PLC Components Used in FTTH Access Networks

Yasuyuki Inoue†, Motohaya Ishii, Yasuhiro Hida, Masahiro Yanagisawa, and Yoshitaka Enomoto

Abstract

NTT is the first company in the world to actively install fiber-to-the-home (FTTH) access networks. Silica-based planar lightwave circuits (PLCs) are widely used as key devices for constructing FTTH access networks because they are compact, mass-producible, and highly reliable. This article reviews PLC devices for FTTH access networks.

1. Silica-based PLCs in FTTH access networks

The NTT Group has announced its plan to provide optical access to 30 million customers by 2010 as part of its medium-term management strategy. It is now actively developing the access networks, which employ a broadband/gigabit Ethernet passive optical network (B/GE-PON) [1], which is an economical system where an optical transceiver in a central office called a B/GE optical line terminal (B/GE-OLT) is shared among up to 32 customers, and a stable reliable system is constructed solely with passive devices outside the central office and the customer's home.

The B/GE-PON system is shown in **Fig. 1**. The system is composed of a B/GE-OLT, an optical splitter inside the central office, several optical splitters outside the central office, a B/GE optical network unit (B/GE-ONU) inside each customer's home, and optical fiber lines that connect these components. Up- and downstream data communication uses light with wavelengths of 1.31- and 1.49-µm, respectively. In addition to providing this bidirectional data communication, the B/GE-PON can also broadcast video data using 1.55-µm light. A video-OLT (V-OLT) and a video-ONU (V-ONU) are located in parallel to the B/GE-OLT and B/GE-ONU using WDM (wavelength division multiplexing) filters. NTT has developed an automatic optical fiber line monitoring system called AURORA [2] to maintain the high reliability of the optical access networks. It is composed of an optical testing module and optical couplers both located inside the central office, and an optical fiber termination filter located at the customer's home. The optical testing module is composed of an optical time domain reflectometer (OTDR) and an optical fiber switch to select an optical subscriber line. An OTDR test pulse can be coupled into the optical subscriber line by a wavelength-insensitive coupler (WINC) and used to monitor the optical subscriber line.

We have been developing silica-based planar lightwave circuits (PLCs) for twenty years. They have several advantages: they are compact because they are integrated circuits, have good mass-producibility because they are fabricated using photolithography and reactive ion etching which were mainly developed as LSI processes, and they have high reliability because they are composed of extremely stable silica glass. The optical splitter, WINC, and WDM filter have been developed through the use of silica-based PLCs, and some of these devices have already been installed in commercial systems.

2. Optical splitter for PON

NTT's optical access networks use both 1 × 4 and 1 × 8 optical splitters [3]. They are installed inside the central office and in closures or cabinets near customers' homes to enable the B/GE-OLT to be used

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

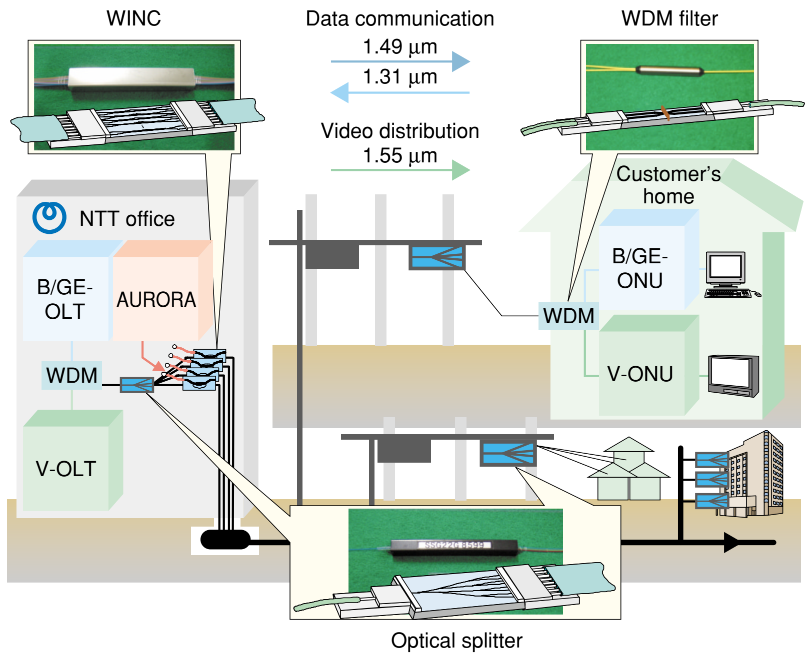


Fig. 1. Configuration of FTTH system.

