Subminiature Micro-Optic Devices with Mini Quartz-Rod-Lens

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In order to miniaturize micro-optic devices, we have developed a novel mini quartz-rod-lens collimator by using plasma-activated chemical vapor deposition (PCVD) method and CO_2 laser splicing technology. By employing these collimators, roughly 90% volume reduction has been achieved in micro-optic devices compared with conventional ones.

1. Introduction

Since the late 1990's, wavelength division multiplexing (WDM) technologies have been introduced to the optical communication networks in order to accommodate the rapid increase of demand for data communications. Recently, the WDM technologies have been expanding to metropolitan and access networks.

In this paper, we will introduce the newly developed micro-optic devices[1)] which are the key components for WDM systems.

2. Micro-Optic Devices

Micro-optic devices such as dielectric-thin-film-type gain flattening filter (GFF), pump/signal combiners for optical amplifiers, and mux/demux modules have been widely used in optical communication networks. In the application of micro-optic devices to metropolitan and access networks, further downsizing and cost reduction of the devices have been strongly required.

A structure of a general micro-optic device is shown in Fig. 1. An optical functional element is placed between two collimate lenses. On one end surface of the collimate lens, the optical fiber is connected. This type of device has the ability to achieve the various optical performances by changing only the optical functional element. An example of an optical functional element is the thin film filter or the optical isolator core.

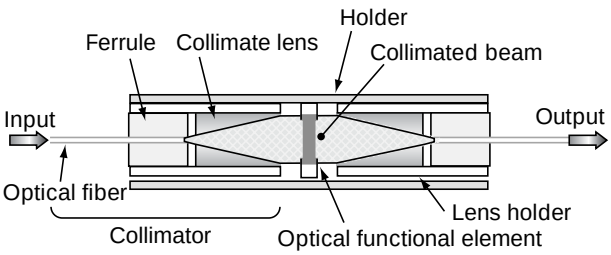

Fig. 1. Structure of a Micro-Optic Device.

A collimator is an optical component, which is composed of a collimate lens and an optical fiber connected together. Its functions are collimating a diverging beam from the fiber face, and focusing the collimated beam into an optical fiber.

In order to miniaturize the micro-optic device, it is essential to develop a smaller collimator. Upon development of the smaller collimator, smaller optical functional element could be used for micro-optic device. As a result, the miniaturization and cost reduction of micro-optic device are successfully achieved.

3. Mini Quartz-Rod-Lens Collimator

3.1 Design of the Mini Quartz-Rod-Lens

Downsizing of the collimate lens is necessary in miniaturizing micro-optic devices. However, there is a problem that the collimated beam diameter becomes smaller with reduction of the diameter of the lens. The working distance (WD), which beam can reach without suffering effect of diffraction, shortens with decreasing diameter of the collimated beam. Fig. 2 shows the well-known relationship between collimated beam diameter and WD. We have to take into consideration this relationship in order to design the optimized beam diameter. Dimension-wise, such as thin

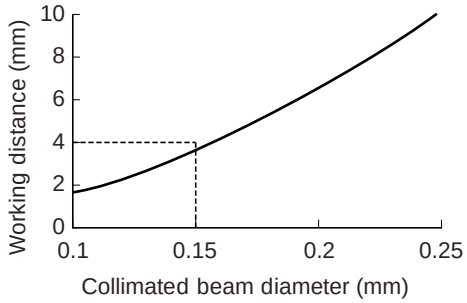

Fig. 2. Relationship between Collimated Beam Diameter and WD.

film filter elements or isolator core used in micro-optic devices, the WD is required to be from 3 to 6mm. From Fig. 2, we choose the beam diameter to be 0.15mm. Furthermore, taking account of the dual fiber collimator, which is needed for a WDM add/drop module, the effective lens diameter should be more than 0.25mm because the diameter of a general fiber is 0.125mm. With these calculated figures in mind, we designed the lens diameter to be 0.4mm.

