PLC Optical Switch that Enhances the Optical Communication Network

Hiroshi Takahashi†, Toshio Watanabe, Takashi Goh, Shunichi Sohma, and Tetsuo Takahashi

Abstract

By introducing optical switches into the optical communication network, we can drop or redirect specific signals without converting them into electrical signals. This will lead to a great reduction in node equipment cost and more flexible system operation. This article introduces the characteristics of an optical switch based on planar lightwave circuit (PLC) technology developed by NTT Photonics Laboratories.

1. Optical switches and the optical communication network

Optical switches can be broadly classified into two types. One type has 1 input port and 1 output port, and it switches on and off as required. This is generally called a time switch (or gate switch). In particular, a switch that can switch on and off under the control of a high-speed binary data stream is called a modulator. The other type has multiple input/output ports to redirect optical signals. This is called a space switch. The number of input ports is generally denoted by N and that of output ports by M, so it is called an N × M switch. This article explains such a space switch (hereafter, space switch is shortened to switch). The minimum switch is the 1 × 2 switch, which is used for switching primary and secondary transmission devices. The mechanical type (which switches the light path by moving a fiber, prism, or mirror etc.) is the conventional version.

More recently, along with the popularization of the Internet, WDM (wavelength division multiplexing) transmission systems have been introduced, and the transmission capacity has been greatly increased because one optical fiber can now transmit multiple wavelength channels. In future, when triple-play services (which bundle telephone, Internet connection, and TV/video distribution) become common on fiber-to-the-home (FTTH) systems, not only the backbone but also metro or access layer networks are expected to utilize WDM. At that time, the amount of traffic that must be processed by nodes will be much greater.

In that context, recent research has studied how to select particular optical signals arriving at the node and pass them straight through without converting them into electrical signals (namely without any intervention by the router). This network node configuration is called ROADM (reconfigurable optical add/drop multiplexing) or OXC (optical cross connect). As this configuration needs many optical switches to redirect the optical signals, there is increasing demand for optical switch technology that offers miniaturization and integration—attributes that are difficult for mechanical switches to provide.

2. Principle and basic characteristics of PLC switch

PLC (planar lightwave circuit) is a generic term used to refer to an optical circuit consisting of a light waveguide whose section size is of the order of micrometers. As with an electronic IC (integrated circuit), it is formed on the surface of a substrate using technologies such as thin-film formation, photolithography, and dry etching. We use silicon as the substrate and silica glass (the same material as used for

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

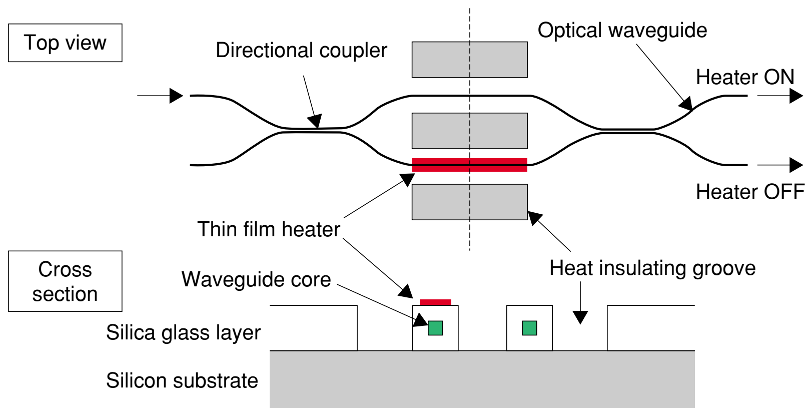


Fig. 1. Switch element based on MZI.

optical fiber) as the waveguide. This provides us with low loss and high reliability [1], [2] and lets us make various PLC devices. Switches are one of the main research topics.

