Innovation for New-Generation Optical Communication Based on Photonic Device Breakthrough

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Abstract: *Activities of a goverment-funded project on optical communication in Japan are introduced. More than 20 professors and researchers from univiersities and national laboratories are involved in the project INGOC, Innovation for New-Generation Optical Communications. The fundamental objects are to create and expand a new area of science and technology of optical communications through the breakthrough of the photonic devices.*

Introduction

Strong increase in the communication traffic has been continuing steadily over recent 10 years, mainly due to the drastic growth of Internet traffic. A high volume contents such as musics, pictures and movies began to distribute over the world through the global networks. The spread of the broadband access such as ADSL and FTTH accelerates the increase in the network traffic. NTT has announced their medium term management strategy claiming that they will accomplish 30 million optical fiber broadband access by 2010[1]. As a result of the strategic efforts, the FTTH subscriber number in Japan exceeded 7 millions in the middle of 2006 and is keeping its growth speed. The distribution of the huge amount of the information data has been supported by the progress of photonic technologies such as direct optical repeater systems with an Er-doped fiber amplifier and dense wavelength multiplexing (DWDM) systems. In addition to the simple increase in the high-volume contents, transition to the higher-quality, including high-density TV (HDTV) and/or Super Hi-vision[2] in a future will induce further strong motivation to realize extraordinary higher-performance network, two or three orders magnitude higher than that of the existing network. To cope with the requirement, extensive research efforts are strongly anticipated.

Project Formation

We have started a new research project under the MEXT(Ministry of Education, Culture, Sports, Science and Technology) Grant-in-Aid for Scientific Research on Priority Areas in the middle of 2005. The project title is "Innovation for New-Generation Optical Communications (INGOC)". The project structure is shown in Fig. 1. It consists of three research groups and an executive committee. The research groups are entitled as A01: Function Innovation group, A02: Structure Innovation group and A03: Integration Innovation group. In the research groups, tweleve principal research topics and eleven supporting research topics were selected in 2005-2006 and 2006, respectively. The project aims to

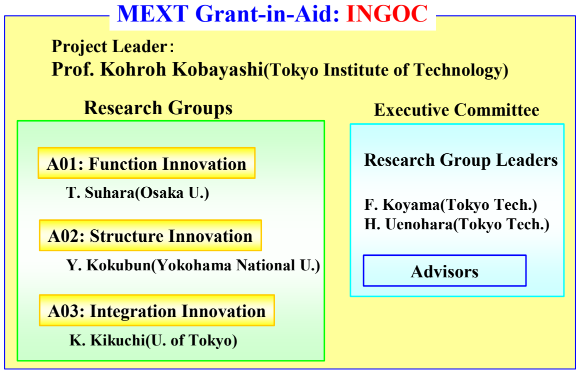

Fig. 1: Configuration of INGOC: Innovation for New-Generation Optical Communication

create a new area of science and technology and to achieve innovation for the transmission as well as for the signal processing for future optical communicaitons through breakthorugh of photonic devices. In order to achieve remarkable progress in the optical communication technology, we would like to explore new functions of light, which have not been yet fully utilized. We call them "higher-order functions of light". Among them are phase, polarization, quantum state of light, velocity of light, and so on. In other word, we try to make full use of the undeveloped ability of light in this project. The conceptual image is shown in Fig. 2 with the logo mark.

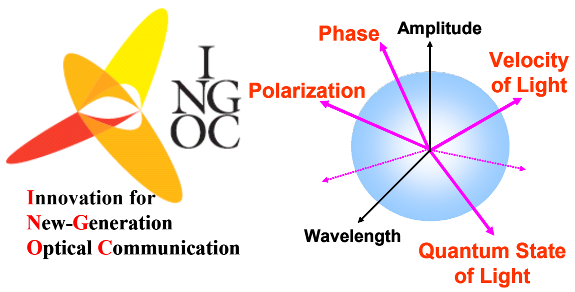

Fig. 2: Conceptual image of the project and the logo mark.

