Production Engineering of Polarization Beam Combiner

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ABSTRACT A Polarization beam combiner has been developed, which is capable of doubling the output power of semiconductor pumping lasers by way of polarization multiplexing, thereby making it applicable to Raman amplifiers and high-power optical amplifiers for DWDM (Dense Wavelength Division Multiplexing) systems. The combiner has high reliability since its mechanical parts are high-strength welded using a YAG laser and also no adhesives are used in its optical paths. By optimizing optical parts characteristics and optical coupling, a broad bandwidth ranging from 1410 nm to 1580 nm has been realized together with a low insertion loss of 0.2 dB on average.

1. INTRODUCTION

At the beginning of the 1990s, the Internet that had been developing in North America showed an explosive growth worldwide thus requiring even greater capacity of optical fiber transmission lines. To deal with this requirement, fiber-optic telecommunications technologies including, in particular, erbium-doped fiber amplifier (EDFA) that was put into practical use at about the same period were applied to increase the transmission capacity. Fortunately, the gain bandwidth of EDFAs is comparatively wide, so that wavelength division multiplexing (WDM) using all the optical signals included in this wavelength band was identified as a method superior to time division multiplexing (TDM), and was rapidly implemented.

Optical amplification that comprises the core of WDM technology started from 1550 nm, where gain flattening is easily accomplished, but soon spread to the 1530-nm band and has recently been employed in the 1580-nm band, where the small gain coefficient had made it impracticable. Since wider gain bandwidth with larger number of wavelengths necessitates higher pumping power, EDFAs of these days increasingly require pumping sources of higher output power because of the above-mentioned movement toward wider bandwidth and more channels.

In addition, Raman amplifier that operates outside the EDFA bandwidth is recently drawing attention. In the Raman amplifiers the gain bandwidth is determined by the wavelength of the pumping light, making it possible to amplify any desired wavelength simply by selecting the appropriate pumping wavelength. Although much research was done in the 1970s to take this advantage, practical application was abandoned because several hundred milliwatts of pumping power was required at that time. As high-power pumping sources have improved along with the improvement of EDFAs, however, a new outlook for practical application is emerging. Recent research has identified such advantages unattainable with EDFAs as low noise and wide bandwidth in amplification, so that development activities aimed at practical application are accelerated together with a keen competition for developing pumping light sources of higher output power.

Furukawa Electric has been developing, since the early days of optical communication, pumping laser modules (LDMs) as pumping light source, and is now capable of supplying the world's top ranked products with an output power of as high as 300 mW. Moreover, we have developed wide bandwidth, high-power pumping units (HPUs) with an output power exceeding 1W using silica glass planar light circuitry (PLC), thus contributing a great deal to the practical application and development of optical communication technology.

This paper reports on the development and engineering technology of polarization beam combiner (hereafter called PBC) of low insertion loss and wide bandwidth, which are capable of obtaining, in an easy and cost-effective manner, an optical output power of 500-mW class by polarization multiplexing the outputs of LDMs having polarization maintaining optical fibers.

2. STRUCTURE AND PERFORMANCE OF PBC

A PBC is basically structured, with reference to Figure 1, such that two polarized beams that are input through two polarization maintaining fibers --PMF1 and PMF2-- are polarization multiplexed using birefringent crystal into an output single mode fiber --SMF. The end facet on the module side of each fiber is antireflection (AR) coated and

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is provided with an aspherical lens, making the diverging beams from the fiber ends parallel in shape. A beam-separating element is used to secure the distance between PMF1 and PMF2. All mechanical parts are high-strength welded using a YAG laser eliminating any adhesive on the optical paths. Figure 1 shows the appearance of a PBC module.

2.1 Application

Figure 2 illustrates an application of PBC for the DWDM amplifier. The 1480 nm pumping lights from LDMs are polarization multiplexed by a PBC and the multiplexed light beam with built-up power is fed to a backward pumping unit (BPU). The BPU is incorporated with a high pass filter (HPF) which reflects pumping lights ranging from 1450 nm to 1500 nm and transmits signal lights ranging from 1520 nm to 1570 nm, so that the pumping light is reflected by the HPF into an EDF (erbium-doped fiber) while the signal light amplified by the EDF is transmitted through the BPM.

