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The fields of Electronics and Photonics are huge and include many active sub-fields therein. We have summarized the trend of these technical fields in the last several years, which includes the time period of the interest in this report, years from 2004 to 2007. Japanese leading researchers overviewed recent conspicuous progresses of their respective sub-fields.

The following is a list of the sub-fields that the chapter editors have taken up.

D1. Electro-optic Sensing Devices and Systems
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D2. Semiconductor Lasers (Light sources for optical communication)
Mitsuru Naganuma
Teikyo University of Science & Technology

D3. Tbps optical modulators
Tetsuya Kawanishi
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D4. Photonic Signal Processing
Tazuko Tomioka
Toshiba Corp.

D5. THz Technology
Tadao Nagatsuma
Osaka University

D6. Silicon Devices
Kazukiyo Joshin
Fujitsu Laboratories Ltd.

D7. A brief view on the ultra wideband (UWB) status in Japan
Kenichi Takizawa
National Institute of Information and Communications Technology

D8. Body Area Network Devices
Kiyoshi Hamaguchi
National Institute of Information and Communications Technology

D9. Millimeter-Wave Antennas
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D1. Electro-Optic Sensing Devices and Systems

Abstract

Here, an overview on recent advance of electro-optic (EO) sensing devices and relevant systems is provided with emphases on those in R&D phases in Japan. After an introductory part, some categorizations for the EO sensing are given. This is aimed at readers' better understanding on the relevant technical trends and their recent progresses in the fields. Some eye-catching demonstrations are explained as pioneering examples for the novel EO sensing schemes. In other words, some strong emphases are cast over the devices and systems described here, in which fundamental issues of the EO sensing paradigm have been ultimately pursued, while some other recent practical developments are missing.

I. Introduction

[1] EO sensing devices and systems

Among many sensing devices and systems, those based on the electro-optic (EO) effect, Pockels effect in other words, are rather noteworthy recently [1] and, hence, we focus ourselves within this sort of technologies here. The reason why the EO sensing devices and systems are attracting considerable amounts of technological attentions could be that their fundamental features be essential to the evolution of information and communications technologies in the last decade as well as in the future.

As well known, accelerating increase in demand for ultimate speeds both in fiber-optic and wireless communications technologies have been prominent. More and more requirements will be cast henceforth on the developments of higher speed fiber optic networks, broader bandwidth wireless access networks, and their efficient and cost-effective convergence.

Advanced measurement techniques for devices, modules, and circuits of high speed and highly dense packages have been and will be demanded in this context. The scheme of EO sensing devices and systems have provided and will provide some attractive measurement features for this purpose as listed in the followings:

a. Ultra-high speed
b. Very low invasiveness
c. Sub-wavelength spatial resolutions.
d. Distant lead wire configurations

(a) An EO measurement bandwidth is not restricted by electrical circuit parameters but by the response speed of the EO effect, which is inherently high-speed. Even THz frequencies are in the range.

(b) No metal electrodes in probe heads are necessary in the EO sensing scheme and, therefore, the measurement circumstances can be metal-free. This leads to significant reduction in measurement invasiveness to devices and circuits to be analyzed. Additional reduction of invasiveness is possible if needed volume of high-index EO crystal is compressed down to those of optical beams.

(c) A dominant factor for the spatial resolution of the measurements is the sensitive volume defined within an EO crystal [2], which is usually much smaller than wavelengths of radio signals to be measured. This feature provides a measurement scheme, which is impossible without photonic methods: measurements with a sub-wavelength spatial resolution provided without serious invasiveness. This is attractive for the microscopic analyses of highly dense circuits.

(d) In many RF measurement methods, lengths of lead wires are restricted and to be short enough to avoid attenuation of detected signals and interference caused by metal wire cables: presence of long lead wire cables itself causes possible malfunctions of measurements. Optical methods, especially fiber optics, can relax this stringency and enlarge the degree of freedom in the measurements.

[2] Technical trend

As shown in Fig. 1, there are two kinds of categorized functions in EO sensing systems: EO measurements and EO imaging. The former is rather conventional while the latter is new.

Regarding the former, relevant devices are categorized into two types: optical waveguide type and optical probe type [1]. Because of the stability and sensitivity, the former with metal electrodes has been in the marketplace already although some drawbacks exist regarding the above-mentioned benefits. Hence, hereafter, we exclude commercially available EO sensing devices and we concentrate ourselves within those in the R&D phases together with EO imaging scheme.

In other words, we are going to depict here those having some eye-catching demonstrations during the time period from November 2004 to October 2007, with special emphases, in which some fundamental features of EO sensing scheme have been ultimately pursued. Those correspond to the categories "probe" and "image sensor" in Fig. 1. Also, one should note that we have had the third and fourth generation of the EO sensing configurations, which are indeed the configurations in which recent progresses have been made intensively. In more details, the following four examples are described below. (a) A fiber-edge EO sensing device with directly deposited EO material on its fiber facet, which provides an ultimately small size of probe head. (b) An EO probe with an EO crystal of an ultra-high Q optical cavity, which brings about the ever highest EO sensitivity. (c) An EO sensing system with the ultra-parallel nature of photonics, which enables the real-time imaging of RF electrical field distributions with a high definition for the first time. (d) With the real-time EO imaging system, a demonstration was performed for aqueous sample investigation by electromagnetic wave images.

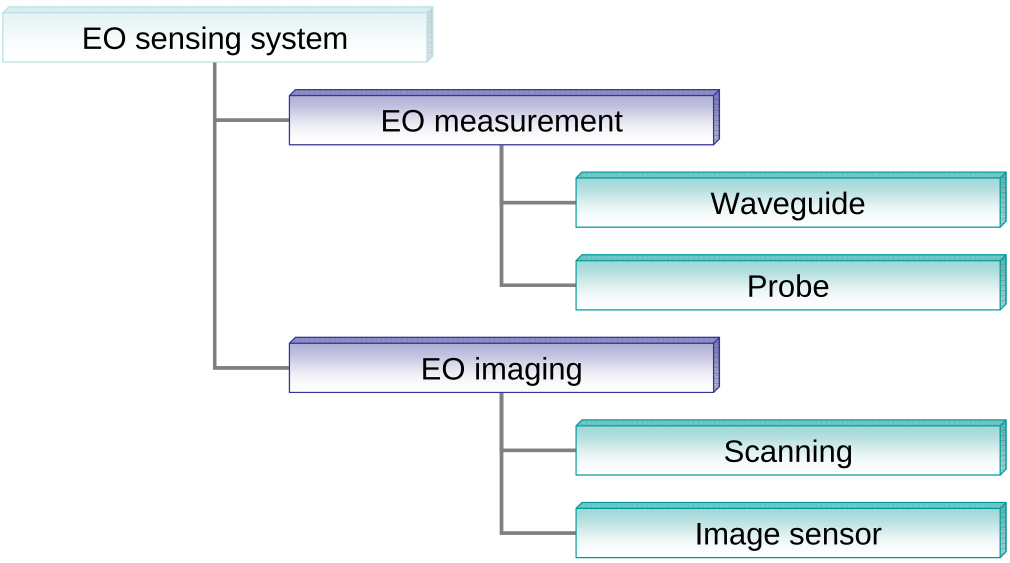


Fig. 1 Categories of EO sensing systems and relevant devices

II. EO sensing of RF signals

[1] Principle and categorization of schemes

Figure 2 shows schematically the basic elements and principle of EO measurements [3]. A probing light beam is incident from the left to an EO crystal. An applied electrical field *E* gives rise to instantaneous index change of the crystal through the EO effect. The resultant polarization modulation on the light beam is then transformed to the intensity modulation. This is brought about by a polarizer. The relationships among the polarization states of the probing light beam and the orientations of EO crystal and polarizer are optimized so that the EO sensitivity is maximized. This optimization is performed with properties of the light source and photo-detector taken into considerations.

