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1. Ultracompact Optical Amplifier with Bi_2O_3-based Erbium-Doped Fiber

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An ultracompact gain block with Bi_2O_3-based erbium-doped fiber (Bi-EDF) is presented. The ultracompact gain block includes two pump LDs, two isolators, a photodiode, dichromatic mirrors and a Bi-EDF 23 cm long in the amplifier package with a size of only 45 × 43 × 10 mm. We can obtain a net gain of 25 dB and output power of 10 dBm at 1560 nm in the C-band region.

A compact amplifier is required to meet the small-space and cost effective demands for metropolitan area network (metro) use. We have fabricated Bi_2O_3-based Er-doped fibers (Bi-EDF) with Er concentration of 6,500 ppm and reported that the fusion-spliceable Bi-EDF exhibited a net gain of 18 dB at 1560 nm and more than 9 dB gain in the C + L band with only a 22 cm length.[1][2] Moreover, a Bi_2O_3-based Er-doped waveguide (Bi-EDW) for integrated optical amplifiers have been fabricated.[3] We believe Bi-EDF and Bi-EDW to be candidates for broad-band and compact amplifiers required in metro WDM systems as well as for compact L-band amplifiers in long-haul applications. Here, we propose the ultracompact EDFA (Er-doped fiber amplifier) using Bi-EDF. We used forward and backward laser diodes for pumping, two isolators, a photodiode, dichromatic mirrors, and a 23-cm-long Bi-EDF in an amplifier package of the size of only 45 × 43 × 10 mm. This is the smallest EDF gain block in the world, as far as we know.

The appearance of ultracompact EDFA is shown in **Fig. 1** and a Compact Flash™ memory is also shown for comparison. A schematic configuration is shown in **Fig. 2**. We fabricated a single-mode Bi-EDF with a plastic coating. The Er^{3+} concentration is 6,500 ppm in this fiber. The refractive index of the core is 2.03 and NA is 0.2 at 1550 nm. A propagation loss of 0.7 dB/m was measured at 1310 nm by the cut-back method. The Bi-EDF with a length of 23 cm was rolled into a diameter of 1 inch. The ends of Bi-EDF were coated with antireflection (AR) material and they were connected to fiber collimators. The signal beam enters from the input fiber collimator and is input to the Bi-EDF through a dichromatic mirror (signal beam: transmittance, pump beam: high reflectance) following

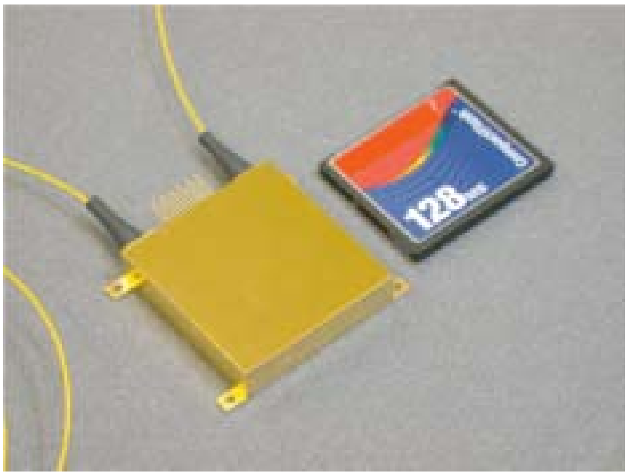

Fig. 1 Appearance of ultracompact EDFA. Forward and backward laser diodes for pumping, two isolators, a photodiode, dichromatic mirrors, and a 23 cm-long Bi-EDF are used in the amplifier package with a size of only 45 × 43 × 10 mm. A Compact Flash™ memory is also shown for comparison of size.

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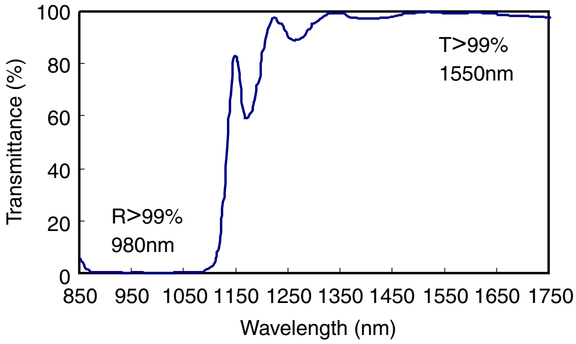

Fig. 2 Transmission spectrum of dichromatic mirror.

