PLC Optical Signal Processing Devices for Developing Highly Functional Optical Networks

Koichi Takiguchi†, Katsunari Okamoto, Takashi Saida, and Tomohiro Shibata

Abstract

The development of optical devices that can process optical signals directly in the optical layer is essential for the construction of next-generation advanced optical networks. Making full use of the superior characteristics of waveguides formed by planar lightwave circuit (PLC) technology, NTT Photonics Laboratories is researching and developing high-performance optical devices that can perform high-speed and flexible optical-signal processing for various purposes.

1. Introduction

The coming of high-speed, broadband communications is creating a strong demand for networks that can transmit large volumes of information at high speed and systems that can perform high-throughput information processing. To this end, it is important to promote node "opticalization" (i.e., the replacement of electrical processing by all-optical processing), rather than simply that of links as in the past, and to eliminate the costs incurred by optical/electrical (O/E) and electrical/optical (E/O) conversion and the data-transfer bottlenecks caused by electrical processing.

Figure 1 shows how optical networks are expected to evolve and the optical devices that will be needed. To expand the capacity of conventional point-to-point multi-wavelength optical transmission, studies are

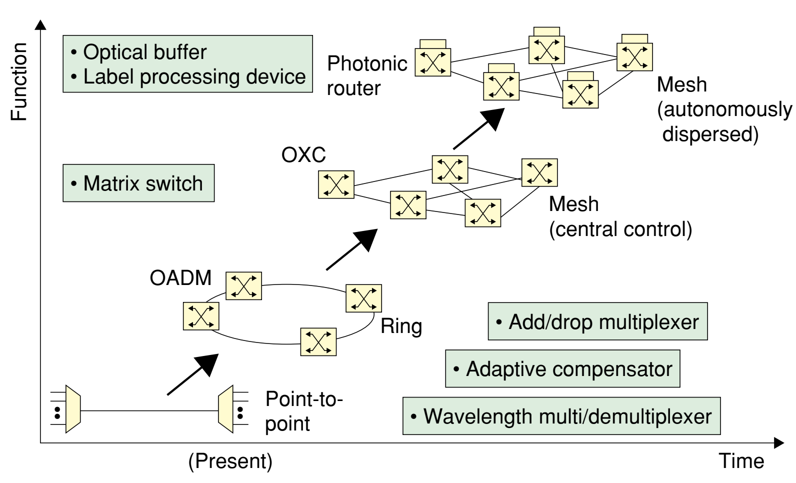

Fig. 1. Evolution of optical networks and related optical devices.

† NTT Photonics Laboratories
Atsugi-shi, 243-0198 Japan
E-mail: taki@aecl.ntt.co.jp

progressing on the development of an advanced optical network architecture using optical add/drop multiplexers (OADMs), optical cross connects (OXCs), and photonic routers. These new formats will increase the demand for new and advanced optical processing functions above and beyond the conventional splitting and combining of wavelengths. They will include add/drop multiplexing, cross-connection, adaptive compensation (e.g., for dispersion and gain fluctuation), label processing for label recognition and switching, and optical buffering.

Silica-based planar lightwave circuit (PLC) waveguides can perform optical phase control and spatial/temporal multiple beam interference in a stable and low-loss manner, unlike other waveguide materials. They can be used to achieve complicated circuit configurations with the waveguide lengths required by optical signal processing functions. In addition, functions like optical detection/emission, modulation, amplification, and wavelength conversion can be provided as needed through the hybrid integration of active elements such as ferrodielectric and semiconductor devices. In short, a variety of optical devices can be developed by exploiting the features of both active and passive devices.

In this article, we introduce a label recognition device, an optical code division multiple access (CDMA) device, and a pulse waveform-shaping device that make use of the superior characteristics and diverse functions of PLC technology. These devices are being researched and developed for application to next-generation networks.

2. Label recognition device

Technology that can process address labels of high-speed packets in the optical domain and promote the opticalization of nodes is becoming increasingly important in achieving ultrahigh-speed packet routing.

