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QNERC Quantum Nanoelectronics Research Center

Overseas researchers praise facilities at QNERC

Kunji Chen

Professor,
Nanjing University, China

Mohamed Boutchich

Associate Professor,
Pierre and Marie Curie University, France

Kunji Chen, a professor of physics in Nanjing University, China, is investigating semiconductor nanostructures and nano-electronics. He has visited QNERC four times over the past decade and has worked closely with Shunji Oda, a professor of engineering at Tokyo Tech and a steering committee member of QNERC.

“QNERC is a famous research center for nano-quantum electronics, and Professor Oda’s group is one of the most active and innovative groups in the world researching nano-semiconductors and devices,” says Chen. “In particular, it was the first to report a new preparation method for controlling single silicon-quantum dots using VHF PECVD to fabricate nano-electron devices.”

Among the research subjects Chen has focused on during his visits is the preparation of silicon-based nanostructures such as nc-Si thin films and silicon-based nanoelectronics, including charge storage and resonant tunneling in nc-Si quantum dot structures. “These subjects are at the frontier of research and advanced technologies for creating a new generation of nano-electronic and nano-photoelectronic devices,” notes Chen.

He also helped work out an agreement between his and Oda’s group to promote collaborative research and to cooperate in post-doctoral training of graduates. To date, three graduates from Nanjing University have taken part in the program.

The first visit to QNERC for Mohamed Boutchich, an associate professor at Pierre and Marie Curie University in France researching nanomaterials for nanoelectronics applications, was as a postdoctoral researcher in 2004. He was invited to return again for several months near the end of 2012.

“During my first visit, I was impressed by the research facilities QNERC has,” says Boutchich. “This was a place where you could think of running an experiment on a daily bases, for everything is set up for best practices and the optimum use of the facilities.”

His main research focus was advanced opto-electrical characterizations of nanomaterials that he wasn’t yet able to carry out in his own lab. In addition, together with Oda, he has set up an exchange program that will enable the two groups to collaborate with Taiwan and Thailand research labs.

“QNERC is the kind of place you miss once back home,” says Boutchich. “I will definitely come back again.”

Adrian Ionescu

Professor,
EPFL, Switzerland

Adrian Ionescu is a full professor at the Swiss Federal Institute of Technology, Lausanne, Switzerland, and also heads the Nanoelectronic Devices Laboratory there, which focuses on low power nanoelectronics and new device concepts like steep slope transistors.

He visited QNERC in February last year for several reasons. “Japanese research in nanoelectronics takes a deep and serious approach to experimental verification and design of experiments,” says Ionescu. “And Professor Oda’s group is well known in the field, while Tokyo Tech is well connected with leading Japanese companies active in the area. So I took the opportunity to exchange ideas with the different researchers in the field of nanoscale fabrications and new low-power device concepts.”

He is also working to establish a long-term cooperation framework with Tokyo Tech in the field of zero power technologies, which aims to combine energy efficient electronics with new devices that harvest energy from surrounding light, vibrations, temperature differences etc.

“QNERC is an excellent place for research and I learned a lot about nanofabrication, and in particular about the Japanese style of work,” he says. “I’d be happy to return for a longer period in the future.”

Akira Matsuzawa

Director, QNERC;
Professor, Tokyo Tech

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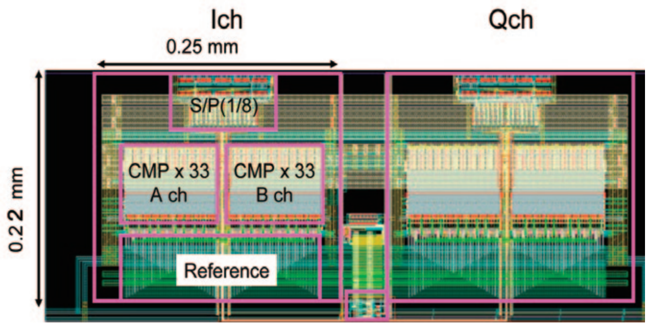
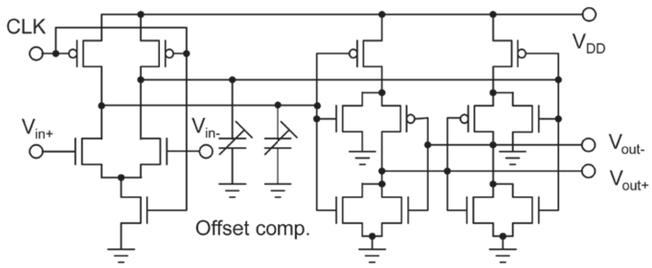
Ultra-High Speed and Ultra-Low Power Flash ADC With Dynamic Comparator For 60 GHz Millimeter Wave Applications

