

## NEAR INFRARED AMPLIFIED SPONTANEOUS EMISSION OF BISMUTH DOPED FIBER

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We report the effect of pumping wavelength on the performance of amplified spontaneous emission (ASE) generation in a singly-doped Bismuth active fiber. The Bismuth doped fiber (BDF) was obtained by drawing a preform, which was fabricated using a deposition of porous layer by the modified chemical vapor deposition (MCVD) process in conjunction with solution doping technique. It is observed that the ASE peak shifted from around 1055 to 1145 nm when the pumping wavelength is increased from 802 nm to 1050 nm. The highest ASE spectrum was peaked at -47 dBm with full-width at half-maximum (FWHM) of 437 nm centered at 1120 nm with 2-meter-long BDF at a fixed 170 mW of 980 nm pump. The infra-red emission characteristics of this material indicate that it might be a promising candidate for optical fiber amplifiers and laser application in 1.1 to 1.2 micron wavelength region.

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### 1. Introduction

Fiber lasers have become a workhorse in telecommunication application. With growth demand of 40-50% per year towards the increasing quantities of information and communication has provoked an intense research in the development of a new near-IR region [1-3]. As of now, only rare-earth doped optical fibers have been used in the accretion of fiber laser and optical amplifiers. However, within a spectral region of 1100-1500 nm, no efficient rare earth doped fiber exist [1]. Since this wavelength region is near the zero dispersion (1300nm) of silica fibers, an optical amplification at this wavelength region can increase considerably the information capacity by utilizing dense wavelength division multiplexer (DWDM) [4]. Bismuth active material shows a promising candidate to utilize the wavelength region from 1100 to 1300 nm. It is also reported that this active medium has a broad pumping wavelength ranging from ~450 to ~1500 nm. However, bismuth based fiber remains a challenging task with their post-transition metal apart from conventional rare-earth materials. This supported from the variation of fabrication process, ion concentration, mol percentage of host material and also including an oxidation of bismuth ion itself leads to a different output characteristic especially in terms of ASE spectra [5-6]. Hence, numbers of reports discussed a different output with different operating wavelength regarding the bismuth doped fiber as the intention still towards on utilizing the low loss region (less 0.35 dB/km)

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Previously, number of studies was done on silica glass doped with bismuth active ions and this led a scarce information on fiber based bismuth ion. Therefore, normal refractive index (RI) coating with circular cladding based bismuth doped fiber was fabricated using the modified chemical vapor deposition (MCVD) process. In addition, silicate host are known to be particularly attractive because they are potentially easier to incorporate into existing silica fiber networks and potential for low loss transmission [7]. In this paper, we report an amplified spontaneous emission (ASE) generation in the near-infrared region using a new yttria-alumino-silicate fiber, which was heavily doped with Bismuth ions. The Bismuth-doped fiber (BDF) was drawn from nano-engineered yttria-alumino-silica based preforms and obtained through the Modified Chemical Vapor Deposition method in conjunction with the Solution-Doping technique. The ASE is obtained from the emission characteristics of active gain medium, which the reaction between energy structure of dopant ions in the glass host and the pumping wavelength. The pump laser source energizes the dopant ions so that spontaneously emitted light from one ion propagates along the fiber and later interacting with the next emission from the other ion along fiber inducing the ASE [8].

## 2. Experimental setup

A BDF, doped with  $\text{Bi}^{3+}$  (~1.0 wt. %), also co-doped with  $\text{Al}_2\text{O}_3$  (~8.0 wt. %),  $\text{Y}_2\text{O}_3$  (~2.5 wt. %) and a small amount of  $\text{P}_2\text{O}_5$  (~0.2 wt. %), was used in the experiment as a gain medium. BDF was obtained by drawing a preform, which was fabricated using a deposition of porous layer by the modified chemical vapor deposition (MCVD) process in conjunction with solution doping technique. Co-doping the fiber with  $\text{Al}_2\text{O}_3$  permits easy engineering numerical aperture (NA) of fiber (without a need to add such precursors as Ge) and enhances chemical durability of the core-glass, which is important for our applications. Furthermore, it is required for formation of Bi-Al, which matched with Bi-related “active” centers (BACs). On the other hand, co-doping the fiber with  $\text{Y}_2\text{O}_3$  aimed to facilitate the radiative transitions between the electronic levels of BACs (the phonon energy of  $\text{Y}_2\text{O}_3$  is one of the lowest cutoffs among oxides [9-10] and, eventually, enhancing the light emission ability of BACs in the near-infrared. Furthermore, adding a small amount of  $\text{P}_2\text{O}_5$  helped in producing phase-separated particles enriched with Bi and softening of the core-glass. A detailed analysis of the preforms and fibers of this type is presented in [11].