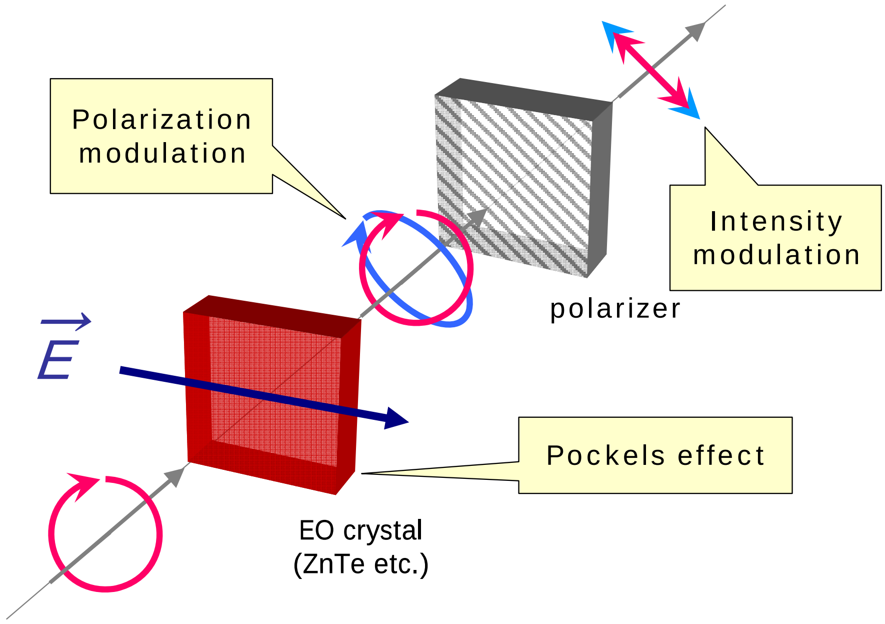


Fig. 2 Basic elements and principle of EO measurements

Shown in Fig. 3 is a categorization of the EO sensing schemes performed regarding the variety of light sources and EO signal detection techniques. The EO sampling scheme [3] is the most well known, in which very short light pulses are indispensable and a slow photo-detector can be used. The timing control of the sampling pulses is an issue. It is powerful when one measures temporal waveforms of ultra high-speed signals. The EO heterodyne is an alternative to the EO sampling scheme. A probing light beam of high frequency sinusoidal modulation, an optical LO (OLO) signal in other words, is necessary and frequency down-conversion is carried out at the EO crystal in the system shown in Fig. 2. An optical IF signal resultantly generated is detected by a slow photo-detector, which corresponds to the high frequency component of interest. Therefore, the EO heterodyne scheme is essentially suitable for a spectrum analyzing measurement and, therefore, for a measurement of wireless communications apparatus. The third category is the direct EO measurement scheme, in which a continuous wave probing light beam is used. While requirements for light sources are much relaxed, a high speed photo-detector and subsequent high speed measurement instruments are needed. Except for those outer instruments, the setup could be beneficially simple.

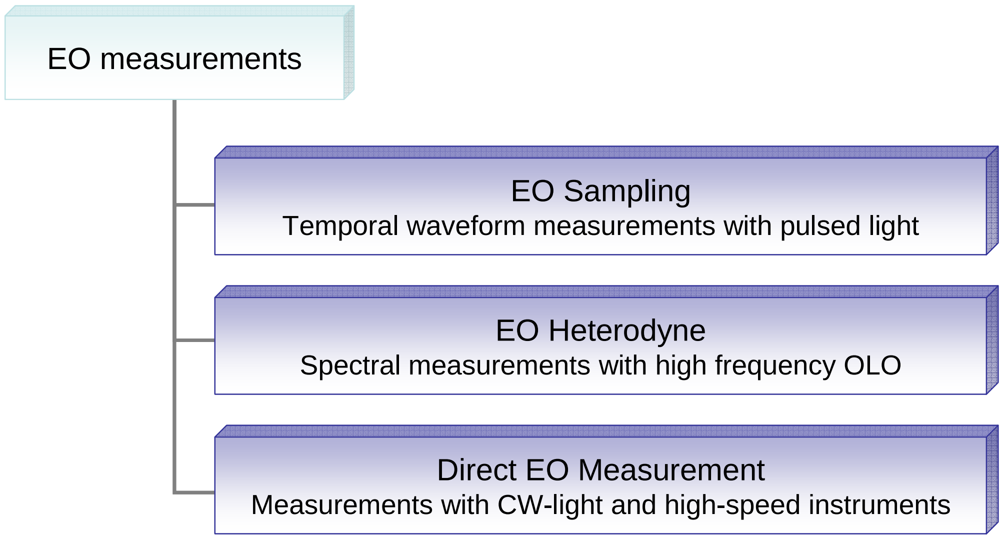


Fig. 3 Categories of EO measurements

[2] Generations of EO sensing system configurations

It might be interesting to trace the historical evolution of measurement technologies for EO sensing scheme in correspondence to the basic elements shown in Fig. 2 and relevant system configurations. Figure 4 shows four stages of generations for the EO measurement configurations.

In the first generation, a large pulse laser such as an Ar^+ laser pumped mode-locked dye laser was placed on a large optical bench and was used for EO measurements. Thus, the laser pulse source was the principal issue while other elements were rather commonly arranged.

In the second generation, some variation was brought about regarding the laser pulse source, which is down-sizing. On the basis of developments of diode laser based pulse sources and fiber-optics in late 80s and 90s, some compact, stable, and easy-to-operate light sources became available and were incorporated into the EO measurement configurations. The paradigm thus shifted from systems on optical tables to desk-top measurement instruments. The shift was based on the innovation of pulse light source.

In the third generation, configurations around EO crystals have been modified significantly. Probe heads were miniaturized and the role of optical fiber was set two-fold: an EO crystal holder and a waveguide for a probing light beam [4]. Those were brought about by the developments of fine fiber-optics and micro-optics. As results, the alignment-free EO probe head was realized and mobility of the probe head was also. In addition, the low-invasive nature was enhanced.

In the fourth generation, the trend of EO crystals has been in an opposite direction. Rather large EO plate has been utilized for the scheme of EO imaging. This is indeed what has happened in the time period of this national report's interest. One of the most significant breakthroughs regarding this aspect is the introduction of ultra-parallel nature of photonics [5-8], which will be described in more details later.

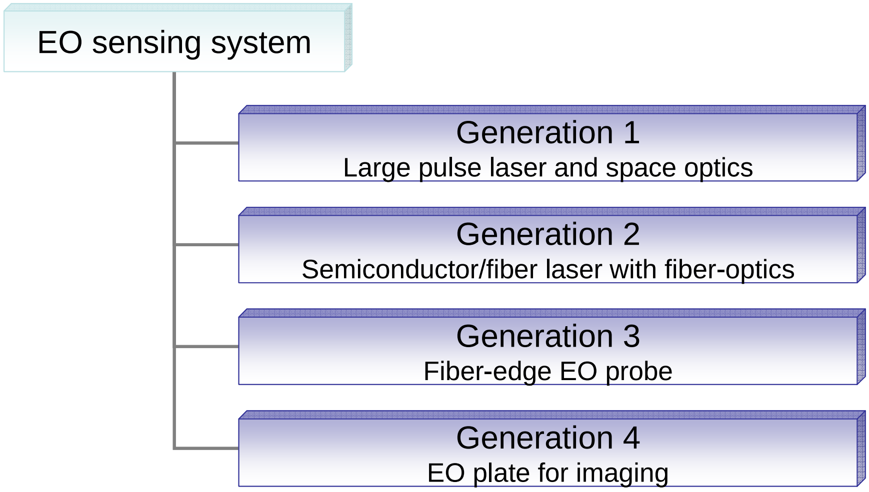


Fig. 4 Generations of EO sensing systems

III. Fiber-edge EO sensing device

One of the ultimate EO sensing devices is those fabricated on the facet of optical fibers [9-15]. This configuration gives highest spatial resolutions of the EO measurements, which are determined by the beam diameter of optical fiber and the thickness of the crystal. Minimum of the resolution volume has been thus as small as 10x10x10 μm^3.

