La-silicates leads to a reduction in the gate leakage current and an increase in the effective mobility of nMOSFETs with La-silicate gate structures; (2) a combination of high temperature annealing of so-called metal-inserted poly-Si (MIPS) stacks yielded high performance nMOSFETS exhibiting and equivalent oxide thickness (EOT) of 0.62 nm and effective electron mobility of 155 cm^2/Vs at 1 MV/cm.

Recent research includes experimental analysis of gate metals for preventing the collapse of drain current in AlGaN/GaN Schottky high electron mobility transistors. "We found that TiN was better than conventional Ni gates because it passivates electrically active defects in the AlGaN layer," says Kawanago. "These results are important for applications of nitrides for high power and high frequency devices."

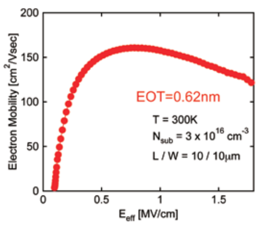
Kawanago says he looking forward to working with the researchers at QNERC to open up new areas of research in nanoelectronics.



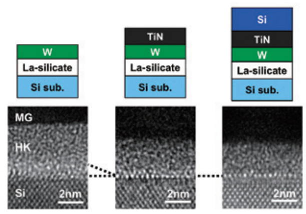
Capacitance vs Voltage characteristics of the transistor fabricated in this research



Relationship between electron mobility and dielectric thickness achieved the highest electron mobility (at the time)



Electron mobility of the transistor fabricated in this research



Cross section transmission electron microscope electrode structure dependence of the interface reaction

Akira Matsuzawa

Director, QNERC

http://www.ssc.petitech.ac.jp

World's First 64QAM and world's fastest 60GHz CMOS transceiver with data-rate of 28Gbps

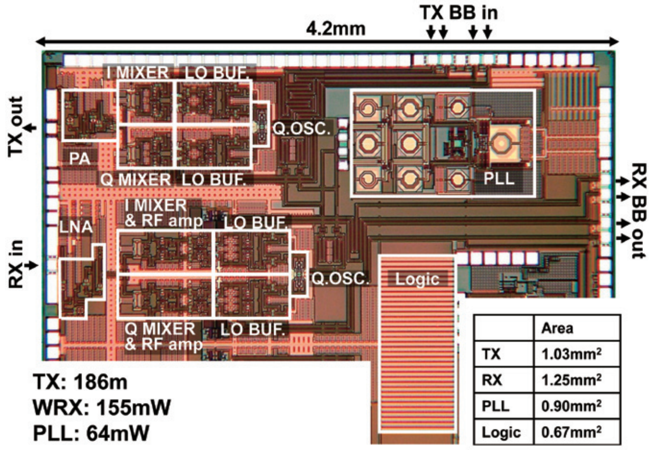
The development of 60GHz millimeter wave communication is important for the realization of ultra-high speed Giga-bit wireless communication.

Akira Matsuzawa and his colleagues have developed the world's first 64QAM and the world's fastest 60GHz CMOS transceiver with a data-rate of 28Gbps. The success of this development demonstrates the high potential of CMOS technology for millimeter wave applications to realize ultra-high data-rate wireless communications.

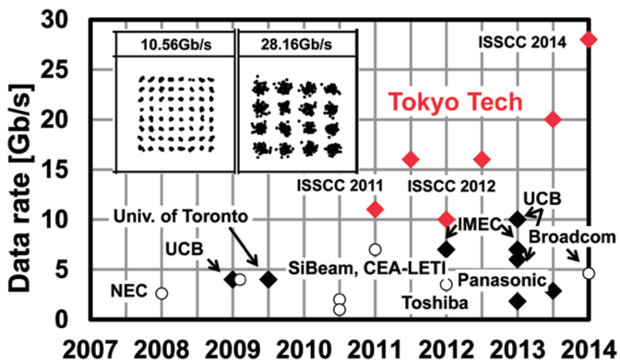
64QAM modulation technique is expected to increase the transfer data-rate by increasing the modulation bit with the same bandwidth in millimeter communication, however it has been very difficult to realize. Matsuzawa and co-workers have developed widely a flat frequency characteristic amplifier and very low phase noise 60GHz quadrature oscillator using the injection locking method. Data rate of 10.56 Gbps was realized using the world's first 64QAM modulation technique with a single channel of 1.76GHz bandwidth.