Figure 2 shows a label recognition device consisting of a PLC and a high-speed semiconductor gate device. This device first splits an input serial-label signal into four signals and gives each of these signals a different delay corresponding to an integer multiple of the bit interval. After adjusting the phase of each signal using a thermo-optic phase shifter, it then subjects each signal to amplitude weighting according to

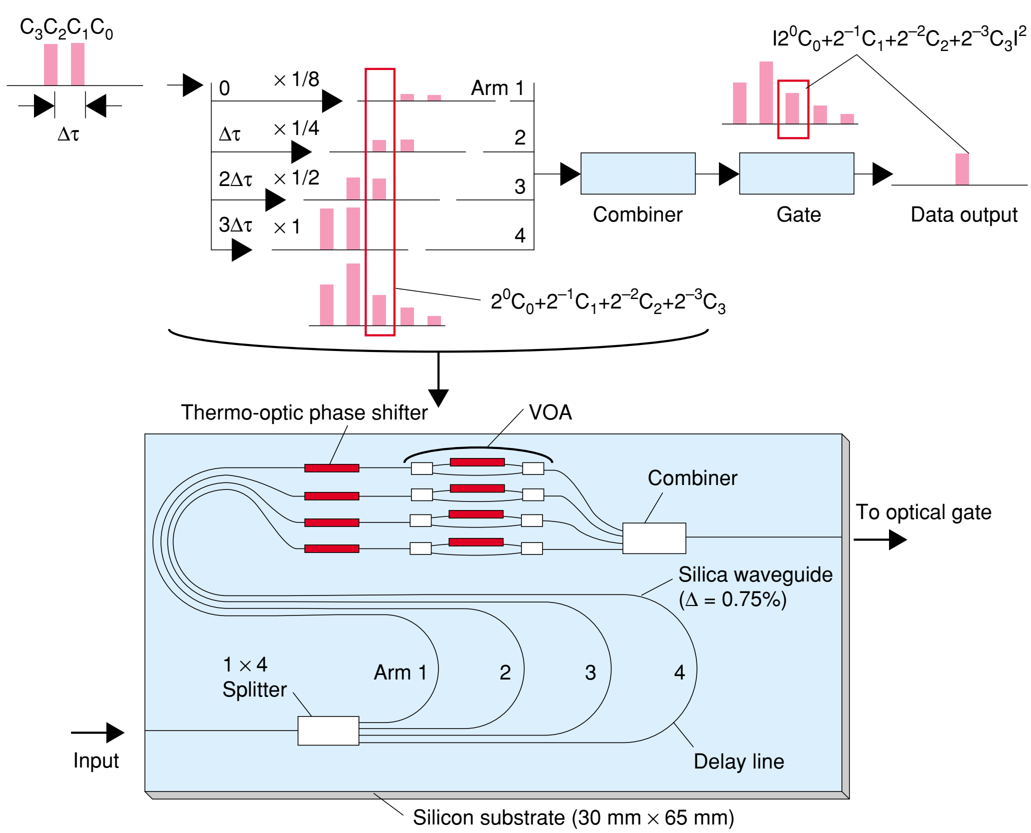

Fig. 2. Label recognition device.

its arm number using a variable optical attenuator (VOA) of the Mach-Zehnder interferometer (MZI) type. Next, the device combines the signals by means of interference. Finally, the device uses a time gate to extract from this combined signal only the serial/parallel converted part of the source signal. As a result of these operations, the output signal changes in an analog way in accordance with pattern changes in the input digital address signal, i.e., by a digital/analog (D/A) conversion process. The output here does not depend on the signal transmission speed, which means that label recognition that is not limited by electrical processing speeds can be achieved by determining the value of that output.

We performed a label-recognition experiment using a 10-Gbit/s, return-to-zero (RZ) 4-bit-label signal and found that the device operated effectively [1]. To take this device to the next step where it can recognize label signals of even more bits, future research must look at ways of raising device performance.

