Wavelength-tuneable thulium-doped fiber laser based on fiber Bragg grating stretching

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A tuneable Thulium-doped fiber laser (TDFL) operating at 1900 nm region is demonstrated based on fiber Bragg grating stretching. The laser uses a 1552 nm pumping to generate a population inversion between $^3F_4$ and $^3H_4$ levels of the Tm ions, which generates amplified spontaneous emission (ASE) at around 1905 nm region. The ASE oscillates in a linear cavity to generate a tuneable laser where the efficiency varies from 29.2 to 32.5 % as the operating wavelength is tuned from 1890 to 1910 nm. The highest efficiency of 32.5 % is obtained at 1890 nm while the lowest threshold pump power of 366 mW is obtained at 1910 nm. The maximum output power of 95 mW is achieved at the pump power of 650 mW with the operating wavelength of 1910 nm. The results are of great interest for many application areas such as medical, remote sensing, and eye-safe LIDAR.

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1. Introduction

Recently, thulium (Tm)-doped fiber lasers (TDFLs) have gained tremendous research interest due to its great potential as a promising laser source for many applications [1-4]. One of the advantages of the TDFL is that its lasing wavelength is located within the “Eye-Safe” range that will be absorbed by the cornea rather than the more sensitive retina. Therefore, TDFLs could be more safely used for applications in bio-medical treatment, remote sensing, spectroscopy and nonlinear frequency conversion. For example, many animal/human tissues have absorption bands between 1.94 µm and 2.05 µm [5-6], so that lasers operated at these wavelengths could be used for tissue-welding efficiently. The thulium-doped fiber also provides broad gain spectrum at around 1.9 µm due to thulium ions' $^3F_4 \rightarrow ^3H_6$ transition, which then generated considerable interest and resulted in vigorous development of tunable fiber lasers. In various biomedical, remote sensing and spectroscopy applications, broadband tunability is essential because it allows control over the optical penetration properties in tissues and matches the absorption spectra of atmosphere gases. In this letter, we report a tunable TDFL based on a mechanically stretched fiber Bragg grating. The required architecture is proposed and the characteristics of the proposed tunable TDFL are experimentally demonstrated.

2. Configuration

The configuration of the proposed tunable TDFL is shown in Fig. 1. The cavity of the laser comprises of a piece of the TDF, which was pumped by a 1552 nm Erbium-Ytterbium fiber laser via 1550 / 2000 nm wavelength division multiplexer (WDM). The TDF used has a core diameter of 9 µm, numerical aperture of 0.15, peak core absorption of 27 dB/m at 793 nm. It employs a fiber Bragg gratings (FBG) to establish linear laser cavity in conjunction with the fresnel reflection from the output end of the fiber laser. The FBG has a reflectivity of about 90 % with 3 dB spectral width of 0.4 nm and its operating wavelength can be tuned within 1890 nm to 1910 nm by stretching technique. The output spectrum and power of the tunable laser are measured by an optical spectrum analyzer (OSA) and power meter, respectively.

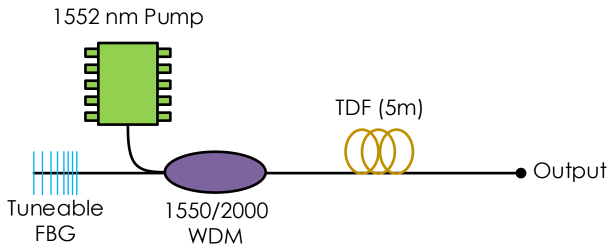

Fig. 1. Configuration of the proposed tunable TDFL.

3. Result and discussion

At first, the amplified spontaneous emsission (ASE) characteristic of the TDF used in this study is investigated by forward pumping the fiber with a 1552 nm Erbium-Ytterbium co-doped fiber laser (EYDFL) at the maximum pump power of 950 mW. This pump is used because it operates at near peak absorption wavelength of Tm ions. It is found that the optimum length for the laser operation is around 5 m, where the highest ASE is achieved at relatively lower pump power. Then the lasing characteristic of the TDF is investigated by incorporating a FBG in the setup as illustrated in Fig. 1 to form a linear cavity. The output end of the TDF is perpendicularly cleaved to reflect about 3-4% light back into the gain medium via the fresnel reflection. The ASE is then oscillated inside the linear cavity, which is formed between the FBG and output end to the TDF to generate laser at FBG's center wavelength.

Fig. 2 shows the output spectrum of the proposed laser at 1552 nm threshold pump power of 426 mW. As shown in the figure, the laser operates at 1890 nm, which coincides with the FBG's wavelength (without stretching) with the separation between the peak laser power and the residual pump is more than 4 dB. It is also observed that the separation between peak laser and residual pump increases as the pump power increases. Inset of Fig. 2 shows the ASE emission at 500 mW pump power, which was measured by using an OSA. As seen in the inset figure, the spectrum shows a broadband ASE ranging from 1800 to 2100 nm with the peak emission is observed at around 1905 nm region. This is attributed to the 1552 nm pumping, which excites the Tm ion from the ground state to the higher energy levels of $^3F_4$. Then, the Tm ions decay to create a population inversion between $^3F_4$ and $^3H_4$ levels of the Tm ions, which generates spontaneous emission at around 1905 nm region. The ASE power increases with the pump power due to the population inversion, which increases with the increase of pump power.

