Multichannel Optical Coupling Technique and Its Application to a SIPAS Module

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Abstract

We propose a novel multi-channel optical coupling technique called MOCA (multichannel optical coupling with an aspherical lens) to simplify the packaging of opto-electronic functional devices whose optical I/O ports are arrayed optical waveguides. MOCA uses only an aspherical lens to couple an optical waveguide array to an optical fibre array. In spite of its simplicity, MOCA provides efficient optical coupling for each optical I/O port and high performance for module reliability.

To evaluate the performance of MOCA, we applied it to an all-optical wavelength converter chip known as a SIPAS (Sagnac interferometer integrated with parallel amplifier structure), which will be a key device in near-future WDM networks. The fabricated module, which has a coupling loss of less than 3.5 dB per I/O port, acts as an all-optical wavelength converter for 10-Gbit/s RZ optical signals.

1. Introduction

The recent exponential growth of communication traffic due to the deployment of multimedia and the Internet is creating a demand for higher network throughput. Wavelength division multiplexing (WDM) is an effective way to raise network throughput and it is spreading widely. In the present WDM network, the optical layer is mainly responsible for signal transmission. Signal processing, such as path routing, multiplexing, and demultiplexing, is done electrically in the network node system after optical-to-electrical (O/E) conversion. Further improvements in network throughput require the development of electronic network nodes and management systems whose capacities are much larger than present ones. For lower power consumption, all-optical signal processing is far superior to large-capacity electronic systems. Therefore, the development of all-optical signal processing modules will be important for large-capacity WDM optical networks. In spite of the need for such modules, progress in their development has been relatively slow. One of the major difficulties in packaging these devices is the lack of a highly reliable, cost-effective multichannel optical coupling technique.

We have developed a technique called MOCA, which stands for multichannel optical coupling with an aspherical lens, and clarified its performance [1]. MOCA provides a simple, low-loss, and cost-effective multichannel optical coupling system. It has been applied to the packaging of an all-optical wavelength converter module consisting of a Sagnac interferometer monolithically integrated with a parallel amplifier structure (SIPAS) [2]. Successful wavelength conversion was achieved using a SIPAS module with MOCA.

2. Development of MOCA

2.1 Concept

To date, two optical coupling techniques have mainly been used in assembling multichannel optical modules:

(a) Direct butting of the optical fibre array aligned on V-grooves and optical device array [3], [4] and

(b) Multichannel optical coupling using a micro-lens array [5].

The optical coupling configurations for these techniques are shown in Figs. 1(a) and (b), respectively. The former is cost effective, but not appropriate for the above-mentioned devices because of its relatively

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large coupling loss and hermetic sealing problems. The latter has sufficient coupling efficiency and reliability for all-optical signal processing modules, but its assembly process is complex and the array requires highly uniform lens properties.

MOCA was designed to solve these problems. A typical optical coupling configuration of MOCA is schematically shown in Fig. 2. In this figure, the optical device has 4-channel waveguides as optical I/O ports whose spot diameter and pitch are S µm and L µm, respectively. These waveguides are coupled to a 4-ch single-mode fibre (SMF) array with a 250-µm pitch by an aspherical lens whose magnification is M. The values of M and L are simply determined by

$$S \times M = 10 \text{ (spot diameter matching)} \quad (1)$$

$$L \times M = 250 \text{ (array pitch matching).} \quad (2)$$

The spot shape of a rectangular waveguide is usually elliptical. The effective spot diameter of the rectangular waveguide is estimated approximately by

$$S_{eff} = (\varepsilon_l \times \varepsilon_s)^{1/2}, \quad (3)$$

where ε_l and ε_s are the major and minor axes of the ellipse, respectively. S_{eff} is used instead of S in the design of MOCA for a rectangular waveguide array.