The researchers also realized the world's fastest data-rate of 28Gbps using 16QAM modulation with the four channel bonding method with a 8.64GHz bandwidth. The proposed mixer fast circuit with resistive feedback can increase the signal bandwidth up to 10GHz. Furthermore, the wideband and highly linear amplifier using a flipped voltage follower enabled the realization of the ultra-wide band baseband circuit.

The CMOS transceiver occupied an area of only 3.85 mm^2 and the power consumption was only 186mW for TX, 155mW for RX, and 64mW for the oscillator in 65nm CMOS technology. This small chip and low power CMOS transceiver with very high data-rate of 28Gbps will contribute to the realization of ultra-high speed wireless data-links for future mobile communications.



60GHz CMOS transceiver



Progress in the data-rate of 60GHz millimeter-wave transceivers.

Kenichi Okada et.al (13 other authors)
"A 64-QAM 60GHz CMOS Transceiver with 4-Channel Bonding," IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, CA, pp. 346-347, Feb. 2014.

Collaboration between members of the Department of Physical Electronics, Tokyo Tech., and Quantum Nanoelectronics Research Center, Tokyo Tech.

Shigehisa Arai

Professor, Tokyo Tech

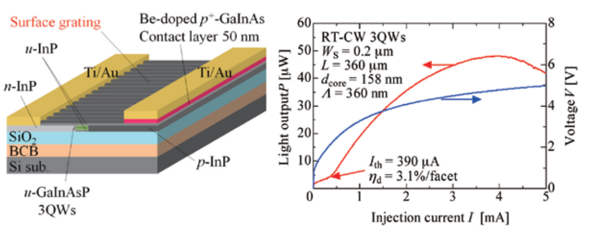
http://www.pe.titech.ac.jp/AraiLab/index-e.html

Lateral-Current-Injection Type Lasers for Optical Interconnection

Ultra low-power consumption light sources and low-noise photodetectors are essential to exploit the advantages of optical systems in the short-reach and on-chip optical interconnections. High-index contrast, strong optical confinement structures — composed of a thin semiconductor core (membrane) and polymer claddings — are of interest to achieve low threshold operation of semiconductor lasers.

Shigehisa Arai and his colleagues are engaged in research of electrically driven membrane lasers for on-chip optical interconnection. They successfully realized the room-temperature continuous-wave (RT-CW) operation of a lateral current injection (LCI) membrane Fabry-Perot cavity laser. A threshold current I_{th} of 2.5 mA and an external differential quantum efficiency of 22% per facet were attained for a five quantum-well device with a stripe width of 0.7 μm and cavity length of 350 μm. Moreover, an extremely low threshold operation (I_{th} = 390 μA) was achieved with an LCI membrane distributed feedback (DFB) laser with a stripe width of 0.2 μm and cavity length of 360 μm under RT-CW conditions by adopting a surface grating structure.

These experimental results suggest that this membrane structure has great potential for photonic global wiring in future LSI circuits.



Schematic diagram (left) and light output property (right) of LCI membrane DFB laser structure.

K. Doi[1], J. Lee[1], D. Inoue[1], Y. Atsuji[1], T. Hiratani[1], T. Amemiya[2], N. Nishiyama[1], and S. Arai[1,2]

1 Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8552, Japan
2 Quantum Nanoelectronics Research Center, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8552, Japan

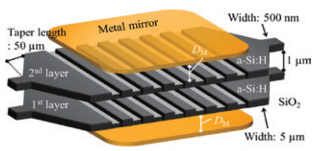
Publication: Appl. Phys. Express, vol. 7, 072701 (2014).
The 26th International Conference on Indium Phosphide and Related Materials (IPRM2014), Montpellier, We-D2-2 (2014).