3. Optical CDMA device

We are also researching and developing ways of making more effective use of the optical-signal band by exploiting the features of optical coding technology. The configuration of an optical CDMA device (encoder/decoder) fabricated using PLC technology is shown in **Fig. 3**. This device encodes an optical signal by using the delay incurred in optical circuits so that multiple access can be achieved not by time or wavelength as in other transmission schemes but by code. In this configuration, an array of variable delay lines in a lattice-type configuration featuring cascade-connected MZIs is placed between arrayed-waveguide gratings (AWGs) having a wavelength splitting and combining function. These variable delay lines are used to give each wavelength a different delay and thereby spread the optical signal in both the time and wavelength domains, enabling two-dimensional coding. This provides a greater number of codes than just one-dimensional coding by means of either time or wavelength, so it enables more flexible signal spreading. Referring to the figure, each variable-delay-line section features asymmetrical MZIs that successively double the optical path length and symmetrical MZI switches that are placed between asymmetrical MZIs. This minimum configuration can achieve delays from 0 to $(2^i-1)\ \Delta L$ (i: number of asymmetrical MZIs) in units of ΔL. Since delays may be set here in a semi-fixed manner, the switching time of the thermo-optic phase shifters (of the millisecond order) does not present a problem. Placing this device on the transmitter and receiver sides of a communication system as an encoder and decoder, respectively, enables reproduction on the receive side of only those signals for which the encoded and decoded pattern agrees (for which the total delay of each wavelength agrees). Thus, in addition to enabling efficient spectrum usage, this device can be expected to provide a variety of useful functions such as asynchronous connections, random access by coding without the use of optical switches, and self routing.

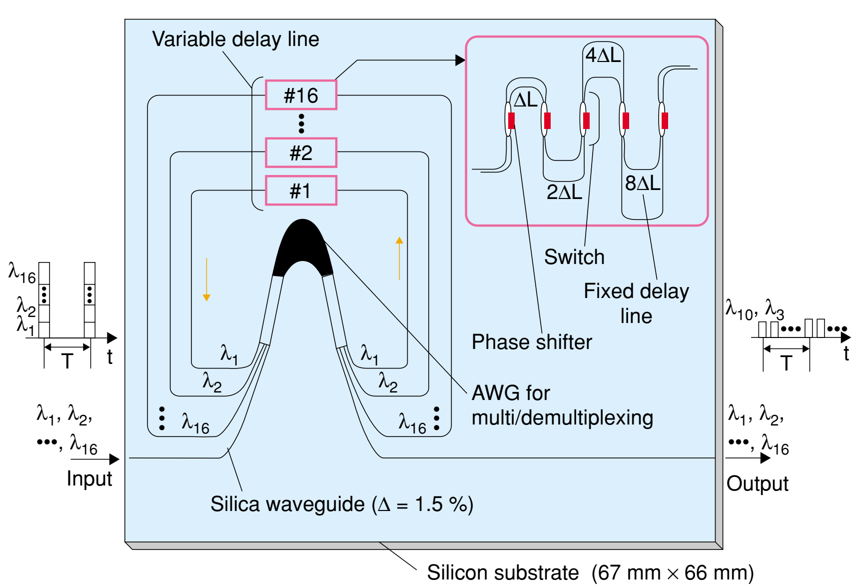

Fig. 3. Optical CDMA device.

Using a 10-Gbit/s RZ signal, we measured autocorrelation (for code matching condition between transmitter and receiver) and cross-correlation (for code unmatching condition between transmitter and receiver) characteristics and obtained a good extinction ratio (12 dB) between these characteristics as intended by the design. We also performed an actual transmission experiment that confirmed the effectiveness of this device [2].

Important issues in future research are increasing the number of codes to support a large-scale system with many users and developing a simple configuration that can be applied to a subscriber system.

4. Waveform-shaping device

High-speed optical communications of 40 Gbit/s and higher per wavelength requires optical-signal processing functions for shaping the waveform such as signal chirp compensation and gate-oriented rectangular-pulse generation. However, it has been difficult to directly control the output waveform of a pulse light source by electrical means. The spectrum shaping method, on the other hand, can control waveforms by directly adjusting the amplitude and phase of repeating pulse-spectrum components in the optical domain. This is especially advantageous because it can achieve waveform shaping using only a passive device without the use of high-speed optical modulators or optical non-linear effects.