A01: Function Innovation Group

Professor T. Suhara, Osaka University, is a leader of this research group. This group is investigating new principles to conrol light.

Prof. Suhara's research is aiming to realize various quantum photnic devices[3] for quantum information processing and/or quantum cryptography. He demonstrated sum-frequency generation using a photon

wavelength converter based on the non-linearity of the waveguide quasi-phase matching (QPM). The wavelength conversion from 1.55 μm to 0.7 μm enables the use of highly sensitive Si-APD for efficient single photon detection. Domain-inverted grating are formed on Mgo:LiNbO3 crystal by applying high-voltage under high-temperature.
Ti-diffused channel waveguide combined with domain-inverted grating is pumped by a wavelength tunable AlGaAs semiconductor laser as depicted in Fig. 3. As clearly shown in a histogram in Fig. 4, cross-polarized twin-photons were generated for the first time with the waveguide devices.[4] Entangled quantum state was experimentally confirmed with the cross-polarized twin photons.

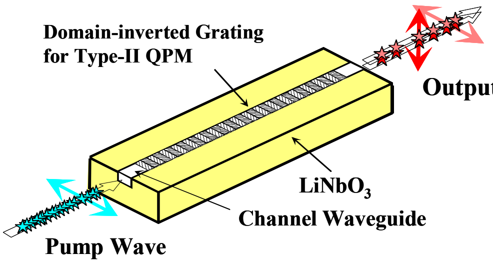

Fig. 3: Cross-polarized twin photon generatin devces.

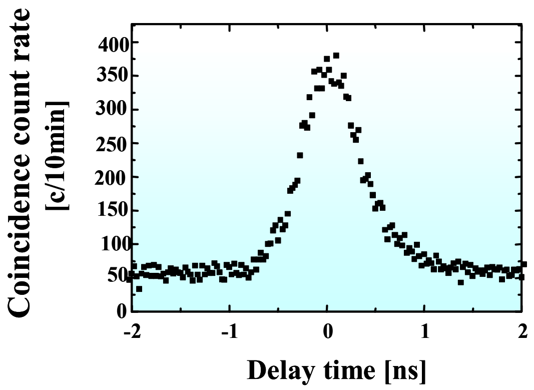

Fig. 4: Measured correlation of cross-polarized twin photons.

Other research topics assigned in this Function Innovation group are single photon and single photon pair generation from single InAlAs/GaAs quantum dot[5] by Prof. I. Suemune, Hokkaido University, light velocity control in a photonic crystal waveguide with a chirped structure and dispersion compensator and their application to an optical buffer memory by Prof. T. Baba, Yokohama National University, optical control of various functions of light using ultrafast optical nonlinearity of optical fibers induced by ultrashort pulse[8] by A. Prof. N. Nishizawa, Nagoya Univiersity and some others.

A02: Structure Innovation Group

The main mission of this group, headed by Prof. Y. Kokubun, Yokohama National University, is to create novel optical devices in collaboration with other groups.
Prof. Y. Kokubun is concentrating on multiwavelenght mutliport wavelength selective switching circuits to apply to a reconfigurable optical add/drop multiplexer (ROADM) based on a hitless wavelength selective switch. The switching element consists of waveguides and double series-coupled ring resonators with a tuning micro heater.[7] A fundamental layout of the multi-port hitless wavelenghth selective switch is depicted in Fig. 5. The switching element structure is also shown in the figure. A Ta_2O_5-SiO_2 core is embedded in SiO_2 cladding on a Si substrate. The multi-layered dielectric material system was found to be suitable than the polymer system from a view point of switching response time. Basic wavelength selective switching characteristics were successfully demonstrated.[8]