The experimental setup for the ASE generation is shown in Fig. 1. It resembles a fundamental linear fiber setup with BDF as a gain medium. Isolator is used inside the experiment setup as a key device to avoid any back propagating spontaneous emission from gain medium into the pump source which possibly leads to detrimental effects. Reference value of input pump power is measure and recorded at the isolator end. The gain medium length was varied from 2 to 9 m to optimize and maximize the ASE generation output. Three different wavelengths of laser diode namely 802, 980, and 1064 nm is used as a pump source with forward pumping method in conjunction with an optical spectrum analyzer (OSA) to investigate the output ASE behavior.

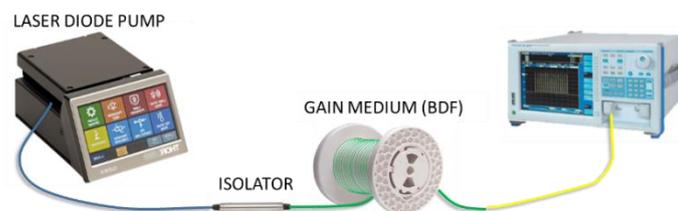


Fig. 1: Experimental setup for the ASE generation with a BDF

### 3. Results and discussion

The ASE spectra under different excitation wavelength at a fixed pump power of 170mW for 2m long BDF are investigated and results are summarized in Fig. 2. In the experiment, three commercial pump were tested as the input source namely 802, 980 and 1064 nm. As seen in Fig. 2, 980 nm pumping wavelength exhibit highest ASE peak power output of -47 dBm with broad full-width at half-maximum (FWHM) of 437 nm centered at 1120 nm. This attributed by excitation of ions from ground state of  $^3P_0$  to higher energy level of  $^3P_2$ . After losing small energy through non-radiative relaxation ( $^3P_2 \rightarrow ^3P_1$ ), ions decayed to the ground state emitting an energy at specific wavelength which in this case at 1120 nm ( $^3P_1 \rightarrow ^3P_0$ ). Next, when pumped with 1064 nm, the 2 m long BDF produces broadband NIR fluorescence centered at 1145 nm peaking at -53 dBm. ASE spectra was also observed when pumping with 802 nm wavelength and peaked at -60.8 dBm centered at 1055 nm. As we observed from the Fig. 2, the peak was moved from around 1055 to 1120 nm when the pumping wavelength is increased from 802 nm to 980 nm. Further increase of the pump wavelength does not improve the ASE generation.

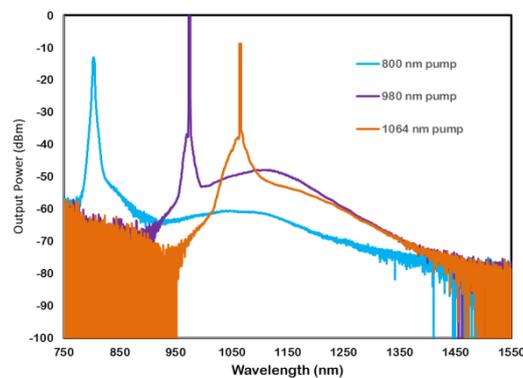


Fig. 2: ASE spectra from a 2m long BDF under three different excitation wavelengths (pump power is fixed at 170mW)

