Development of High-Power Stable PLC-Type Pump Combiner

by Koji Seo *, Mitsuhiro Iwaya *, Masato Shiino * and Kanji Tanaka *2

ABSTRACT A PLC-type pump combiner has been developed, which is capable of multiplexing for 15 wavelength channels between 1410 and 1510 nm, thereby making it applicable to Raman amplifiers and high-power optical amplifiers for dense wavelength division multiplexing (DWDM) systems. Our device has a narrow spectral pass-band spacing of 1 THz, and a total insertion loss below 2.0 dB. Both input and output connections between PLC and fibers are physical contact (PC) with a mechanically transferable (MT) connector-like structure and are adhesive free in the optical path, so they show good stability for a high input power more than 1.2 W.

1. INTRODUCTION

The capabilities of optical communications networks have been increased rapidly with the progress and introduction of wavelength division multiplexing (WDM) technology in the past several years. There has been a slowdown in higher speed and greater capacity trunk lines for networks recently, because of the influence of the recession due to over-investment and the collapse of the IT-market in North America; however, taking a long and global view, it is certain that the volume of communications traffic will increase, and construction of optical networks which has stopped is expected to accelerate if a broader band access network becomes popular.

By having all optical signals in the gain bandwidth of an erbium-doped fiber amplifier (EDFA), WDM technology has been successful so far. On the other hand, EDFAs with a larger number of wavelengths necessitates higher pumping power [1), 2)]. In addition, the Raman amplifier, which operates outside the EDFA bandwidth, has recently been drawing attention. Although Raman amplifiers were researched in the 1970s, practical application was abandoned because several hundred mW of pumping power were required at that time. However, new proposals for practical application are emerging as high-power pumping sources have improved along with the improvement of EDFAs. The gain wavelength band is determined by the energy level of erbium ions in EDFAs, whereas it is determined by the wavelength of pumping light in Raman amplifiers [3)]. This makes it possible to amplify any desired wavelength simply by selecting the appropriate pumping wavelength.

Therefore, the gain bandwidth can be broadened in a way that is not achievable with EDFAs by broadening the bandwidth of the pump using WDM [4), 5)].

In Raman amplification, around the 1500 nm band, gain is produced at approximately 110 nm on the long wavelength side, so if the pumping unit is multiplexed around 1450 nm to have a broad bandwidth of 100 nm, Raman amplification also occurs in a broad band of 100 nm around 1560 nm. Moreover, it is possible to make the gain even flatter by increasing the number of pumping wavelengths.

Meantime, the high-power durability of optical devices around the optical amplifiers is an important problem. For example, when an optical power as high as several hundred mW is input, the end-face of the optical connector is sometimes damaged if there is contamination on it, due to optical absorption of the contamination [6)], and when a device has a connection using adhesive, it also absorbs the optical power, heats up the device, and sometimes lowers its performance. In this paper, we report the development of a high-power stable PLC-type pump combiner, which is capable of multiplexing for 15 wavelength channels between 1410 and 1510 nm, thereby making it applicable to Raman amplifiers and high-power optical amplifiers for DWDM systems.

2. PLC-TYPE PUMP COMBINER

2.1 Configuration

Figure 1 shows the appearance of the 15-wavelength PLC-type pump combiner developed.

The small size of 10(W)×8(H)×130(L) mm is realized using an integrated wavelength multiplexer applying silica-based planar lightwave circuit (PLC) technology, which is connected to two ribbonized 8-fibers at the input port and with a 0.25 mm fiber at the output port.

Figure 2 is a schematic illustration of the PLC used in this device. Fourteen Mach-Zehnder-interferometers (MZI)

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are fabricated on a silicon substrate, and channel spacing is designed approximately 7 nm from 1410 to 1510 nm, which provides a flat gain for Raman amplification.

Using this device can make the composition of a Raman amplifier simpler, less expensive, and more compact than using multilayered dielectric thin film filters or fused fiber couplers, because we use only one multiplexer to integrate all wavelengths [7)-9)].

2.2 Demands for High-Power Durability

Figure 3 shows one of the high-power pumping units (HPU) for a Raman amplifier. Generally, PLC is connected to fibers arrayed on a V-groove using adhesive after their alignment to lower the connection losses [10)]. However, a connection using adhesive cannot withstand a high power above 200 mW, because optical absorption of adhesive or connection loss leads to the connection heating and losses. Nowadays, the power of 1480 nm band laser diodes (LD) for HPU is reaching as high as about 300 mW, so input multi-channels of this PLC-type pump combiner should be guaranteed for 600 mW considering that two LDs may be multiplexed by a polarization beam combiner (PBC). Polarization multiplexing of LDs is designed to increase pumping unit output, as well as to suppress the polarization dependence of Raman gain. The output single channel of this combiner should be guaranteed for 3 W under present conditions, because all LDs are not always used at maximum power, but at the power that makes the gain flat for Raman amplification.