Akira Matsuzawa and his colleagues have developed the world's top class 5 bit 2.3 GS/s CMOS flash ADC. It consumes only 12 mW which is three to four times lower than conventional circuitry and occupies an area of only 0.06 mm^2 [1]. A new dynamic comparator was invented to reduce the power consumption, thermal noise, offset mismatch voltages, and chip-area. Use of complementary circuits between the dynamic amplifier and the latch led to reductions in the thermal noise, and the capacitive offset mismatch compensation circuit reduces transistor size and power consumption while keeping high speed operation. This comparator is widely used by many research groups over the world.



5 bit 2.3 GS/s 12mW Flash ADC using 40nm CMOS



High seed dynamic comparator with offset compensation

M. Miyahara[1], H. Sakaguchi[1], N. Shimasaki[1] and A. Matsuzawa[1,2]

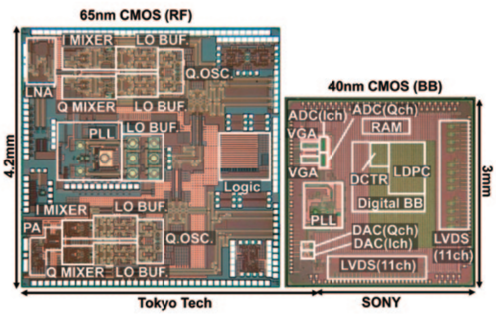
1 Department of physical Electronics, Tokyo Tech.
2 Quantum Nanoelectronics Research Center, Tokyo Tech.

"An 84 mW 0.36 mm^2 Analog Baseband Circuits for 60 GHz Wireless Transceiver in 40 nm CMOS," IEEE Radio Frequency Integrated Circuits Symposium. Dig., pp. 495-498, June 2012.

World's First Full 4-Channel 6.3Gb/s 60GHz CMOS Transceiver with Low-Power Mixed Signal Baseband Circuitry

60 GHz millimeter wave communication shows promise for the realization of ultra-high speed giga-bit wireless communication systems. However, a full four channel (57.24GHz–65.88GHz) transceiver has not been realized.

Akira Matsuzawa and his colleagues have developed the world's first full 4-channel 6.3Gb/s 60GHz CMOS transceiver with low-power mixed signal baseband circuitry in collaboration with Sony. This success demonstrates the high potential of CMOS technology for millimeter wave applications. CMOS can realize not only 60 GHz RF circuits but also low power and high speed mixed signal baseband circuitry. The transmitter and receiver consume 320 mW and 220 mW, respectively. Also base-band circuitry for the transmitter and the receiver consume 200 mW and 400 mW, respectively. These numbers are about five times lower than conventional other chips. The world's lowest phase noise 60 GHz quadrature VCO, high gain 60GHz differential power amplifiers using a cross coupled capacitance method, and a wideband multi-stage low noise amplifier were integrated to realize the wideband direct conversion circuit with 16QAM modulation.