2.2 Comparison with Different PBCs

Some manufacturers use polarization beam splitter (PBS) in their PBC products as a polarization-multiplexing element and these products are commercially available. The PBS is known for its easy and low-cost manufacturing method such that the long side of a right-angled triangle prism is deposited, and the prism is bonded with the long side of another prism using organic adhesive. Generally speaking, however, the PBC using a PBS has a narrow transmission bandwidth. In addition, such a PBC has low reliability in terms of optical power rating since it is likely to be damaged, when an optical power of as high as several hundred mW is input, due to optical absorption of the bonding adhesive or burning of foreign inclusions contained during manufacturing. Moreover, there is fear that the insertion loss might increase due to deflection of collimated beam, which sometimes occurs unless the characteristics and thickness of the bonding adhesive are controlled with extreme preciseness to avoid uncontrollable displacement of the prism caused by temperature changes.

We use, in contrast to this, birefringent crystal with small wavelength dependence and low absorption for the PBC products, taking into consideration future high-power applications including Raman amplifiers. Figure 3 schematically compares the structures of PBCs that use birefringent crystal and PBS.

3. SPECIFICATIONS

We have designed a PBC considering the conditions of wide bandwidth for Raman amplifiers and low insertion loss for efficient pumping together with requirements for higher power handling capability. Subsequently, performance deviation and yield rate were calculated based on trial production so as to determine the product specifications as shown in Table 1.

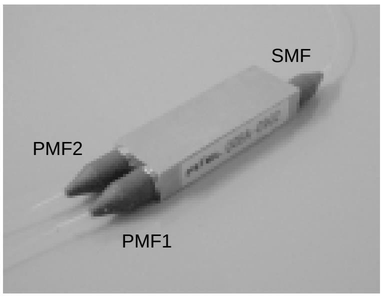

Figure 1 Appearance of polarization beam combiner

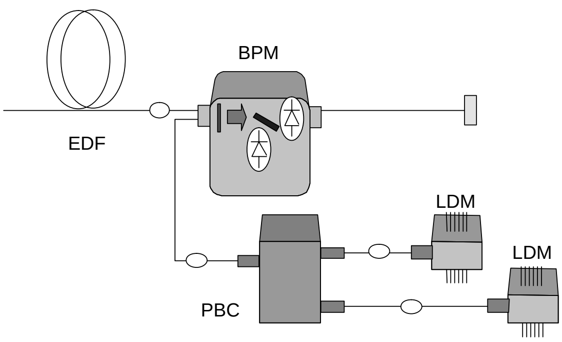

Figure 2 Schematic diagram of erbium-doped amplifier, an application of PBC

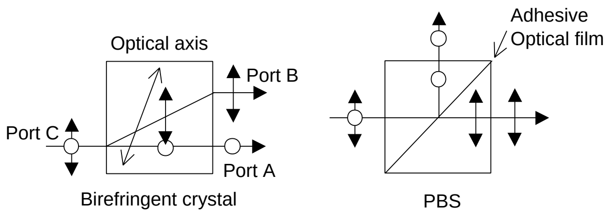

Figure 3 Schematic structures of PBCs using birefringent crystal and PBS

Table 1 Specifications of PBC

Item	Input / Output port	Criteria	Measured value (Average)
Insertion loss	Port A to C	<= 0.5 dB	0.18 dB
	Port B to C		0.22 dB
Extinction ratio	Port A	>= 17 dB	29 dB
	Port B		28 dB
Reflection loss	Port A,B,C	>= 45 dB	56 dB
Allowable input power	Port A,B,C	< 600 mW	1 W
Dimensions	L33×W11×T6 (mm)		

λ= 1410-1580 nm

4. PRODUCT PERFORMANCE

Every item of product performance is described below based on the evaluation of 800 PBC products that have been consecutively manufactured.

4.1 Insertion Loss

Port A in Figure 3 corresponds to the port designated as PMF1 in Figure 1. A polarized beam entering this port is adjusted to be an ordinary ray in the beam-combining crystal, while another polarized beam enters port B or PMF2 to be an extraordinary ray so that the combined beam exits from port C equipped with an SMF. Figure 4 shows the histogram of insertion loss, where the beam entering port B that passes the beam-separating element is seen to have an averaged insertion loss 0.04 dB greater due to wave front distortion and the AR coat.

