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Short note

Compact and flat-gain fiber optical amplifier with Hafnia-Bismuth-Erbium co-doped fiber

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ABSTRACT

For the first time, we demonstrated a compact Erbium-doped fiber amplifier (EDFA) using a newly developed Hafnia Bismuth Erbium co-doped fiber (HBEDF) as a gain medium. The HBEDF was fabricated using a modified chemical vapor deposition process in conjunction with solution doping technique. The fiber has high doping levels of Erbium ion of 12,500 wt ppm through incorporation of Hafnium and Bismuth ions, which prevents the clustering effect. At the input signal power of −10 dBm, a flat gain of 10.9 dB is obtained from the wavelength region of 1525 to 1565 nm with a gain variation of less than ± 0.5 dB. The noise figure is maintained below 4.4 dB at the flat-gain region. The proposed amplifier has the potential applications in dense wavelength division multiplexing communication system due to its simplicity and compact design.

1. Introduction

In the telecommunications field, there is an ever-increasing demand for higher levels of integration and for smaller fiber-optic equipment and components [1]. For instance, optical amplifiers and fiber laser devices are desirable to use a gain medium with a large active ions concentration to shorten the length of the device and to reduce the size and cost of the device [2]. One of the disadvantages of current standard fused silica based Erbium-doped fiber (EDF) is their relatively limited capacity for producing large gain per unit length [3–5]. This leads to gain devices composed of individually fiber pigtailed components typically employing long fiber lengths (10–50 m) requiring fiber wraps with bend radii of > 30 mm. This produces amplifier or fiber laser architectures that are difficult to miniaturize, and incompatible with trends towards: automated assembly of small form factor modules, multi-channel devices, and integrated hybrid optics.

To shorten the length of the gain medium, the active fiber needs to be doped with so much higher erbium ion concentration [6,7]. However, a high concentration of erbium ions may result in pair-induced quenching (PIQ) effects, which potentially degrades the pump power conversion efficiency (PCE) and rise the noise figure for EDFA [8,9]. For increasing the limit of erbium doping concentration while maintaining the amplification performance, various glass hosts and co-doped materials have been proposed and

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investigated. Up to date, the advance in optical fiber fabrication technology has resulted in the productions of bismuth-based erbium-doped fiber (Bi-EDF) [10,11] and Zirconia Erbium co-doped fiber (Zr-EDF) [12,13] which have an erbium ion concentration of 6300 and 2800 ppm, respectively. Both fibers act as an effective gain medium for realizing the compact optical amplifier and laser devices. However, Bi-EDF cannot be spliced with a standard single mode fiber (SMF) using the standard splicing machine. This is attributed to the difference in their melting temperatures [13]. On the other hand, Zr-EDF needs longer length of the gain medium (2 m) to achieve a comparable performance with Bi-EDF amplifier [13,14].

Recently, the interest has also obtained for Hafnia-Bismuth co-doped silicate fibers that can be useful for near infra-red applications compared to a standard silica-based one. This is attributed to its large effective phonon energy and, thus, reduces fundamental loss in the NIR [15]. The choice of SiO_2-HfO_2 network of core-glass stems from the known fact that HfO_2 is a material with a high refractive index (RI),transparent over a wide wavelength range, 0.4–6.0 µm [16]. Doping of Hafnia having more than four co-ordination numbers in silica glass creates non-bridging oxygens in silica network [17] which allow the host glass to accommodate other optically-active in NIR co-dopants such as rare-earths Er, Yb, Ho etc along with Bi [18]. HfO_2 can be capable to slightly modify the overall core-glass structure, facilitating dispersion of active co-dopants for development of tunable CW fiber laser at NIR region. In this paper, the performance of Hafnia-Bismuth-Erbium co-doped Fiber amplifier (HBEDFA) was investigated for 1.5 µm region operation. The amplifier was obtained using the newly developed Hafnia Bismuth Erbium co-doped fiber (HBEDF) as the gain medium. The proposed HBEDFA has successfully achieved a comparable performance with the conventional Bi-EDFA and Zr-EDFA. However, the proposed amplifier used a shorter gain medium length than that of Zr-EDF amplifier. In addition, the HBEDF can be easily spliced with a standard SMF due to the similarity in the melting temperature

