Novel bidirectional optical subassembly with embedded filter, 45-degree angle polished fiber cladding and etched fiber core

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Abstract. The optical wavelength-division-multiplex filter for bidirectional optical subassembly (BOSA) is embedded to the fiber core, which results in simplicity of the BOSA module. The fiber cladding is 45-deg angle polished to receive a downstream signal. The core is etched by a femtosecond laser to have a normal core facet and to transmit an upstream signal. The downstream signal, which is core mode, is coupled to the cladding mode by the long-period fiber grating and then detected by a photodiode by means of the total internal reflection effect at the 45-deg angle polished cladding facet. The measured transmitted and received coupling efficiencies are 27.3 and 43.8%, respectively.
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Subject terms: bidirectional optical subassembly; embedded filter; polished fiber cladding; etched fiber core.

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1 Introduction

While the fiber to the home (FTTH) became solid as the broadband access network of the next generation, much research has been in progress to find a small and cost-effective solution of an optical network unit (ONU) and an optical network terminal (ONT) for a passive optical network (PON). Intensive research is being conducted on an improved PON system and application of PONs.[1–3] Usually, a thin-film filter (TFF) is used as the wavelength-division-multiplex (WDM) filter for separating the upstream and downstream signals. Because the filter is a bulk optical component, it requires fixing and arrangement in the free space.[4–6] On the other hand, in our previous works, as a optical WDM filter, the tilted fiber Bragg grating (TFBG), which can be embedded into the optical fiber, was suggested.[7,8] These methods did not require a type of free-space process for filter alignment.

In this research, a long-period fiber grating (LPFG) was used for the WDM filter. Generally, its resonance bandwidth is wider than a fiber Bragg grating (FBG) so that even if there was some deviation in the wavelength of the downstream signal, filtering is still possible because the wavelength is within the resonance bandwidth of the LPFG. Moreover, in case of the TFBG, the forward-propagating core mode is coupled to the backward-propagating cladding mode. Therefore, to out-couple the cladding mode, one side of the cladding region was etched and the other side was not.[7] In this case, only about one-half of the total power can be out-coupled because of the structural limitation. In contrast to the FBG, because the LPFG converts the core mode to the cladding mode maintaining the same propagation direction, whole power can be out-coupled by the total internal reflection (TIR) effect at the polished cladding surface. This feature can enhance the out-coupling efficiency of the module.

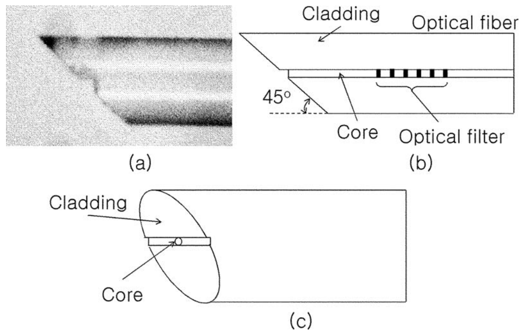

Fig. 1 Processed fiber facet of suggested BOSA, detailed schematic of (b) side view and (c) perspective view.

2 Structure of the Proposed Bidirectional Optical Subassembly (BOSA)

A photograph of the proposed BOSA is shown in Fig. 1(a). The schematic of the detailed structure is shown in Figs. 1(b) and 1(c). To make a proposed BOSA, first the LPFG, which is the optical filter, is fabricated by using an amplitude mask and an excimer laser. And second, as shown in the Fig. 1 the facet of the optical fiber was polished at 45-deg angle, including the core and cladding. If the cross section of a core is maintained as a polished shape, the upstream signal cannot be launched into a fiber core because of the severe reflection at the polished surface. Therefore, finally, the fiber core was etched to form a normal facet by using the femtosecond laser.

3 Experiments and Results

The length of the LPFG filter is 2 cm. The transmission spectrum of the filter is shown in Fig. 2. The measured loss is not absolute but relative value because it was measured by tapping the small portion of the transmitted power after

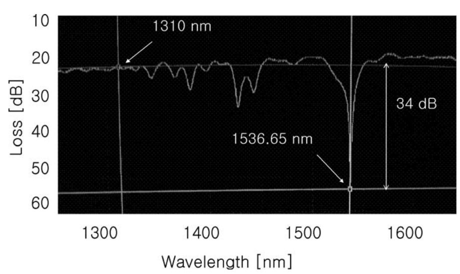

Fig. 2 Transmission spectrum of the optical filter.

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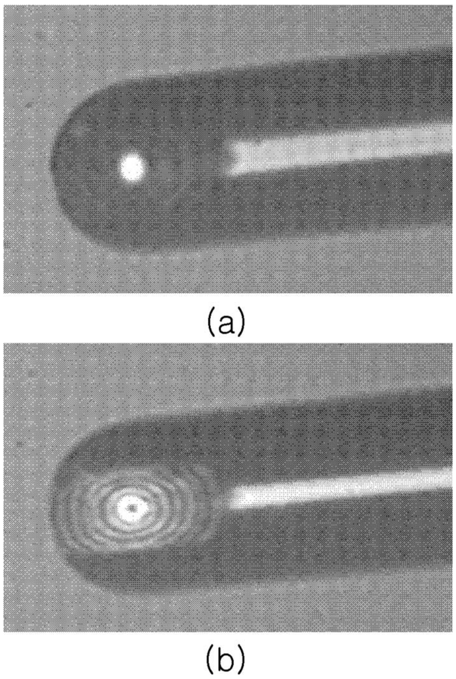

Fig. 3 Infrared camera view of the received modes when both the core and cladding were polished with 45-deg angle. Out-coupling characteristics of (a) out-of-resonance mode and (b) resonance mode of the optical filter.

the fiber facet was processed. It has a core-to-cladding mode coupling characteristic of >30 dB at 1536.65 nm, where the maximum resonance wavelength of the LPFG is. This wavelength is used for the downstream signal. As can be seen in Fig. 2, because 1310 nm is in the out-of-resonance region, this wavelength is not influenced by the LPFG. Therefore, we can use it for transmitting the upstream signal through the fiber core without significant insertion loss of the LPFG. The measured relative losses at 1310 and 1536.65 nm are 19.4 and 53.7 dB, respectively. Therefore, the isolation characteristic of the LPFG between the wavelengths is about ~34 dB.