We are developing various switches including two that are described below. They all use the Mach-Zehnder interferometer (MZI) as an element, as indicated in **Fig. 1**. In this interferometer, the first coupler splits the input light into two (50:50 power ratio) and the second coupler merges them causing interference. When it is not driven, 100% of the light is output from the bottom-right port because it consists of two-tiered couplers of 50%. When we drive the thin-film heater and heat one waveguide, the light propagation speed decreases and the two lights are out of phase when they are merged in the second coupler, so the light is output from the top-right port. This is the operating principle of the MZI switch element.

As it has no moving parts, there is no fluctuation in output characteristics due to external vibration or shock. In addition, as the relationship between the power supplied to the heater and the light output is stable, there is no need for feedback control. This means that we can achieve stable operation with a simple electronic drive circuit. As indicated in the cross-section view of the waveguide in Fig. 1, we tried to lower the power consumption by forming heat insulating grooves around the thin-film heater to prevent horizontal heat loss. The ordinary power consumption of one element is 100–200 mW (depending on the design), but at the research level, it is now as low as 45 mW [3]. In addition, the time required to switch the output after powering the heater is just a few milliseconds.

3. Optical switch for ROADM

In the ROADM system, each node can switch optical signals of any wavelength; that is, it can let the signal pass straight through or connect the signal channel to a transponder. There are several types of node configurations, but the basic configuration is the combination of demultiplexer-switch-multiplexer, as indicated in **Fig. 2**. Each switch has two states, i.e., the through state and the add-drop state, and it can choose the state for each wavelength. The most recent node we have made is a 32-wavelength ROADM device in which 32 of these switches are integrated on a 24 mm × 56 mm chip. As shown in **Fig. 3** (right), it is very compact [4].

The average loss is 0.76 dB between the IN-OUT ports and 0.69 and 0.61 dB between the ADD-OUT and IN-DROP ports, respectively. The average extinction ratio is 72.2 dB between the IN-OUT ports and 56.5 dB between the ADD-OUT ports. These values are satisfactory for ROADM operation. In addition, we studied the effect of changes in environmental temperature on the optical characteristics and found that there was little fluctuation in insertion loss and extinction ratio within the range of 15–80°C (**Fig. 4**). This is because the MZI is unaffected by the temperature of the chip itself since its operating principle is based on the temperature difference between the two waveguides.

The multiplexer/demultiplexer is an AWG (arrayed-waveguide grating) wavelength multiplexer/demultiplexer, which also uses PLC technology. As indicated in Fig. 3 (left), we have succeeded in developing a module incorporating three PLC chips: one switch and two AWGs. By integrating all optical compo-

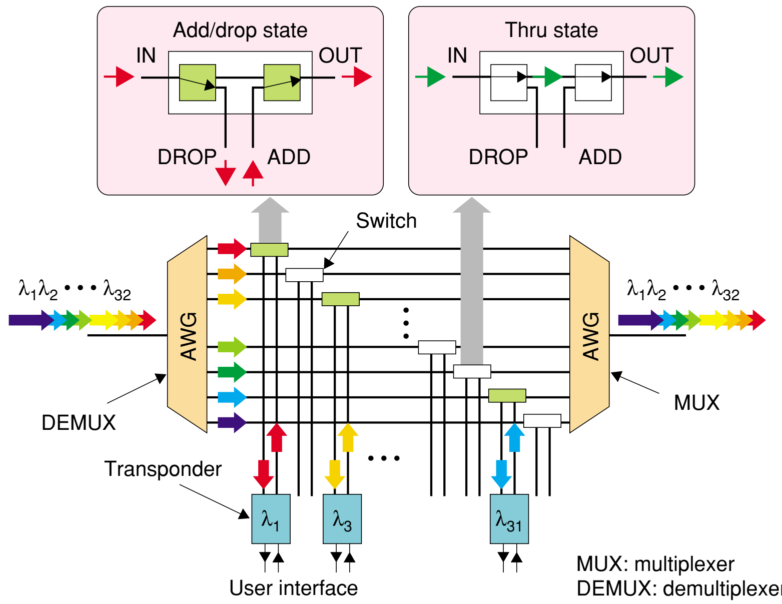


Fig. 2. ROADM node configuration.