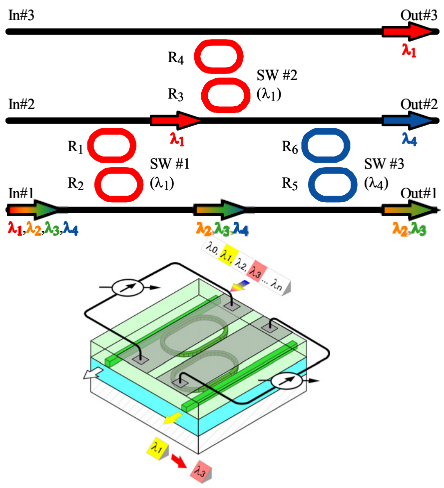

Fig. 5: Multi-port hitless wavelength selective switching circuit layout and a switching element.

Among other research topics in the A02 group are research on propagation characteristics of tunable hollow waveguides[9] and their applications for photonic integrated circuits such as widely tunable dispersion compensator,[10] WDM multiplexer/demultiplexer coupled with vertical cavity devices by Prof. F. Koyama, Tokyo Institute of Technology, investigation of MEMS technologies for highly functional telecommunication devices such as tunable grating optical reflectors[11] and valuable optical attenuation filters by Prof. K. Hane, Tohoku University, research on a ultrafast all-optical switch using intersubband transition of an InGaAs/AlAs/AlAsSb muti-quantum well[12] by Dr. H. Ishikawa, National Institute of Advanced Industrial Science and Technology, and some others.

A03: Integration Innovation Group

This research group takes most system-oriented approach in our project. Prof. K. Kikuchi, University of Tokyo, serves as a leader.
Prof. Kikuchi is tackling an issue of upgrading the

transmission capacity by utlizing multi-level modulation formats. He has been investigating the multi-level demodulation scheme, where a phase diversity homodyne receiver followed by an electronics digital signal-processing (DSP) circuit is utilized. In Fig. 6, a diagram of the phase diversity homodyne receiver and an example of the pattern of 20 Gb/s QPSK demodulation.[13] He has recently succeeded to construct 1000km-20Gb/s QPSK transmission systems using the developed digital coherent optical receivers.[14]

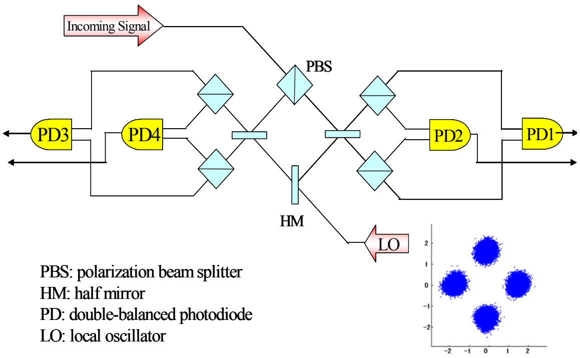

Fig. 6: Schematic diagram of the phase diversity homodyne receiver and a demodulated pattern.

The author (K. Kobayashi) and A. Prof. H. Uenohara, Tokyo Institute of Technology, are involved in the A03 group. They are mainly concentraing on all-optical packet processing/routing to provide solutions to the feasible bottleneck in the network nodes in future. Among the various functions in the packet routing system (Fig. 7), the first bit extraction, the label-payload separation and the label information recognition[15] were experimentally demonstrated with SOA-MZI all-optical 1x2 swithces. Self-switching scheme, where the input signal to the SOA-MZI switch is used as the optical control signal, is utilized to simply realize the avove functions. Four-bit label was extracted from the time sequential bit stream at 20 Gb/s as shown in Fig. 8.[16] Optical buffering was investigated with optical fiber delay lines combined with optical switches and optical wavelength converters.