Among the several types of lens used for collimate lens, such as gradient-index (GRIN) lens, ball lens, aspherical lens, etc, we chose the GRIN type lens from those types of the lenses. It has the distribution of the refractive index given from the following formula:

$$n(r)=n_0\left(1-\frac{A}{2}r^2\right)$$

n (r): Refractive index profile
n_0 : Refractive index at the center of a lens
A : Refractive index gradient constant
r : Radius

The refractive index decreases gradually from the lens center to outer.

3.2 Fabrication of the Mini Quartz-Rod-Lens Collimator

This time we have studied miniaturization and cost reduction of GRIN rod-lens by using optical fiber manufacturing technology. We chose the silica glass for the material of the lens and made a lens preform using PCVD method.[2] The PCVD method has excellent refractive index controllability required for fabrication of high performance rod-lenses. The refractive index profile of the lens preform is shown in Fig. 3. The preform is drawn down to a rod-lens with diameter of 0.4mm, in the same manner as optical fiber drawing. These rods are cut into pieces of targeted length. Fig. 4 shows the fabrication process of the mini quartz-rod-lens.

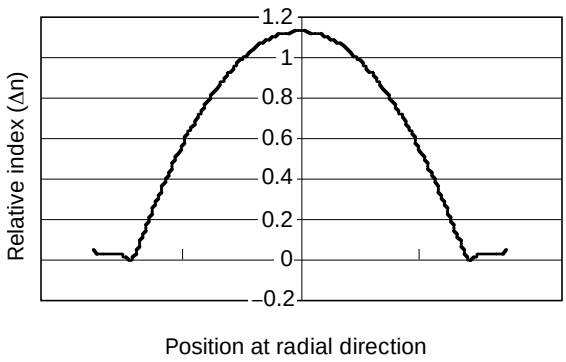

Fig. 3. Refractive Index Profile of the Lens Preform.

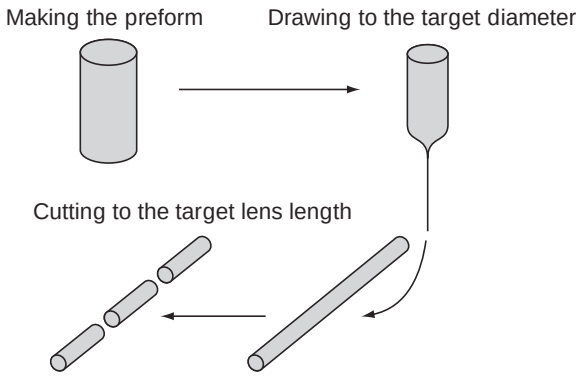

Fig. 4. Fabrication Process of the Mini Quartz-Rod-Lens Using Optical Fiber Manufacturing Technology.

The quartz-rod-lens has another great advantage over conventional collimate lenses. It can be fusion-spliced directly with an optical fiber because the lens material is the same as that of the fiber. We have developed a fusion splicing technology using CO_2 laser. Fig. 5 shows the photograph of the mini quartz-rod-lens collimator fusion-spliced to the optical fiber pigtail. Because no adhesive is used in the light path, the collimator has higher reliability and optical power durability than conventional ones. Furthermore, the AR coating on the surface of the fiber and the lens at the spliced point are not required. This simple structure of the collimator enables a lower manufacturing cost compared with conventional ones.

3.3 Packaging

The packaged mini quartz-rod-lens collimator is shown in Fig. 6. The size of the collimator is 6mm in length and 1.2mm in diameter. A metal sleeve is used to cover the spliced point and the quartz-rod-lens and low-melting-point glass is used to fix the lens in the metal sleeve. Adopting the low-melting-point glass

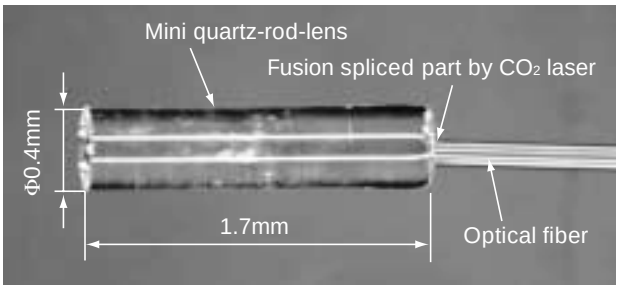

Fig. 5. Fusion Spliced Quartz-Rod-Lens Collimator with Pigtail Fiber.

