

AMPLIFICATION AND LASING CHARACTERISTICS OF THULIUM YTTERBIUM CO-DOPED FIBER

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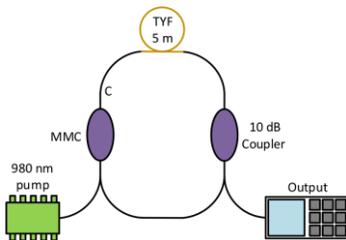
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Graphical abstract



Abstract

The amplification and lasing characteristics of the newly developed Thulium-Ytterbium co-doped fiber (TYDF) are investigated. It is obtained that both TYDF amplifier and laser operate at 1950 nm region. The maximum gain of 22.4 dB is obtained for 1942 nm signal when the 980 nm multimode pump power, TYDF length and input signal power are fixed at 1.2 W, 5 m and -20 dBm, respectively. At 5 m long of TYDF, the laser produces two prominent lines at 1960 nm and 1965 nm with peak powers of 2.8 dBm and 3.1 dBm, respectively due to the nonlinear polarization rotation (NPR) effect in the cavity.

Keywords: Thulium Ytterbium co-doped fiber laser, double-clad fiber, 2 μ m laser

Abstrak

Amplifikasi dan Pelaseran ciri-ciri gentian yang baru dibangunkan tulium-Iterbium bersama didopkan (TYDF) disiasat. Ia diperolehi bahawa kedua-dua penguat TYDF dan laser beroperasi pada tahun 1950 rantau nm. Keuntungan maksimum 22.4 dB diperolehi untuk 1942 isyarat nm apabila 980 nm pam mod kuasa, panjang TYDF dan isyarat input kuasa yang ditetapkan pada 1.2 W, 5 m dan -20 dBm, masing-masing. Pada 5 m panjang TYDF, laser menghasilkan dua talian terkemuka di 1.960 nm dan 1965 nm dengan kuasa puncak dBm 2.8 dan 3.1 dBm, masing-masing disebabkan oleh putaran polarisasi tak linear (NPR) kesan dalam rongga.

Kata kunci: Tulium Iterbium didopkan laser serat, serat dua berpakaian, 2 μ m laser

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1.0 INTRODUCTION

2 μ m laser emissions using Thulium-doped fiber (TDF) have attracted numerous interest in recent decades for a number of potential applications, including

LIDAR, remote sensing, longer-wavelength laser pumping, material processing, biomedical sensors and medical applications [1-3]. Several design have been proposed to date in enhancing TDFs including co-doping Yb³⁺ ions as a sensitizer to the Tm³⁺ ions in

the fiber [4, 5]. This design approved theoretically because of the Yb³⁺ emission at 1200 nm wavelength is one of the absorption bands of Tm³⁺. The excited Yb³⁺ ions at ²F_{5/2} energy level release their energy which is (quasi-) resonant to the Tm³⁺ energy level of ³H₅. In addition, the high absorption of Yb³⁺ ions and the uniqueness of the energy level of Yb provide sufficient contribution to the high power laser application. The low quantum defect of the Yb enables pumping at high power [6].

In this paper, the amplification and lasing performance of a new Thulium Ytterbium co-doped fiber (TYDF) with orthogonal shape double-cladding features are described based on 980 nm multimode pumping. The proposed laser operates in 2 μm wavelength region conjunction with 1 W pump power. On the other hand, the proposed design for the amplifier operates at 1942 nm wavelength, with maximum gain of 22.4 dB.

2.0 EXPERIMENTAL

In this work, the main component of the proposed 2 μm fiber laser is the gain medium, which is TYDF. At first, a double-clad octagonal shaped TYDF was fabricated by the modified chemical vapor deposition (MCVD) process in conjunction with the solution doping technique. A pure silica glass tube of outer/inner diameter 20/17 mm was used for deposition of two porous unstinted SiO₂ soot layers to make a preform while maintaining a suitable deposition temperature at around 1550 ± 100°C. An alcoholic solution containing doping elements i.e. Tm, Yb, Y, Al in terms of their chlorides of Alfa standard, was used to soak the porous layer for about 30 min to achieve efficient doping. Then, dehydration and oxidation were performed at the temperature around 900-1000°C. Sintering of the unsintered layers was also done by slowly increasing the temperature from 1500 to 2000°C using the conventional MCVD technique. Upon completion of sintering as well as oxidation, the tube was slowly collapsed to convert it into optical preform. The fabricated optical preform consists of Al₂O₃, Y₂O₃, Tm₂O₃ and Yb₂O₃ dopants with average weight percentage of 5.5, 3.30, 0.70 and 4.0, respectively measured from electron microprobe analyses (EPMA). The presence of Y₂O₃ helps to decrease the phonon energy of alumino-silica glass, which assists in preventing the clustering of Yb and Tm ions into the core glass matrix and thus increases the probability of radiative emission.

