QNERC NEWSLETTER

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QNERC Quantum Nanoelectronics Research Center

Yukio Kawano awarded the Sir Martin Wood Prize and the IBM Japan Science Prize

Major Advances in THz detection and imaging

Utilizing the terahertz (THz) electromagnetic spectrum is challenging because of difficulties in its detection and imaging due to the very high frequencies and low energy levels associate with this range of frequencies. To overcome these limitations, Yukio Kawano, an associate professor at Tokyo Tech's QNERC has integrated carbon nanotubes and graphene with a GaAs/AlGaAs heterostructure and created a highly sensitive THz detector.

"It works on the principle that the carbon nanotube transistor senses electrical polarization induced by the terahertz-excited electrons and holes," explains Kawano. "This enables it to detect terahertz photons."

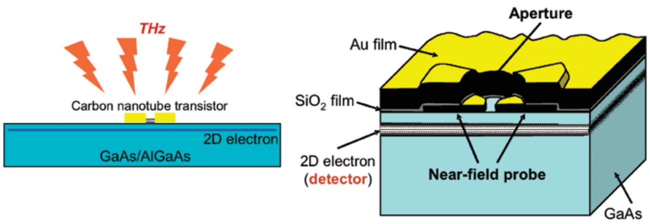
Using the same materials he employed to create the detector, Kawano turned his attention to THz imaging and developed a near-field THz imager in which an aperture, a planar probe and a detector composed of two-dimensional electron gas are closely integrated on one semiconductor chip. This structure eliminates the need for complicated optical and mechanical components and results in a simple and robust device.

"The presence of the planar probe changes the distribution profile of the THz evanescent field, and this enhances the coupling of the field to the detector." says Kawano. "This effect enables very high spatial resolution beyond the diffraction limit."

The potential for improved THz imaging applications is enormous. Medical researchers have already started using the technology to detect and image cancer cells, while its nondestructive characteristics means it could be used in such areas as inspecting sensitive electronic equipment for defects, monitoring the quality of packaged foods, and detecting hazardous materials at airports.

Kawano is interested in applying the technology to study individual nano-materials and bio-molecules. "Terahertz spectroscopy and imaging will help create sophisticated tools to study the electronic properties of various materials such as semiconductors, superconductors, carbon nanotubes, and graphene."

As a result of his research, Kawano was awarded two prestigious prizes in 2011. On November 9 he received the Sir Martin Wood Prize at the British Embassy in Tokyo for outstanding work as a young researcher under 40. And in December he was awarded the IBM Japan Science Prize for outstanding research results.



Receiving the Sir Martin Wood Prize at the British Embassy in Tokyo (right: David Warren, HM Ambassador to Japan).

Receiving the IBM Japan Science Prize from Prof. Leo Esaki (Nobel Prize in Physics 1973), Director of Judging Committee.

Acceptance speech for the IBM Japan Science Prize.

Akira Matsuzawa

Director of QNERC

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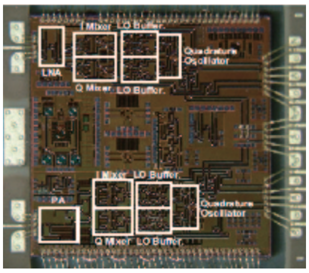
World First 60GHz CMOS Direct Conversion 16QAM Transceiver LSI That Attains the World Fastest Data-Rate of 16Gbps in Wireless Communication

Wireless networking is becoming popular worldwide and ultra-high speed data transfer is critical to process the dramatic increases in data size and number of users. To-date, in spite of the tremendous potential of millimeter wave technology for high speed wireless communication, its speed has been limited to only 4 Gbps so far.

Akira Matsuzawa and colleagues have realized the world's first 60GHz CMOS direct conversion 16QAM Transceiver LSI [1] and attained the world's fastest data-rate of 16Gbps in wireless communication [2]. The researchers achieved this remarkable ultra-high speed data-rate by developing the world's lowest phase noise quadrature VCO of which phase noise is -96dBC/Hz@1MHz offset that is 20dB lower than that of previous reports. Furthermore, the team also developed high gain 60GHz differential power amplifiers using a cross coupled capacitance method and a wideband multi-stage low noise amplifier to realize the direct conversion architecture with 16QAM modulation.
These results demonstrate the high potential of CMOS technology for millimeter wave applications and that the data rate of wireless communication could reach the same level as hard wire communications technology.