The conventional method to fabricate those fiber-edge EO sensing devices is rather straightforward, simple and difficult. A piece of EO crystal was adhered to the optical fiber facet. In some cases, a piece of EO crystal bonded to a glass wafer was used. Unfortunately enough, the size reductions of the EO crystals thus adhered are limited because of difficulties in their handling procedures. The crystal sizes are usually larger than optical fiber diameters (125 μm) and consequently degrade much the easy-to-insert-anywhere feature of the fiber-edge scheme.

Recently, Iwanami et al. has made a breakthrough regarding this aspect of optical fiber based EO sensing devices [16-18]. They have succeeded in direct depositions of EO crystal (lead zirconium titanate: PZT) films on an optical fiber facet. A scanning electron micrograph of a device thus fabricated is shown in Fig. 5. One should note that the area of the EO crystal is almost the same as that of an optical fiber facet or even smaller. This feature is considerably attractive as follows. (a) The shape and size of the EO crystal, which has been a limiting factor of the EO probe head size, is no longer larger than the optical fiber facet diameter. Hence, the easy-to-insert-anywhere feature of the fiber-edge scheme is highly enhanced. (b) One can reduce the thickness of the crystal down to the nanometer range if desired. In combination with optical fibers of finer core diameters, the minimum sensitive volume can be reduced down by one order of magnitude or more. It may lead to creation of new EO measurement paradigm. Fig. 6 shows a schematic of the aerosol deposition method, which was utilized for the EO sensing device fabrication.

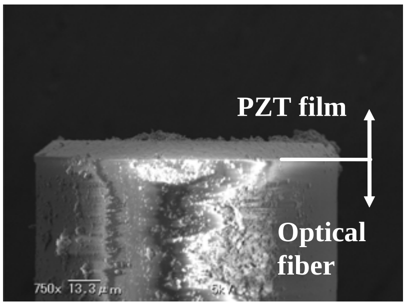


Fig. 5 Lead zirconium titanate (PZT) deposited fiber-edge EO probe

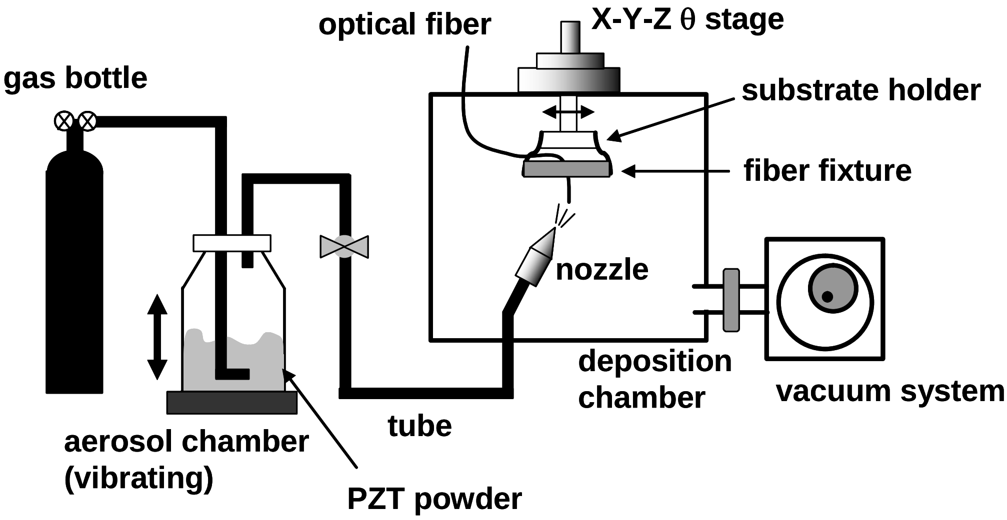


Fig. 6 PZT-deposition method for fabrication of fiber-edge EO probe

IV. LN disk resonator for EO sensing

One of the most effective methods to improve the sensitivity of an EO probe is to enlarge the interaction length between a light-wave and an electrical signal to be measured. Usages of optical cavities are fairly effective for this purpose since the interaction length is effectively enlarged by a cavity quality factor (Q factor) [9], provided that the measurement bandwidth suppression given by the corresponding photon lifetime of cavity can be managed somehow for practical measurements. Recently, as well known, high-Q optical cavities are available, mainly on the basis of optical disk resonator scheme and its whispering gallery mode (WGM). Especially, It has been reported that a cavity having a Q factor of 10^8 or more can be made of an EO crystal [19][20].

Sasagawa and Tsuchiya have performed an experiment in which such a high-Q cavity is applied to the EO sensing scheme [21-24]. The $LiNb_3$ (LN) disk resonator which they made is shown in Fig. 7 and the relevant experimental setup is indicated in Fig. 8. The axis of disk rotation symmetry is parallel to the c-axis of LN crystal. A sensing light beam is coupled to the LN disk resonator trough a rutile prism, which is shown in the upper part of Fig. 7. The radius of the disk is 3.3 mm while its rim curvature radius is 3.3 mm. The LN disk resonator, an EO sensing head in other words, was allocated on a micro stripline as shown in Fig. 8, which is a device-under-test (DUT) in the measurement. Thus, some evanescent waves of RF signals in the stripline were measured and the sensitivity was investigated.

Figures 9 show (a) EO signal power thus obtained at the RF spectrum analyzer in Fig. 8, which is plotted against the RF power launched to DUT, and (b) a temporal waveform measured by a oscilloscope for a photonically down-converted IF signal at 500 kHz. The frequency of the original RF signal is 6.72 GHz and the impedance of the stripline is 50 Ω . Note that the estimated minimum detectable RF power on the stripline is as low as -60 dBm, which corresponds to the minimum detectable voltage of 0.13 $mV/Hz^{1/2}$. Those values indicate the highest EO sensitivity ever reported. Such a high sensitivity allows one to observe the temporally sinusoidal waveform with a digital oscilloscope as shown in Fig. 9 (b), which is rather difficult in the EO sensing scheme conventionally.

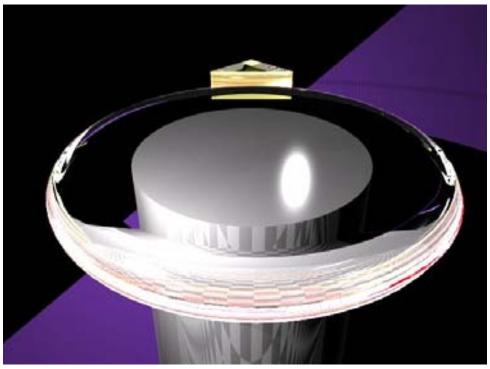


Fig. 7 A photograph of LN disk resonator together with a lutile prism in the back. The prism is for the optical coupling between WGM and a sensing light beam..