The operating principle and configuration of an integrated waveform-shaping device are shown in **Fig. 4**. The device features a monolithically integrated array of amplitude-and-phase adjustment sections, each comprising a VOA and thermo-optic phase shifters, which is located between two AWGs for wavelength splitting/combining. This configuration makes it possible to independently adjust the amplitude and phase of multiple frequency components with high accuracy. A good VOA extinction ratio and amplitude setting accuracy of 30 dB and 0.1 dB, respectively, has been obtained with this device.

To evaluate the operation of this device, we tried generating rectangular pulses for gate signals and other uses by giving the electrical-field spectrum component the shape of a sinc function. We were successful in generating rectangular pulses with a frequency of 40 GHz and a pulse width that could be varied in the range from 4.4 to 10.5 ps [3].

In addition to the field of communications, this device shows promise for use in other fields such as signal generation for measurement purposes. As with the other devices introduced in this article, we aim to improve the performance of this device and explore

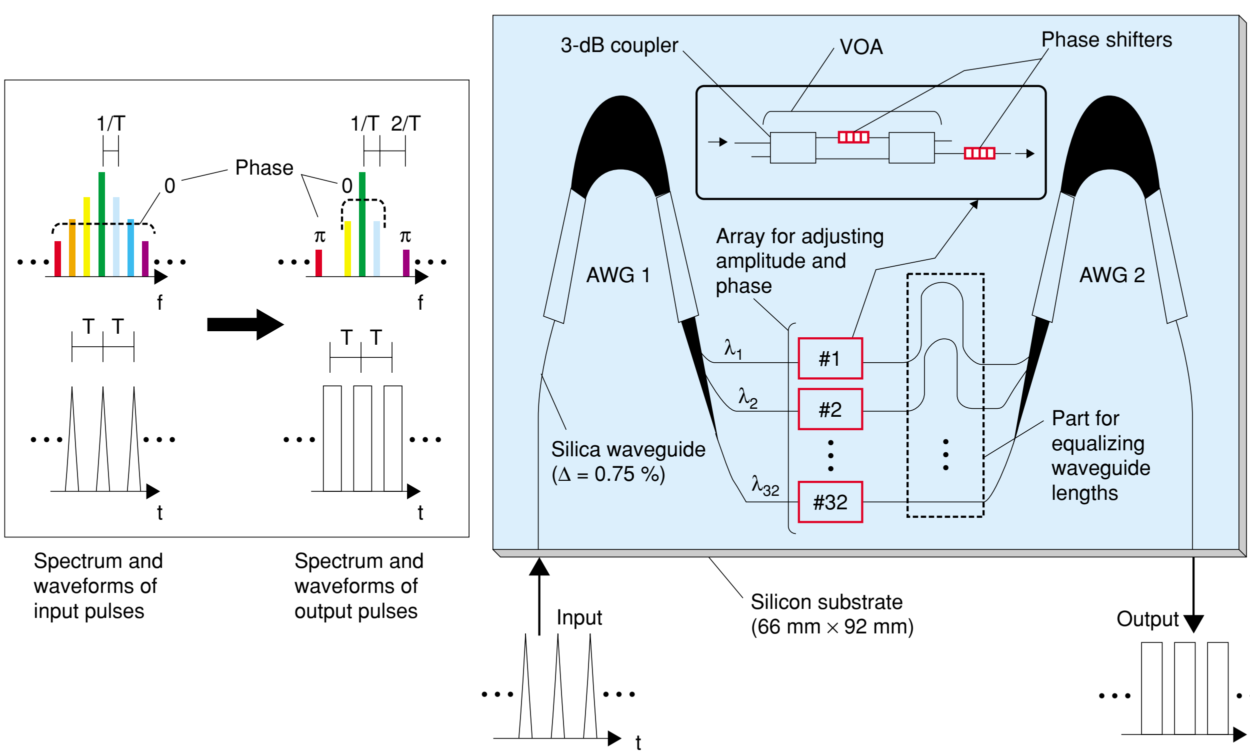

Fig. 4. Waveform-shaping device.

its use in opening up new application fields.