60GHz CMOS Direct Conversion Transceiver using 65nm CMOS Technology

Constellation	9506 points	19912 points	13502 points	42024 points
Modulation	QPSK	16QAM	QPSK	16QAM
Symbol rate	1.76GS/s	1.76GS/s	5.0GS/s	4.0GS/s
Data rate	3.52Gb/s	7.04Gb/s	10.0Gb/s	16.0Gb/s
EVM (withDFE)	-30.5dB	-28.2dB	-15.2dB	-16.1dB

Data transfer performance

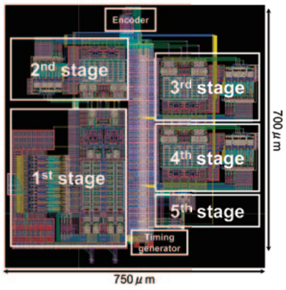
[1] K. Okada, K. Matsushita, K. Bunsen, R. Murakami, A. Musa, T. Sato, H. Asada, N. Takayama, N. Li, S. Ito, W. Chaivipas, R. Minami, and A. Matsuzawa, *IEEE ISSCC Dig. Tech. Papers,* **9.1**, pp. 160–161, Feb. 2011.

[2] H. Asada, K. Bunsen, K. Matsushita, R. Murakami, Q. Bu, A. Musa, T. Sato, T. Yamaguchi, R. Minami, T. Ito, K. Okada, and A. Matsuzawa, *IEEE A-SSCC Dig. Tech. Papers,* pp.373–376, Nov. 2011.

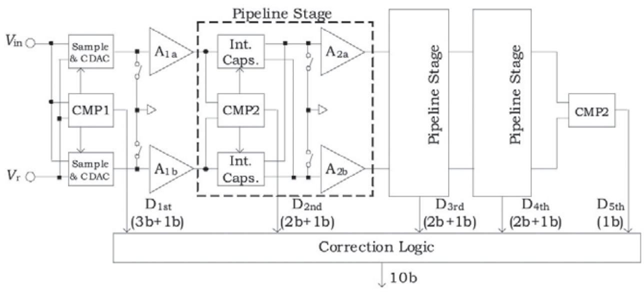
High speed and high resolution A/D converter with novel conversion method

High speed and high resolution A/D Converter (ADC) circuits are important for the realization of high data rate communication systems because the data-rate is in principal proportional to the product of conversion rate and resolution of ADC. However, conventional ADC circuits require high gain operational amplifiers (OpAmps), which makes it difficult to realize high voltage gain with scaled CMOS technology due to the voltage lowering and reduction of drain resistance.

Akira Matsuzawa has invented a new A/D conversion method that does not require high gain OpAmps, but instead uses a pair of low gain amplifiers and capacitive interpolation circuits to realize both high speed and high resolution ADC. Matsuzawa and colleagues developed 10bit 320MSps 40mW ADC and achieved the world's top Figure of Merit of 390fJ/conv. steps in 90nm CMOS technology. This ADC circuit has contributed to the development of 40GHz 1Gbps long distance millimeter wave communication (1–4 km) systems, which require the highly multi-valued modulation method—for example 64QAM with narrow signal bandwidth of 230 MHz. Furthermore, this ADC circuit shows the direction of future analog circuits employing deeply scaled CMOS technology in which intrinsic voltage gain and operating voltage will be reduced along with technology scaling.



Photograph of the microchip



Functional block diagram of proposed ADC circuit

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IEEE Symposium on VLSI Circuits, Kyoto, Japan, pp.126–127, June 2011.

Shigehisa Arai

Professor, Tokyo Tech

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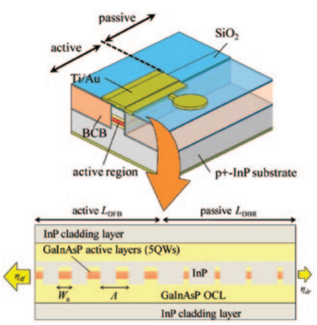
Distributed Reflector Lasers for High-Speed Access Networks

The explosive growth of data communications has led to a rapid increase in demand for high bit-rate access networks. Furthermore, high-speed optical interconnects—such as active optical cables—have attracted great interest to handle the resultant large data capacity. For such short distance applications, low-power consumption is an essential requisite for optical transmitters.