The fabricated circular preform is converted to octagonal shaped through grinding followed by polishing method. Such octagonal shaped low RI coated fiber is then drawn at temperature of 2050°C with outer cladding diameter of 125 μm from such geometrically modified preform. As opposed to the conventional single mode fiber where the pump light

is coupled directly into the core, the pump light travels down the fiber in the first cladding and get absorbed by the dopants, in this case the Yb ions when it overlaps with the core. Such octagonal geometry of the cladding improves the pump absorption efficiency. The doping levels of Tm³⁺ and Yb³⁺ ions of the fabricated TYDF are measured to be around 4.85 x 10¹⁹ ions/cc and 27.3 x 10¹⁹ ions/cc, respectively using an electron probe micro-analyser (EPMA). The Tm³⁺ and Yb³⁺ cladding absorptions of the fiber are measured to be 0.325 and 3.3 dB/m at 790 nm and 976nm respectively.

The schematic configuration of the Thulium Ytterbium co-doped fiber laser (TYDFL) is shown in Figure 1. It consists of 5 m long of TYDF, a multimode combiner (MMC), and a 10 dB output coupler in a ring configuration. The fabricated TYDF has a core and inner-cladding diameters of 5.96 μm and 123.86 μm, respectively. The numerical aperture of the fiber is calculated to be around 0.23. The double-clad TYDF is pumped by a 980 nm multimode laser diode via the MMC. The output of the laser is tapped from the ring cavity through a 10 dB coupler with only 10 % of the light is extracted for measurement, while the rest of the light resonates in the cavity. The cavity length is measured to be approximately 10 m. The optical spectrum analyzer (OSA, Yokogawa, AQ6370B) is used for the spectral analysis of the TYFL with a spectral resolution of 0.05. All components included in our setup were polarization independent, i.e. they support any light polarization. No polarization controller (PC) was used in the laser cavity as we had observed earlier that a PC did not improve the laser stability.

For TYDF amplifier, the proposed design was divided into two parts; laser and amplifier. Since we are studying on 980 nm pump conjunction with 5 m TYDF as an amplifier, another pump of 905 nm was used to generate laser at 2 μm region. The laser output was tapped from the ring using a 3 dB coupler through an isolator into the amplifier. Isolator is used to avoid reflection from amplifier into the laser source. The tapped laser and 980 nm pump is combined via another MMC. The gain medium of 5 m long TYDF is pumped by the 980 nm pump to provide amplification. The output of the amplifier is observed as shown in Figure 2.

