COMMISSION D: ELECTRONICS AND PHOTONICS

Edited by Masayuki Izutsu and Masahiro Tsuchiya

Since the fields of Electronics and Photonics include too many technological areas for us to cover every detail of their research subjects, we focus ourselves into the following representatives. Indeed, these are the subjects studied by Japanese research groups actively in the last three years, and you may be able to overview related progresses. The following reports are written by some Japanese world-leading researchers in respective research areas.

D1.Vertical Cavity Surface Emitting Lasers

Extensive studies and realization trials have been made on high performance vertical cavity surface emitting laser (VCSEL), which was invented by the author in 1977 at Tokyo Institute of Technology. It is a semiconductor laser which can be monolithically fabricated and considered as a promising candidate for Gigabit Ethernet, high speed LANs, computer links, optical interconnects, and so on. What have been achieved by the author's group regarding the technical progress of devices range from infrared to ultraviolet wavelengths. The expansion of operating spectra was made by developing advanced materials and fabrication technologies. For instance, a GaInNAs VCSEL device was demonstrated by the author's group, which can be formed on a GaAs substrate and can emit 1300nm band laser light. It has contributed to the wavelength coverage extension of VCSEL to longer wavelength regions. Also, a polarization controlled VCSEL was realized by using (311)B substrates. This is another development made by the author's group. It was found that this device is almost insensitive to temperature variation, which is highly advantageous for network applications of diode lasers. In conjunction with those VCSEL related technical progresses, a new technology for optical communication components has been proposed by the author's group, which is based on a planar microlens array. The device was also invented by the author and

has been shown to be a promising candidate for effective packaging technology.
Related references are listed in Reference D1.

(Kenichi Iga)

D2.Optical Devices for Optical Fiber Networks

NTT Network Innovation Laboratories is one of the major Japanese research centers for optical device studies for their uses in optical fiber networks. It is affiliated with the NTT Science and Core Technology Laboratory Group, one of NTT's three laboratory groups. The mission of NTT Network Innovation Laboratories, with a five-year and a ten-year outlook, focuses on the followings:

1. Creating innovative services as well as the network concepts that will support these services.
2. Providing the new network core technologies required to win out in business competition.
3. Being a leading force in the field of innovative, core technologies.

Their details are available in the references listed in Reference D2.

(Masao Kawachi)

D3. Femtosecond Technology

In 1995, a technological consortium named FemtoSecond Technology Association (FESTA) was established in the Tsukuba area and also in the related company laboratories, where world-leading research and development activities for ultrafast all-optical devices have been performed intensively for the application to future ultrahigh throughput optical telecommunication systems. In addition, fiber-optic transmission of femtosecond laser pulses, photonic microstructures, and X-ray femtosecond techniques have been investigated in the FESTA Laboratories. The FESTA Laboratories have been operated under a governmental MITI (Ministry of International Trades and Industries) project on Femtosecond Technology, where the author's group has focused ourselves into the all-optical device researches. There, world-leading development attempts have been made for advanced all-optical switching devices, and several interesting results have been obtained up to date. They include (a) implementation of femtosecond all-optical switches using intersubband transitions in Sb-based and GaN-based QWs, (b) a 1 Tb/s all-optical demultiplexing demonstration with Sb-based prototype devices utilized, (c) picosecond-response optical amplifiers with quantum dot laser amplifier structures, which also can act as wavelength converters based on the four-wave mixing phenomenon, and (d) sub 100 fs all optical switches with organic thin film (squarylium dye) together with the demonstration of serial to parallel signal conversion to 1 Tb/s bit rate signals.

In 2001, the author moved to the Kobe University and started related works on III-V semiconductor materials and their optoelectronic device applications. In our laboratory at Kobe, we focus on, for example, investigation on formation mechanism of quantum dots in molecular beam epitaxy (MBE) growth and limit of response speed in quantum dot devices.
Related references are listed in Reference D3.

