Optical Amplification in Bi-doped Silica Fiber

Young-Seok Seo, Yasushi Fujimoto and Masahiro Nakatsuka

INTRODUCTION

The C-band, between 1530 and 1565 nm, has been the spectral region of choice for dense wavelength division multiplexing (DWDM) telecommunications during the past decade, because erbium-doped fiber amplifiers (EDFAs) provide efficient, broadband gain in that region, and because conventional silica-glass fibers have minimum loss there. As the load demand on existing systems increases, however, telecommunications engineers have been eying the possibility of using both the C-band and the O-band simultaneously to carry information. The O-band, between 1260 and 1360 nm, is attractive because conventional fibers have minimum dispersion in that region [1].

The problem with the O-band is the absence of an EDFA-like device that can efficiently amplify wavelengths across that entire region. Researchers have explored both praseodymium-doped fluoride fiber amplifiers, and fiber Raman amplifiers, but while both provide amplification in the O-band, both suffer from narrow bandwidth and low efficiency. Moreover, praseodymium-doped fluoride fibers are brittle and cannot readily be fusion spliced with conventional silica fibers [2].

We previously reported a new infrared luminescent bismuth-doped silica glass (BiSG) material which can complement the problems of the other optical amplifiers [3]. A BiSG has wide-band luminescence of 300-nm full width at half-maximum (FWHM), and emission peak at 1250 nm with 800 nm excitation. Also, we achieved optical amplification in a BiSG at 1310 nm with 810-nm excitation [4, 5]. Recently, there are several reports on infrared luminescence from bismuth-doped glasses [6-12] (germanate, phosphate, borate et al.). According to their research, Bi-doped glasses seem to add proof or certainty with near infrared emission. In addition, cw lasing was obtained in the spectral region between 1150 and 1300 nm in a bismuth-doped alumino-silicate glass fiber [13]. However, the origin of luminescence mechanism is still unclear.

Bi-doped glasses have many attractive features, which make it suitable as core fiber material of optical fiber. The near-infrared spectral regions with wide luminescence in the range from 1000 1600 nm and the long lifetime of luminescence make such fiber promising for the development of lasers and amplifiers. In this paper, we demonstrate optical amplification at 1260 1360 nm region (O-band) in bismuth-doped silica fibers (BiDF), which is more than the previous result [14]. We also investigate the gain characteristics at the 1300 nm wavelength region in a 5.0 cm long with 1.54 µm core diameter BiDF. In addition, we report simultaneous amplification results for BiDF at two different wavelengths in the 1300 nm range. This technique can be useful for wavelength division multiplexing (WDM) optical amplifiers at the second telecommunications window.

EXPERIMENTAL

BiDF sample was fabricated by modified rod-in-tube method [15]. Glass core was inserted into a tube of glass cladding to form a preform, which was drawn by heating in the drawing furnace. The fiber with refractive index difference, ∆n=0.017, was drawn from the perform. Its core diameter and outer diameter was 1.54 µm and 125 _m, respectively.

The experimental setup for optical gain measurement in BiDF is shown in Fig. 1. An 810-nm cw laser diode was used as the pump source. A 1308 nm distributed feedback (DFB) laser diode and four laser diodes with different wavelengths were used as probe beam. The wavelengths of the four DFB laser diodes were 1272, 1297, 1323 and 1347 nm, and these probe beams can be adjusted using a single laser driver. The probe laser beams were combined with the excitation beam using WDM coupler (810/1310 nm), and then fusion spliced with single-mode fiber (SMF). The gained probe beam was detected by an optical spectrum analyzer (Ando: AQ6317B).

![Fig. 1. Schematic diagram for optical gain measurement.](image)

RESULTS

The optical amplification in a 5.0 cm long BiDF sample at single wavelength, 1310 nm, is shown in Fig. 2. The maximum optical gain was calculated to be 9.13 (9.6 dB) and therefore, gain coefficient was 0.096 dBm/W. The optical gain increased linearly with excitation power up to 100 mW. The measured signal input/output power for BiDF was -30.0 dBm / -20.4 dBm (@ 1310 nm), exhibiting much lower power conversion efficiency. The optical gain in the previous result with a bulk-type BiSG was 1.16 with excitation power of 1.0 W, though the sample thickness was 0.24 cm. Because the specific gain coefficient of the bulk sample was 0.62 cm/W, the fiber shape affects the gain increment due to beam mode
matching between the pump and the probe.

![Optical gain profile of bismuth-doped silica fiber at length 5.0 cm.](image)

Fig. 2. Optical gain profile of bismuth-doped silica fiber at length 5.0 cm.

Figure 3 shows simultaneous amplification at two wavelengths near the 1300 nm region. The signal wavelengths to measure the simultaneous amplification in the BiDF were adjustable wavelengths (1297 nm) and anchor wavelength (1310 nm). The maximum gain coefficient at the adjustable wavelengths (0.23 cm⁻¹) and the anchor wavelength (0.25 cm⁻¹) was obtained. The optical gain shown in simultaneous measurements of two wavelengths suggests that it is possible to realize WDM optical fiber amplifiers in O-band (1260–1360 nm).

![Simultaneously optical amplification properties at two wavelengths: 1310 nm and 1297 nm.](image)

Fig. 3. Simultaneously optical amplification properties at two wavelengths: 1310 nm and 1297 nm.

Performance of fiber amplifier largely depends on the fiber specification. Optical gain in this experiment was much smaller than that for EDF or PDFFA. The smaller core cross section gives promising potential to the practical gain performance. The gain characteristics will be further improved by optimizing the fiber structure, such as a partially doped core structure and deformed shape of first clad layer for efficient pumping.

DISCUSSION

The origin of light emission in a BiSG, which is still unclear, is the valence electrons of the bismuth ions. We are considering more important reasons why aluminum ions are needed to generate BiSG luminescence. Aluminum ions are needed to generate BiSG luminescence. Aluminum is expected to have a special role in the formation of Bi luminescent center. Therefore, discovering the aluminum status in BiSG, especially the aluminum coordination state, will help us understand the unknown luminescent center. Aluminum coordination state can be investigated by using 27Al-NMR and XAFS. Co-doping of Al and Bi is indispensable for the broadband infrared luminescence of BiSG. The aluminum ion has to roles in BiSG: assisting the configuration of the peculiar luminescent center of Bi ion with some coupling effect, and increasing compatibility with the silica network [16].

In conclusion, we have demonstrated optical amplification in a bismuth-doped silica glass and fiber at the second telecommunication window. We reported the optical amplification phenomenon in a 5.0 cm long bismuth-doped silica fiber at 1310 nm with 810-nm excitation and discussed simultaneous amplification at two wavelengths of the 1300 nm region. These spectroscopic characteristics and the amplification observed at 1300 nm range have shown that such fibers are good candidates for cw and pulsed fiber lasers and fiber amplifiers for the spectral range of 1100–1400 nm.

REFERENCES