4.2 Temperature Characteristics of Insertion Loss

Judging from the purpose of its application, it is very likely that PBC devices are placed near to the LDM in device arrangement. Accordingly, appropriate care should be taken to make the device performance least influenced by the heat emitted by the LDM, while not only PBCs but also all components to be used in optical amplifiers are required to be checked, before shipping, for the loss changes due to temperature. Figure 5 shows the histogram of the insertion loss changes, i.e., the differences between the maximum and the minimum losses measured in the storage temperature range of between -40°C and 85°C. All products showed an insertion loss change of 0.15 dB or less at the operating temperature range of between 0°C and 65°C. This loss change due to temperature presumably results from refractive index changes of optical materials and fixed position changes of optical elements including the beam collimating mechanism.

4.3 Reflection Loss

Figure 6 shows the histogram of reflection loss changes for all ports consisting of ports A, B and C. The measured values fully meet the specifications and it turned out that little influence was seen when the measuring wavelengths were changed.

4.4 Extinction Ratio

Extinction ratio is one of the most important items that ought to be degradation free since it is directly related with insertion loss increase. Accordingly, the PBC module is manufactured using a production line equipped with a special light source and a phase-controlling algorithm for adjustment so that a high extinction ratio is attained in a short time. Figures 7 and 8 show the histogram of extinction ratios for ordinary ray (designated as n_o) and extraordinary ray (designated as n_e), respectively. The performance of ordinary ray is slightly better in terms both of averaged value and variance since the ray does not pass the beam-separating element.