(Osamu Wada)

D4.Ultrafast Phenomena

Development of ultrashort pulse lasers

In the last 30 years, the generation of extremely short optical pulses has always been recognized as one of the most vital frontiers of science. Generation of shortest 4.7 - fs visible pulses by noncollinear optical parametric amplifier (NOPA) was demonstrated by the author's group: World shortest pulses in the visible wavelength range was obtained by two sets of carefully designed chirped mirrors and a prism pair. Sub-5-fs real-time spectroscopy systems have been constructed on the basis of this pulse source.

i) Solitons in polyacetlenes:
Time dependent frequencies of carbon-carbon stretching modes were for the first time measured by using the sub-5-fs pulses. This phenomenon is explained by the formation of breather, the bound state of the charged soliton pair, which had been theoretically predicted but has not been found.

ii) Novel vibrational dynamic behaviers in molecules:
Excitation-induced modulation of vibrational frequency and amplitude in dye molecules was studied by using the sub-5-fs pulses. The frequency and amplitude modulations of the ring-breathing mode of cresyl violet doped in poly (vinyl alcohol) film were clearly observed, indicating that the mode is coupled to another vibrational mode. The mode coupling represents the Duschinsky effect.

iii) Dye molecules:
Dynamics of C--N stretching mode and N=N stretching mode of azobenzene dimethyl sulfoxide solution was investigated by using the sub-5-fs pulses. The vibrational spectra during the photo-isomerization reaction was observed successfully for the first time.

iv) Dynamic intensity borrowing in J-aggregates:
Sub-5-fs spectroscopy of phorphyrin J-aggregates has lead to a new discovery, which reveals a coherent molecular vibration coupled to the Frenkel exciton. The bleaching and induced absorption signals show synchronous oscillations with the frequency of 244-cm^{-1}. The coherent oscillation is explained by a modulated transition dipole moment, which is due to dynamic intensity borrowing from an intense B-transition to a weak Q-transition through the ruffling mode with the 244~cm^{-1} frequency.

v) Quasi-one-dimensional halogen-bridged mixed-valence metal complex:
Ultrafast optical response has been extensively studied in $Pt(en)_2\ Pt(en)_{-2}\ I_2\ ClO_4\ 4$ with the sub-5-fs time-resolution. The followings are new findings. Wave packet motions both in ground and self-trapped exciton (STE) states are observed as oscillatory modulations in the time-resolved reflectivity. The wave packet motion on the STE potential surface begins after about 50-fs with respect to the

photoexcitaion. This delay is attributed to the lattice relaxation from the free exciton state to the STE state.

Development of new measurement system

i)Multiplex method for nonlinear susceptibility spectrum measurement:
Continuous spectrum of nonlinear susceptibility can be measured by a single shot in this system. Convolution term and chirp effect were calculated and quantified.

ii)Mid-infrared time-resolved spectroscopy apparatus:
Ultrashort pulse laser in mid IR was constructed by optical parametric amplifier. The spectrum region was 5μm - 10μm. Dynamics of Carbon-Carbon stretching mode in excited state of polydiacetylenes was investigated by using the system.

iii)Scanning near-field optical microscope(SNOM):
In order to observe an optical nonlinearity property of a single J-aggregate, a SNOM has been constructed. Both fluorescent and absorption spectra are successfully observed with a special resolution higher than 100 nm at room temperature and liquid helium temperature.

Quantum optics and teleportation

i)Frequency-resolved optical gating (FROG):
Second-harmonic-generation FROG (SHG FROG) and cross-correlation FROG (XFROG) have been used as a characterization method of pulses propagating through an optical medium. Time variations of intensity and phase of ultrashort pulses transmitting through a Nd^{+3} -doped glass plate were measured by using these techniques.

ii)Quantum teleportation and quantum information:
The goal of our research is to achieve more than 0.58 fidelity which is the current limit of accuracy in quantum teleportation. Detection system of quantum noise and optical parametric oscillator were constructed.
Related references are listed in Reference D4.

