# COMPACT TUNABLE HAFNIA BISMUTH ERBIUM Co-DOPED FIBER LASER

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We experimentally demonstrate a compact and tunable fiber laser using a 20 cm long of Hafnia Bismuth Erbium co-doped fiber as a gain medium in conjunction with tunable bandpass filter. The HBEDF was fabricated using a modified chemical vapor deposition in conjunction with solution doping and it has an Erbium ions concentration of 12500 wt. ppm. Compared to forward pumping scheme, the backward pumping provides a better performance in term of threshold pump power and slope efficiency. With the backward pumping, the slope efficiency of the laser varies from 1.98% to 2.79% as the operating wavelength is increased from 1535 to 1565 nm. The threshold pump power was only 30 mW.

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*Keywords:* Tunable fiber laser; Hafnium Bismuth Erbium co-doped fiber

## 1. Introduction

There is an ever-increasing demand for smaller fiber-optic equipment and components especially in telecommunication industry [1]. Therefore, optical amplifier 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 size and cost of the device. To realize a compact optical amplifier and laser devices, bismuth-based erbium-doped fiber (Bi-EDF) [2] and Zirconia Erbium co-doped fiber with an erbium ion concentration of more than 6000 ppm [3] have been previously proposed and demonstrated. Recently, the interest has also obtained for Hafnia-Bismuth co-doped silicate fibers. Doping of Hafnia having more than four coordination numbers in silica glass create non-bridging oxygens in silica network [4]. This allow the host glass to accommodate other optically-active co-dopants such as rare-earths Er, Yb, Ho along with Bi [5].

Tunable fiber lasers are also gaining a great interest in recent years because their emission wavelength can be systematically tuned within a certain spectral range [6-7]. This allows the use of a single source instead of several sources, which is convenient and cost-effective especially for telecommunication and sensing system applications. In this letter, we demonstrate a compact and tunable fiber laser using a newly developed Hafnia-Bismuth-Erbium co-doped Fiber (HBEDF) as a gain medium. The performance of the laser is investigated for both forward and backward pumping schemes.

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## 2. Characterization of HBDF and experimental setup

The HBDF was obtained from Hafnium Bismuth Erbium co-doped Yttria-Alumina-Silica glass based preform, which was fabricated using the modified chemical vapor deposition (MCVD) process in conjunction with solution doping technique. The solution doping was used to incorporate co-dopants such as $Al_2O_3$, $HfO_2$, $Bi_2O_3$, $Y_2O_3$ and $Er_2O_3$ into the core of the preform. The HBEDF was drawn from the preform by using a fiber drawing tower. The fiber has a core and cladding diameters of 3.71 and 123.94 µm, respectively, numerical aperture of 0.21. The absorption loss of the fiber was measured to be 100 dB/m at 980nm, which is equivalent to 12500 wt ppm of $Er_2O_3$. The high erbium ions concentration was possible due to the co-doping with Hafnium and Bismuth ions, which reduces the ions clustering effects.

The ASE spectrum from the HBEDF is investigated by pumping the fiber with 140mW of 980 nm laser diode in an open cavity. It is observed that the ASE power increases as the active fiber length is increased from 0.1 to 0.2 m. The long fiber length consists of more Erbium ions, which increase the population inversion rate and light emission at 1550 nm region.

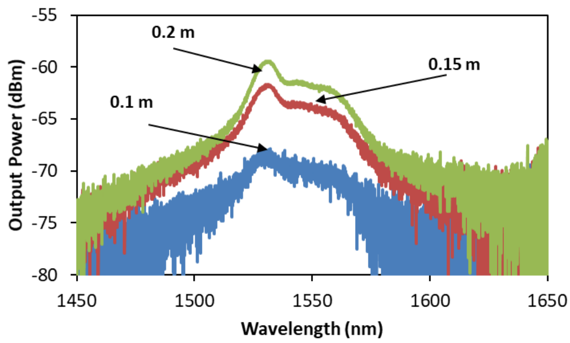
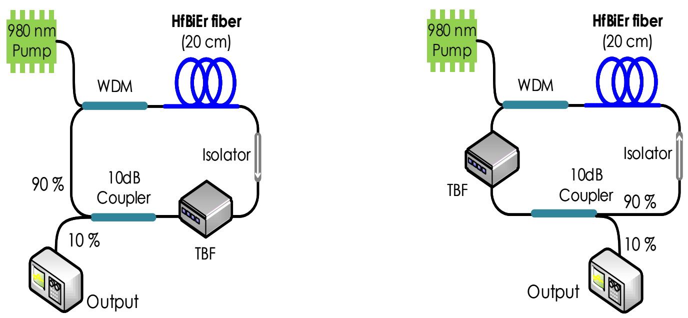



*Fig. 1. ASE spectra of the HBEDF at different lengths with 980nm pumping at 140 mW*

The tunable HBEDF laser (HBEDFL) was fabricated using a standard ring cavity configuration which is shown in Fig. 2. Figs. 2(a) and (b) shows the laser configuration with forward and backward pumping, respectively. A 980 nm laser diode with 150mW of maximum output power was used as the pump source. The pump was coupled into the cavity using a 980/1550 wavelength division multiplexer (WDM). The WDM was fusion-spliced with a 20 cm long HBEDF, which functioned as a gain medium. A band pass filter is added in the cavity to tune the operating wavelength. An isolator is incorporated in the cavity to ensure unidirectional operation of the laser. 10 dB output coupler is used to allow 90% of light to oscillate in the cavity. The output laser is tapped out through 10% port of the coupler. The output spectrum of the laser is measured using an optical spectrum analyzer (OSA) while the output power is measured by using a power meter.