Full 4-channel 6.3Gb/s 60GHz CMOS transceiver with low-power mixed signal baseband circuitry

Channel	ch.1	ch.2	ch.3	ch.4	Max rate
Constellation					
Spectrum					
Back-off	4.4dB	4.6dB	5.0dB	5.7dB	5.0dB (ch.3)
Data rate*	7.0Gb/s	7.0Gb/s	7.0Gb/s	7.0Gb/s	10.0Gb/s (ch.3)
EVM	-23.0dB	-23.0dB	-23.3dB	-22.8dB	-23.0dB (ch.3)
Distance**	0.3m	0.5m	0.5m	0.3m	>0.01m (ch.3)

*The roll-off factor is 0.25. The bandwidth is 2.16GHz except for Max rate.
**Maximum distance within a BER of 10^{-3}. The 6-dBi antenna in the package is used.

Communication performance for each channel

Kenichi Okada and Akira Matsuzawa et al (23 authors)

"A Full 4-Channel 6.3Gb/s 60GHz Direct-Conversion Transceiver With Low-Power Analog and Digital Baseband Circuitry," IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, CA, pp.218–219, Feb. 2012.

Collaboration between members of the Department of physical Electronics, Tokyo Tech., Sony Corporation, 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 Membrane Lasers for Optical Interconnection

Ultra low-power consumption light sources and low-noise photodetectors are essential to exploit the advantage 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 have been engaged in the research of electrically driven membrane lasers for on-chip optical interconnections. They successfully realized a room-temperature operation of GaInAsP/InP lateral current injection (LCI) type membrane lasers with the semiconductor core thickness of 450 nm (Fig. 1). A threshold current of 3.8 mA, which was almost 1/3 of that of previously reported devices, was attained for five quantum-wells active region with a stripe width of 1 μm and cavity length of 250 μm (Fig. 2).

Photodiodes (PDs) with a lateral junction structure were also realized with a responsivity of 0.39 A/W at 1550 nm for a device length of 390 μm. By reducing the stripe width to 0.85 μm, a 3-dB bandwidth of 8.8 GHz was obtained at a bias voltage of -2 V, and 10 Gbps operation was achieved (Fig. 3).

These experimental results suggest that this membrane structure has great potential for not only light sources but also detectors for on-chip optical interconnects in next generation LSI circuits.

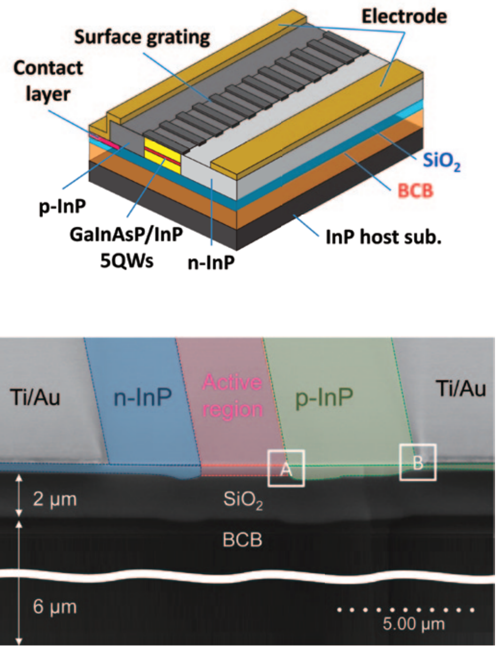


Fig. 1
Schematic diagram and cross sectional view of LCI membrane laser structure.

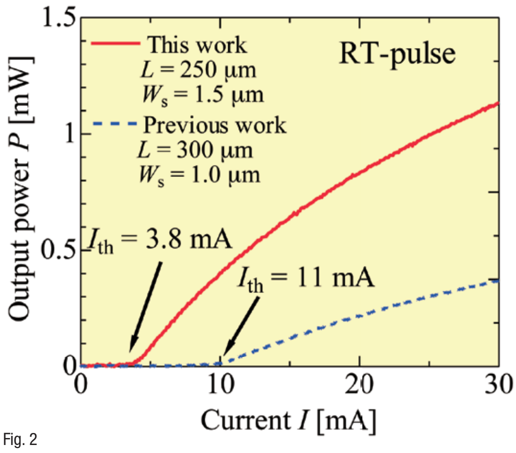


Fig. 2
Lasing properties of LCI membrane lasers.