As one can see in Fig. 2, MOCA can cope with hermetic sealing as well as the insertion of an optical isolator, which are both essential for a highly reliable high-performance optical module. In addition, the assembly process with MOCA is almost the same as that for ordinary laser transmitter modules. These advantages make MOCA a simple, reliable, and cost-effective multichannel optical coupling technique.

2.2 Optical coupling performance of MOCA

We measured the coupling efficiency of MOCA for a 4-ch waveguide array whose S_{eff} was designed to be 2 µm. We also estimated the coupling efficiency by a ray-tracing simulation. In the measurement and simulation, M and L were 5 and 50 µm, respectively; an aspherical lens whose cross sectional diameter and thickness were 1.8 and 1.3 mm, respectively, was used; and the ratio of $\varepsilon_l/\varepsilon_s$ was 2. The aspherical lens and waveguide were located at the optimum positions.

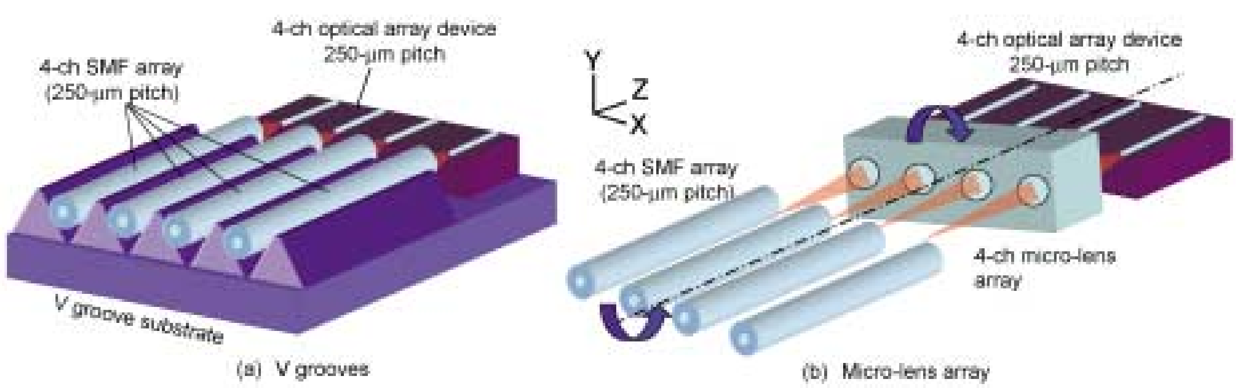

Fig. 1. Conventional multichannel optical coupling techniques.

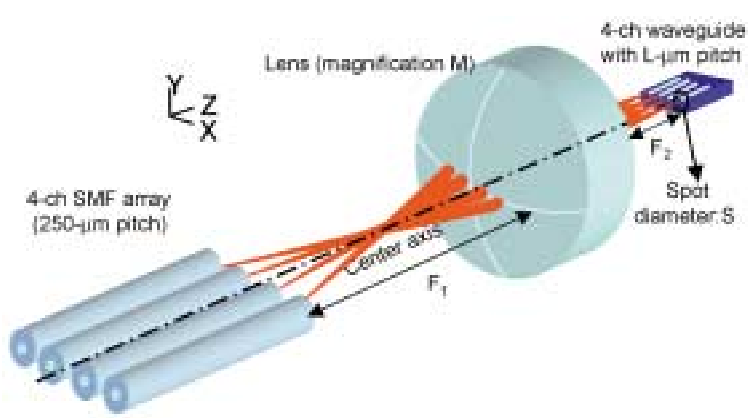

Fig. 2. Concept of MOCA.