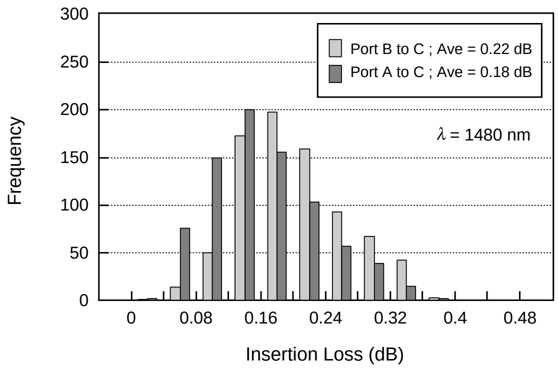

Figure 4 Histogram of insertion loss

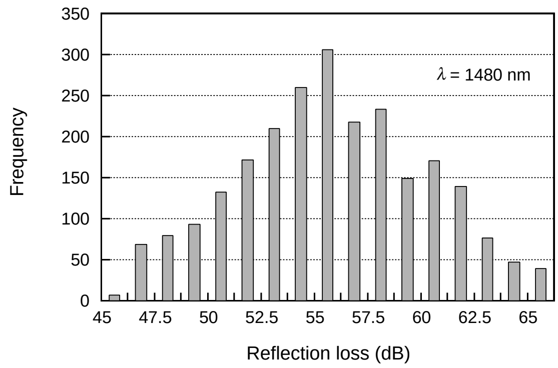

Figure 6 Histogram of reflection loss

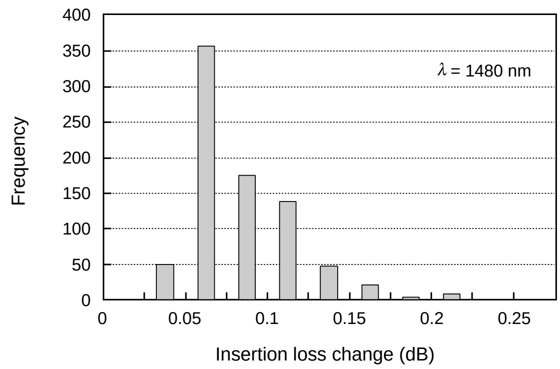

Figure 5 Histogram of insertion loss change due to temperature

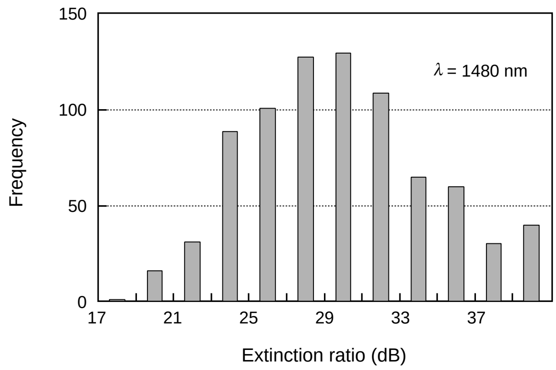

Figure 7 Histogram of extinction ratio for ordinary ray (n_o)

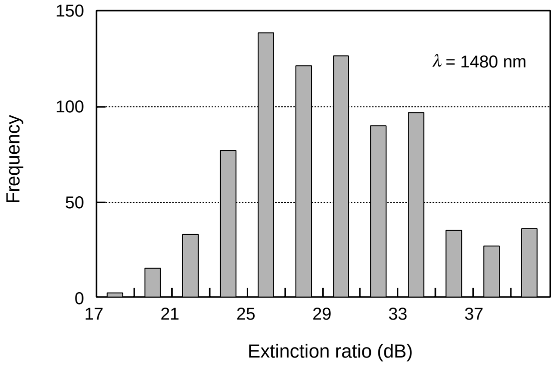

Figure 8 Histogram of extinction ratio for extraordinary ray (n_e)

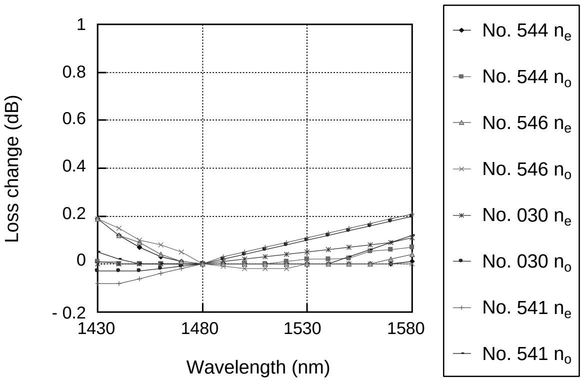

Figure 9 Wavelength characteristics of insertion loss for selected PBCs

4.5 Wavelength Characteristics of Insertion Loss

The wavelength characteristics of transmission are rather flat as shown in Figure 9, while a small gradient can be seen around a wavelength of 1480 nm probably resulting from the dispersion of glass material parameters. Thus, the insertion loss can be minimized when module assembly is done at a wavelength for use.

5. RELIABILITY

Table 2 shows the results of Bellcore 1221 tests including, at the bottom, those of fiber pulling tests under Bellcore 1209 which are essential for evaluating the reliability of fiber termination. Needless to say, all products passed Bellcore 1209 tests.

6. CONCLUSION

We have developed and put into the marketplace a polarization combiner which is provided with high reliability, compactness, wide bandwidth and ultra-low insertion loss. The product is expected to contribute a great deal to multiplexing of pumping powers for Raman amplifiers along with upgrading the output power of optical amplifiers for DWDM systems.

Table 2 Results of the Bellcore 1221 and 1209 tests

Heading	Test	Criteria	Status
Mechanical integrity	Mechanical shock	± 0.2 dB	Passed
	Vibration		Passed
	Thermal shock		Passed
Endurance	High temp storage		Passed
	Damp heat		Passed
	Low temp storage		Passed
	Temperature cycling		Passed
Fiber termination (1209)	Side pull		Passed
	Cable retention		Passed

ACKNOWLEDGMENTS

The substance of this paper belongs to the achievements of the members of Functional Optical Components Group and Optical Components Department of FITEL Products Division, and has been compiled by the authors who represent these members. The authors would like to thank the members of Optical Equipment Department and Optical Communication Material Research Group in addition to Dr. Shii, Senior Staff Researcher at the Yokohama Laboratories, Mr. Fukazawa, General Manager of the FITEL-Photonics Laboratory and Mr. Miyazawa, Manager of WP Team for their helpful advice and kind cooperation during the development.

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Manuscript received on December 14, 2000.