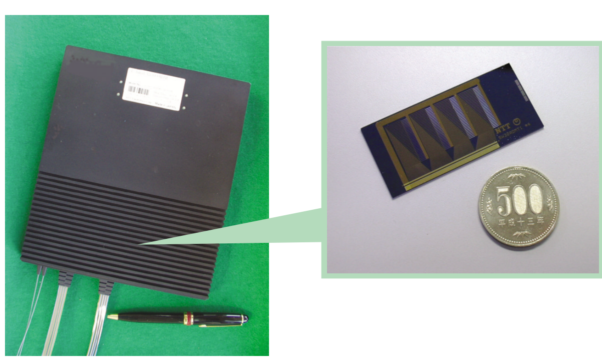


Fig. 3. 32-channel ROADM module and PLC switch chip.

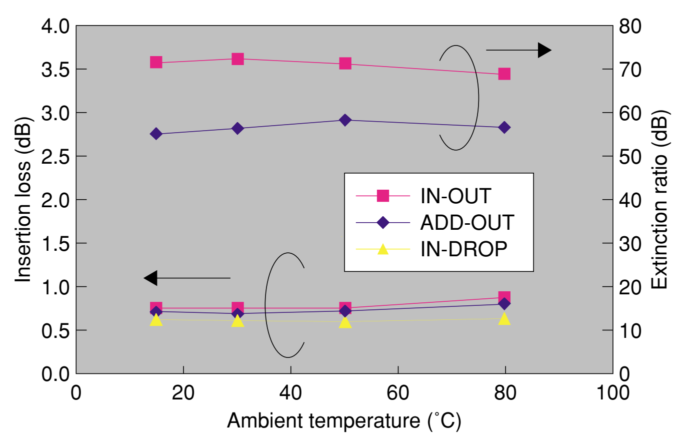


Fig. 4. Temperature dependence of ROADM switch.

nents required for ROADM operation, we can mount optical modules on printed circuit boards as easily as normal electronic components. This means that this module is not merely smaller, but has reached the practical level. Preliminary devices have passed reliability tests etc. and have been put on the market.

4. Matrix switch

The matrix switch connects N inputs and M outputs in any combination. An OXC or ROADM network needs to be able to switch multiple light paths or flexibly assign the wavelengths in conjunction with wavelength-tunable light sources. As indicated in **Fig. 5** (for N=M=4), it is generally configured by connecting $N \times M$ sets of 2×2 switches in the form of a mesh. The extinction ratio of our Mach-Zehnder interferometer is generally 20–30 dB. To obtain an extinction ratio of over 40 dB, we used the double-gate configuration where two MZIs are connected to form a single 2×2 switch. The maximum number of ports in the current matrix switch is 16×16. In this case, we need to integrate 512 MZIs onto one PLC chip. The silica waveguide we usually use can be bent with a minimum radius of 5 mm, but this time, we chose to use a waveguide with a minimum radius of 2