It is also noted in Fig. 3(a) that as we increased the BDF length from 2 to 9 m, the output power was decreased. This arise from the factor of high concentration of bismuth ion. As we increase the length of gain medium, more power being absorbed rather than emission and this makes 2 meter BDF as the optimized length. The impact of different input pump power on the performance of ASE was also further investigated as depicted in Fig. 3 (b). Unfortunately, only small improvement was observed as the pump power increased from 80mW to 170mW. Since the nature of Bi-related NIR emission remains uncertain, Peng et. al proposed that the Bi energy levels are defined by the absorption spectrum based on the germanate glasses host [12]. The results specify that the absorption of pump takes place at different wavelength region namely around ~802, ~980, and ~1064 nm and can be simplified as in Fig. 4. Green arrow is the process of non-radiative relaxation which occurs when the ions move quickly from a high energy level to a meta-stable level before the radiative transition occur (dashed red arrow). The final transition is depicted with dashed red arrow to illustrate the NIR-emissions, as in our case 1055, 1120, and 1150 nm emissions. Most oxidation-reduction (redox) equilibrium processes of metal ions moves towards the reduction side as the melting temperature increased [13]. Uniquely, bismuth ions is like no other element as their reduction reaction greatly proceed and producing a diversity of products. This phenomenon leads to a challenging task to determine the valence state of the bismuth ion. However, number of definite experimental facts classify that the  $\text{Bi}^{+3}$  and  $\text{Bi}^{2+}$  ions emit a visible luminescence and no near-IR luminescence [14-15]. Therefore we assume that  $\text{Bi}^+$  or  $\text{Bi}^0$  is the basis of the near-IR (1000nm – 1600nm) luminescence in our fiber [16].

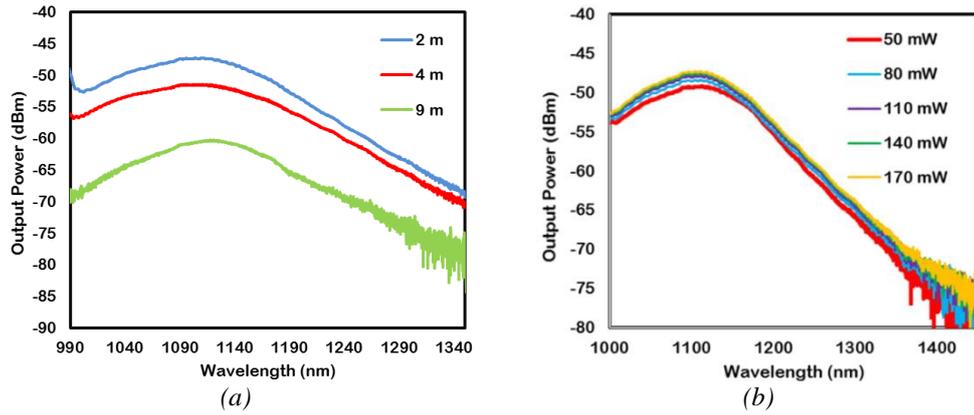


Fig. 3: Spectrum of amplified spontaneous emission for 980 nm pump excitation wavelength for (a) different BiDF length and (b) different input pump power.

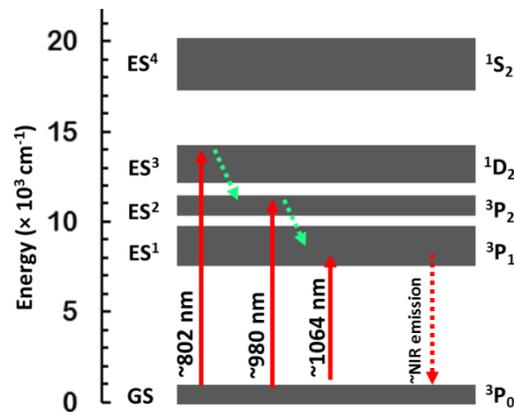


Fig. 4. Simplified energy level diagram for  $\text{Bi}^+$  in silica fiber.

#### 4. Conclusions

ASE generation in BDF has been established, which operates at peak wavelength within 1055 to 1145 nm region when pumping with 802, 980 and 1064 nm excitation wavelength. The gain medium has been drawn from a preform, which has been fabricated using an MCVD and solution doping processes. The forward pumped BDF with 980 nm single-mode laser generates highest output ASE peaked at -47 dBm with FWHM of 437 nm centered at 1120 nm. The ASE generation is due to the transition of bismuth ions from  $^3\text{P}_1$  to  $^3\text{P}_0$ .

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