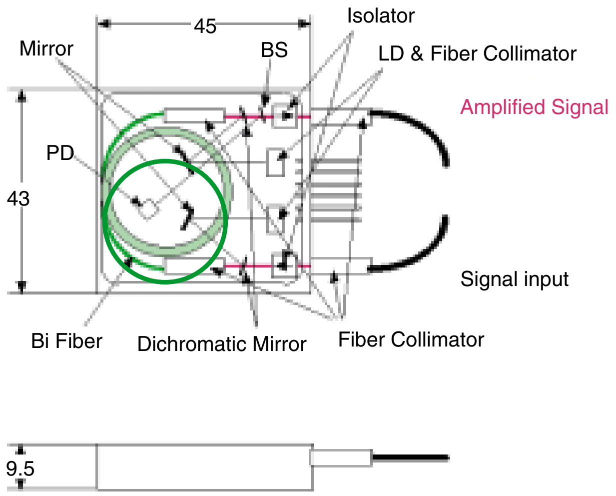

Fig. 3 Schematic configuration of ultracompact EDFA with Bi-EDF. Bi-EDF with a length of 23 cm was rolled into a diameter of 1 inch. The ends of Bi-EDF are coated with antireflection (AR) material, and they are connected to fiber collimators. Collimated forward and backward LD beams at 976 nm of wavelength are coupled with the signal beam using high reflectance mirrors and dichromatic mirrors.

an isolator. **Figure 3** shows transmission spectrum of the dichromatic mirror. The amplified signal beam output from Bi-EDF is input to the output fiber collimator through an isolator following a dichromatic mirror. Part of the signal beam is reflected at the other side of this dichromatic mirror and is aligned with a photodiode to monitor the signal intensity. Collimated forward and backward LD beams at 976 nm wavelength are coupled with the signal beam using high-reflectance mirrors and dichromatic mirrors. The maximum output power of LD was 400 mW, and the forward coupling loss to Bi-EDF of 3.7 dB (43%) and the backward coupling loss of 4 dB (40%) was estimated. Thus the maximum input pump power to Bi-EDF was estimated to be 170 (forward)+ 160 mW (backward).

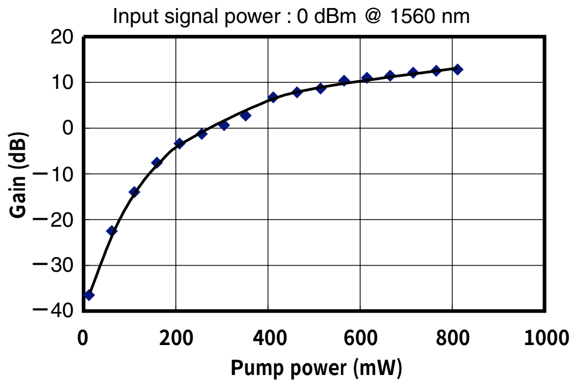

Fig. 4 Applied pump power dependence of net gain at 1560 nm with input signal power of 0 dBm. The maximum output power of 13 dBm was obtained with an applied pump power of 800 mW, where input pump power to Bi-EDF was 330 mW.

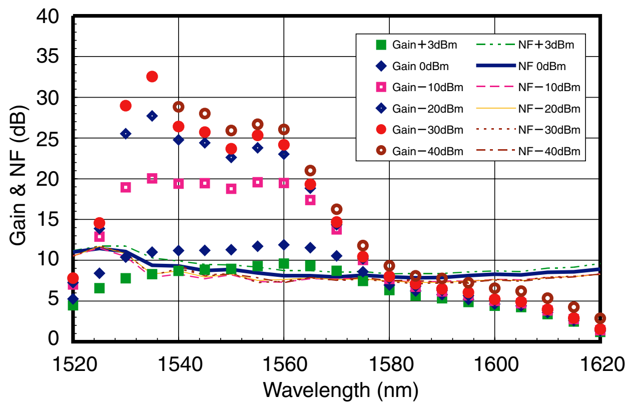

Fig. 5 Gain profile and NF of ultracompact Bi-EDFA with various signal powers from -40 dBm to +3 dBm. The input pump power was estimated to be 128 (forward) + 119 mW (backward).

The estimated insertion loss of the compact Bi-EDFA for the signal beam was 3.8 dB. Since the length of SiO_2-based EDF is commonly required to be at least 5 meters and fiber-type couplers are used for pump LD coupling, large size is needed for conventional gain blocks. The ultracompact gain block was successfully realized with a very short Bi-EDF and the space coupling technique.

Figure 4 shows the pump power dependence of net gain at 1560 nm with an input signal power of 0 dBm. The maximum output power of 13 dBm was obtained with an applied pump power of 800 mW, where the input pump power to Bi-EDF was 330 mW. High output power of >10 dBm was achieved even with the ultracompact EDFA. This output power is highly enough for metro amplifier applications. **Figure 5** shows the gain profile of the Bi-EDFA with various signal powers from −40 dBm to +3 dBm. The input pump power was estimated to be 128 (forward) + 119 mW (backward). We can obtain high gain (> 25dB) throughout entire C-band region with a small input signal power of -30 dBm. When the signal power is 0 dBm, more than 10 dB gain can be obtained from 1530 to 1570 nm. This result indicates that more than 10 dBm can be obtained throughout the entire C-band region when using the ultracompact EDFA. These gain characteristics and the ultracompactness make the EDFA a candidate for an advanced WDM amplifier for metro use.

We believe that gain can be improved by optimizing the length of Bi-EDF. Moreover, a short EDF can be expected to contribute to the improvement of the stability of the amplifier against temperature or polarization and also to reduce the influence of the dispersion.

—References—

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