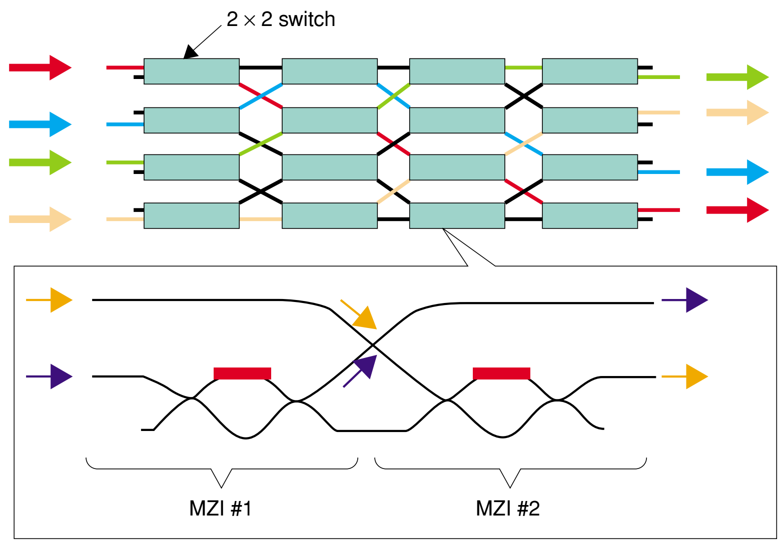
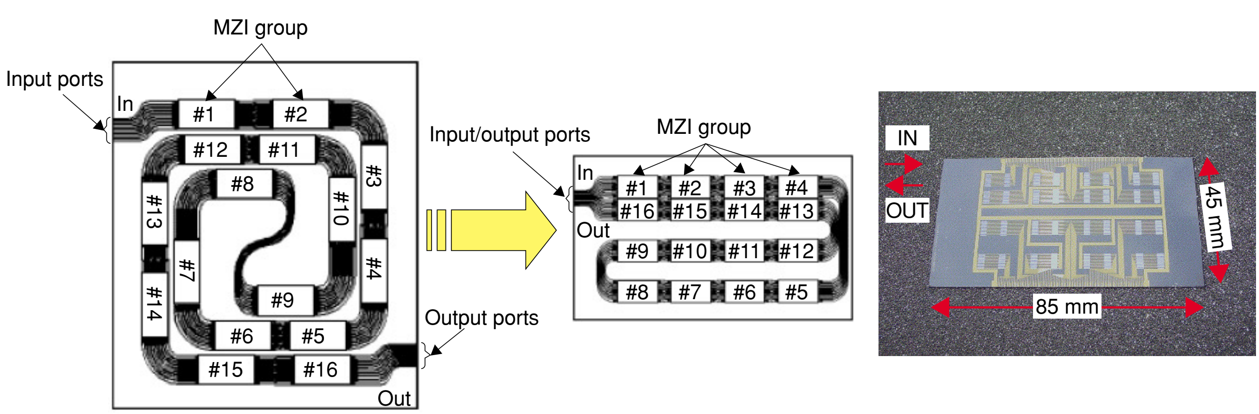


Fig. 5. Configuration of whole matrix switch and 2 × 2 building block.



a) Conventional

b) Newly developed

Fig. 6. 16 × 16 matrix switch.

mm, which we achieved by doubling the difference between the refractive indices of the core and cladding (called Δ) from the conventional 0.75% to 1.5% so that the light is strongly confined in the waveguides.

Figure 6 shows the chip design of the conventional and new 16 × 16 matrix switches [6]. By grouping 32 MZIs together, we were able to align them into four groups of four rows in the new design. Since the dead space is considerably reduced, the chip area is 60% less (conventional: 100 mm × 107 mm, new: 85 mm × 45 mm). This time we used a waveguide with higher Δ, so the fiber-waveguide coupling loss and the propagation loss are higher than ever before, and the average insertion loss is 6.5 dB. However, these losses should be reduced through future improvements. The average extinction ratio is 55 dB, a value good enough for OXC operation. The power consumption of one MZI is 0.15 W. As only 32 heaters need to be driven at the same time, the maximum power consumption of the switch is only 4.8 W. Thus, even though it actually has 512 thin-film heaters, which might lead one to expect the power consumption to be very high, the actual power consumption is less than that of the CPU (central processing unit) of an ordinary personal computer. Moreover, this switch can easily be used in a practical system because we can pack the drive/control circuit of the thin-film heaters and the external communication interface circuit with the matrix switch onto a single board.