(Takayoshi Kobayashi)

D5.THz Technology

The THz-wave (very far-infrared) region has attracted significant interest in recent years. The generation of THz radiation by optical rectification or photo-conductive switching has been extensively studied by using femto-second laser pulses. Applied research, such as time domain spectroscopy (TDS), makes use of the high time resolution of THz-waves and ultra broad bandwidth up to the THz region. In contrast, our research focuses on the development of tunable THz-wave sources with high temporal and spatial coherence. Specifically, widely

tunable coherent sources have a wide range of applications, such as in material science, solid state physics, molecular analysis, atmospheric research, bioscience, chemistry, gas tracing, material testing, food inspection, etc. Tunable sources already exist in the sub-THz (several hundreds GHz) frequency region, such as a backward-wave-oscillator (BWO). However, a widely tunable THz-wave source has long been desired in the frequency region above 1 THz, where the tuning capability of a BWO rapidly decreases. Several candidate schemes have been reported, although they do not avoid one or more of the following problems: large size, operational difficulty, liquid He requirement, and low output power. A compact user-friendly source will inevitably find many applications in laboratory-based research, or even commercially.

Several decades ago, it was pointed out that far-infrared or THz-wave generation could be realized by using the lattice vibrations in semiconductors. We have researched a THz-wave parametric oscillator (TPO) and THz-wave parametric generator (TPG) based on the polariton mode scattering of $LiNbO_3$ or MgO: $LiNbO_3$ crystals. The TPO has proved to be a useful coherent THz-wave source that operates at room temperature. It is continuously tunable in the 100- to 300-mm (1- to 3-THz) range in one operation and can emit peak powers of up to several tenths of a milli-Watt. The difference between a TPO and a TPG is that the former has an idler cavity while the latter does not. The THz-wave linewidth of a conventional TPG exceeds 500 GHz and the THz-wave output is much smaller than that from a TPO. Therefore, we concentrated our efforts on the development of a TPO system, although its linewidth was several tens of GHz.

The TPG spectrum was narrowed to the Fourier transform limit of the pulsewidth by introducing an injection seeding to the idler. The purity of the THz-wave frequency was dramatically improved to $\Delta\nu/\nu < 10^{-4}$. Simultaneously, the output obtained was several hundred times higher than that of a conventional TPG. In addition, wide tunability and fine resolution were demonstrated using a tunable seeder. As far as we know, injection seeding to ns optical parametric generators (OPG) has not been reported until recently, due to the limit of parametric gain.

Related references are listed in Reference D5.

(Hiromasa Ito)

D6.Sensing Photonics

Fiber optic distributed sensing techniques have been extensively studied, which have provided schemes to measure, for example, distribution of longitudinal strain or lateral force along an optical fiber. In these systems, the fiber can act as a nerve network to sense damages of materials or structures in which the fiber is embedded. These techniques are the key to realize "smart materials" and "smart structures" for improving reliability, safety and security of the society. Some representatives are described in the followings.

A novel technique for fiber-optic strain-distribution sensing has been proposed and studied based on the Brillouin scattering in a fiber. A down-shifted frequency of the Brillouin scattering is changed in proportion to the applied longitudinal strain. The pump and prove lightwaves, propagating in the fiber in opposite directions with each other, are modulated in frequency, which realizes localized excitation of the stimulated Brillouin scattering. By this "correlation-based continuous-wave technique," a spatial resolution of 1.0 cm has been demonstrated. This is 100 times higher than the inherent limitation of conventional pulsed lightwave techniques. Smart materials with enough spatial resolution have been realized with

