Amplifier and laser demonstrations in Bi-doped silica optical fibers

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Abstract: We will review the influence of fiber fabrication and selection of pump wavelengths on gain, noise figure and laser efficiency of Bismuth (Bi)-doped fiber amplifiers and lasers operating in the wavelength region of 1150-1400nm.

OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (060.2270) Fiber characterization; (060.2280) Fiber design and fabrication; (060.2290) Fiber materials.

1. Introduction

Over the years the performance of rare earth (RE)-doped fibers have been improved significantly in the wavelength bands around 1, 1.5 and 2µm using Ytterbium, Erbium and Thulium or Holmium, respectively [1]. Concurrently, exploring new dopant materials as a gain media in optical fibers has become a burgeoning research area [2, 3], especially for the wavelength bands inaccessible by RE-elements. The interest stems from the widespread applications offered by the amplifiers and lasers in these wavelength bands such as medicine, astronomy, material processing and particularly for extended optical fiber communications [3]. Bismuth (Bi)-doped fibers in different glass hosts (i.e., aluminoslicate, phosphosilicate and germanosilicate) have shown broad luminescence covering from 1150-1800nm [3, 4]. Initial demonstrations based on these fibers have created interest in the scientific community, and efforts are now focused on improving the performance in terms of amplifier gain and laser efficiency [3, 5]. However, few challenges need to be addressed to improve the performance of Bi-doped fiber amplifiers and lasers. Among them, one is the unknown Bi-state that contributes to NIR luminescence, which is heavily dependent on the conditions such as temperature, atmosphere etc. during preform and fiber fabrication [6-8]. Another one is the unwanted losses of these fibers caused by unsaturable loss (UL) and excited state absorption (ESA) [9, 10]. In this paper, we will review the fabrication of Bi-doped aluminosilicate fibers (BASF) and phosphosilicate fibers (BPSF) for 1180nm and 1330nm wavelength bands, respectively. The 1180nm wavelength has specific application in astronomy as a laser guide star and the 1330nm wavelength region is to access the O-band for optical fiber communication. The fabricated fibers are characterized for absorption and UL. These measurements are used to optimize the pump wavelength in order to develop efficient Bi-doped fiber amplifiers and lasers.