efficiently. The B/GE-PON system provides broadband service to up to 32 customers by combining these 1 × 4 and 1 × 8 optical splitters. The optical splitters located outside the central office must be highly reliable. Moreover, compactness and mass-producibility are necessary. Silica-based PLCs satisfy these requirements. The silica-based PLCs and optical fibers are directly connected with UV-curable adhesive (UV: ultraviolet light), and the long-term stability of the connection has been confirmed [4]. This lens-free butt-joint connection lets us provide simple, compact, and mass-producible optical modules. The splitter module is only 4 mm × 4 mm × 40 mm.

As shown in **Fig. 2(a)**, the optical splitter is formed by arranging several Y-branches in series. The optical loss spectra for a 1 × 8 optical splitter module are shown in **Fig. 2(b)**. Very uniform and flat spectra are obtained for wavelengths from 1.2 to 1.7 µm. The insertion loss is less than 10 dB including an intrinsic dividing loss of 9 dB. This loss uniformity and flat wavelength response is a feature of the PLC splitter.

This excellent optical splitter developed in NTT is one of the fundamental technologies that let us construct the first commercial B/GE-PON system in the world.

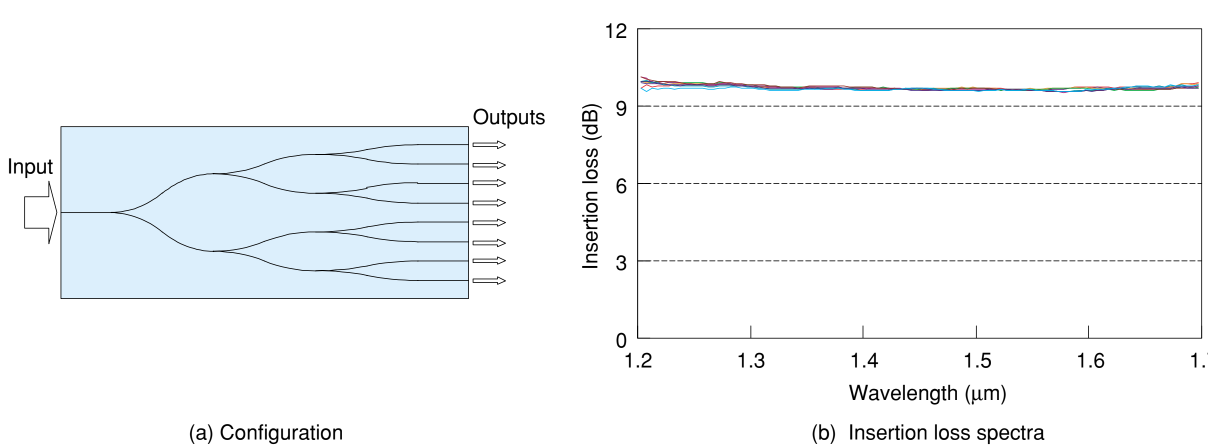


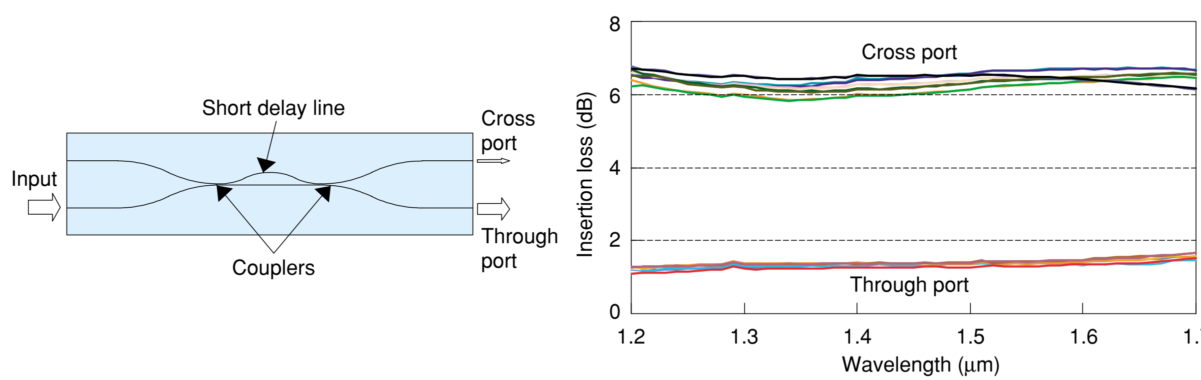
Fig. 2. Configuration and optical performance of 1 × 8 PLC splitter.