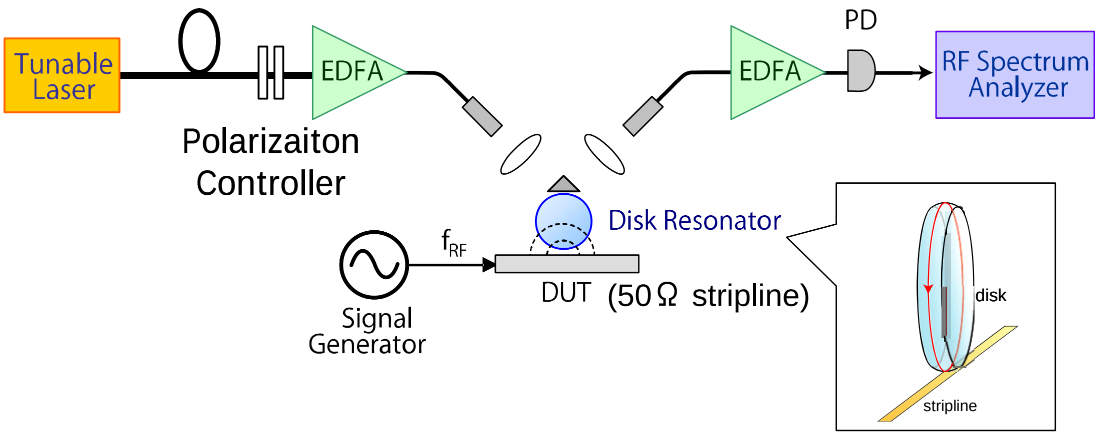
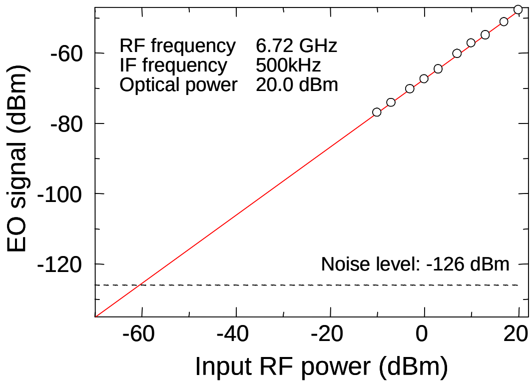
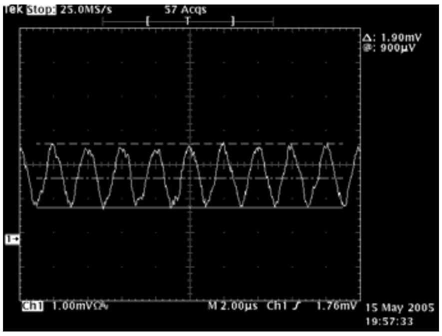


Fig. 8 Experimental setup for the disk resonator EO probe



(a)



(b)

Fig. 9 EO signal power plotted against RF power (a). Temporal waveform of the RF signal (b).

V. Live Electro-optic Imaging (LEI)

One of the most eye-catching inventions in this field is the realization of ultra-parallel RF signal measurement scheme and its application to the real-time visualization of RF electrical field distributions. This was done by Sasagawa and Tsuchiya, and the technology is called as LEI [5-8]. The degree of parallelism is 10,000, which is outstanding in comparison with the conventional single channel nature in standard RF measurements. The availability of 10,000 parallel RF measurements thus obtained has led to the real-time visualization of RF field distributions, live imaging in other words.

Shown in Fig. 10 is the latest prototype of LEI camera provided by Sasagawa, Kanno, and Tsuchiya. The area of the prototype base is as small as that of A4 letter paper size and therefore the prototype is portable. The insets of Fig. 10 are top view pictures of a patch antenna taken simultaneously by the camera, which are by a CCD image sensor (left) and a LEI view (right), respectively. One should note that intense electrical fields are observed clearly on the four corners of the patch as conventionally indicated by the electromagnetic theory.

The performance specifications of the prototype are as follows. The size of view area, which is located on the top surface, is 25 mm x 25 mm. Thus the device-on-the-top configuration is brought about, which enables the face-down measurement scheme and eventually easy-and-prompt handling of DUT for its RF field visualization. The observation bandwidth is as high as 10 GHz and the highest frame rate is 30 frames per second.

A series of images shown in Fig. 11 are taken from a LEI video stream and indicate a temporal evolution of the LEI view for the patch antenna. Here the LEI video stream was taken in the real-time mode with the phase evolution imaging scheme. This was made possible by intentional insertion of a slight discrepancy in frequencies of the DUT signal and the LO signal, which is shown in Fig. 12 in more details. Indeed, it is clearly seen that the phase of DUT electrical field proceeds as the time goes.

Figure 12 shows schematically the optical system of the LEI camera. One can see here that it includes rather new elements of EO sensing scheme: the image sensor scheme listed in Fig. 1, the EO heterodyne scheme listed in Fig. 3, and an EO plate of the fourth generation shown in Fig. 4.

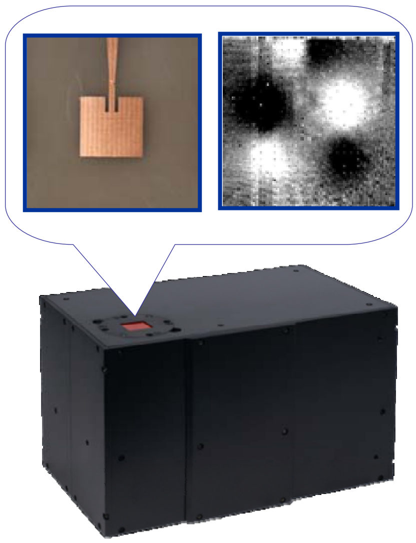


Fig. 10 LEI prototype with CCD image (left) and LEI image (right) of a patch antenna

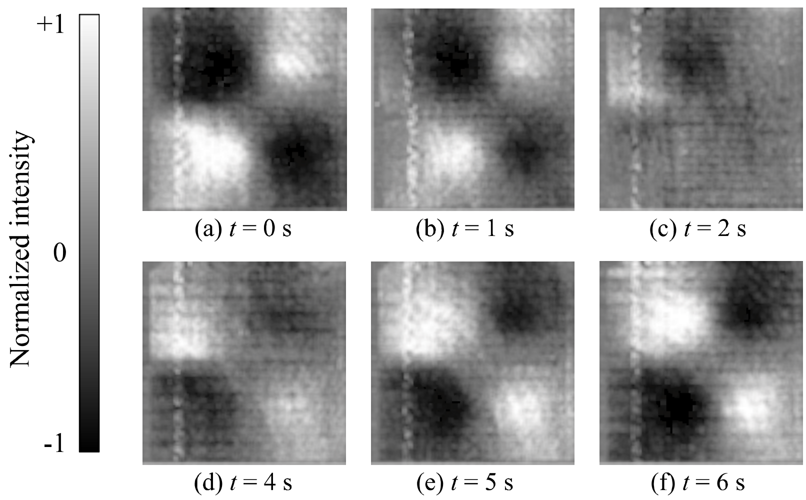


Fig. 11 A temporal evolution of LEI view in the phase evolution real-time imaging mode.

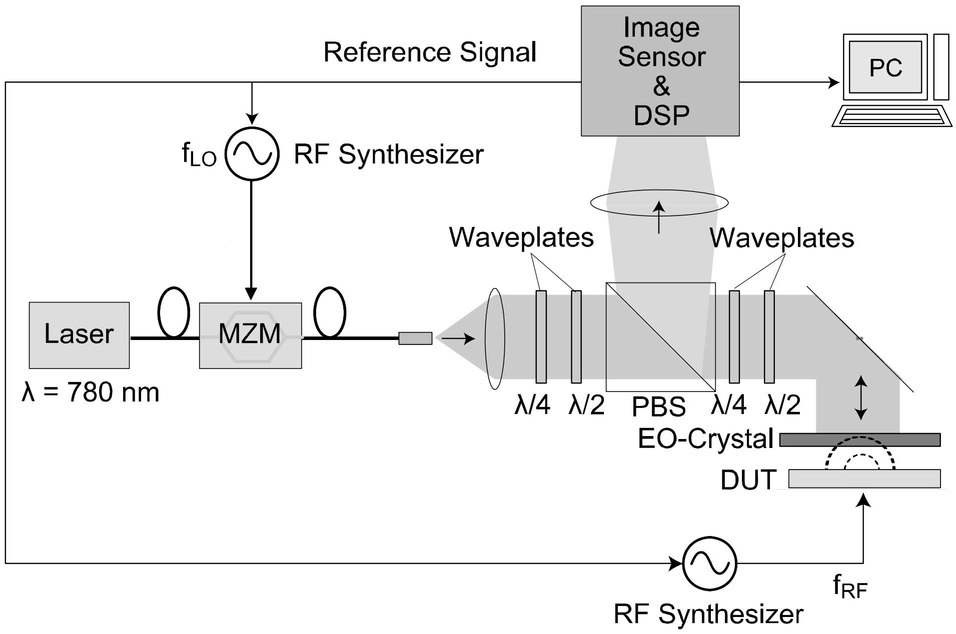


Fig. 12 Optical system of LEI camera

VI. Aqueous EO imaging

Kanno, Sasagawa, and Tsuchiya have shown an interesting demonstration of LEI camera: its application to aqueous EO imaging [25]. The imaging configuration is shown in Fig. 13, where an aqueous sample is placed in front of the sensing area of a LEI camera. This configuration enables one to perform instantaneous characterization of aqueous specimens. Examples are shown in Figs. 14, in which high resolution images of transmitted microwave intensity and phase distributions for a water capsule sample was successfully obtained. Note that those were obtained in less than one second. Dramatic changes in EO intensity components at the edges of the sample were visible, which is possibly due to diffraction of the incident microwave. The phase components clearly show the shape of the sample on the basis of absorption and phase delay. Higher contrast in images was obtained by the combination of the EO intensity and phase components: phasor imaging.