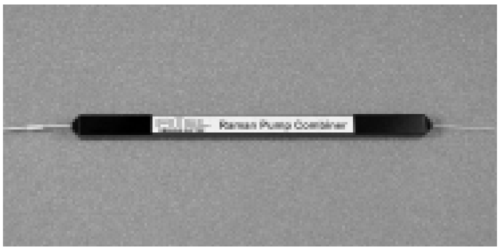


Figure 1 Appearance of 15-wavelength PLC-type pump combiner.

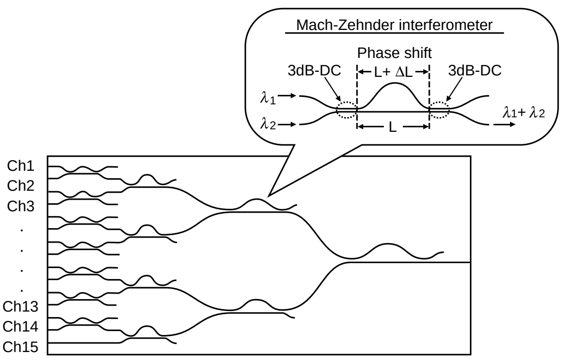


Figure 2 Schematic illustration of 15-wavelength PLC.

3. STRUCTURE

Both input and output connections of this PLC-type pump combiner are made of a PC with a MT connector-like structure, with adhesive-free optical path, and low losses. So, this pump combiner shows good stability at a high input power. Figure 4 shows the structure of a 15-wavelength PLC-type pump combiner. Each end of 15×1 PLC fits with a MT-compatible ferrule, which has two guide holes. They are assembled at a precise position decided by V-grooves formed in both of them, and this can make the connection loss lower. A MT ferrule with a single mode fiber is coupled with the output single channel, and a MT ferrule with fifteen single mode fibers is coupled with the input multi-channel. Using guide pins, they are connected with passive alignment like the connections of a MT connector. Figure 5 shows the cross-section of the connection between the waveguide device and a MT connector. The input multi-channel side and the output single channel side have the same structure. The end-face of the MT connector is specially polished so that the fibers protrude slightly, and both end-faces of the waveguide device and MT connector are polished at an angle of 8 degrees. The PC is realized by mating them with a clip.

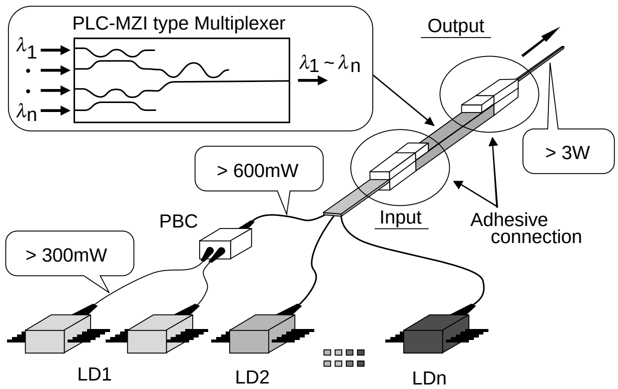


Figure 3 HPU for Raman amplifier.

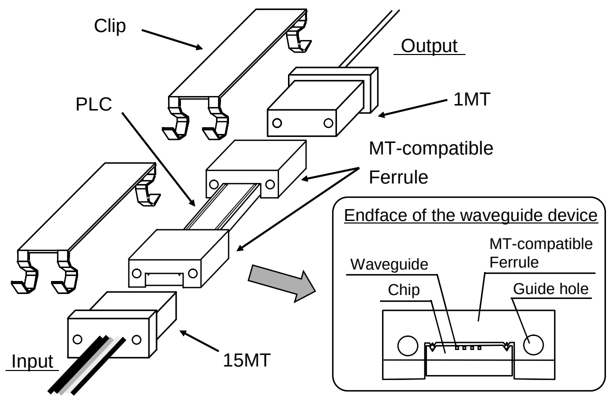


Figure 4 Structure of 15-wavelength PLC-type pump combiner.