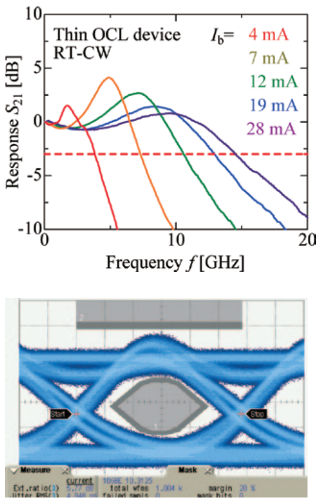
Shigehisa Arai and his colleagues are engaged in distributed reflector (DR) lasers with wire like active regions, which are good candidates for low threshold and high efficiency operation because of their small active volume and strong index coupling grating structure.

The slope of the relaxation oscillation frequency f_r of 3.0 GHz/mA$^{0.5}$ was demonstrated due to the low threshold current characteristics of DR lasers, and a 3 dB bandwidth over 15 GHz was achieved with a relatively low bias current of 28 mA. Furthermore, a mask test of 10 GbE with 20% margin was passed with a bias current as low as 10 mA and modulation voltage of 0.53 V_{p-p}.

These results show that the DR laser with wire like active regions is promising as a light source for access network applications and optical interconnections.



Schematic and cross-sectional structures of DR laser with wire like active regions



(Top): Small signal response of DR lasers. (Bottom): Eye diagrams under high-speed modulation (10 Gbps).

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Optics Express, Vol. **18**, No. 16, pp. 16370-16378 (2010).
IEEE Photonics Technol. Lett., Vol. **23**, No. 18, pp. 1349 - 1351 (2011).

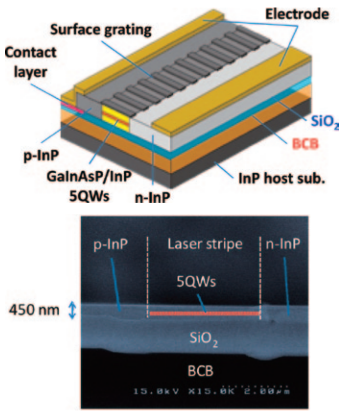
Lateral Current Injection Type Laser and Photodiodes for Optical Interconnection

Ultra low power consumption light sources and low noise photodetectors are essential to exploit the advantage of optical systems in 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.

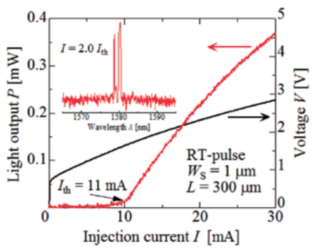
Shigehisa Arai and his colleagues are engaged in research on electrically driven membrane lasers for on-chip optical interconnection. They successfully realized room-temperature pulsed operation of GaInAsP/InP lateral current injection (LCI) type membrane DFB lasers with a surface grating. A threshold current of 11 mA was attained for a device with five quantum-wells, with stripe width of 1 μm and the cavity length of 300 μm.

Photodiodes with a lateral junction structure with a responsivity of 0.27 A/W at 1550 nm were also fabricated. A 3-dB bandwidth of 8 GHz and 7 Gbps error-free operation under non-bias conditions were achieved.

These experimental results suggest that this membrane structure has great potential as a light source in LSI circuits.



Schematic diagram and cross sectional view of LCI membrane structure



Lasing properties of LCI membrane lasers

Takahiko Shindo[2], Mitsuaki Futami[2], Tadashi Okumura[2], Ryo Osabe[2], Takayuki Koguchi[2], Tomohiro Amemiya[1], Nobuhiko Nishiyama[2], and Shigehisa Arai[1,2]

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Shunri Oda

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Phosphorous doping of silicon nanocrystals for nanoelectronic devices

Silicon nano-crystals (SiNCs) exhibit unique electronic, optical, and quantum mechanical properties, which are promising for nano-electron devices.

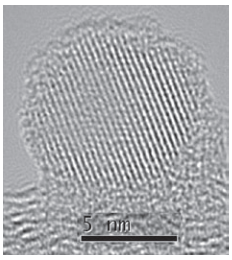
However, the electrical conductivity of SiNC films is too low for the fabrication of electron devices. Therefore, phosphorous doping (P-doping) of SiNCs is an important approach for the improvement of the electrical properties the films. However, doping of SiNCs is difficult because of the so-called self purification effect.

Shunri Oda and co-workers at Tokyo Tech, in collaboration with Martin Stutzmann group's at Technische Universitat Münhen are investigation the possibility of producing P-doped SiNCs using a high frequency (VHF) plasma deposition system.