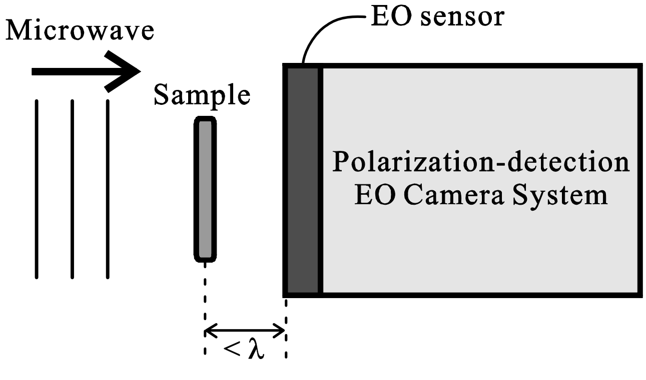


Fig. 13 Concept of aqueous EO imaging with LEI camera

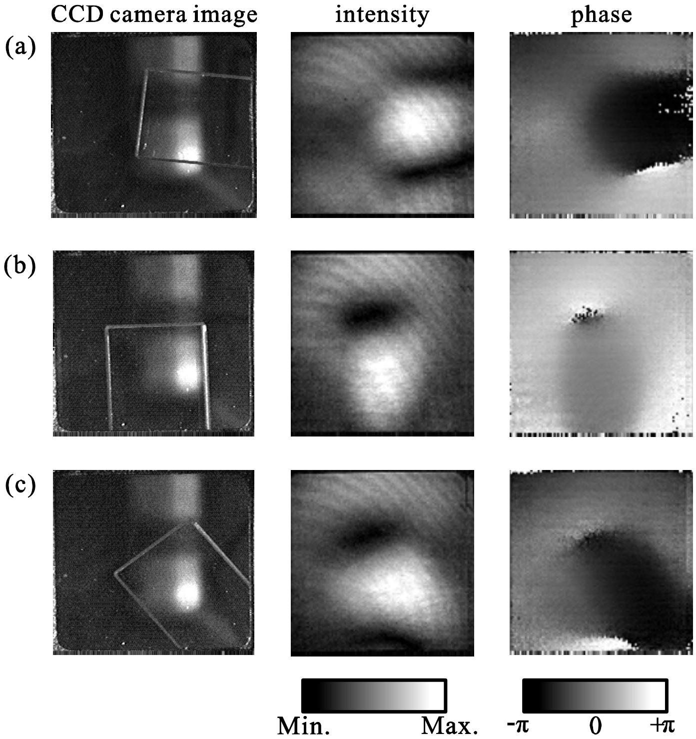


Fig. 14 CCD images and LEI images for a water capsule

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D2. Semiconductor Lasers (Light sources for optical communication)

Semiconductor laser is a key device both in the core and the periphery networks carrying explosively increasing Internet traffics. The transmission capacity of the each channel of WDM system has been raised up to meet the increased traffics. This section pays attention to development of the light sources for the up-to-date optical communication networks, categorizing 4 application fields depending on transmission distances.

1. The ultra-short haul (<1km) transmission

The systems using the combination of the Fabry-Perot laser and the multimode fiber (MMF) are developed, which are capable of 10Gb/s bit rate with 300m distance (IEEE802.11aq)[1]. Since reduction of the cost of light source assembly is the most important issue the vertical-cavity surface-emitting laser (VCSEL) is a promising light source[2]. Characteristics of driving current vs. light output of VCSEL chip can be measured on wafer because its cavity is vertical to the wafer surface, which pushes down the overall cost. Transmission distance and bit rate of VCSEL are typically less than 600m and 1Gb/s, respectively.

2. The short to medium haul (1-25 km) transmission

Since the cost issue is still important even for the medium haul system the distributed feedback (DFB) laser is used under direct current modulation scheme. However the lasing frequency fluctuation during dynamic modulation (chirping) is unavoidable, which is caused by injection current change followed by carrier density and refractive index change in active region. This results in transmitted waveform distortion because the wavelength dispersion exists even in a single mode fiber (SMF). One of the solutions of this problem is to use DFB laser emitting 1.3-micrns wavelength, in which the wavelength dispersion of SMF is nearly zero.

The light source free from temperature control reduces substantially the cost of the system. Carrier overflow from the quantum well consisting of the active layer degrades temperature characteristics. Aluminum based mixed crystal is used instead of Phosphorus based one to achieve large electron barrier height of quantum well to prevent the carrier overflow. The dynamic single mode operation at temperature rage of –40 to 85 degrees Celsius is achieved by Al based laser and applied 10Gb/s system.

3. The medium to long haul (25-80km) transmission

The narrower line-width of optical source is demanded as longer transmission length. To address this request the external modulator is used with cw DFB laser. For the medium haul system the semiconductor electro-absorption (EA) modulator is used as the external modulator and monolithically integrated with DFB laser. EA modulator based on the Quantum Confined Stark Effect (QCSE) has electric field dependent sharp absorption edge and is capable of more than 10dB extinction ratio even with 200 microns device length, which realizes small optical sources. Moreover, layer structure of EA modulator is similar to that of the laser, which makes it easy to integrate monolithically each other and to reduce the fabrication cost. On the other hand there still remains instantaneous frequency chirp caused by a refractive index change upon applied electric field, which limits transmission length. Recently EA modulator with special core structure is developed and successfully applied to the system with the fiber dispersion of 1600ps/nm (corresponding to 80km-SMF). The integrated light source with the temperature control free laser is developed and realized the operation temperature of 90 degrees Celsius[3].

4. The long to ultra-long haul (>80km) transmission

The limitation coming from the chirping characteristic is much more strict for this transmission length with more than 10Gb/s rates. The Mach-Zehnder (MZ) modulator is used instead of the EA modulator. A MZ modulator consists of dielectric material LiNbO3 is generally used for the practical systems because of its chirp-less characteristics. However, there remain some difficulties such as large size, large driving voltage, and drifting of driving voltage balance. To address these problems the semiconductor MZ modulator is developed with a footprint size comparable to that of a semiconductor laser and capable of 40Gb/s modulation[4].

As an advanced structure the DQPSK modulator composes of two MZ modulators is developed and applied to the 80Gb/s modulation experiment[5]. The semiconductor integrated light sources including modulators, lasers and other photonic devices are promising for the future advanced communication networks[6].

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D3. Tbps optical modulators

Optical modulators using electro-optic (EO) or electro-absorption (EA) effect play important roles in high-speed optical communication systems. Recently, over 20Tbps optical fiber transmission was demonstrated by using integrated lithium niobate (LN) optical modulators for ultra high-speed differential phase shift keying (DQPSK) signal generation [1, 2]. Intensity modulation (IM) and on–off keying (OOK) are commonly used in commercial systems. However, recently, various types of modulation techniques, for example, differential phase-shift-keying (DPSK) [3], DQPSK [4–7], amplitude- and phase-shift-keying (APSK) [8, 9], frequency-shift-keying (FSK) [10–14], single-sideband (SSB) modulation techniques [15]–[17], etc., were investigated to obtain enhanced spectral efficiency or receiver sensitivity in optical transmission systems. Orthogonal modulation techniques with OOK and FSK or OOK and DPSK are also attractive for optical labeling in optical systems [12, 18, 19]. Integrated LN modulators, such as dual-parallel Mach-Zehnder modulators (DPMZMs), quad-parallel Mach-Zehnder modulators (QPMZMs), etc., can generate advanced modulation format signals, such as high speed 16QAM (see figure 1), whose constellations are complicated [20, 21]. Precise lightwave control was also investigated to achieve pure optical clock signal generation and high-performance digital modulation [22, 23].