2. Optical fiber fabrication and characterization

The HBDF was obtained from Hafnium Bismuth Erbium co-doped Yttria-Alumina-Silica glass based preform. The preform was fabricated through deposition of porous silica layer at around 1500 °C temperature by the modified chemical vapor deposition (MCVD) followed by the solution doping (SD). Suitable strength of $Al(NO_3)_3.9H_2O$, $HfCl_3$, $Bi(NO_3)_3.xH_2O$, $Y(NO_3)_3.6H_2O$ and $ErCl_3$, xH_2O were used for soaking of the porous layer for a period of one hour in the SD process to incorporate all the co-dopants such as Al_2O_3, HfO_2, Bi_2O_3, Y_2O_3 and Er_2O_3. All the halide and nitrate salts retain into porous layer after draining out of the solution followed by air drying with the flow of N_2 gas at room temperature. Such salts were converted to their respective oxides through an oxidation process with a flow of O_2 gas at around 800–900 °C temperature. Sintering of the porous layer containing such oxides was done by gradually increasing temperature from 1300 to 1900 °C to form a transparent glass. The glass was converted to a solid preform by collapsing stages where it was overcladed with a thick silica tube to reduce the core diameter. The final fiber was drawn from the preform by a conventional way using a fiber drawing tower, at ∼2000 °C.

The doping level within the core region of the fabricated fiber was measured by electron-probe micro-analysis (EPMA). It is found that the fiber core glass contains 6.0 wt% Al_2O_3, 1.23 wt% Er_2O_3, 2.2 wt% HfO_2 and 0.035 wt% Bi_2O_3. The fiber cross sectional view

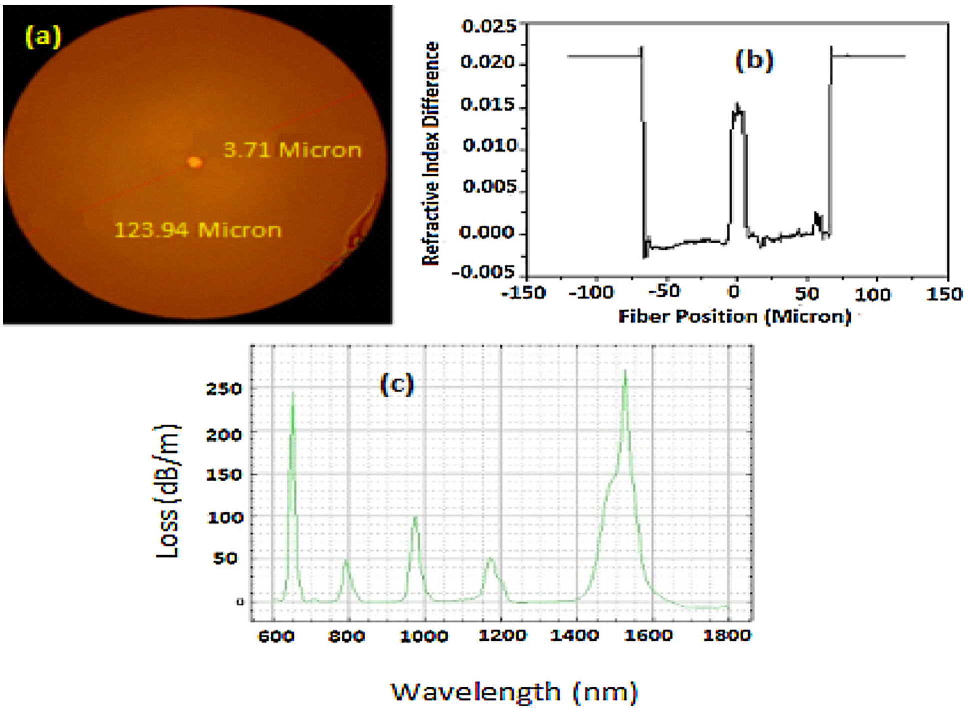

Fig. 1. HBEDFcharacteristics (a) Microscopic view (b) Refractive index profile and (c) optical loss.