5. Conclusion

The PLC-based optical signal processing devices introduced here are expected to play a vital role in creating the next-generation high-speed optical networks. We plan to raise the performance of each of these devices knowing that system requirements will become even more severe in the years to come.

References

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Koichi Takiguchi

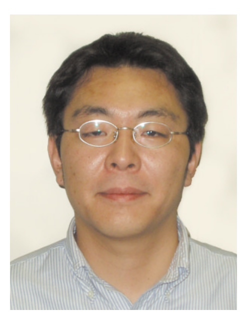
Senior Research Engineer, Hyper-Photonic Component Laboratory, NTT Photonics Laboratories.

He received the B.S. degree in electronic engineering and the M.S. and Ph.D. degrees in electrical engineering from the University of Tokyo, Tokyo in 1987, 1989, and 1992, respectively. His graduation thesis and dissertation were on a GaAs/AlGaAs distributed feedback (DFB) semiconductor laser and a resonator-type fiber-optic gyroscope, respectively. Since joining NTT in 1992, he has been engaged in R&D of silica-based planar waveguide devices and high-speed optical transmission systems. He is now interested in photonic functional devices and their applications to next-generation optical network systems. From 1998 to 1999, he was at the University of California at Santa Barbara (UCSB) as a visiting scholar, where he studied semiconductor-based photonic functional devices. He is a member of IEEE, the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, the Japan Society of Applied Physics (JSAP), and the Optical Society of Japan.

Katsunari Okamoto

NTT R&D Fellow.

He received the B.S., M.S., and Ph.D. degrees in electronics engineering from the University of Tokyo, Tokyo in 1972, 1974, and 1977, respectively. He joined Ibaraki Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation (now NTT), Ibaraki, Japan in 1977 and was engaged in research on the transmission characteristics of multimode, dispersion-flattened single-mode, single-polarization (PANDA) fibers and fiber-optic components. He was the first to propose dispersion-flattened fiber (DFF) and succeeded in fabricating DFF that had chromatic dispersion less than ±1 ps/km/nm over a wide spectral range. Since 1990, he has been working on the analysis and synthesis of guided-wave devices, computer-aided-design, and the fabrication of silica-based PLCs at Ibaraki R&D Center, NTT Photonics Laboratories. He has developed a 256 × 256 star coupler, various kinds of AWGs ranging from 8-ch 50-nm-spacing AWGs to 128-ch 25-GHz AWGs, flat-spectral-response AWGs, and integrated-optics reconfigurable add/drop multiplexers. In 2003, he started Okamoto Laboratory Ltd., an R&D consulting company that deals with the custom design of optical fibers and functional PLCs. He has published more than 220 papers in technical journals and international conferences. He has authored and co-authored eight books including "Fundamentals of Optical Waveguides". He is an IEEE fellow and a member of Optical Society of America and IEICE.



Takashi Saida

Research Engineer, Hyper-Photonic Component Laboratory, NTT Photonics Laboratories.

He received the B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Tokyo, Tokyo in 1993, 1995, and 1998, respectively. His dissertation work involved research on interferometric optical sensors. Since joining NTT Opto-electronics Laboratories, Ibaraki, Japan in 1998, he has been engaged in research on functional PLCs for use in next-generation communication systems. From 2002 to 2003, he was a visiting scholar at Stanford University studying the design of periodically poled lithium niobate waveguides. He is a member of IEEE, IEICE, JSAP, and the Ceramic Society of Japan.

Tomohiro Shibata

Senior Research Engineer, Hyper-Photonic Component Laboratory, NTT Photonics Laboratories.

He received the B.S. degree in physics, the M.E. degree in applied physics, and the Ph.D. degree in crystalline materials science from Nagoya University, Nagoya, Aichi in 1983, 1985, and 1995, respectively. In 1985, he joined NTT Laboratories, where he engaged in research on the epitaxial growth of thin-film semiconductors utilizing ECR plasma technology. He is now engaged in the fabrication of silica-based PLCs. He is a member of IEICE and JSAP.