2. Results and discussion

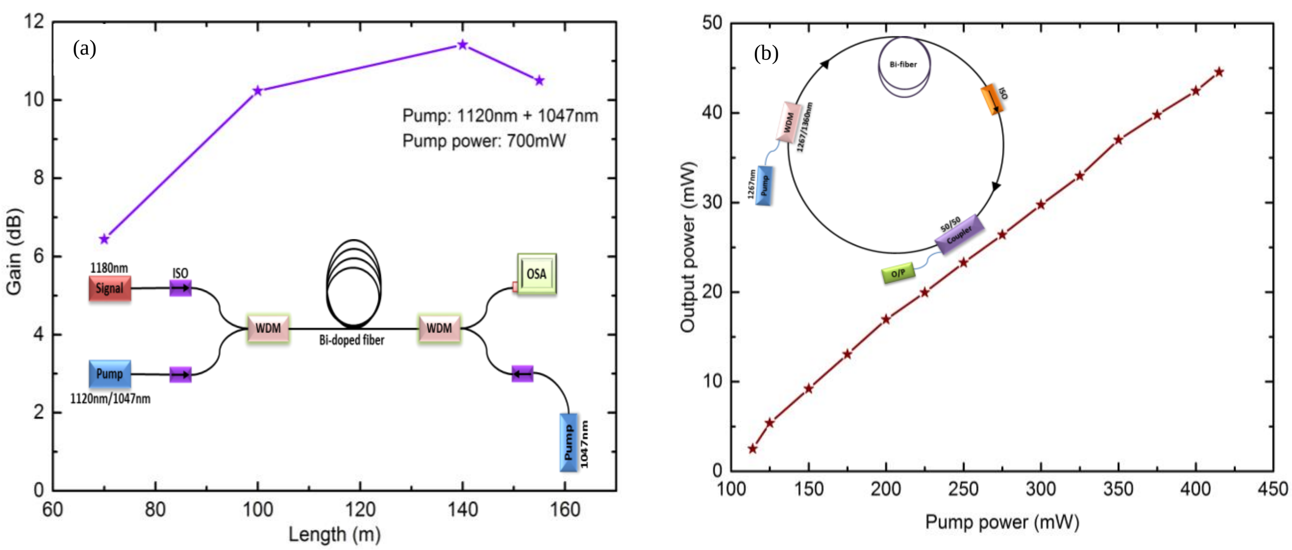

Fig. 1 (a) Gain Vs fiber length in BASF amplifier operating at 1180nm for bi- directional pumping (b) Output power in BPSF laser with launched pump power for 50% output coupling (OC) with 50m long fiber (Pump and laser wavelengths: 1267 and 1360nm)

The Bi-doped fiber preforms were fabricated by the modified chemical vapor deposition (MCVD)-solution doping technique. The resultant fibers have the core diameter of 8 and 13μm, with an index difference (Δn) of 0.008 and 0.004, for BASF and BPSF, respectively. The cladding diameter of these fibers was 100μm [11, 12]. The pump wavelength was chosen by measuring the absorption spectra and UL. In BASF, the absorption was 0.35 and 0.7dB⁄m, whereas UL was found to be 35% and 65% at 1120 and 1047nm pump wavelengths, respectively. The availability of a commercial laser diode (LD) operating at 1120nm and low UL measured in BASF made us to explore 1120nm pumping of BASF and compare its performance with more traditional pump wavelength around 1047nm. The experimental schematic and the corresponding gain characteristics with varying fiber length of a BASF amplifier using bi-directional pumping are shown in Fig.1 (a). Initially, an 1120nm LD with an output power of 350mW was used. We obtained a maximum gain of 8dB at 1180nm for a fiber length of 100m.The input signal power was -4dBm. It was observed that 1120nm pump provided a gain enhancement of 70% compared to 1047nm pumping. A maximum gain of 11.5dB was obtained via simultaneous pumping of BASF at 1120 and 1047nm as shown in Fig.1 (a). A relatively small gain enhancement under dual pumping conditions can be explained by an increase in UL with the addition of 1047nm pump [11]. This clearly indicates that higher pump power at a wavelength around 1120nm will be more suitable to increase gain in BASF operating at 1180nm. In case of phosphosilicate glass host, three BPSFs were fabricated with different Helium (He) /Oxygen (O_2) flow ratio during the preform fabrication, while maintaining the total gas flow constant (see Table 1). All other fabrication conditions remain same for all preforms. The preforms were then drawn into fibers (from here onwards named as BPSF-1, BPSF-2, and BPSF-3), respectively. The core and cladding diameters and index difference (Δn) between the core and cladding for all BPSFs were same as mentioned at the beginning of this section. The absorption values at 1210 and 1267nm pump wavelengths measured by the conventional cut-back method using a white light source are shown in Table 1. We also performed UL measurements in all BPSFs using LDs pumped at 1210 and 1267nm wavelengths, respectively. The influence of fabrication conditions on the UL can be seen from Table 1. Due to the low UL and highest lasing performance of BPSF-3 amongst all three BPSFs, the same fiber preform was over jacketed and drawn into a single mode fiber. The cut-off wavelength of the fiber was measured to be around 1100nm. This single mode BPSF-3 was then used to demonstrate a Bi-doped fiber laser and a wideband amplifier [12, 13]. A 1267nm LD pumped all-fiber laser in a ring cavity has been developed as shown in Fig.1 (b). The absorption at 1267nm pump wavelength was found to be 1dB/m. The ULs measured for 1267 and 1210nm pump wavelengths were 7% and 14%, respectively. Because of its lower UL at 1267nm in BPSF-3, the 1267nm pumping wavelength was chosen from among the available LDs. The laser efficiency was around 14% for an output coupling ratio of 50/50 with a fiber length of 50m. An output power of 45mW at 1360nm was obtained as shown in Fig.1 (b).