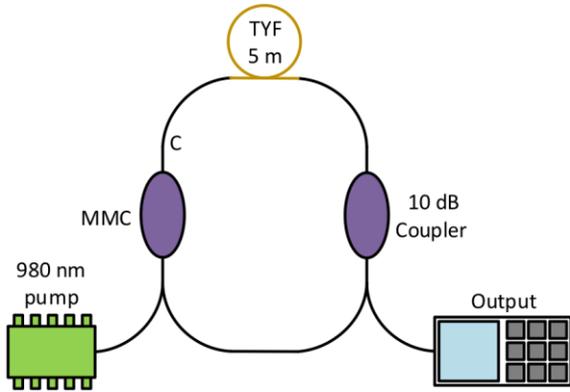


Figure 1 Proposed design of TYDF laser

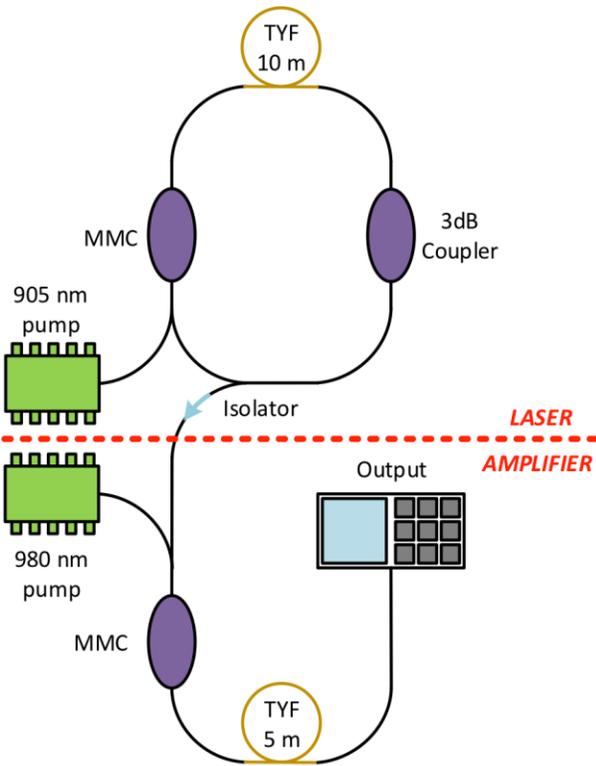


Figure 2 Proposed design of TYDF amplifier

3.0 RESULTS AND DISCUSSION

At first, the performance of the continuous wave TYDFL is investigated. The performance of the laser is investigated using TYDF optimum length of 5 m. This laser configuration contains no adjustable parts and can only be controlled externally by the amount of pump power into the gain medium. The double-clad TYDF is clad-pumped to generate an amplified spontaneous emission (ASE) at 1950 nm region, which

oscillates in the ring cavity to generate laser. Fig. 3 (inset) shows the output spectra of the ring TYDFL as the multimode 980 nm pump power is fixed at 1 W. At 5 m long of TYDF, the laser produces two prominent lines at 1960.0 nm and 1965.4 nm, as in Fig. 3 with a similar peak power of around 3 dBm due to the nonlinear polarization rotation (NPR) effect in the cavity.

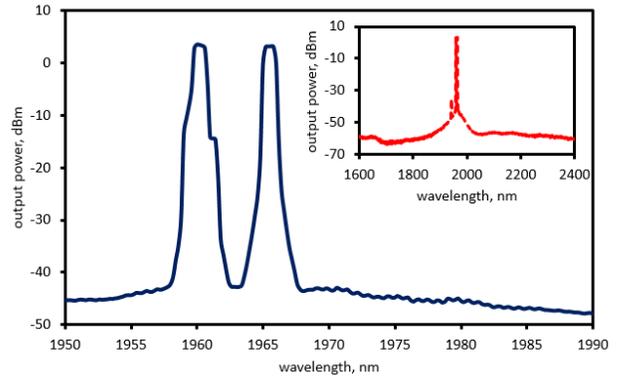


Figure 3 Output spectra from OSA of the proposed TYDFL in 2 μm region

The CW laser starts to lase at certain threshold pump power and the output laser power increases almost linearly with the increment of the pump power. Figure 4 shows the output power trend of the laser against the pump power for 5 m long TYDF as a gain medium. As shown in the figure, the threshold pump powers are obtained at 0.4 W in the ring cavity. The maximum output power is obtained at 6.5 mW with pump power of 1.3 W. The slope efficiency of 0.73% is obtained with 5 m long TYDF, as the gain medium. This shows that the use of 5 m long TYDF produces the high efficiency, hence it is the optimum length ever tested. In addition, the laser produces a dual-wavelength output at pump power of 1 W with side mode suppression ratio of more than 38 dB.

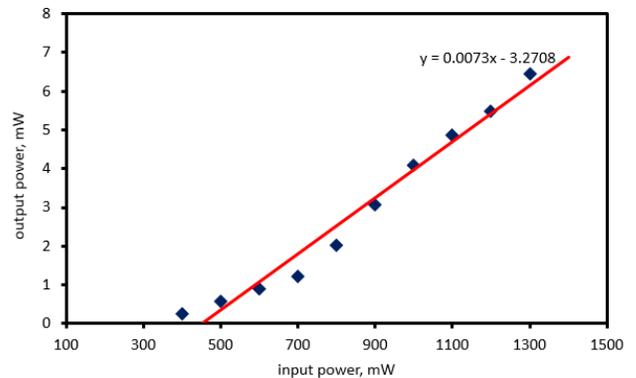


Figure 4 Output power trend in increment of input power for proposed TYDFL

By using quite a similar method of laser generation above, the performance of TYDF amplifier is investigated. 10 m long double-clad TYDF is pumped using 905 nm source via MMC to oscillate in a cavity to generate laser. As in figure 5, the laser produces in the cavity operates at 1942 nm wavelength. 50% of the light is extracted into the amplifier using a 3 dB coupler. The extracted light is transferred into the amplifier via another MMC. The extracted light went through an isolator before entering MMC. Isolator in this configuration is used to avoid any reflected light going back into ring cavity. In the amplifier, 5 m long TYDF used in previous experiment is pumped by 980 nm source.