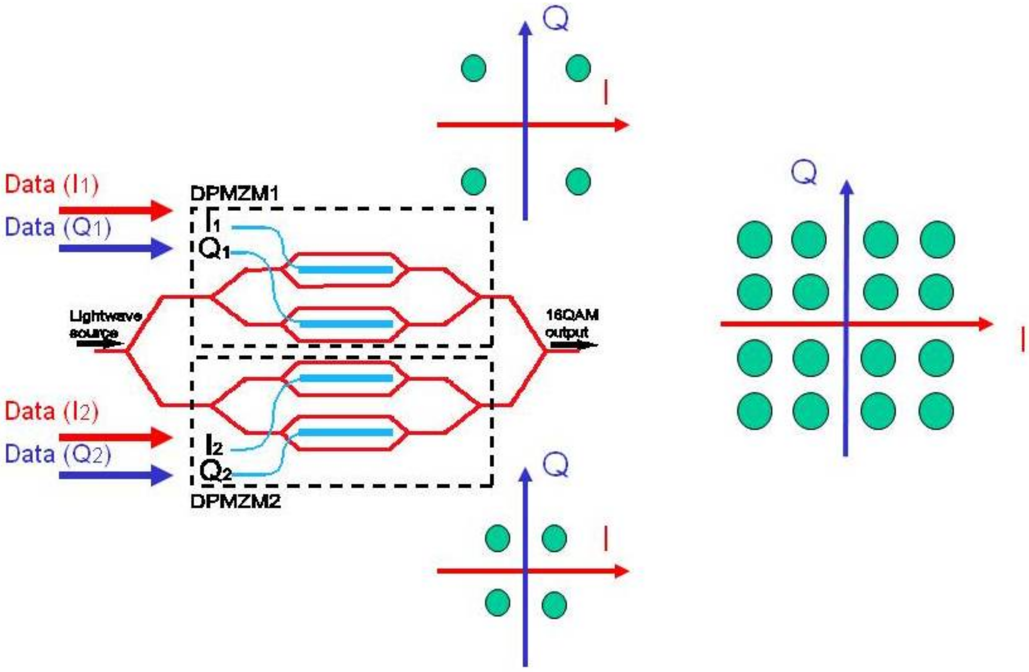

Fig.1 Optical 16-QAM signal generation using a QPMZM [20]

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D4. Photonic Signal Processing

The final target of photonic signal processing is to realize all optical switching and all optical logical processing, and very wide range of topics are included. Recently, more sophisticated signal processing is enabled due to the appearance of high power optical sources and high-nonlinearity media. The kinds of nonlinearity utilized are increasing and SHG (sum frequency generation), DHG (difference frequency generation) and two photon absorption are also utilized in addition to well-known XPM (cross phase modulation), FWM (four wave mixing), Raman scattering and Brillouin scattering.

As for optical fiber signal processing, concerns on optical pulse compression with CPF (comb-like profiled fiber) and supercontinuum light generation with very wideband, stable and excellent frequency characteristics are increasing. On wavelength conversion, many new schemes with superior performance are proposed, using HNLF (high nonlinearity fiber) and SOA (semiconductor optical amplifier) that both of them are used in variation of configuration of MZI (Mach-Zehnder interferometer) and ring interferometer.

Optical functional devices are being advanced rapidly. For example, optical label recognition of OCDMA (optical code division multiplexing) signal using SSFBG (superstructured fiber Bragg grating) and optical logic device (bistable device, optical memory, optical switch, optical NOR gate, etc.) are included. The papers on all optical regeneration (2R and 3R) using these functional devices are often found.

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D5. THz Technology

Terahertz (THz) electromagnetic waves, which cover an unexplored portion of spectrum between infrared and microwaves at frequencies from 100 GHz to 10 THz, have been expected to offer innovations in sensing, imaging, spectroscopy, and communications. In Japan, several organizations, which contribute to accelerate the THz science and technology in both academic societies and industries, have been established; Terahertz Technology Forum, Technical Group on Terahertz Application Systems in the Institute of Electronics, Information and Communication Engineers (IEICE), Terahertz Technology Professional Group in the Japan Society of Applied Physics (JSAP), Technical Group on Terahertz Electromagnetic-wave Industrial Applications in Japan Science and Technology Agency (JST), Division of Terahertz Spectroscopy in Spectroscopical Society of Japan, etc.

Generation of high power THz signals is the most important for the continuing advance of THz technology. Photonic generation of THz signals based on photomixing in nonlinear optical (NLO) crystals and photodiodes has been studied in the continuous-wave (CW) as well as pulsed operations. Using an organic NLO crystal, DAST (4-dimethylamino-N-methyl-4 stilbazolium tosylate), Suizu et al. succeeded in the generation of high power THz waves up to mid-IR range. Ito et al. reported CW generation of 10 microwatts power at 1 THz using an antenna-integrated uni-traveling-carrier photodiode (UTC-PD), which is the highest ever obtained with photodiodes. Purely electronic devices have been examined with a resonant tunneling diode (RTD) by Asada et al., and a Bloch oscillation by Hirakawa et al. A novel THz emitter based on plasma-waves has been developed by Otsuji et al. A terahertz quantum cascade laser (QCL) technology led by Hosako et al. is an alternative promising approach, though a low-temperature operation is required. As for THz-signal detection technologies, Komiyama et al.

developed a highly-sensitive THz detector, or a single photon counter based on quantum dots.

In recent years, there have been increasing research and development on real-world applications of the THz technology. They include measurement and sensing systems, such as real-time THz spectrometer (Guo et al.), real-time 2D imaging (Hattori et al.), detection of crystalline defects (Nishizawa et al.), detection of illicit drugs in mail (Dobroiu et al.), detection of inflammable liquids (Ikeda et al.), gas sensing (Song et al.), detection of protein (Yoshida et al.), diagnostics of cancer tissues (Nakajima et al.), THz spectroscopy in water and biological solution (Nagai et al.), compact sensor chips for THz spectrometer (Kitagawa et al.), LSI testing (Yamashita et al), measurement of paint film thickness (Yasuda et al.), etc.

There is an urgent demand for higher data rate in wireless access systems in order to keep up with the remarkable speed-up of fiber-optic networks. 10-Gbit/s data rate is now required for the wireless transmission of 10-Gigabit Ethernet (10GbE) signals, and multiplexed transmission of uncompressed high-definition television (HDTV) signals. NTT has demonstrated the highest data rate of 10 Gbit/s using 120-GHz and 240-GHz carrier frequencies. Use of higher frequencies of over 300 GHz is one of the trends from now on as the IEEE 802.15 Terahertz Interest Group was launched in late 2007.