5. Future plans

The optical switch is the key to making flexible networks like ROADM or OXC networks, where wavelength paths of WDM signals can be configured/modified flexibly without any optical-electrical-optical conversion. The PLC switch is expected to be introduced into commercial systems in the future because it is compact and has high stability and reliability. After that, complex integration or monolithic integration of the switch and AWG chips will be needed to further reduce the size and cost of the optical modules. In addition, the switch scale, i.e., the number of wavelength channels or transmission paths connected to each node, is expected to increase in response to increases in traffic. To meet these needs, we will continue to actively promote the research and development of our PLC switches.

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Hiroshi Takahashi

Group Leader, Lightwave Circuit Research Group, Photonics Integration Laboratory, NTT Photonics Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Tohoku University, Sendai, Miyagi in 1986 and 1988, respectively. In 1988, he joined NTT Laboratories where he has been engaged in research on the fabrication and design of silica-based optical waveguide devices including wavelength multiplexer and optical switches and the integration of such devices. In 1997, he received the Ph.D. degree from Tohoku University for research on arrayed-waveguide grating wavelength multiplexers. He is interested in the creation of new functional optical circuits based on PLC technology. He is also the project leader of the *ad hoc* development project of PLC switches and is responsible for the development of the devices described in this article. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, the Japan Society of Applied Physics (JSAP), and IEEE.

Toshio Watanabe

Senior Research Engineer, Lightwave Circuit Research Group, Photonics Integration Laboratory, NTT Photonics Laboratories.

He received the B.E., M.E., and Dr.Eng. degrees in organic and polymeric materials engineering from Tokyo Institute of Technology, Tokyo in 1990, 1992, and 2001, respectively. In 1992, he joined the NTT Opto-electronics Laboratories, Tokai-mura, Japan and engaged in research on polymeric materials for optical waveguides. From 1997 to 1999, he was with NTT Network Service Systems Laboratories, Yokosuka, Japan, where he researched photonic network systems. Since 1999, he has been involved in developing silica-based PLC switches and is currently a member of the *ad hoc* development project of PLC switches and in charge of the design of add/drop switches. He is a member of IEEE and JSAP.

Takashi Goh

Senior Research Engineer, Lightwave Component Research Group, Photonics Integration Laboratory, NTT Photonics Laboratories.

He received the B.E. and M.E. degrees in electronic and communication engineering from Waseda University, Tokyo in 1991 and 1993, respectively. In 1993, he joined the NTT Opto-electronics (now Photonics) Laboratories, Japan, where he has been engaged in research on silica-based planar lightwave circuits. During 2002 to 2004, he was engaged in development of photonic network systems in NTT Network Innovation Laboratories, Kanagawa, Japan. He is currently a member of the *ad hoc* development project of PLC switches and in charge of the ROADM module. He is a member of IEICE and JSAP.

Shunichi Sohma

Research Engineer, Lightwave Circuit Research Group, Photonics Integration Laboratory, NTT Photonics Laboratories.

He received the B.E. and M.E. degrees in electronic engineering from Tohoku University, Sendai, Miyagi in 1997 and 1999, respectively. In 1999, he joined NTT Photonics Laboratories, Ibaraki, Japan. He received Young Researcher Awards from the International Conference on Solid State Devices and Materials in 2002 and from IEICE in 2005 for research on PLC optical switches. He is currently a member of the *ad hoc* development project of PLC switches and in charge of the design of matrix switches. He is a member of IEICE.

Tetsuo Takahashi

Senior Research Engineer, Photonic Transport Network Laboratory, NTT Network Innovation Laboratories.

He received the B.S. and M.S. degrees in physics from the University of Tokyo, Tokyo in 1989 and 1991, respectively. In 1991, he joined NTT Transmission Systems Laboratories, Yokosuka, Kanagawa, Japan. In 1991, he began researching submarine optical fiber communication systems. In 1997 he worked on the development of high-speed SDH ring systems. Since 1998, he has been engaged in research on WDM and photonic network systems. He received the NTT President's Award in 2000. He is a member of IEICE.