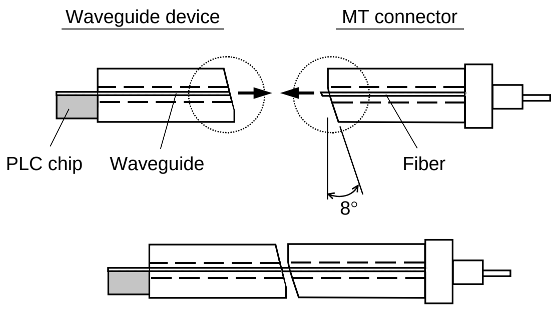


Figure 5 Cross-section of the connection.

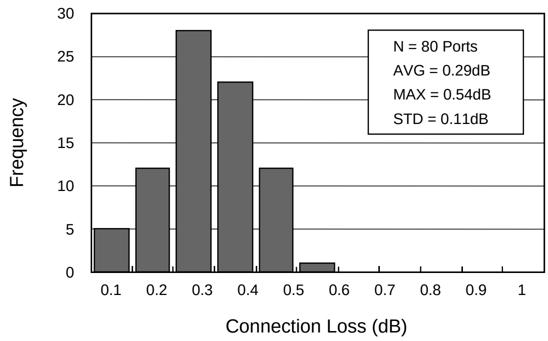


Figure 7 Connection loss without index-matching.

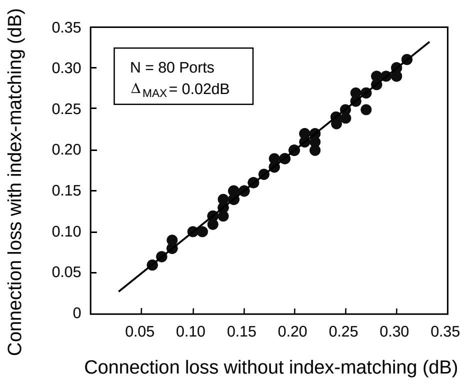


Figure 6 Test of physical contact (PC).

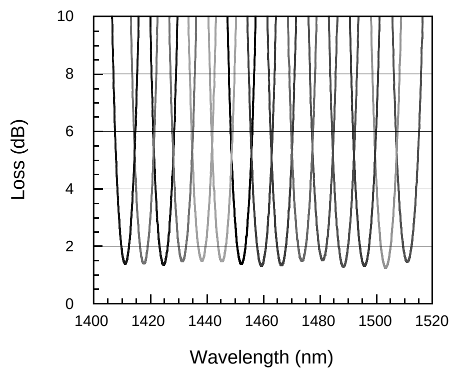


Figure 8 Loss spectrum of a PLC-type pump combiner.

4. OPTICAL PROPERTIES

4.1 Test of Physical Contact

As stated above, except for adhesive, having no contamination is also important for a connection under high power conditions. However, this can be prevented by thorough inspections during the manufacturing process. In the case of this device, it is most significant that multi-reflection for insufficient PC might heat the device or lead to the destruction of the fiber end-faces. So, all fiber-to-waveguide PC must be inspected. Suitably designing the configurations of both the waveguide device's and the MT connector's end-face, the clip achieves the quality shown in Figure 6. Figure 6 shows the correlation between the connection losses without and with low-viscosity index-matching oil that is dropped on the input end of the device. If PC is incomplete and there is a microscopic space between the mated cores, dropped oil fills the space and reduces the connection loss. However, the loss reduction may be regarded as zero, so PC is completely achieved with these devices.

4.2 Connection Loss

Under high power conditions, connection loss also becomes one of the causes of lower device quality. Because the loss of optical power is changed into thermal energy, it heats the device to a temperature that is above the heat-resistance of the material and leads to greater loss changes when the connection loss is large. So, the target loss was set below 0.3 dB, considering the heat-resistance of the epoxy resin that makes up the ferrules. Figure 7 shows the measured values of connection loss. It was 0.29 dB on average and 0.54 dB at maximum without index-matching including two connection losses generated at the input/output ends of the device.

Then, the value can be reduced by half to be 0.15 dB on average and 0.27 dB at maximum at a single end, which is low enough to attain the target loss.

4.3 Loss Spectrum

Figure 8 shows the loss spectrum of a 15-wavelength PLC-type pump combiner. The insertion losses are approximately 1.5 dB at all channels, so it bears comparison with the losses multiplied by fifteen wavelengths with several multilayered dielectric thin film filters. Besides, all channels achieve high return losses larger than 50 dB.

5. RELIABILITIES

5.1 Mechanical and Environmental Characteristics

Table 1 shows the mechanical and environmental characteristics under normal power based on Telcordia GR1209-CORE or Telcordia GR1221-CORE. Loss changes were all below 0.2 dB, and peak wavelength shifts were all within 0.2 nm during the tests.

5.2 High-Power Durability

We also examined high-power durability based on our guideline [11]. The tests were carried out with more than

Table 1 Results of reliability test.