The measured coupling losses for each channel of the SMF array are plotted in Fig. 3 along with the simulated coupling loss curves. The horizontal axis indicates the mis-alignment of the 4-ch SMF array from the optimum position. We think the deviation of the simulation results from the measured values is caused by S_{eff} differing from the design value. That is to say, S_{eff} was actually larger than 2 µm and the projected spot diameter on the optical fibre cross-sectional surface was larger than 10 µm. This mismatch in spot size causes excess coupling loss around the optimum position. On the other hand, the increase in coupling loss due to the misalignment was more gradual than in the simulation because of the large projected spot diameter. Therefore, we checked the S_{eff} value of each waveguide as follows. Each channel of the 4-ch waveguide array was coupled with an SMF through the same aspherical lens as mentioned above. The relationship between coupling losses and M is shown in Fig. 4. The minimum coupling loss was obtained at around M of 4.3. This indicates that S_{eff} of the 4-ch waveguide array is 2.3 µm.

In spite of the spot-size mismatch, each 4-ch SMF can be coupled with the corresponding waveguide with high efficiency (less than 2.5-dB coupling loss) at the optimum position. The coupling loss deviation among the four channels was suppressed to less than 0.7 dB. These results show that MOCA is a promising technique for multichannel optical coupling.

2.3 Expandability of MOCA

The optical coupling losses of MOCA for an 8-ch waveguide array with 50-µm pitch were measured at the optimum position (Fig. 5). The measurement was done using the same configuration as mentioned above. In this figure, the horizontal axis indicates the distance between each waveguide channel and the central axis of the lens. The coupling losses increased with distance because both the lens aberration and photon incident angle increase with distance from the central axis. If the threshold coupling loss is set at 4 dB, MOCA can be applied to a waveguide array with at most six channels. This means that a waveguide array with at most 12 channels with 25-µm pitch can be coupled with a 12-ch SMF array with 125-µm pitch in the MOCA configuration. Further expansion of waveguide channels requires a larger lens diame-

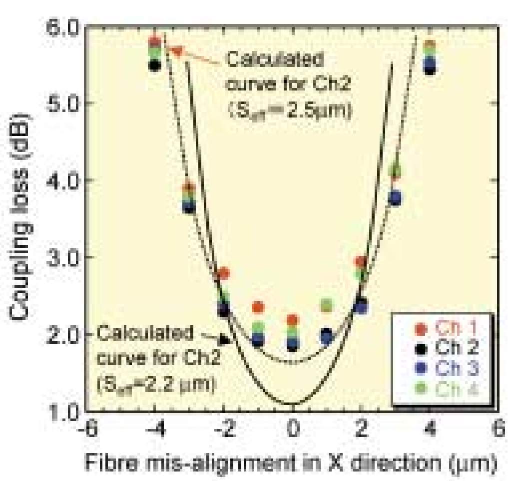

Fig.3. Measured and calculated coupling losses of MOCA.

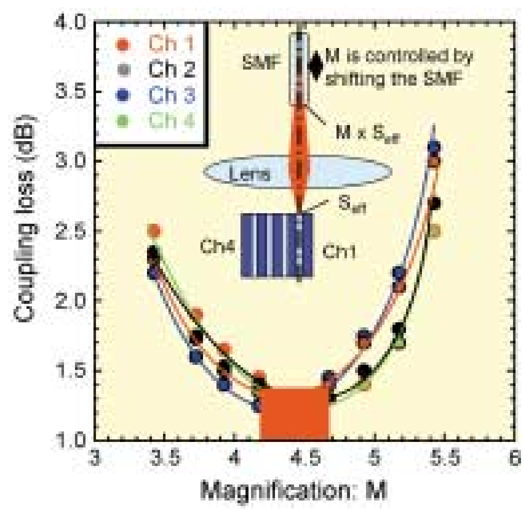

Fig. 4. Relation between coupling loss and magnification M.