3. WINC for optical line monitor

The fiber monitoring system AURORA monitors the time-dependent reflection of a short optical pulse. The pulse generated by the testing module is coupled into an optical subscriber line via the WINC to monitor the line. The WINC is used to couple not only the test pulse but also the optical communication signal. Therefore, its coupling ratio should be insensitive to the wavelength. Its wavelength insensitivity is attained by combining two directional couplers with different coupling ratios and a short delay line of less than 1 µm, as shown in **Fig. 3(a)** [5]. Although the conventional directional coupler has strong wavelength dependence, the WINC achieves wavelength insensitivity by canceling out the wavelength dependence of the two directional couplers with a phase mismatch induced by the short delay line. The wavelength response of a 16-channel integrated WINC is shown in **Fig. 3(b)**. The wavelength dependence is successfully suppressed and the spectra are flat. As this example shows, a PLC can utilize the wave nature of light. A WINC is also superior in terms of compactness, and an 8- or 16-channel WINC can be integrated on a single chip.

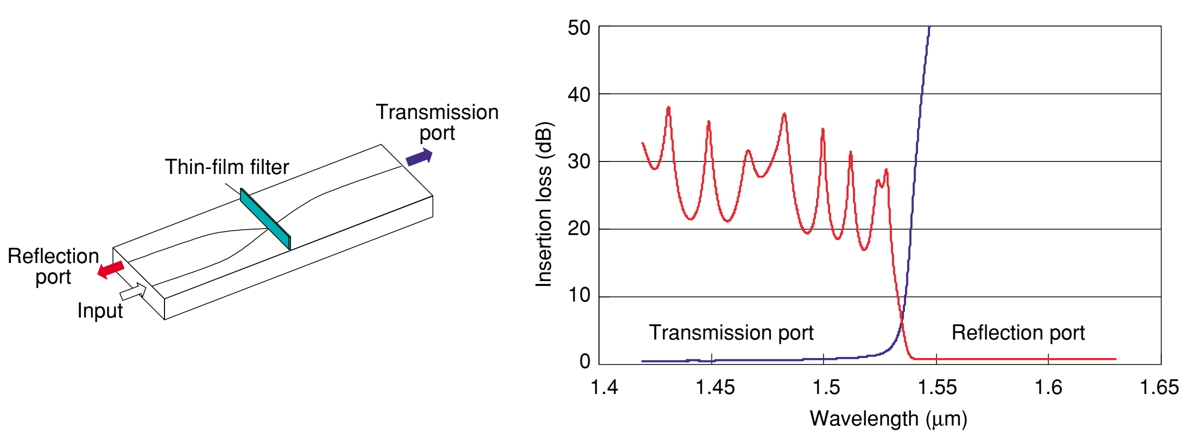
4. WDM filter for video distribution

The B/GE-PON can provide a video distribution service as well as bidirectional data communication by using a different wavelength band. A WDM filter is used to multiplex/demultiplex video distribution and data communication signals. The WDM filter in each customer's home must be both inexpensive and compact. The configuration of the WDM filter and its wavelength spectra are shown in **Fig. 4**. The WDM filter consists of intersecting waveguides and a thin-film filter located in a groove formed at the intersec-



(a) Configuration of a WINC (b) Insertion loss spectra of 16-channel WINC

Fig. 3. Configuration and optical performance of 16-channel WINC.



(a) Configuration (b) Wavelength spectra

Fig. 4. Configuration and optical performance of WDM filter for video distribution.

tion. The insertion loss increases with the filter thickness, so this circuit employs a thin-film filter based on a polyimide substrate [6], instead of a glass substrate, because it allows a much thinner filter: 5 µm compared with 100 µm for glass. In the intersecting waveguide, diffraction in the thin-film filter is suppressed by enlarging the spot size by using a tapered waveguide [7]. This suppression of diffraction is effective in achieving a sharp roll-off spectrum. As a result, a low loss of less than 1 dB and a sharp spectrum are obtained as shown in **Fig. 4(b)**. A WDM filter using a PLC is simple and can be constructed with a small number of elements, so it is superior in terms of compactness and cost.