this technique. An international conference report (K. Hotate et al., Intern. Conf. on Optical Fiber Sensors, Venice, Oct. 2000) on this technique was evaluated as the best paper there in.
Interference characteristics in an interferometer can arbitrarily be synthesized by a technique, "synthesis of optical coherence function," which has been invented by Japanese researchers. On the basis of this technique, the fiber optic distributed force sensing has been proposed and studied. The sensing mechanism is based on the polarization mode coupling, due to the force, in a polarization maintaining fiber. Propagation speed difference between the two polarization modes is used to resolve the force-applied position. Introducing a SSG-DBR (super-structured grating-distributed Bragg reflector) laser diode as a light source, which has quite a wide frequency-tunability, the spatial resolution has been improved to be about 2m. Additionally, a way to overcome the sensitivity instability of the polarization maintaining fiber as the lateral force sensor has successfully been developed.
Techniques for diagnosing fiber optic subscriber networks have also been studied also using "synthesis of optical coherent function". We must measure the reflectivity distribution around the optical elements, which locate at the end of the network beyond a 5km length optical fiber, with cm order spatial resolution. A system with 6cm resolution for this purpose has already been developed. Such a high resolution have not been realized by other ways.
Utilizing the technique, "synthesis of optical coherence function," a scheme to control the characteristics and the location of a dynamic grating in an Er-doped fiber due to its gain saturation has also been proposed, and various filter characteristics have been demonstrated. Recently, it has been found that the spatial phase of the dynamic grating can also be controlled, which realizes a filter with a notch at the center frequency of the reflection band. Basic experiment has successfully been done to verify the proposal.
Related references are listed in Reference D6.

(Kazuo Hotate)

D7.Systems Photonics

Systems photonics on optical signal processing, optical image processing, digital holography, and optical interconnections have been intensively studied in Japan. The technologies are aimed at the futuristic versatile optics-based systems using the advanced optoelectronic devices and components.
Related research activities are summarized as follows;
(1) Ultrafast Optical signal processing
(2) Optical interconnections
(3) Optical sensing
(4) Digital holography
(5) Optical functional devices
(6) Optical image processing
(7) Optical powering systems
As one of the representative research attempts, the following subject is described here in more details. Inter-chip free-space optical interconnection modules have been investigated intensively. This is aimed at solving the pin-I/O bottleneck problem at the interfaces of silicon integrated circuits. The scalability of the photonic circuit is theoretically analyzed by taking account of the minimum feature size requirement of each diffractive optical element used in the connection. The study showed that interconnection densities of 1000 to 2000 channels / cm is possibly available for a 40 mm interconnection length over a 3-mm-thick optical substrate.

Diffraction-limited imaging capability has been demonstrated by using a fabricated proto-type, which have shown clearly its applicability to inter-chip free-space interconnections. Photonic circuit insertion losses of -23.4 dB for TE polarization and -25.9 dB for TM polarization as well as a polarization dependent loss of 2.5 dB are found to be primarily caused by a pair of binary linear gratings used for beam deflections. Design modifications aimed at insertion loss reduction and further improvement of the tolerance are also discussed.
Their details are described in references in Reference D7.

(Takashi Kurokawa and Hironori Sasaki)

D8.Microwave Photonics

As well known, the fiber-optic communications technologies have made tremendous progresses in the last decade. It is no doubt that the long distance communications are and will be dominated by the fiber-optic transmission techniques. As a consequence of the trend and it's extension, the technologies have been brought from the standard long distance point-to-point communications through the large and small size multi-points-to-multi-points networking systems into the new area: the user access systems. On the other hand, the mobile telephone is another recent huge technological innovation of telecommunications, which has been aimed at convenience mainly for many end users. One of the biggest related topics in Japan is, indeed, the start of the third generation mobile phone service in October 2001, which was the earliest in the world. The general trends of the mobile phone developments are now focused into the broadband nature as in the case of the third generation service.
It is rather clear that these two major telecommunication technologies are getting closer: the broadband fiber-optic communications technologies have attempted to approach end users and the end-user-friendly mobile telephone services have started seeking for the broadband properties. What is expected to happen technically where those two streams meet each other? One fairly likely situation is effective merge of the two technologies. The field of Microwave Photonics stands on this idea, in which the interdisciplinary research activities have been performed. Indeed, many radio-on-fiber systems have been constructed in subway systems, large brides, submarine tunnels, and hotels in Japan. It is also notable that techniques in this interdisciplinary research field have been extended their possible application frontiers to high frequency electromagnetic field measurements and high-density wavelength division multiplexed fiber-optic communications.
The related papers of the author's group can be found in Reference D8.

(Masahiro Tsuchiya)

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