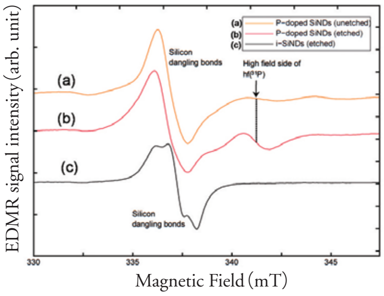
P-doped SiNCs were fabricated by decomposing of SiH_4 and phosphine (PH_3) gases in an argon plasma. The properties of the resulting P-doped SiNCs were measured by transmission electron microscopy (TEM) for crystalline structure and electrically detected magnetic resonance (EDMR) for the location of the phosphorous atoms.

Fig.1 shows the TEM image of one P-doped SiNCs. A spherical interference pattern is clearly observed, which implies that this method of P-doping does not affect the crystallinity. Fig. 2 shows the EDMR spectra of SiNC films with (a, b) and without (c) P doping. For P-doped films the resonance due to the hyperfine structure of ^{31}P in silicon is clearly observed at a magnetic field of 341.5 mT. These findings suggest that P atoms substitute Si sites and are located in the core crystal rather than in the oxide.

This approach the control of the electrical properties of SiNC films by P-doping for electron device applications.



TEM image of one P-doped SiNCs



EDMR spectra from (a, b) P-doped SiNCs and (c) un-doped SiNCs. Surface oxide is removed with HF for (b) and (c).

Yoshifumi Nakamine[1], Naoki Inaba[1], Tetsuo Kodera[1], Ken Uchida[2], Rui N. Pereira[3], Andre R. Stegner[3], Martin S. Brandt[3], Martin Stutzmann[3], and Shunri Oda[1,2]

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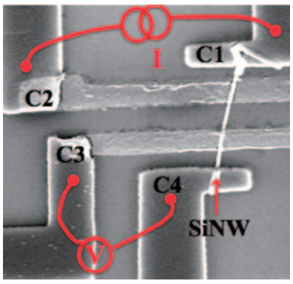
Japanese Journal of Applied Physics **50**, 025002 (2011).

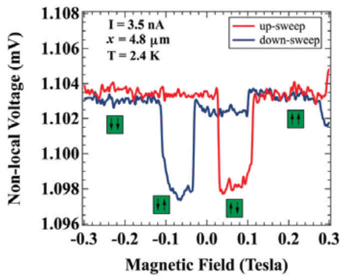
Silicon Nanowires: Efficient Conduits for Electron Spin Transport

Silicon (Si) is the workhorse of the semiconductor industry and continues to be explored for use in semiconductor spintronics due to its anticipated long spin lifetime and coherence length. Most research to-date has focused on spin valve structures utilizing Si in bulk or thin film forms. Nanometer-sized, single crystalline Si nanowires (SiNWs) are an attractive alternative, offering the prospect of studying spin-polarized transport coupled with electron confinement.

Shunri Oda and co-workers at Tokyo Tech, in collaboration with National Institute of Materials Science and RIKEN, have successfully demonstrated injection of spin-polarized electrons in SiNWs. The SiNW-based lateral spin valve devices were fabricated using two-step electron beam lithography, metal evaporation, and liftoff techniques. A nonlocal (four-terminal) measurement configuration, wherein the spin injection circuit was completely separated from the spin detection circuit, was employed. Recently, the researchers found the highest nonlocal spin signal ~130 μV (4.4 kΩ) at 2.4 K in a device with injector-detector separation distance of 6.15 μm. This spin signal is significantly higher than previous reports on bulk Si, and is evidence of efficient spin injection and transport within the SiNW. Indeed, with optimization of the spin valve device parameters, the SiNW promises to be a viable nanostructure for use in future spintronic devices.



SEM image of a silicon nanowire in contact with four electrodes used for the nonlocal spin valve measurements. C2-SiNW-C1 is the spin injection circuit, while C3-SiNW-C4 is the spin detection circuit.



Nonlocal voltage as a function of in-plane magnetic field. The voltage dips are a measure of the spin accumulation at the SiNW/contact C3 interface, when C2 and C3 have antiparallel magnetization alignment.

Jean Tarun,[1,2] Shaoyun Huang,[2] Yasuhiro Fukuma,[2] Hiroshi Idzuchi,[2,5] YoshiChika Otani,[2,5] Naoki Fukata,[4] Koji Ishibashi[2,3] and Shunri Oda[1]

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Journal of Applied Physics **109**, 07C508 (2011).

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