12E4-1 (Invited)

Compact ROADM devices based on PLC technology

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Abstract

This paper reviews recent progress on compact ROADM devices based on planar lightwave circuit (PLC) technology. These compact devices with high levels of optical performance are very attractive for constructing metro-WDM systems at reduced cost.

1. Introduction

Recently the demand has been growing for increased transmission capacity on the metro infrastructure, and thus a large number of carriers and multiple systems operators (MSOs) are deploying WDM systems with fixed and reconfigurable optical add/drop multiplexing (ROADM) functions in their optical networks. Such metro WDM systems should be realized compactly and inexpensively to reduce capital expenditure (CAPEX) owing to the limited number of regional network subscribers.

Since the ROADM function is composed of many optical functions such as WDM filtering, switching, variably attenuating and power monitoring, the most attractive way to make ROADM systems more compact is to integrate these functions into a single package [1-6]. Single-package multi-function modules also enable WDM system suppliers to reduce the cost of complex board design and the reliability testing of individual optical modules as well as the system assembly cost including fiber splicing and electrical soldering. This paper reviews recent progress on such compact ROADM devices based on planar lightwave circuit (PLC) technology. PLC technology enables us to realize a variety of compact ROADM devices whatever their channel number and functions.

2. Comparison of PLC integration techniques

Table 1 summarizes the characteristics of the PLC integration technique for multi-function PLC devices. The conventional integration technique involves connecting different optical elements by using optical fibers. With this technique, fiber splicing and routing increase not only the module size but also the cost of the fiber elements and their assembly. The second integration technique involves the direct bonding of different PLC chips [2-4]. Since most of the fiber splicing and routing can be eliminated, this technique makes the devices very compact especially when a large number of optical functions are integrated. Note that, since this connection is based on the same technique as fiber-PLC bonding, the reliability is sufficient for actual applications such as ROADM devices. The final goal of integration is to realize all the optical functions on a single PLC chip. In this case, except for input/output fiber connections, optical connection with optical fibers is totally unnecessary, which means that optical connection loss can completely be eliminated and optical connection reliability is reinforced. On the other hand, since all the optical elements are fabricated simultaneously on a single wafer, a high quality optical waveguide fabrication process is needed to maintain a good PLC chip yield. Then, in practice, a suitable integration technique is adopted for ROADM devices after taking optical architecture, channel number and detailed specifications into consideration.

	Discrete assembly	Multi-chip direct bonding integration	Single chip integration
Simplicity of optical connection	Fair	Good	Excellent
Smaller packaging	Fair	Good	Excellent
Reliability improvement vs. discrete assembly	–	Good	Excellent
Yield of optical connection vs. discrete assembly	–	Good	Excellent
Yield of PLC chip	Excellent	Excellent	Fair

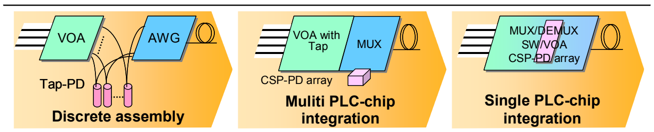

Table 1 Comparison of PLC integration techniques

3. Wavelength selective switch (WSS) based on multi-chip direct bonding technique

The WSS is a key device for a multi-degree hub node, which connects plural ROADM ring networks with optical transparency. Currently, WSS modules employ micro-electro mechanical system (MEMS) technology [7]. However, the MEMS-based WSS package becomes thicker because of the use of bulk optics. Therefore, we developed a PLC-type 1 x 4 WSS module with a thinner package by utilizing planar optics [3]. This module can be applied to a 4-degree hub node.

Figure 1 shows the configuration of the 1x 4 WSS module with 100 GHz spacing and 32 channels. To realize this function, we needed 5 arrayed waveguide gratings (AWGs), a 32 channel 4 x 1 switches switch array with

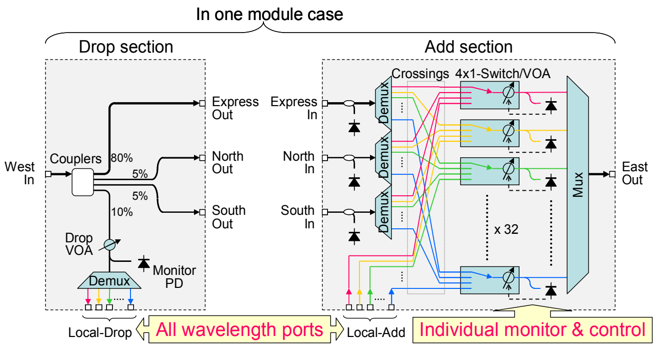

Fig.1 Schematic diagram of PLC-based 1 x 4 WSS module.