*(a)* *(b)*

*Fig. 2. Configuration of the tunable HBEDFL with (a) forward and (b) backward pumping scheme*

### 3. Results and discussion

Fig. 3 shows the output spectra of the HBEDFL configured with the forward pumping at various tuning wavelength ranging from 1540 to 1560 nm. The pump power was fixed at 140 mW. It is clear from the graph that the laser exhibits a total tuning range of more than 20 nm. We should also highlight that the laser wavelength can be adjusted continuously within the tunable range. Fig. 4 shows the output power against the pump power for the laser with forward pumping. The threshold pump power of the laser was around 35 mW. The slope efficiency of the laser varies from 1.16% to 1.69% as the operating wavelength is changed from 1540 to 1560 nm. The highest efficiency was obtained at 1560 nm due to the stimulated emission, which is strongest at this wavelength region.

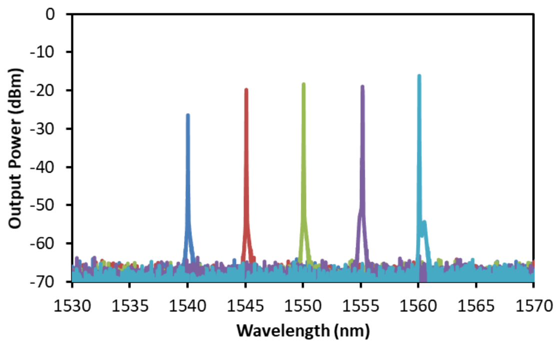



*Fig. 3. Output Spectra at various tuning wavelength wavelength at pump power of 140 mW under the forward pumping scheme*

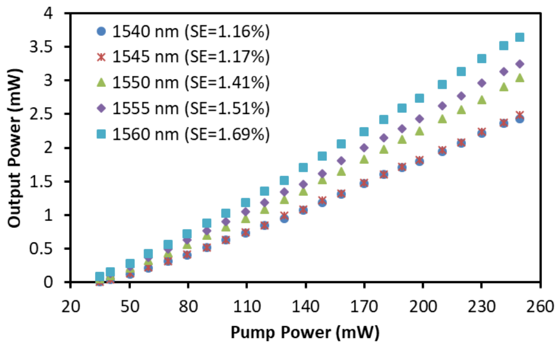



*Fig. 4. Output power against the pump power with the forward pumping scheme*

The output spectra with backward pumping scheme is shown in Fig. 5. It is shown from the figure that the laser exhibits a total tuning range of 30 nm covering a wavelength range from 1535 nm to 1565 nm. We should also highlight that the laser wavelength can be adjusted continuously within the tunable range with a smaller power variation compared to the forward pumping based laser. The signal-to-noise ratio (SNR) is more than 35 dB. The output power against the pump power for the backward pumping is shown in Fig. 6. It shows a lower threshold pump power of 30 mW compared to the forward pumping. The slope efficiency of the laser varies from 1.98% to 2.79% as the operating wavelength is increased from 1535 to 1565 nm. The highest efficiency was obtained at 1565 nm. Compared to the forward pumping, the backward pumping generates tunable laser with a higher efficiency. This is attributed to the higher population inversion at the output end of the gain medium, which improves the gain inside the laser cavity.

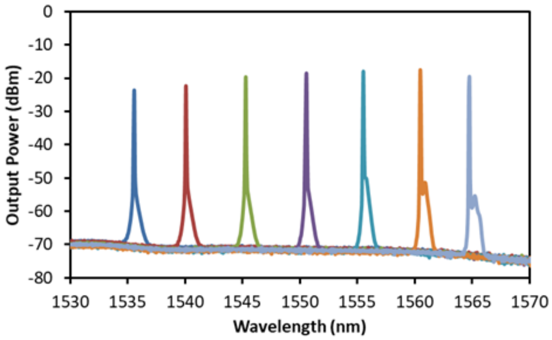



*Fig. 5. Output Spectra at various tuning wavelength wavelength at pump power of 140 mW under the backward pumping scheme*

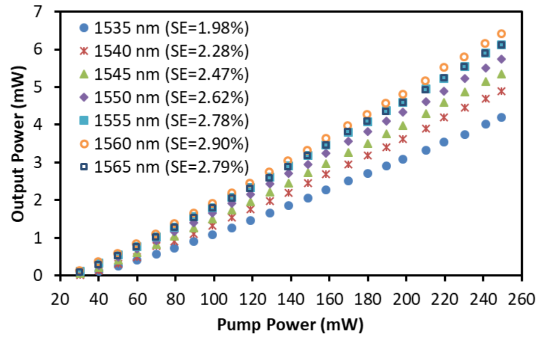



*Fig. 6. Output power against the pump power with the backward pumping scheme*

## 4. Conclusions

A widely tunable HBEDFL was demonstrated using only a 20cm long of the active fiber with concentration of 12500 wt. ppm. The tuning mechanism relies on a tunable bandpass filter and the gain spectrum of the active fiber. Compared to forward pumping scheme, the backward pumping provides a better performance in term of threshold pump power and slope efficiency. The threshold pump power was only 30 mW with the backward pumping while the slope efficiency varies from 1.98% to 2.79% as the operating wavelength is increased from 1535 to 1565 nm. The tunable laser is remarkably inexpensive and uniquely portable due the simplicity of the constituent elements. This tunable laser has potential applications in optical communication, specifically in DWDM and CWDM, and also in medicine, for example, in skin treatments.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