Figure 3 shows the infrared camera view of the received modes when both the core and cladding were polished with a 45-deg angle (i.e., it is when the core was not yet etched by the femtosecond laser). This photograph was taken from the upper side of Fig. 1(b); thus, the left side of the optical fiber looks round.

The Fig. 3(a) is for when the wavelength of the downstream signal is in the out-of-resonance region of the LPFG, such as 1310 nm. Therefore, the power of the mode is maintained within the fiber core without the influence of the LFPG. The core mode is total internal reflected at the surface of the polished core; thus, its pathway is perpendicularly changed. The detected core mode is shown in Fig. 3(a). It is true that the out-of-resonance mode is no longer reflected and detected if the fiber core is etched by the femtosecond laser because the total internal reflection condition is not formed.

Figure 3(b) is when the wavelength of the downstream signal is in the resonance region of the LPFG, such as 1536.65 nm. At this resonance wavelength, the core mode is converted into the cladding mode by the LPFG. On the way of propagation, the cladding mode is total internal reflected at the surface of the polished cladding. Subsequently, its pathway is perpendicularly changed, and then the cladding mode is out-coupled and detected. Without any perturbations, usually a LPFG couples the LP_{01} core mode to the LP_{0m} cladding modes whose field pattern has rings, which is clearly shown in Fig. 3(b). Definitely, as shown in Fig. 3(b) there is no power in the core area because the core mode was coupled to the cladding mode by the LPFG. Therefore, even if the core is etched by the femtosecond laser, the mode of resonance wavelength of the LPFG is still detected as the cladding mode by TIR at the polished surface.

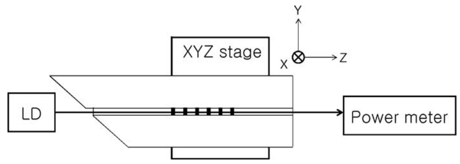

Fig. 4 Conceptual experimental setup for measuring the transmitted (upstream) coupling efficiency.

The automated and motorized three-axis *XYZ* stage was used to search the maximum transmitted and received coupling efficiency. Once the *Z*-axis distance is fixed, the power is continuously monitored while the stage scans *XY*-axis. It is repeated until finding a maximum coupling efficiency as varying the *Z*-axis distance.

The setup for measuring the coupling efficiency of the transmitted signal is shown in Fig. 4. As to the upstream signal, a distributed-feedback laser diode (DFB-LD) with a transistor outline-can package is used with a built-in cap lens. The operating wavelength is 1310 nm. By using the DFB-LD driver, the output power was controlled and we confirmed it to be 0.988 mW. The focused DFB-LD light was launched to the etched optical fiber core and transmitted as the upstream signal. As we could know from Fig. 2, there is some transmission loss at 1310 nm but it is as low as 1 dB. Including this and other measurement losses, the measured power was 0.27 mW, which was 27.5% of the DFB-LD output power.

The setup for measuring the coupling efficiency of the received signal is shown in Fig. 5. In order to have a maximum coupling efficiency using the LPFG, the operating wavelength of the tunable laser source (TLS) for the downstream signal was adjusted to 1536.65 nm, where the core-to-cladding mode coupling is a maximum. When the downstream signal coming into the proposed BOSA is propagated through the optical fiber core, it is coupled to the cladding mode by the LPFG with the coupling factor of >30 dB or 99.9%. Once the core mode is coupled to the

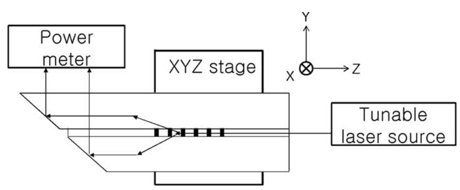

Fig. 5 Conceptual experimental setup for measuring the received (downstream) coupling efficiency.

cladding mode, it propagates in the cladding region and is tightly guided by the air-cladding boundary. As mentioned before, the TIR occurs when the cladding mode is reflected at the polished facet. As shown in Fig. 3(b), most of the reflected downstream signal is out-coupled to the power meter, which has a large active area. The output power of the TLS was 0.848 mW, and the detected power was 0.371 mW. Using the proposed BOSA, the 43.8% of the TLS power was received.

4 Conclusions

A novel and simple bidirectional optical subassembly was proposed, and we obtained the 27.5 and 43.8% of transmitted and received coupling efficiency, respectively. Because the optical filter for separating the upstream and downstream signal is implemented inside the optical fiber, the filter arrangement in the free space is not necessary. The suggested design can simplify the manufacturing process, and this technology can be used for a small-size and low-cost transceiver fabrication. Furthermore, the transmitted and received coupling efficiency can be improved by carefully etching the fiber core. In our sample, not only core area but also cladding area was etched as shown in Fig. 1(c). By selectively etching the core area, the TIR region, where the cladding mode can be reflected, will be enlarged. Therefore, the received coupling efficiency will be increased effectively. A cleaner and flatter surface of the etched core can increase the transmission coupling efficiency. On the other hand, to make a reliable surface, another method such kind of splicing a 45-deg polished hollow optical fiber to the normal core is in progress.

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