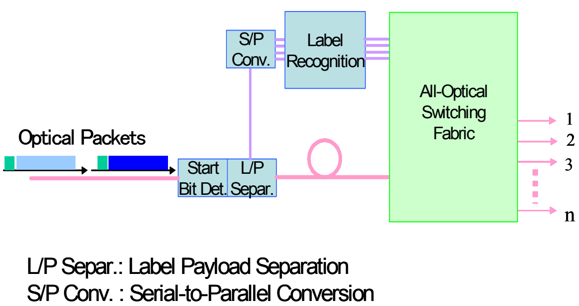

Fig. 7: Schematic diagram of the all-optical packet routing subsystem.

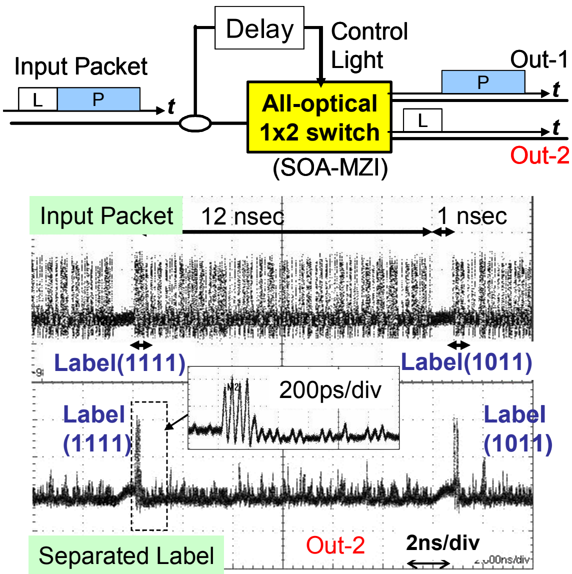

Fig. 8: Experimental result of the label separation by self-switching scheme of SOA-MZI all-optical switch.

All-optical signal processing with a different device and toward a different direction has been doing by Prof. H. Kawaguchi, Nara Institute of Science and Technology. He has been focusing on all-optical technology with polarization bistable VCSELs. He has demonstrated all-optical buffering and its shift resister function using fast polarization switching of VCSEL output light.[17]

Prof. K. Kodate, Japan Women's University, is working wideband optical spectrum processing, in collaboration with Dr. N. Wada, National Institute of Information and Communications Technology, using arrayed waveguide grating with amplitude and phase tunablity.[18] Multiple label generation and processing have been realized by utilizing Fourier transformation[19] of the light signal.

Concluding Remarks

As described above, this project is aming to explore and create a new scienc and technology area which is necessary to future photonic networks. The target area is described in a space defined by three axes, ie. higher-order functions, optical transmission/control and optical signal processing, as depicted in Fig. 9. Although optical communication technologies seem to have reached to fairly high levels, they are still in a very limited space as shown in Fig. 9. So far, only fundamental parameters of light, such as amplitude, intensity, and wavelength have been widely used in optical communications. There remains a wide room to be explored. Signal processing so far has been fully relied on the progress of electronics. With the increase in the signal bitrate, power consumption will become a serious issue. Optical signal processing will be a potentially strong candidate to overcome this problem. We hope that our effort to expand the conventional sciense and technology area to the wider and fruitful one will contribute to cope with the strong demand for the extremely huge amount of information exchange in the future next generation photonic networks.

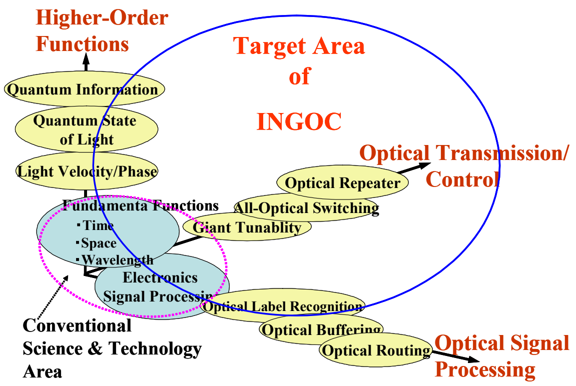

Fig.9: Target area of INGOC.

Acknowledgement

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