Amorphous Silicon Interlayer Grating Couplers for Optical Interconnection

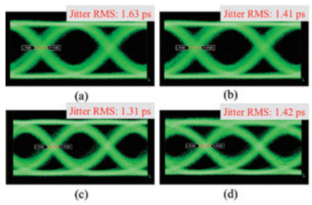
The integration of multistacked layers of 3D optical interconnects on a silicon (Si) platform is very attractive for future photonic integrated circuits. Hydrogenated amorphous silicon (a-Si:H) is a promising core material for photonic waveguides because it can be deposited at a process temperature of 300 °C, which satisfies the temperature limitations of the CMOS backend process.

Shigehisa Arai and his colleagues realized multi-stacked layers of 3D optical interconnects based on a-Si/SiO_2 and gratings for vertical coupling. They demonstrated a coupling efficiency of 83% between the a-Si interlayers by introducing a pair of metal mirrors so as reflect back the light to the interlayer grating couplers with a layer distance of 1 μm. Furthermore, they demonstrated a wide-band signal transmission capability up to 50 Gbps with clear eye openings.

These results show that a-Si/SiO_2 multistacked layers with gratings for vertical coupling are promising for functional 3D optical interconnects on a Si platform.



Device structure of the inter-layer grating couplers with metal mirrors.



Measured eye pattern for 40 and 50 Gbps. (a) F-to-F and (b) DUT @40Gbps. (c) F-to-F and (d) DUT @50Gbps.

J.-H. Kang[1], Y. Atsumi[1], Y. Hayashi[1], J. Suzuki[1], Y. Kuno[1], T. Amemiya[2], N. Nishiyama[1], and S. Arai[1,2]

1 Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8552, Japan
2 Quantum Nanoelectronics Research Center, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8552, Japan

Publication: Appl. Phys. Express, vol. 7, pp. 032202-1-3 (2014).

Yukio Kawano

Associate Professor, Tokyo Tech

http://diana.pe.titech.ac.jp/kawano/eng/index.html

Room Temperature Terahertz Detectors Fabricated with Highly Aligned Carbon Nanotube Film

There is strong industrial demand for terahertz (THz) detectors operable at room temperature. However, the photon energy of THz waves is lower than that of the thermal energy at room temperature, making the development of room-temperature THz detectors a formidable task. Although room temperature Schottky-barrier diodes, pyroelectric detectors, and Golay cell THz detectors are commercially available, these devices exhibit low sensitivity thereby limiting their applications.

Here, Yukio Kawano and his colleagues at Tokyo Tech, along with collaborators from Rice University and Sandia National Laboratories in the USA, have developed a novel room temperature THz detector based on a macroscopic highly aligned carbon nanotube (CNT) film (Fig. 1).

Figure 2 shows the *I-V* characteristics of this CNT-film device with (red line) and without (black line) THz illumination at f=2.52THz. THz illumination shifted the *I-V* curve but did not change the conductance of the CNT film. Detection mechanism was understood in terms of THz-induced thermoelectric effect.

This CNT film device also exhibited a strong polarization that depended on the CNT alignment direction enabling its use as a THz polarizer as well. This CNT-array detector and polarizer also responded to visible and infrared light, offering possibilities for ultra-broad band photodetectors.

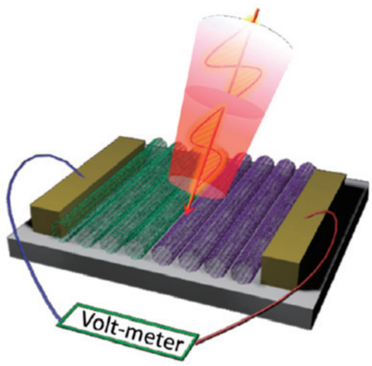


Fig. 1.
Schematic view of the CNT-array THz detector.

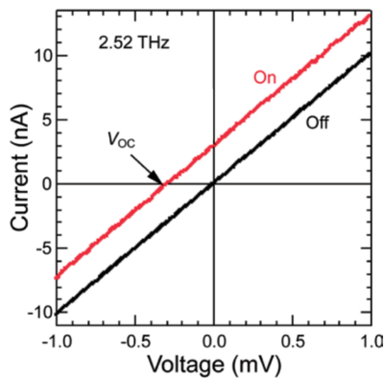


Fig. 2.
I-V characteristics with and without THz illumination at f=2.52 THz.