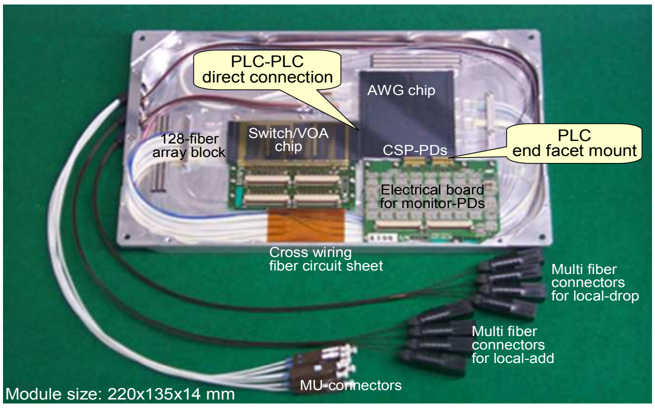

Fig.2 Photograph of PLC-based 1x4 WSS module

a VOA function and 32 channel monitoring PDs in a single package. Also, if we use the single chip PLC integration technique, we have to lay out a large number of optical waveguide crossings, and thus the optical loss of the device increases due to light scattering at the crossing section. Therefore, we utilized the multi-chip direct bonding technique by dividing these functions into three parts, namely the AWGs, the switches with a VOA function and the cross wiring fibers as shown in Fig. 2. Hermetically sealed chip-scale package PDs (CSP-PDs) were attached to the AWG chip edge for optical power monitoring. As a result, we achieved a compact PLC-type WSS device with a package size of 220 x 135 x 14 mm. The package thickness is less than half that of a conventional MSA type variable optical attenuator multiplexer (V-AWG).

In addition to the thin package, this module has many advantages in terms of actual use compared with the MEMS-type WSS. They are a local add/drop capability for the full wavelength range, hitless operation and channel monitoring. On the other hand, the insertion losses are almost twice of that of a MEMS-type WSS. However, use of the low loss AWGs will improve the optical performance to the same level as that of the MEMS-type WSS [8]. The PLC-based WSS will then be a promising solution for metro ROADM systems.

4. Small V-AWG device based on single chip integration technique

Several single chip ROADM devices have been demonstrated, and they all provide the excellent compactness of single chip integration, which eliminates the need for fiber connecting different optical functions [5, 6, 9 10]. On the other hand, the chip sizes of all the devices are still large because they use conventional 0.8% Δ waveguides [5, 6, 9] and 1.5% Δ waveguides [10]. Then we demonstrated a small V-AWG device by using a

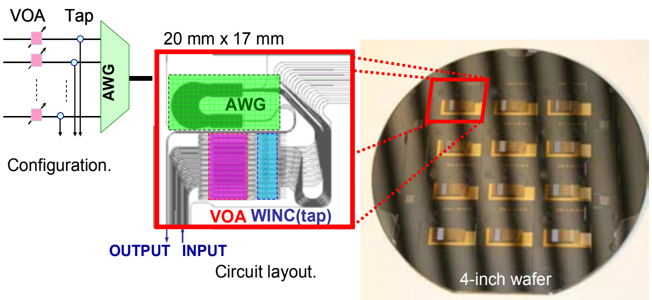

Fig.3 Configuration, circuit layout and photograph of 16 ch V-AWG

2.5% Δ waveguide. Since this waveguide can strongly confine the transmitted light in its core region, we can increase waveguide density and reduce the chip size compared with conventional ROADM devices [5, 6, 8, 9].

Figure 3 shows the circuit configuration, waveguide layout and a photograph of a fabricated 4-inch wafer of a 100 GHz 16 channel V-AWG with 2.5% Δ waveguides. The use of the 2.5 %Δ waveguide reduced the chip size to 20 x 17 mm, and as a result, 12 circuits can be fabricated on a 4-inch wafer. Figure 4 shows the transmission spectra with different attenuation levels. The insertion loss including single-mode fiber coupling at 0 dB attenuation is only 5 dB in spite of use of the 2.5 % Δ waveguide. This low loss transmission is realized by using a tolerance-relaxed narrow laterally tapered spot-size converter (SSC), which can be practically and easily adapted to 2.5 % Δ PLCs [12].

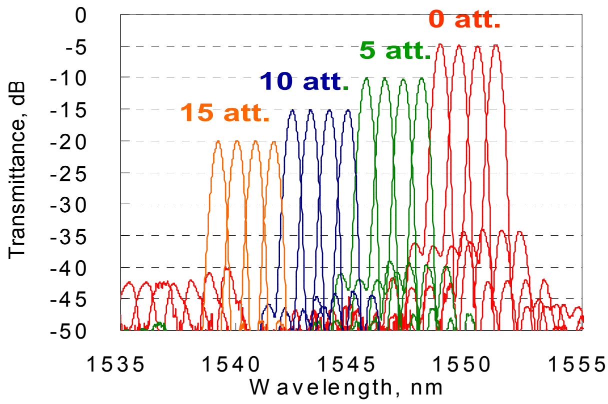

Fig.4 Transmission spectra of 16 ch V-AWG

5. Summary

We demonstrated that both the multi-chip bonding and single chip integration techniques are very attractive and practical ways to construct various PLC-based ROADM devices with a compact size at reduced cost. These PLC devices are indispensable for WDM systems for metropolitan areas.

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