Fabrication and Characterization of Baria-Silicate Erbium-Doped Fiber Amplifiers

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Abstract: We present a baria-silicate erbium-doped fiber, fabricated using solution-doping technique, with 3 mol% BaO concentration. The fiber displays a low background loss (<10 dB/km at 1200 nm) and is used in an extended L-band amplifier.

1. Introduction

Erbium-doped fiber amplifiers (EDFAs) are widely used nowadays to simultaneously amplify a large number of optical communication channels efficiently with low noise figure, and negligible crosstalk. As today's digital communications become increasingly popular, there is an inevitable need to improve the bandwidth and performance of these amplifiers. In rare earth (RE) doped fibers, including erbium-doped fibers (EDFs), the spectral properties of RE ions are strongly dependent on the local environment. Therefore, investigating novel glass former/modifier composition, and searching for new fiber processing technologies, are prominent ways to reach performance improvement. In this regard, different dopants have been introduced into the silica host, such as aluminum or phosphorus, to improve the solubility of Er^{3+} ions and reduce the clustering effect, while controlling the core to cladding refractive index contrast. In this context, BaO is a glass modifier that was not initially known to be miscible with SiO_2. However, successive reports have discussed the glass formation conditions and stability issues of BaO-SiO_2 systems [1], indicating its potential application as a host material for amplifiers and lasers. These earlier results indicated that barium could be used as an alternate co-dopant to increase the refractive index of the core, enhance the solubility of RE ions, and reduce RE ions clustering in silica, while at the same time achieving low background loss performance [1,2]. Nevertheless, to the best of our knowledge, a maximum BaO concentration only 1.4 mol% has been achieved so far by using standard modified chemical vapor deposition (MCVD) with solution doping technique. The immiscibility gap that exists for the binary system of SiO_2-BaO, when BaO is present in the range 0-30 mol%, might lead to a spontaneous phase separation process. The growth of BaO nanoparticles in the SiO_2 glass results in opacity of the core and induces simultaneously undesired scattering losses [3]. In this work, through fabrication process improvement to avoid possible nanoparticle crystallizations, we achieve a low background loss fiber that contains up to 3 mol% of BaO. We characterize the EDF properties and discuss its potential for amplification in the extended L-band.

2. Fiber fabrication and characterization

The doping of Er_2O_3 and BaO into the silica host was achieved via the solution doping process in an un-sintered porous silica layer that was deposited into the inner surface of a silica tube by conventional MCVD process. The porous layer was soaked with a water solution of a mixture of $Ba(NO_3)_2$ and $ErCl_3.6H_2O$. Afterwards, it was sintered and the tube collapsed above 2000 °C, obtaining the final preform. The control of thermal treatment during the fabrication process is crucial since nanoparticles can nucleate and grow in the preform and fiber core, which will induce high background loss. By controlling the fiber manufacturing, and drawing at ~2100 °C, well above the melting point of BaO, 1923 °C, the dissolution of possible BaO nanoparticles nucleated is ensured. The refractive index profile (RIP) and BaO concentration distribution in the preform sample are presented in Figure 1. The barium doping profile is in good agreement with the RIP and, importantly, the BaO concentration reaches a maximum of 3%, with an average of 2.85% over the central area (r<0.5 mm). Also, we note that there is no dip of the BaO concentration at the center of the core. Figure 1 also shows the spectrum of the absorption coefficient of the fiber sample in the 1450–1650 nm spectral region, which is characteristics of the absorption of erbium ions. A scanning electron microscope (SEM) was employed to examine the core–clad interface boundary. As illustrated in the inset of Figure 1 (a), we do not observe the “star-like” pattern, presumably from stress in the fiber, that has been observed in [1]. The star-like pattern and central-dip in the RIP were reported to enhance the scattering loss of the fiber and thus reduce the fiber performance [1,3]. The absence of possible BaO nanoparticles nucleated in the fiber core is also confirmed. The fiber background loss was measured by cut-back at the wavelength of 1200 nm, where Er^{3+} is inactive. We measured a propagation loss of ~10 dB/km, which is significantly lower than the 42 dB/km that was measured in our best in-house fabricated phospho-aluminosilicate erbium-doped fiber (P/Al-EDF). The maximum Er^{3+} concentration of 0.02 mol% in the preform sample was determined by chemical analysis using Electron probe micro-analyzer (EPMA).