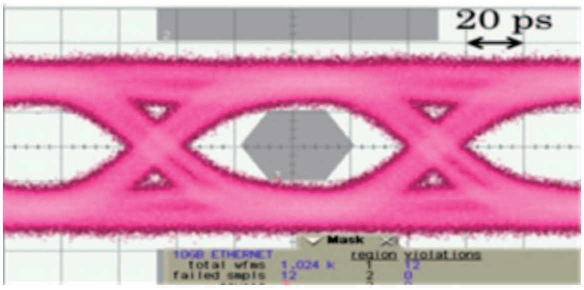


Fig. 3
Eye diagram of lateral junction structure photodiode at 10 Gb/s signal detection (V_{bias} = -2 V).

Takahiko Shindo[1], Mitsuaki Futami[2], Kyohei Doi[2], Yuki Atsumi[2], JoonHyun Kang[2], Tomohiro Amemiya[1], Nobuhiko Nishiyama[2], and Shigehisa Arai[1,2]

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Publication : IEEE J. Sel. Top. Quantum Electron., Vol. 17, No. 5, pp. 1175-1182 (2011).
IEEE Photon. Technol. Lett., Vol. **24**, No. 11, pp. 888-890 (2012).
1st Optical Interconnect Conf., Santa Fe, USA, TuP2 (2012).

Shunri Oda

Professor, Tokyo Tech

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Light-emitting silicon nanocrystals

Silicon is a good material for transistors in integrated circuits, but its optical property is poor because of indirect band structure. Silicon nanocrystals (SiNCs) show luminescent property owing to quantum mechanical effects.

Shunri Oda and co-workers at Tokyo Tech fabricated SiNCs with uniform size less than 10 nm by very high frequency (VHF) plasma deposition system and observed photoluminescence (PL) from SiNCs.

As shown in Fig. 1, with increasing SiH_4 gas flow rates PL peak shifts to the high energy side, which is the evidence of quantum effects.

As shown in Fig. 2, slightly P-doped SiNCs shows higher intensity PL, due to the termination of dangling bonds, but PL intensity decreases in heavily P-doped SiNCs due to Auger effects.

These characteristics are very important for future application of SiNCs in optoelectronic devices.

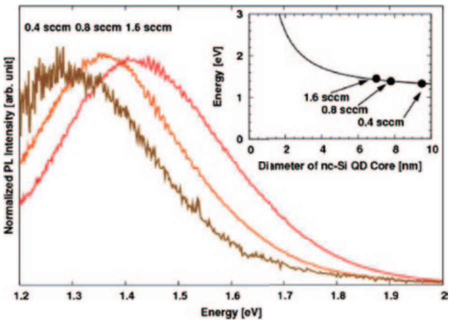

Fig. 1
PL spectra of nc-Si QDs fabricated under SiH_4 gas flow rates of 0.4, 0.8, and 1.6 sccm. In the inset, PL peak energy is shown as a function of the particle diameter of nc-Si QDs.

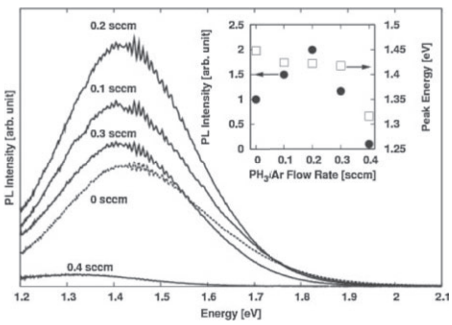

Fig. 2
PL spectra of P-doped nc-Si QDs fabricated under the PH_3/Ar gas flow rates of 0 to 0.4 sccm. In the inset, PL peak intensity (solid circle) and PL peak energy (blank square) are shown as a function of the PH_3/Ar gas flow rate.