Xiaowei He[1,2], Naoki Fujimura[3], J. Meagan Lloyd[4,5], Kristopher J. Erickson[6], A. Alec Talin[6], Qi Zhang[1,2], Weilu Gao[1,2], Qijia Jiang[1,2], Yukio Kawano[3], Robert H. Hauge[2,7,8], François Léonard[6], and Junichiro Kono[1,2,9,10]

Title of original paper: Carbon Nanotube Terahertz Detector
Journal, volume, pages and year: Nano Letters 14, 3953–3958 (2014).
Digital Object Identifier (DOI): 10.1021/nl5012678

Affiliations: [1]Department of Electrical and Computer Engineering, Rice University, [2]The Richard E. Smalley Institute for Nanoscale Science and Technology, Rice University, [3]Quantum Nanoelectronics Research Center, Department of Physical Electronics, Tokyo Institute of Technology, [4]Electrical and Computer Engineering Department, Carnegie Mellon University, [5]NanoJapan Program, [6]Sandia National Laboratories, [7]Department of Chemistry, Rice University, [8]Chemistry Department, King Abdulaziz University, [9]Department of Physics and Astronomy, and [10]Department of Materials Science and NanoEngineering, Rice University

Shunri Oda

Professor, Tokyo Tech

http://odalab.pe.titech.ac.jp/en

Integrated Silicon (Si) Single Hole Transistors for Quantum Computing

Quantum computers that utilize quantum superposition states have been attracting attention for ultra-fast and parallel calculation applications.

Shunri Oda and co-workers at QNERC, Tokyo Tech fabricated p-channel silicon (Si) double quantum dot structures using electron beam lithography. Compared to electron spins, there is less information about hole spins but they have the potential for longer coherence time and different spin-orbit interaction which are interesting for the application to spin base qubits.

A single hole transistors and double quantum dots integrated with charge sensor SHT were fabricated (Fig. 1). Coulomb oscillation was observed in the negative gate voltage region at 4.2K as (Fig. 2 (a) and 2(b)). Honeycomb structures, which are evidence of moderate interaction between double quantum dots, were clearly observed in the stability diagram of devices (Fig. 2 (c) and (d)).

These achievements are important steps for qubit applications using hole spin states in DQDs. This highly controllable p-channel DQD device is expected to enable the control of hole spins by using stronger spin-orbit interactions than those of electrons.

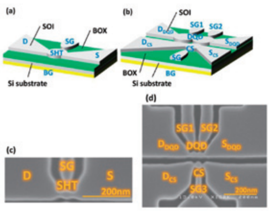


Fig. 1. Schematic diagrams and SEM images of p-channel QD devices. The thicknesses of the SOI and BOX layer are 33 nm and 145 nm, respectively. (a), (c) A single hole transistor. The sidegate SG is used to modulate the potential and the tunnel rate of the SHT. (b), (d) p-channel DQD device integrated with charge sensor SHT.

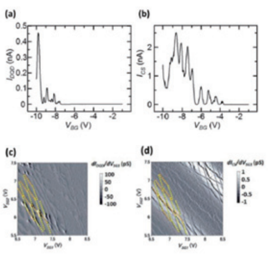


Fig. 2. (a) I_{DQD}-V_{BG} characteristics of the DQD. (b) I_{CS}-V_{BG} characteristics for the single QD as the CS. (c) Charge stability diagram for the DQD. (d) Differential conductance for the CS.

Ko Yamada, Tetsuo Kodera, Tomohiro Kambara, and Shunri Oda

Title of original paper: Fabrication and characterization of p-channel Si double quantum dots

Journal, volume, pages, and year: *Applied Physics Letters*, 105, 113110 (2014).

Digital Object Identifier (DOI): 10.1063/1.4896142

Affiliation: Quantum Nanoelectronics Research Center, Tokyo Institute of Technology

Real Time Control of the Size of Silicon Nanocrystals

Silicon nanocrystals (SiNCs) have attracted much attention due to their unique electrical and optical properties derived from their quantum confinement effects. Therefore many applications are expected such as single-electron transistors and high-efficiency solar cells. Importantly, precise control of SiNC size is essential for these applications.