Category	Test	Criteria	Status
Telcordia GR1209-CORE	Temperature-humidity cycling	Loss change < 0.2 dB Wavelength change < 0.2 nm	Pass
	Temperature-humidity aging		Pass
	Vibration		Pass
	Impact		Pass
	Cable retention		Pass
Telcordia GR1221-CORE	Temperature cycling		Testing
	Damp heat		Testing

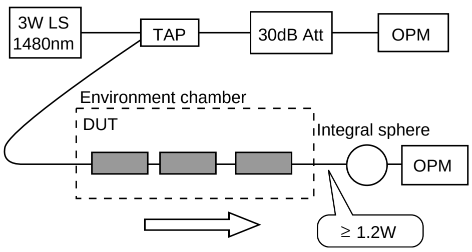


Figure 9 Setup for high-power tests.

Table 2 High-power durability.

Category	Test	Criteria	Status
High-power durability ≥1.2 W	Room-temperature	Loss change < 0.2 dB Wavelength change < 0.2 nm	Pass
	Temperature-humidity cycling Telcordia GR1209-CORE		Pass
	Temperature-humidity aging Telcordia GR1209-CORE		Pass
	Temperature cycling Telcordia GR1221-CORE		Testing
	Damp heat Telcordia GR1221-CORE		Testing

1200 mW, which is twice (= 3 dB up) the required maximum rating of 600 mW of each input multi-channel. Moreover, a long-term reliability test was carried out under accelerating conditions with self-heating and dump-heat. Figure 9 shows the setup for the high power tests. Three samples were daisy chain connected and confirmed for more than 1200 mW at the output end using a calorie meter. Table 2 shows the results for high-power durability. Loss changes during the tests were all below 0.2 dB, and long-term tests are under evaluation. They are making good progress for insertion loss change under a high-power input, 85°C/85%RH, as shown in Figure 10.

To guarantee the 3 W durability of the output single channel connection, we also evaluated them at 3 W for ten minutes as a trial, and we observed a small temperature rise. Figure 11 is a thermo-viewer observation at 3 W input power. Although the observed sample had comparatively high loss connections, the temperature change was

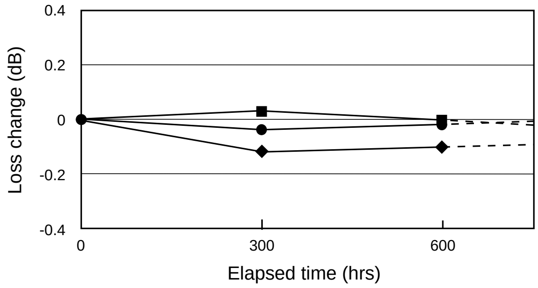
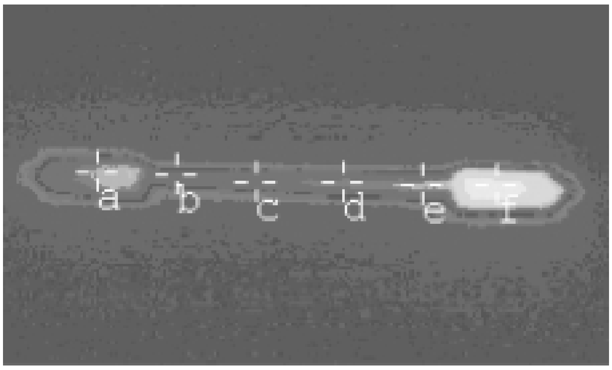


Figure 10 Insertion loss change under high-power input, 85°C/85%.



	a : Input port	f : Output port
Connection loss	0.37 dB	0.72 dB
Room temp.	24.5 °C	24.5 °C
Temp. under 3 W	31.0 °C	33.0 °C
Temp. change	+6.5 °C	+8.5 °C

Figure 11 Thermo-viewer observation at 3 W input power.

within 10°C. This result indicates the stability of this sample at 3 W input power, although long-term tests should be carried out.

6. CONCLUSION

We developed a high-power stable 15-wavelength PLC-MZI pump combiner for 1480 nm band pumping for Raman amplifiers. The low-loss connection and new PC technique for 15 ports between fibers and PLC have improved high-power durability. We evaluated the input multi-channel connection of more than 1200 mW to guarantee a 600 mW and output single channel connection at 3 W as a trial, and will evaluate the output connection at 6 W for a guarantee of 3 W. We expect no failures to occur, considering that the temperature change at 3 W input power was small.

Finally, we can also develop an 8-wavelength PLC-MZI pump combiner for Raman amplifiers, which is the same structure as that of 15-wavelength.

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