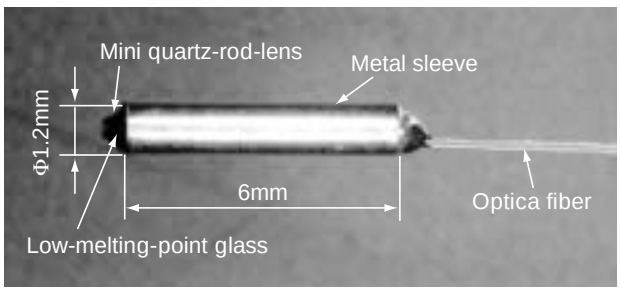

Fig. 6. Packaged Mini Collimator.

Table 1. Optical Characteristics of the Mini Collimator

Item	Result (N=110)
Insertion loss (dB)	0.19 (@1,550nm)(average)
Return loss (dB)	>50 (@1,550nm)

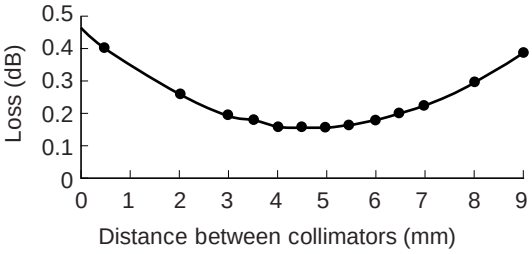

Fig. 7. Insertion Losses under the Various Distances between Lenses.

enables hermetic sealing of the collimator. One can easily realize a hermetically sealed optical device by using these collimators.

3.4 Optical Characteristics

Optical characteristics of the mini quartz-rod-lens collimator with a single fiber are listed in Table 1. The average insertion loss between two collimators is 0.19dB, which is low enough for practical applications. We measured the insertion losses at various distances between the lenses. The results are shown in Fig.7. In the region from 3 to 6mm, the insertion loss is less than 0.2dB. This is in good agreement with the designed value.

We have also developed a dual-fiber collimator that is used for three-port optical devices. The dual-fiber collimator has the same optical characteristics and reliability as the single-fiber collimator.

4. Subminiature Micro-Optic Devices

We have developed several subminiature micro-optic devices using the mini quartz-rod-lens collimators.

4.1 Subminiature Gain Flattening Filter

The structure of the subminiature GFF[3)] is shown in Fig. 8. The thin film filter and the mini quartz-rod-lens collimators are fixed to the holder with low-melting-point glass and solder respectively. Therefore, the device is hermetically sealed. This structure achieves highly reliable performance. The dimension of the GFF is 2.2mm in diameter and 25mm in length.

The subminiature GFF is shown in Fig. 9 together with a conventional GFF in comparison. We have achieved a 90% volume reduction.

Fig. 10 shows the insertion loss spectrum of a GFF. The peak-to-peak error function (difference between target and actual spectrum) is less than 0.40dB from –20℃ to 70℃. The thermal stability of insertion loss and wavelength shift is only 0.0002dB/℃ and

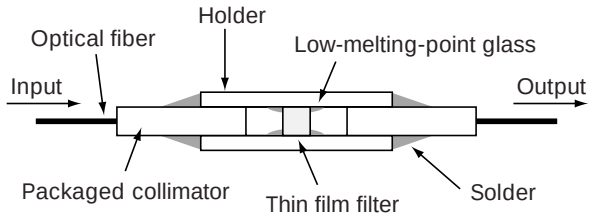

Fig. 8. Structure of the Subminiature GFF.