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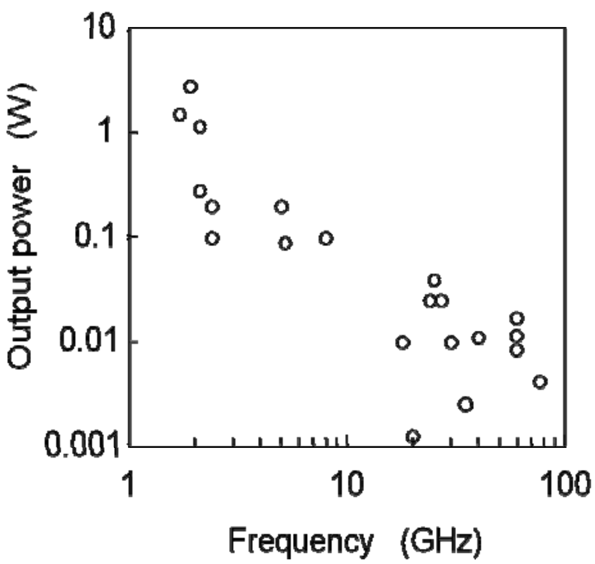
D6. Silicon Devices

Device scaling of Silicon CMOS technology has enabled not only higher speed logic circuits but also higher frequency analog/microwave circuits. As shown in Fig. 1, high frequency performance of typical NMOS transistors in 65 nm technology node reaches their cutoff frequency f_T and maximum oscillation frequency f_{max} of over 200 GHz. The device scaling supported by wide variety techniques, such as high-k dielectric gate insulator, low-k interconnect insulator and thick Cu interconnect metal layer, enables also high Q passive elements. In addition, Si CMOS technology, as well known, has specific features of lower power consumption suitable to battery-driven mobile devices, higher level integration of RF frontend and baseband circuits, and lower fabrication cost in mass production, compared to the III-V compound semiconductor (GaAs, InP) technology.

These high performance Si CMOS analog/microwave circuits has started to prevail as RF frontend ICs in several GHz frequency range applications, such as wireless local network (WLAN; IEEE 802.11a/b/g/n), 2G/3G cellar networks, worldwide interoperability for microwave access (WiMAX; IEEE 802.16e), ultra-wideband impulse radio system (UWB-IR), and electronic toll collection system (ETC). Many types of RF CMOS ICs [1-8] have been developed such as low-noise amplifiers, voltage controlled oscillators (VCO), up/down conversion mixers, power amplifiers, and multi-band multi-mode transceiver ICs.

Recently millimeter wave applications have much attention such as wireless personal area network (IEEE 802.15.3c) and wireless high-definition signal transmission system (Wireless HD) in 60 GHz frequency range, and the vehicle radars including the short range radars and long range radars for collision avoidance systems. The millimeter wave is ideal for short-range high-capacity data transmission systems, as well as for measuring with high resolution and accuracy the distance between two points. Conventionally, the compound semiconductors have been used in the RF front-end circuits of these systems in order to realize high gain, low noise and high output power of high-frequency signals.

On the other hand, remarkable progress in Si CMOS technology, besides SiGe:C BiCMOS [12-16], has been made in regard to operational speeds and it is now possible to apply millimeter wave circuits that were previously achieved through compound semiconductors. Practical application, however, of Si CMOS technology in millimeter-wave circuitry has been problematic due to the occurrence of significant signal loss due to the conductive Si substrate and lack of an accurate device model up to millimeter wave frequency range. Among millimeter-wave circuitry, power amplifiers and VCO are key circuit blocks. As shown in Fig. 2, power amplifier is one of the toughest targets due to the low-breakdown voltage of nm-scaled Si CMOS transistors. In VCO its frequency tuning range is significantly narrowed by the reduced ratio between the tuning varactor diode to parasitic capacitance in the scaled devices. There were several reports relating to technological challenges to overcome these problems [9-11]. Furthermore, by combining baseband circuit with RF front-end circuit on one chip, millimeter-wave band transceiver chips - which had been expensive to produce in the past - can now be made considerably smaller. As a result, widespread applications of millimeter wave Si CMOS technology in both automotive radar systems and wireless communications systems are anticipated in the future.



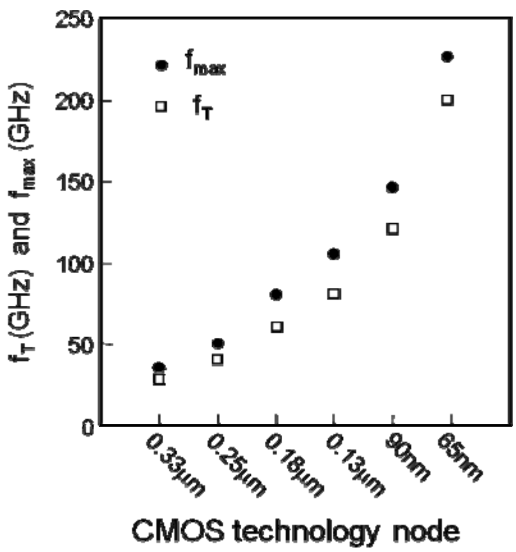


Fig. 1 Trends of f_T and f_{max}

Fig. 2 Output power of CMOS power amplifiers

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D7. A brief view on the ultra wideband (UWB) status in Japan

This report summarizes current status of ultra wideband technologies in Japan, from the viewpoints of standardizations, regulations, and research and development (R&D) activities.

1. Standardizations

The Association of Radio Industries and Businesses (ARIB), Japan, published the ARIB STD-T91 ver. 1.0 [1], a standard for ultra wideband (UWB) radio systems, in December 2006. This standard mainly provides system requirements for UWB radio systems in order to be in operation in Japan. No specifications are given on the physical (PHY) and media access control (MAC) layers for UWB radio systems.

Note: As standardization activities on UWB radio systems, IEEE P802 standard committee had engaged on 15.3a, for high data-rate UWB radio systems, and 15.4a, for low data-rate systems. Two technologies competed in the 15.3a. One is a direct sequence UWB (DS-UWB), which is a single-carrier UWB system using a spread spectrum technology. Another one is a multiband OFDM (MB-OFDM), which is a multi-carrier UWB system with 128 sub-carriers. The 15.3a was finally broken up in January 2006 because none of the two technologies could win out. However, the MB-OFDM was approved as ECMA-368 and 369 in December 2005. Later, it was also published as ISO/IEC 26907 and 26908 in May 2007. The 15.4a, is an impulse-based UWB radio system for low-rate wireless personal area networks. It was published as an official standard of IEEE P802 in March 2007.

2) Regulations

Japanese regulations on the UWB radio systems were issued in August 2007. The permission PSD is -41.3 dBm/MHz in EIRP over the frequency ranges of 3.4-4.8 GHz (low-band) and 7.25-10.25 GHz (high-band). This is equal to the US regulation prescribed by FCC. However, UWB radio systems operating in the low-band are required to be equiped with an interference mitigation technique against other existing radio systems; while as a transition, interference mitigation techniques are not required for 4.2-4.8GHz until the end of 2008. In the Japanese regulations, a UWB radio system is required to has a data rate beyond 50 Mbps, and, a minimum bandwidth beyond 450 MHz at -10 dB from the peak signal level. The Japanese regulations on UWB will be revised after three years since publication.

Note: In the US, FCC deregulated the use of UWB radio systems in February 2002. The permission PSD is -41.3 dBm/MHz in EIRP over frequency range of 3.1-10.6 GHz. In the Europe, EC issued to open the use of UWB radio systems in February 2007. The EU regulation permits the PSD radiation of -41.3dBm/MHz over the frequency bands of 3.4 - 4.8 GHz and 6.0 - 8.5 GHz. However, UWB radio systems operating in the frequency band from 3.4 to 4.8 GHz are required to be equipped with an interference mitigation technique, such as low duty cycling (LDC). The frequency range 4.2-4.8 GHz is available without any interference mitigation techniques until the end of 2010.

3. Research and development (R&D) activities

The R&D activities in Japan mainly follow the progress of its standardizations and regulations.

On UWB radio systems for wireless communications, the main focus goes to the MB-OFDM systems since MB-OFDM has been promised as PHY and MAC technologies in Wireless USB and Bluetooth 3.0. Current R&D activities on the MB-OFDM systems include CMOS implementation for the high-band [2] and development of low-power consumption techniques [3, 4]. As new application areas, UWB technologies have been applied into automotive radars [5] and medical and healthcare field [6, 7].