Table 1. Absorption and UL of BPSFs at two different pump wavelengths

Fiber		BPSF-1	BPSF-2	BPSF-3
He /O_2 flow ratio		1	0.25	only O_2
Absorption (dB/m)	1210nm	2	1.6	0.9
	1267nm	2.8	1.95	1
%UL	1210nm	46	17	14
	1267nm	25	11	7

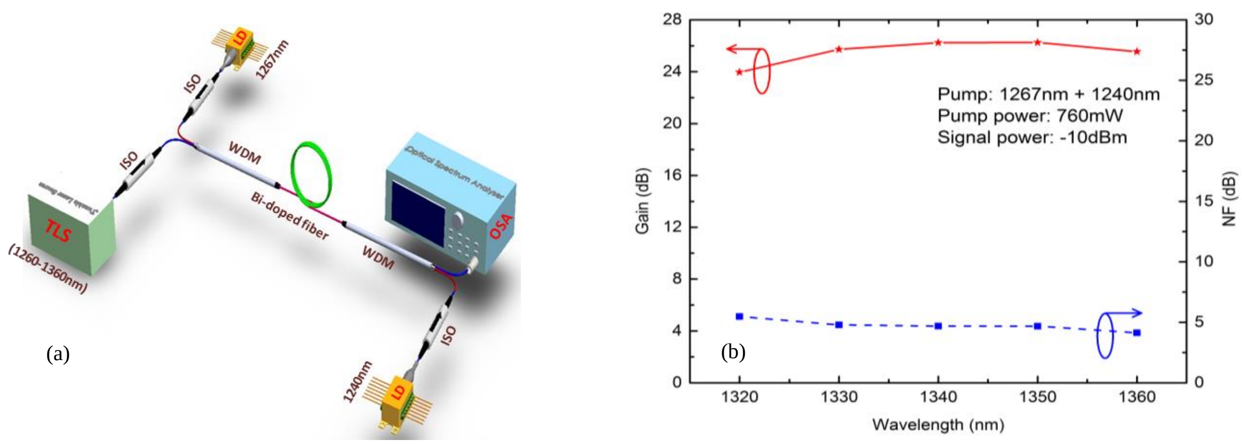

Fig.2 Bi-doped fiber amplifier: (a) Schematic experimental setup, and (b) Gain characteristics with a flat gain of 25±1dB from 1320-1360nm

In addition to the aforementioned demonstrations, a Bi-doped phosphosilicate amplifier was constructed as shown in Fig. 2 (a). Initially, the Bi-doped fiber was individually pumped by 1267 and 1240nm LDs with pump powers of 360 and 400mW, respectively to evaluate the gain and noise figure (NF). The input signal power was -10dBm. The 1267nm pumping provided a maximum gain of 15dB and a NF of 5dB at a wavelength of 1350nm for 100m long fiber while the gain at 1300nm was only 5dB. In the case of 1240nm pump, a maximum gain of 14dB and a NF of 6dB were obtained at 1330nm for 75m long fiber. Here, the gain at 1300nm was 10dB, which is double the gain of the 1267nm pumping. Thus the 1267nm pump can shift the gain toward the longer wavelength whereas the 1240nm pump allows the high gain at a shorter wavelength. In order to obtain a flat gain, the Bi-doped fiber was pumped by using both diodes (1267 and 1240nm) simultaneously. The total pump power of the LDs amounted to 760mW. A flat gain of 25±1dB with a NF of <6dB was achieved over a 40nm bandwidth from 1320-1360nm (limited by our tunable laser source, TLS, wavelength range of operation), for the 150m long single mode BPSF-3 as shown in Fig. 2 (b). Furthermore, a maximum gain of 29dB and a NF of 4.5dB were obtained at 1340nm for an input signal power of -30dBm, which, to the best of our knowledge, is the maximum gain, reported from a BDFA operating in the second telecommunication window [13].

3. Conclusion

In conclusion, the fabrication conditions and selection of pump wavelengths are critical in order to develop efficient Bi-doped fiber amplifiers and lasers. Also, the present work leads to further investigations on Bi-doped fiber technology to obtain the similar amplifier and laser performance currently offered by the RE-doped fibers. Besides power scaling of Bi-doped fiber lasers is an interesting aspect which requires significant increase of Bi concentration in fiber, suitable for cladding pumping. Research leading to better understanding of the Bi active centers in BASFs and BPSFs would greatly assist further optimization of fiber fabrication.

4. Acknowledgement

This work was supported by the UK Engineering and Physical Sciences Research Council grant EP/I01196X/1(Hyperhighway).

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