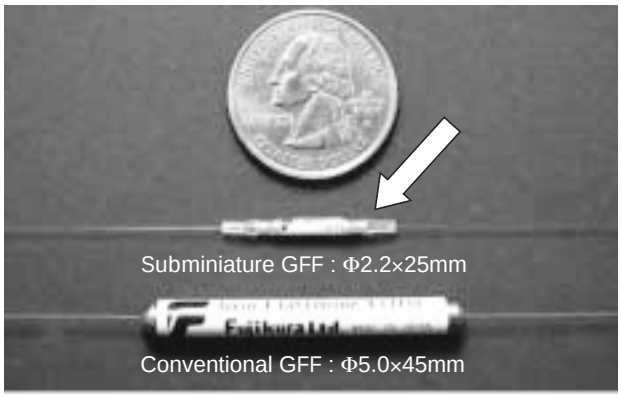

Fig. 9. Comparison of Subminiature GFF and a Conventional GFF.

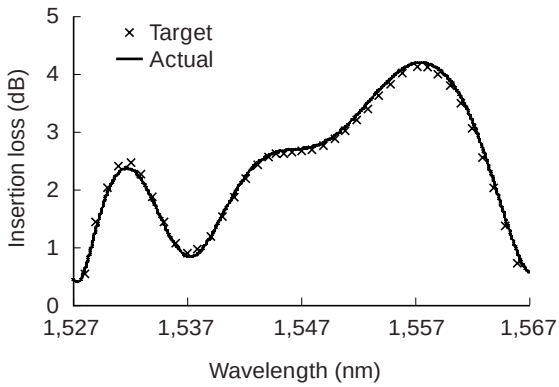

Fig. 10. Insertion Loss Spectrum.

Table 2. Results of High Power Test

Input power level (W)	0.25	0.5	1.0
Insertion loss variation (dB)	0.06	0.04	0.04

0.67pm/℃, respectively.

We have also carried out the high power durability test. The GFF was subjected to launched power of 0.25W, 0.5W, and 1W for 1 hour, each. The test results are shown in Table 2. The variation of the insertion loss was less than 0.1dB. The subminiature GFF has excellent high power durability.

The subminiature GFF has passed the environmental and mechanical reliability test based on Telcordia 1209 & 1221.

4.2 Subminiature Isolator

The subminiature isolator we developed has the

same structure as GFF. The dimensions of the isolator are 3.2mm in diameter and 24mm in length. The optical characteristics of the isolator are shown in Table 3.

4.3 Subminiature WDM Add/Drop Device

We have also developed a 1.48/1.55μm WDM add/drop device. Because this is a three-port device, a dual-fiber collimator is used on one side. The structure is shown in Fig. 11.

The thin film filter between the dual-fiber collimator and the single-fiber collimator is fixed to the holder with low-melting-point glass.

The optical characteristics of the 1.48/1.55μm WDM add/drop device are shown in Table 4 and in Fig. 12.

Table 3. Oprical Characteristics of the Isolator

Wavelength range (nm)	1,530–1,570
Isolation (dB)	41.9
Insertion loss (dB)	0.44
Return loss (dB)	>50
PDL (dB)	<0.1

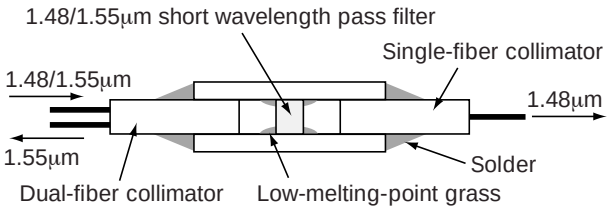

Fig. 11. Structure of the 1.48/1.55μm WDM Add/drop Device.

Table 4. Optical Characteristics of 1.48/1.55μm WDM Add/Drop Device

Insertion Loss (dB)	Reflect band (1.55μm)	0.38
	Pass band (1.48μm)	0.42
Isolation (dB)	Reflect band (1.55μm)	> 30
	Pass band (1.48μm)	> 15
Return loss (dB)		> 50
Directivity (dB)		> 55
Polarization dependent loss (dB)		< 0.1
PMD (ps)		< 0.1

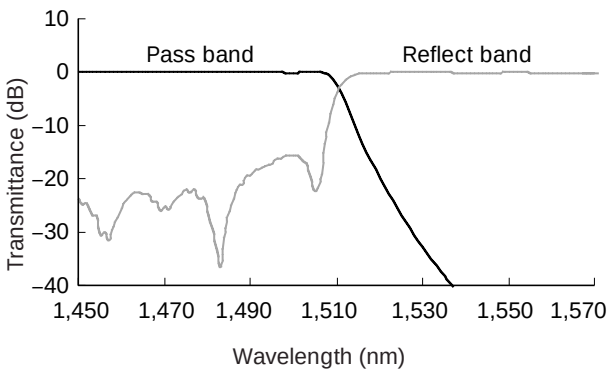

Fig. 12. Transmittance Spectrum of a 1.48/1.55μm WDM Add/Drop Device.