K. Someno[1], K. Usami[1], T. Kodera[1], Y. Kawano[1], M. Hatano[2], and S. Oda[1,2]

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Photoluminescence of Nanocrystalline Silicon Quantum Dots with Various Sizes and Various Phosphorus Doping Concentrations Prepared by Very High Frequency Plasma
Journal : Japanese *Journal of Applied Physics* **51**, 115202 (2012).
Digital Object Identifier (DOI) : 10.1143/JJAP.51.115202

Pauli Spin Blockade in Si Double Quantum Dots

Electron spins confined in semiconductor quantum dots (QDs) are attractive candidates for quantum information processing. Coherent manipulation of individual and coupled electron spin states has been mainly investigated in GaAsbased double QD (DQD) devices. However, nuclear spins of the host material cause decoherence of the electron spin via strong hyperfine coupling. To reduce this effect, group IV materials, such as carbon, silicon (Si), and silicon-germanium (SiGe), have been investigated because their most abundant isotopes have zero nuclear spin. Silicon systems, in particular, have an advantage for future integration because of their compatibility with conventional Si metal-oxide-semiconductor devices.

Shunri Oda and co-workers at Tokyo Tech in collaboration with Prof. Marcus group of Harvard University investigated leakage current in a PSB regime using a lithographically defined Si DQD.

Figure 1 shows a schematic diagram and SEM image of the device, and stability diagram. Figure 2 shows triple point B in Fig. 1(c), with negative (a) and positive (b) bias. PSB is observed only in negative bias. The band diagram (Fig. 2(c)) explains the mechanism of formation of PSB. This result provides an important step for future spin-based qubits.

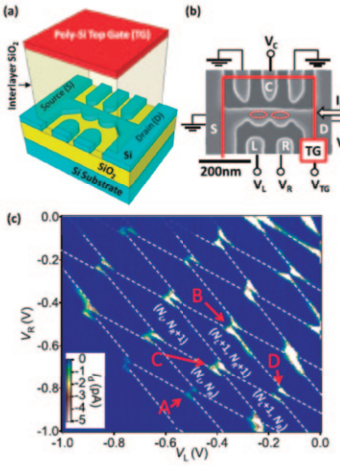

Fig. 1
(a) Schematic of the silicon double quantum dot (Si DQD); (b) Scanning electron microscope image of the Si DQD before the top gate formation; (c) Charge stability diagram of the Si DQD as a function of VL and VR at zero magnetic field.

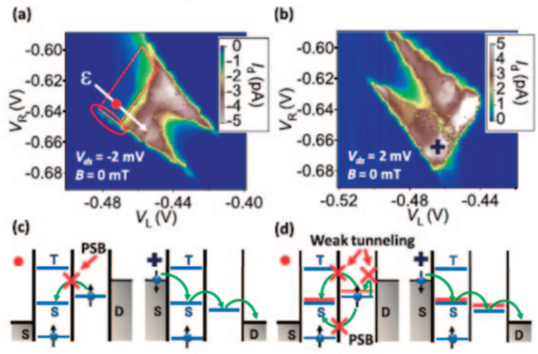

Fig. 2
(a) Triple point B shown in Fig. 1(c) with negative bias, where Vds = −2mV;(c) Energy diagrams of a Si DQD at the circle marked in (a) (the left diagram) and at the blue crossmarked in (b) (the right diagram); (d)Same as 2(c) without an assumption that lifting of the valley degeneracy is small.

G. Yamahata,[1,2] T. Kodera,[1] H. O. H. Churchill,[2] K. Uchida,[3] C. M. Marcus,[2,*] and S. Oda[1]

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Magnetic field dependence of Pauli spin blockade : A window into the sources of spin relaxation in silicon quantum dots
Journal : Physical Review B 86, 115322 (2012).
Digital Object Identifier (DOI) : 10.1103/PhysRevB.86.115322

Yukio Kawano

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Active Signal Modulator in Terahertz Spectroscopy

Terahertz (THz) technology is widely used in industry and medicine. One of next important targets is to produce THz devices with functions such as frequency tunability and amplitude modulation. Although various frequency-agile THz sources and THz transmission modulators have been reported, the frequency tunability and signal modulation in the THz detector remains to be fully explored.