Shunri Oda and co-workers at QNERC, Tokyo Tech can fabricate SiNCs using their unique very-high-frequency (VHF) plasma fabrication system and control the diameter of SiNCs by using a pulsed SiH_4 gas supply into the Ar plasma (Fig.1). Recently, they discovered that the size of SiNCs has correlation with the optical emission of the plasma during SiNC fabrication.

As SiH_4 is supplied into the Ar plasma, an enhancement of optical emission of Ar atoms was observed (Fig. 2(b)) which implies that the growth of SiNCs was taking place in the plasma. The duration of the enhanced emission correlated clearly with the average size of SiNCs (Fig. 2(e)). On the basis of these results, the SiNC size can be controlled precisely by real time monitoring of the optical emission of the plasma.

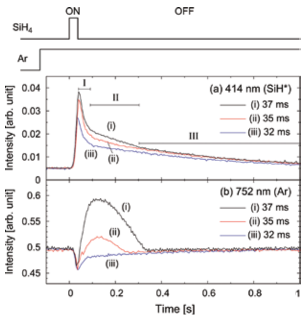


Fig. 1. Time evolution of 414 nm (SiH^*) and 752 nm (Ar) emission lines for each ON time of pulsed SiH_4 supply.

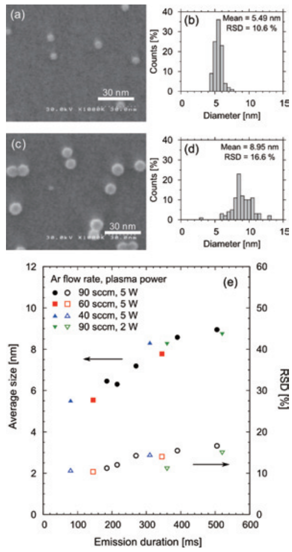


Fig. 2. SEM images and size distributions of SiNCs when the durations of the enhanced emission are (a, b) 80 and (c, d) 505 ms. The average size and relative standard deviation (RSD) of SiNC diameters are plotted in (e) against the duration of the enhanced emission.

Kazufumi Ikemoto, Yoshifumi Nakamine, Yukio Kawano, and Shunri Oda

Title of original paper: In situ monitoring of silicon nanocrystal formation with pulsed SiH_4 supply by optical emission spectroscopy of Ar plasma

Journal, volume, pages, and year: *Japanese Journal of Applied Physics* **53**, 116102 (2014).

Digital Object Identifier (DOI): 10.7567/JJAP.53.116102

Affiliation: Quantum Nanoelectronics Research Center, Tokyo Institute of Technology

Visiting Professor

Kaustav Banerjee
Professor, University of California, Santa Barbara

Simon Deleonibus
Chief Scientist, CEA-LETI

William I. Milne
Professor, University of Cambridge

Mohamed Boutchich
Associate Professor, Pierre & Marie Curie University

Contact Details

For information about research and education at QNERC:
E-mail kawano@pe.titech.ac.jp
Website www.pe.titech.ac.jp/qnerc

Affiliated Researchers

Masahiro Asada
http://www.pe.titech.ac.jp/AsadaLab/toppage_eng.html

Tetsuya Mizumoto
http://mizumoto-www.pe.titech.ac.jp/index.html

Mutsuko Hatano
http://dia.pe.titech.ac.jp/en/index.html

Makoto Konagai
http://solid.pe.titech.ac.jp

Akira Yamada
http://solid.pe.titech.ac.jp

Yasuyuki Miyamoto
http://www.pe.titech.ac.jp/Furuya-MiyamotoLab/e-index.htm

Nobuhiko Nishiyama
http://www.pe.titech.ac.jp/AraiLab/index-e.htm

Safumi Suzuki
http://www.pe.titech.ac.jp/SuzukiLab/index.html

Tetsuo Kodera
http://dia.pe.titech.ac.jp/index_eng.html