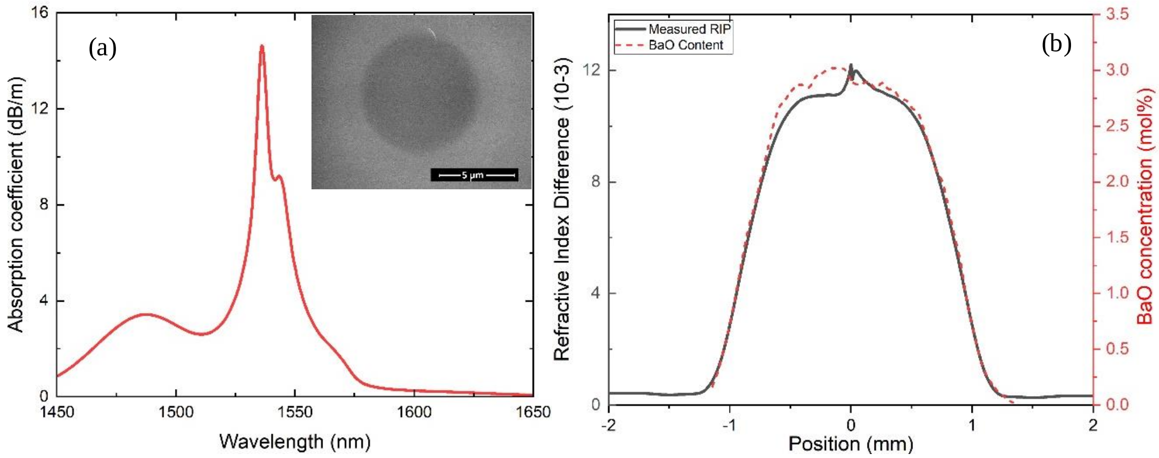

Figure 1. a) Spectrum of the fiber absorption coefficient (insert shows a SEM picture of the fiber core-clad interface) b) Experimentally measured RIP (black, left scale) and barium doping profile (red, right scale) measured on the preform (scaling factor is 296 from the preform to the fiber)

3. Gain measurement and Discussion

The extended L-Band Ba-EDF amplifier setup is shown in Figure 2 (a). The total input power of the 7-channel comb source was set to 1.3 dBm (divided equally between channels). A 95 m long Ba-EDF was bi-directionally pumped by 980 nm laser diodes with 800 mW of per pump laser. A 3-dB coupler was inserted to reduce the power before the OSA that was used to observe and record the spectrum. The spectral loss of all components was characterized and factored. Figure 2 (b) represents the internal gain and NF performance (between point-A and point-B). From 1575 nm to 1620 nm, the minimum gain is 16 dB and the NF is lower than 5 dB.

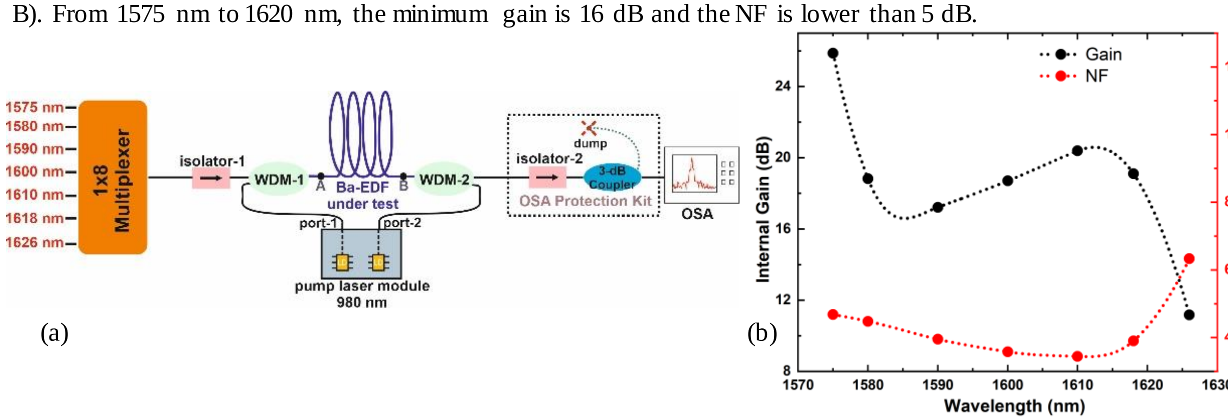

Figure 2. (a) The experimental setup and (b) Gain and NF spectrum from 1575 nm to 1626 nm for Ba-EDF amplifier

4. Conclusion

In this work, an EDF with a BaO concentration up to 3 mol% was successfully fabricated using standard MCVD with solution doping technique for the first time. The fiber exhibits performance characteristics, in terms of background loss and Er^{3+} solubility, that makes it a good candidate for high power laser and amplifier applications. An extended L-Band Ba-EDF amplifier was successfully achieved with an average gain of 18.7 dB and lower than 6.5 dB of NF up to 1626 nm.

5. References

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