4.4 Subminiature CWDM Mux/Demux Module

Fig. 13 shows the structure of a Coarse Wavelength Division Multiplexing (CWDM) Mux/Demux module developed for metropolitan and access networks. It consists of 4 or 8 WDM add/drop devices connected in cascaded structure.

In order to miniaturize the CWDM module, it is necessary to downsize not only optical components but also holding space for optical fibers. We used an originally designed optical fiber with the cladding diameter of 80μm. The fiber is designed to allow a small bending diameter of 10mm without any loss increase. Taking into account of the connectivity to the outer fibers, the 80μm-diameter-optical fibers are used only in the module. The photograph of the developed 8-ch CWDM module is shown in Fig. 14.

The dimension of the developed CWDM module is

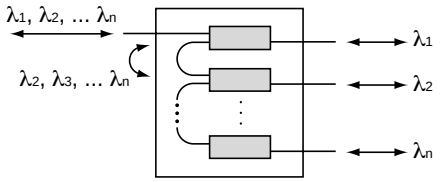

Fig. 13. Structure of the CWDM Module.

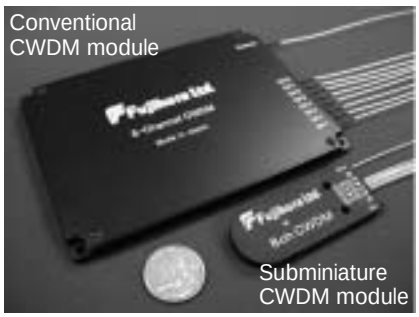

Fig. 14. Comparison of a Subminiature CWDM Module and a Conventional CWDM Module.

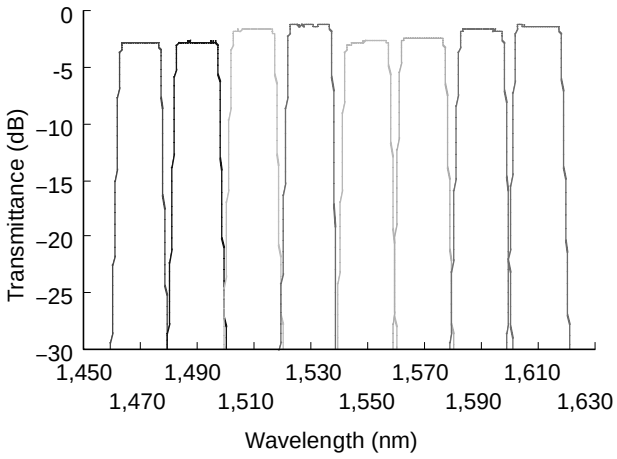

Fig. 15. Wavelength Response of the CWDM Module.

68mm × 28mm × 6mm. We have succeeded in a 90 % volume reduction compared to the conventional type of dimensions of 120mm × 100mm × 10mm.

Fig. 15 shows wavelength response of developed 8-ch subminiature CWDM module. The maximum insertion loss over the 8 channels is 3.9dB, the adjacent channel isolation is more than 30dB, and the pass bandwidth is more than 13nm at 0.5dB down from the peak transmittance.

5. Conclusion

We have developed the novel mini quartz-rod-lens by applying the optical fiber manufacturing technology. We have also developed the fusion splicing technology between the lens and optical fibers by a CO_2 laser to make the quartz-rod-lens collimator. By using these collimators, we realized the significant miniaturization of the micro-optic device with higher reliability for high optical power and ambient environments.

References

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