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D8. Body Area Network Devices

Wireless body area network, BAN or WBAN, consists of a set of small intercommunicating wireless device having compact sensors, either wearable or implanted into the human body, which can monitor vital information, body movement, etc. These devices transmit data from the body to a base station, from where the data can be forwarded to a hospital, clinic, home, etc., in real time. Currently BAN systems are actively being discussed at IEEE802.15.6 BAN standardization group [1]. Besides this standardization activity, research and development on BAN are widely done for realizing medical, health-care and entertainment applications having the frequency range of 400 MHz (medical implanted communication system, MICS band) to 10.4 GHz (UWB band) [2]. Radio propagation analysis and modeling around a body is continuously investigated by using FDTD method or real propagation measurements [4, 5]. One of the research topics needed to be addressed is that the BAN devices and its sensors used in BAN have to be low on complexity, small in form factor, light in weight, power efficient, easy to use and reconfigurable - especially for realizing a small and high-efficient antenna in Figure 1 [6]. Considerable effort would be required to make BAN transmission secure and accurate. It would have to be made sure that the patient’s data is only derived from each patient’s dedicated BAN system and is not mixed up with other patient’s data. Furthermore, the data generated from BAN should have secure and limited access. To realize this, an easily inconvertible and undecipherable device-chip structure is also investigated [3].

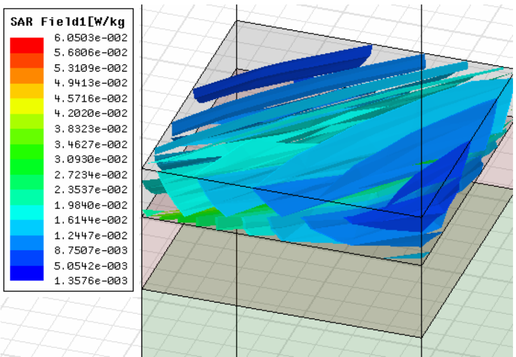

Figure 1 The implant's antenna layout and its SAR distribution for designed implanted antenna at frequency of 403 MHz (Ref. [6]).

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D9. Millimeter-Wave Antennas

The research and development on millimeter-wave applications are getting hot again in recent years, particularly in the field of millimeter-wave wireless communication systems for high speed data transmission, such as millimeter-wave wireless personal network (WPAN). Millimeter-wave antenna is an indispensable device for such systems. Resent research activities on millimeter-wave antennas in Japan can be mainly categorized as below.

High gain and efficiency antenna array using waveguide-fed slot antenna structures. Compact and high gain/efficiency array antennas have been developed for millimeter-wave wireless communications and radars for vehicles at the operating frequencies from quasi-millimeter-wave to 60 GHz and 76-77 GHz bands.

Wideband and relatively high-gain planar antenna have been developed for quasi-millimeter-wave ultra-wideband system and for millimeter-wave WPAN. The developed antennas are of a planar/multilayered structure antenna and a unique feeding/radiating structure which realize a very compact, wide operating bandwidth and relatively high-gain (~10 dBi) antenna. A configuration and primary performance of the developed antennas for 60GHz millimeter-wave WPAN are shown below.

NRD (Non-Radiative Dielectric) waveguide antenna for millimeter-wave applications. NRD antenna can have a low transmission loss and hence high radiation efficiency at 60 GHz 76-77 GHz bands. Works on integration of the NRD antenna with the direct oscillator, mixer and other millimeter-wave circuits, performing a simple millimeter-wave RF module, has been also carried out.

Beamforming/beam-steering array antenna for millimeter-wave wireless communications and radars. The research and development are focused on 60 GHz and 76-77 GHz bands, using switchable sector antenna or phased antenna array to realize the beamforming/beam-steering performance required from the systems.

New antenna at millimeter-wave frequencies. New material or new mechanism, particularly the use of metamatrial, has been studied to realize some antenna performances such as wide beam steering.

Active antenna Integrated with recent Si or SiGe CMOS devices. With the increasing operating frequency of the recent CMOS devices, researches on the integration of such semiconductor devices, including active circuits such as amplifier are paid attention for developing future compact, efficient and easy-controlling antenna modules for the millimeter-wave communication systems and radars.

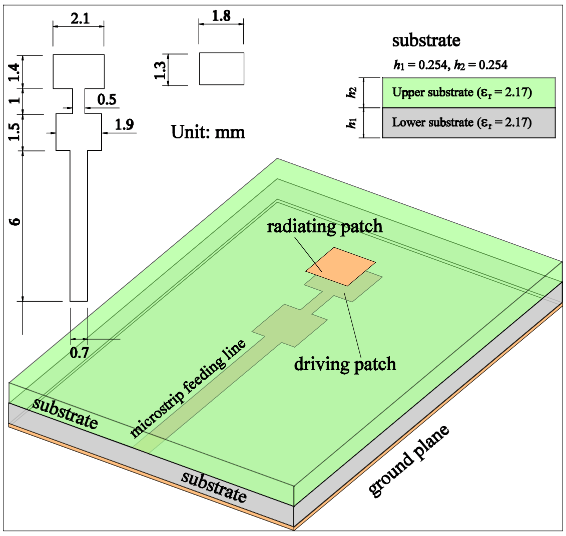

Fig. 1 Stacked patch antenna with two driving patches

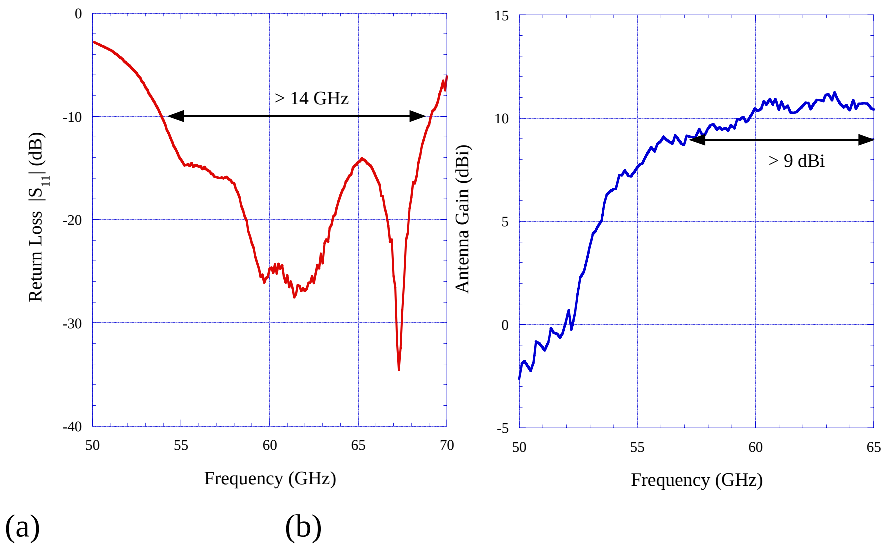

Fig. 2 Measured antenna performance: (a) Return loss and (b) Gain

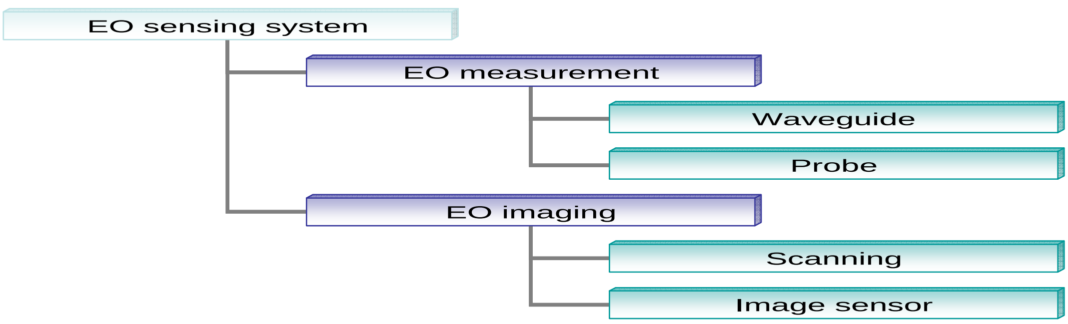

Fig. 3 Measured radiation patterns in H-plane of the developed antenna

(at 58 GHz, 60 GHz, 63 GHz, and 65 GHz, respectively)

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