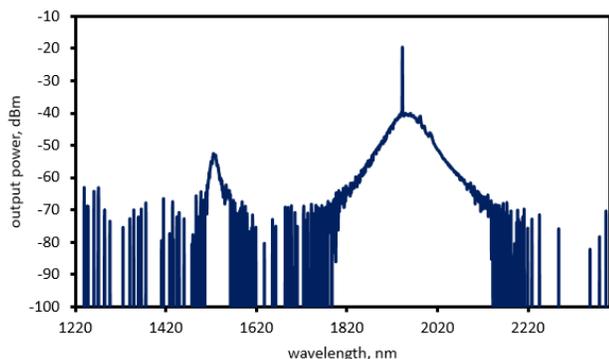


Figure 5 Optical spectra of the TYDFL using 905 nm pump conjunction with 10 m long TYDF

Figure 6 shows the TYDF amplifies the signal of 1942 nm wavelength laser. The gain of the amplifier increases with the increments of the 980 nm pump power. The amplifier will reach a saturation level at certain pump power, where no significant gain can be achieved even the pump power is increased. Figure 7 shows the gain of the amplifier reaching the level of saturation at 1.5 W pump power with gain of 22.429 dB.

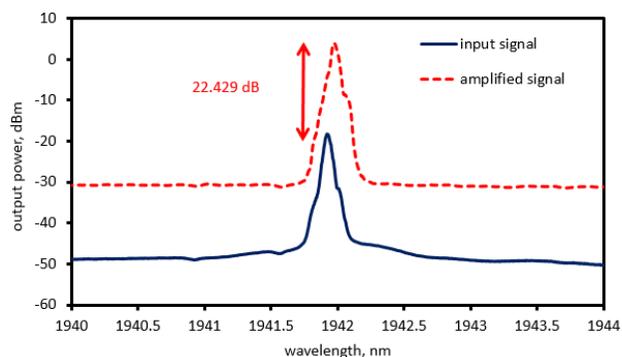


Figure 6 Optical spectra for the maximum gain of the amplifier

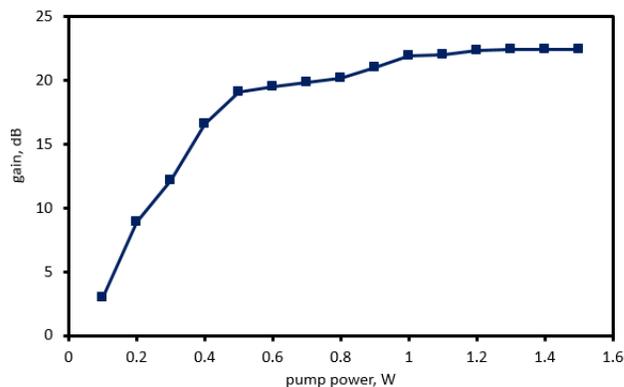


Figure 7 The amplifier gain in increments of the pump power

4.0 CONCLUSION

We have demonstrated a fiber laser operating in 1960 nm using an octagonal shape double-cladding TYDF as a gain medium. The TYDF with Tm^{3+} and Yb^{3+} ions doping levels of 4.85×10^{19} ions/cc and 27.3×10^{19} ions/cc, respectively is successfully fabricated using a MCVD and solution doping processes. The maximum output power achieved for the TYDFL is 6.45 mW with slope efficiency of 0.73%. The laser produces two prominent lines at 1960 nm and 1965 nm with a similar output power of around 3 dBm due to the nonlinear polarization rotation (NPR) effect in the cavity. By using similar gain medium, a TYDF amplifier is demonstrated at 1942 nm wavelength. The maximum gain of the amplifier is 22.429 dB at pump power of 1.5 W. The amplifier reached the saturation level at that pump power.

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