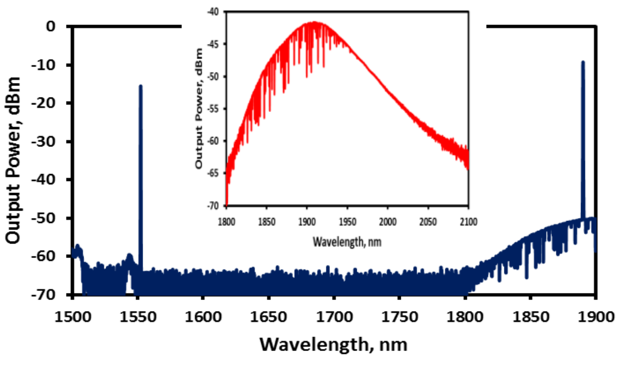

Fig. 2. Output spectrum of the proposed laser at pump power of 426 mW. Inset shows the ASE spectrum from the forward pumped TDF at pump power of 500 mW.

Fig. 3 shows the output spectra of the tuneable TDFL measured by an OSA with a spectral resolution of 0.05 nm for different operating wavelengths, which were obtained by stretching the FBG. In the experiment, the pump power is fixed at the threshold pump powers of 426 mW, 390 mW, 379 mW, 369 mW and 366 mW for operating wavelengths of 1890 nm, 1895 nm, 1900 nm, 1905 nm and 1910 nm, respectively. As shown in the figure, the operating wavelength of the laser could be continuously tuned from 1890 nm to 1910 nm by stretching the FBG. The optical signal to noise ratio (SNR) for each spectrum is better than 40 dB. It is also observed that the SNR increases with the increment of pump power.

The measured output power characteristic with respect to the operating pump power is shown in Fig. 4 for various operating wavelength. The efficiency of the laser varies from 29.2 to 32.5 % as the operating wavelength is tuned from 1890 to 1910 nm. The highest efficiency of 32.5 % is obtained at 1890 nm while the lowest threshold pump power of 366 mW is obtained at 1910 nm. The maximum output power of 95 mW is achieved at the pump power of 650 mW with the operating wavelength of 1910 nm. The pump power threshold for the proposed laser is observed to improve with the pump power due to the population inversion, which highest at around 1910 nm and thus a required pump power to initiate lasing is lower. However, the laser efficiency fluctuates with the operating wavelength due to the stretching, which slightly changes the reflectivity of the FBG. It is expected a tunability of the laser can be extended to a wider range if another tunable FBG with a wider range is used. The slope efficiency of the tunable laser can also be improved by reducing the insertion loss of the tunable filter.

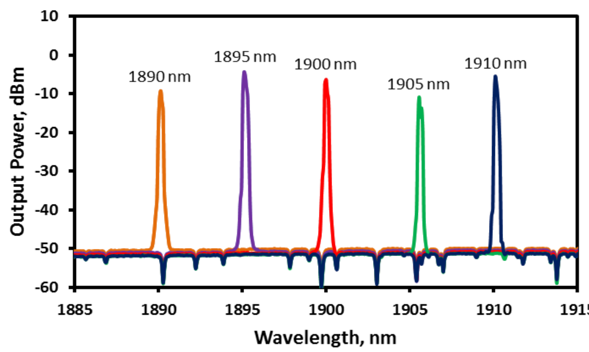

Fig. 3. Output spectra of the TDFL at various tuning wavelengths.

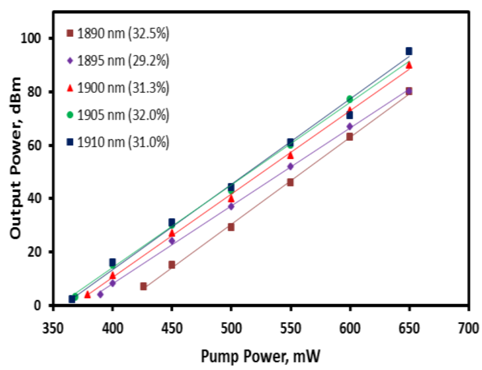

Fig. 4. Lasing characteristics of the TDFL at various tuning wavelengths.

4. Conclusion

We have successfully demonstrated a tuneable TDFL operating at 1900 nm region is using a fiber Bragg grating stretching technique in conjunction with 1552 nm pumping. The laser efficiency varies from 29.2 to 32.5 % as the operating wavelength is tuned from 1890 to 1910 nm. The highest efficiency of 32.5 % is obtained at operating wavelength of 1890 nm while the lowest threshold pump power of 366 mW is obtained at 1910 nm. The maximum output power of 95 mW is achieved at the pump power of 650 mW when the operating wavelength is set at 1910 nm. We believe that the obtained results are of great interest and may open up new prospects of many application areas.

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