Yukio Kawano and his colleagues at Tokyo Tech achieved gate-voltage-controlled signal modulation of a frequency-tunable THz detector with a GaAs/AlGaAs two-dimensional electron gas. The modulation mechanism is based on Landau quantization with magnetic field and Fermi level tuning with the gate voltage.

Figure 1 shows the gate-voltage dependence of the THz response signal at *f*= 2.5 THz. The THz signal is seen to change significantly with gate voltage. The maximum on-off ratio of the modulation was over 40dB. These results may enable the realization of a solid-state signal modulator in THz spectroscopy, where spectroscopic frequency range could be easily selected with the gate voltage.

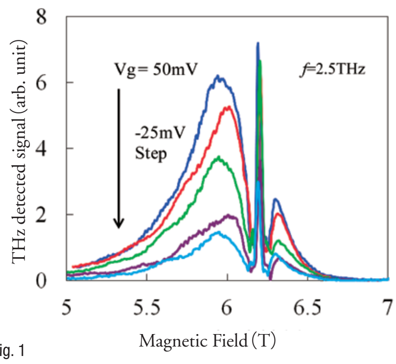

Fig. 1
THz detected signal versus magnetic field for V_G = 50, 25, 0, -25 and -50 mV

D. Suzuki[1], S. Oda[2] and Y. Kawano[2]

1 Department of Physical Electronics, Tokyo Institute of Technology
2 Quantum Nanoelectronics Research Center, Tokyo Institute of Technology

Title of original paper : Gate-Voltage Tunable Terahertz Detection by a GaAs/AlGaAs Quantum Device
Journal, volume, pages and year : Proceedings of 37th International Conference on Infrared, Millimeter, and Terahertz Waves (2012).
Digital Object Identifier (DOI) : 10.1109/IRMMW-THz.2012.6380132

Graphene-based Frequency-Tunable Terahertz and Infrared Detector

Terahertz (THz) and infrared (IR) spectroscopy provide a powerful tool for characterizing physical and chemical properties of various materials. Time-domain spectroscopy and Fourier transform spectroscopy are widely used for such THz/IR spectroscopic measurements. Though these instruments are useful systems, they need an expensive femto-second pulse laser and a Michelson interferometer, respectively. Alternatively, a solid-state compact THz spectrometer is strongly desired. Though previously several types of frequency-tunable THz detectors have been reported, their detection ranges are restricted to a narrow frequency region (below 5THz).

Yukio Kawano at Tokyo Tech developed a graphene-based THz detector with frequency tunability in a much broader band ranging from THz to IR region (Fig. 2). In the graphene material, carriers are regarded as massless Dirac fermions due to linear dispersion relation. Using the unique properties of graphene, Kawano succeeded in detecting the THz and IR waves over wide frequency range of 0.76-33THz, whose resonant frequency is magnetically tunable.

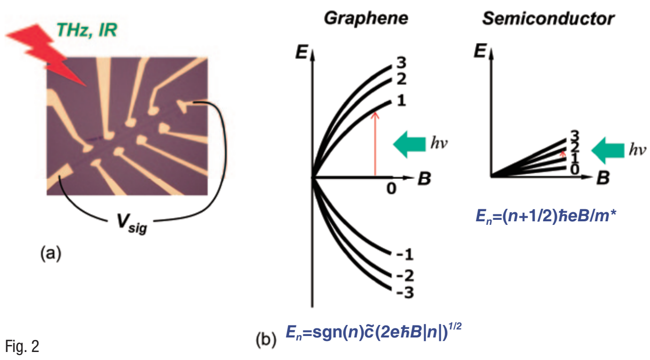

Fig. 2
(a) Photograph of the graphene THz and IR detector
(b) Sketch of Landau-level density of states for the graphene (left) and the semiconductor (right).

Y. Kawano

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Title of original paper : Wide-Band Frequency-Tunable Terahertz and Infrared Detection with Graphene
Journal, volume, pages and year : Nanotechnology (2013) : In press

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