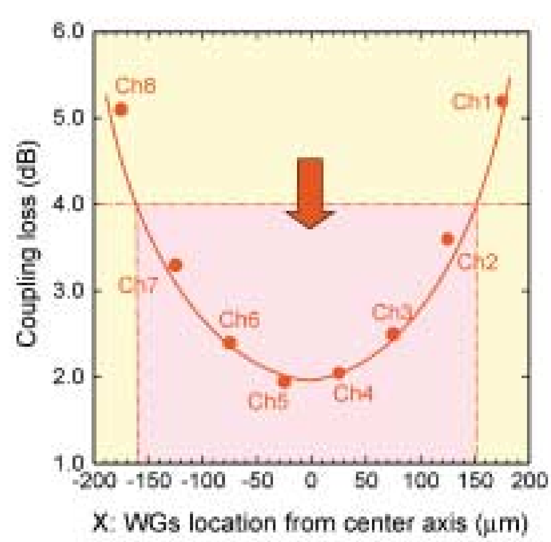

Fig. 5. Coupling losses of MOCA for an 8-ch waveguide array.

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3. Application of MOCA to SIPAS packaging

The MOCA configuration was applied to an all-optical wavelength converter, or SIPAS, having 3-ch optical waveguide I/O ports.

3.1 Structure of the SIPAS chip

Figure 6 is a photograph of the fabricated SIPAS chip. SIPAS is a Sagnac interferometer with a parallel amplifier structure (PAS) consisting of a Mach-Zehnder interferometer (MZI) having polarization insensitive semiconductor optical amplifiers (SOAs) in each arm. It was fabricated monolithically by butt-coupling the high mesa and buried waveguides [2]. Tensilely strained bulk InGaAsP was used for the SOA active layer. The fabrication process is briefly as follows: after 0.1%-tensile-strained SOA active layer growth, 0.5-μm-thick InGaAsP core (λg = 1.05 μm) and 1.0-μm-thick InP cladding layers were butt-joined. Next, the SOA stripe was dry etched, and embedded by a p-n blocking layer and p-doped InP cladding layer. Then, the p-n blocking layer and p-doped InP cladding layer, which were grown over the passive region, were removed to reduce the propagation loss of the passive waveguide. Finally, high-mesa passive waveguides composing the Sagnac and Mach-Zehnder interferometer were fabricated by Br_2-N_2 reactive beam etching [6]. The propagation loss of the high-mesa passive waveguide is about 5 dB/cm. The coupling loss between the SOA and passive regions is about 1 dB, including the active-to-passive coupling loss. The SOA is 900 μm long and the total chip size is 4.5 mm × 1.5 mm. The working principle of our device is similar to that of the SLALOM [7]. An input CW light is divided into clockwise (CLW) and counterclockwise (CCW) traveling lights. Since the PAS is asymmetrically placed in the loop, these lights reach the SOAs at different times, which leads to different phase modulation (DPM) [8] between them when the signal light is input into the SOAs. After traveling around the loop, the CLW and CCW lights are superimposed and transmitted to the output port by means of DPM. We placed the PAS asymmetrically by 0.5 mm so that the switching window due to DPM was about 10 ps, which enables high-speed operation at over 10 Gbit/s. As the PAS is set in the cross state, the signal light cannot enter the loop, resulting in filter-free wavelength conversion.

3.2 Performance of the SIPAS module

A photograph and schema of the module are shown in Fig. 7. The module is compact and has a volume of 1.6 cm^3 (8.2 mm long, 16 mm wide, and 12 mm high). Among the 3-ch waveguide I/O ports, conversion output and pumping input ports are located on the same edge of the SIPAS chip. The effective spot diameters of these two ports were designed to be 2.5 μm. MOCA was used for their coupling. In order to achieve efficient optical coupling, the magnification of the aspherical lens was determined so as to make the spot size of the waveguide around 10 μm in diameter; as a result, it was 4. Then the pitches of the waveguide and SMF arrays were designed to be 62.5 and 250 μm, respectively. After assembling the SIPAS module, we evaluated the actual coupling losses and obtained 3.2 and 3.4 dB. The excess coupling losses are mainly caused by a post-welding shift of the SMF array and the lens after the YAG laser welding process and by spot size mismatch.