5. Next-generation optical devices

Various kinds of PLC-based optical devices that can flexibly meet system requirements are being investigated. One example is an optical splitter incorporating a WDM function as shown in **Fig. 5** [8]. Another is an athermal arrayed-waveguide grating (AWG) wavelength multiplexer whose center wavelength is independent of temperature [9], which means it does not need an electricity supply.

A PLC can utilize the wave nature of light and achieve high functionality. PLCs can be readily designed on a personal computer, and their fabrication and assembly technologies are well established. Their long-term stability has also been confirmed. Therefore, PLC technologies enable highly functional devices to be developed quickly and inexpensively.

6. Future development

Optical devices for the access networks are used under uncontrolled conditions and their acceptable size is limited. Therefore, they must be both highly reliable and compact. Moreover, they must be inexpensive because the cost cannot be shared among many customers in the same way that the cost of the trunk line can. We will continue to develop optical devices based on PLCs and thus contribute to the development of the optical access networks.

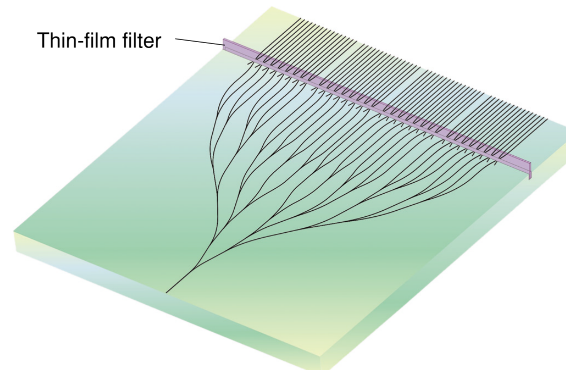


Fig. 5. Configuration of PLC splitter incorporating WDM function.

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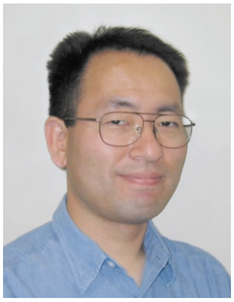
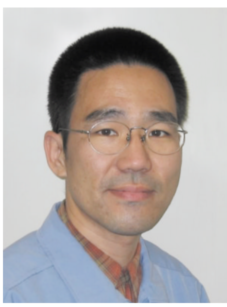


Yasuyuki Inoue
Group leader, NTT Photonics Laboratories.

He received the B.E., M.E., and Ph.D. degrees in electronics engineering from Kyushu University, Fukuoka in 1987, 1989, and 1998, respectively. He joined NTT in 1989. Since then he has been engaged in research on silica-based PLCs. From 1998 to 1999, he worked at Photonic Integration Research Inc. (PIRI) in Ohio, USA and was engaged in the commercialization of silica-based PLC devices such as AWGs and optical splitters. He is a member of IEEE and the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Masahiro Yanagisawa
Senior Research Engineer, NTT Photonics Laboratories.

He received the B.E. and M.E. degrees in electronics engineering from Shizuoka University, Hamamatsu, Shizuoka in 1986 and 1988, respectively. He joined NTT in 1988. Since then he has been engaged in research on silica-based PLCs. He is a member of IEICE.

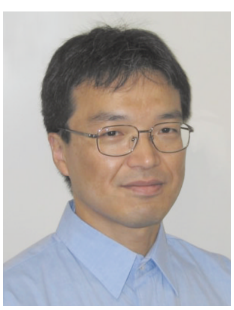


Motohaya Ishii
Senior Research Engineer, NTT Photonics Laboratories.

He received the B.E. degree in electronics and the M.E. degree in information system from Kyushu University, Fukuoka in 1989 and 1991, respectively. He joined NTT in 1991. Since then he has been engaged in research on silica-based PLCs. He is a member of IEICE.

Yoshitaka Enomoto
Research Engineer, NTT Access Network Service Systems Laboratories.

He received the B.E. degree in electrical engineering from Meiji University, Kawasaki, Kanagawa in 1992. He joined NTT Telecommunication Field Systems R&D Center (now NTT Access Network Service Systems Laboratories) in 1992. He has been engaged in R&D of an optical fiber line testing system and an optical fiber distribution system for central offices. More recently, he has been engaged in work on a compact optical splitter for outside plant. He is a member of IEICE.



Yasuhiro Hida
Senior Research Engineer, NTT Photonics Laboratories.

He received the B.E. and M.E. degrees in electronics engineering from Osaka University, Suita, Osaka in 1987 and 1989, respectively. He joined NTT in 1989. Since then he has been engaged in research on PLCs. He is a member of IEICE and the Japan Society of Applied Physics.