To evaluate the performance of the SIPAS module, we performed a wavelength conversion experiment

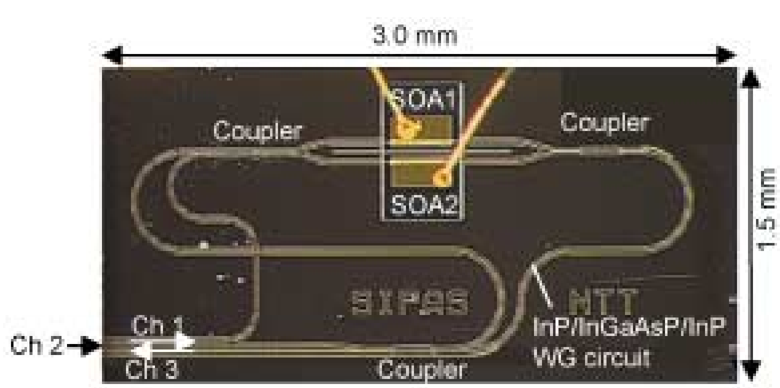

Fig. 6. Photograph of a SIPAS chip.

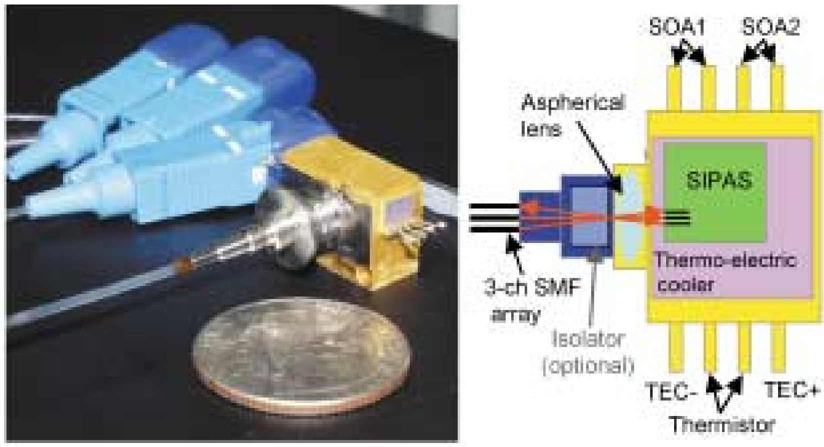

Fig. 7. Photograph and schema of the SIPAS module with MOCA.

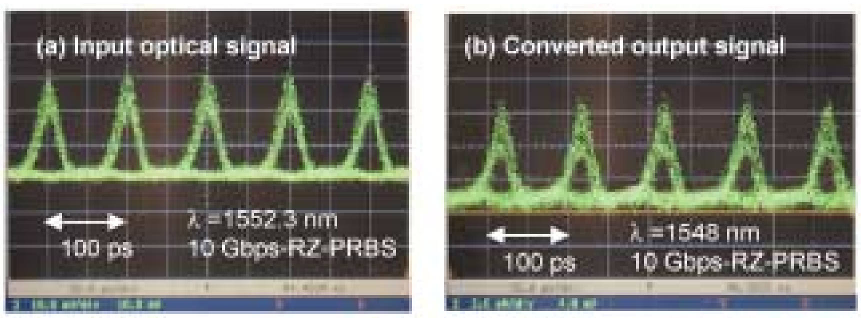

Fig. 8. Eye diagrams. (a) Input signal (1552. 3 nm), (b) Conversion output (1548.0 nm).

using a 1552.3-nm 10-Gbit/s RZ-PRBS input signal and a 1548.5-nm continuous-wave pumping input. The results are shown in Fig. 8. The wavelength of the output optical signal was successfully converted to 1548.5 nm.

4. Conclusion

MOCA (multichannel optical coupling with an aspherical lens) is a simple, low-loss, cost-effective multichannel optical coupling technique. It has been applied to the assembly of an all-optical wavelength converter (or SIPAS) module. The assembled module successfully provides wavelength conversion. This indicates that MOCA is a promising packaging technique for optical functional modules that have multiple optical I/O ports.

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