Indonesian Journal of Electrical Engineering and Computer Science
Vol. 8, No. 2, November 2017, pp. 457 ~ 461
DOI: 10.11591/ijeecs.v8.i2.pp457-461

Dual-Wavelength Thulium Ytterbium Co-Doped Fiber Laser

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Abstract

We report on the generation of dual-wavelength fiber laser peaking at 1990.64 and 1998.92 nm with a simple ring cavity setup. The lasers are demonstrated using a fabricated silica-based nano-engineered octagonal shaped double-clad Thulium-Ytterbium co-doped fiber (TYDF) as a gain medium in a simple all-fiber ring configuration. By using 980 nm multimode laser, a stable dual-wavelength laser is generated at a threshold pump power of 1500 mW due to the non-polarization rotation (NPR) effect occurred in the cavity. The effect has been self-controlled by a suppression of mode competition in the gain medium. The result shows that the slope efficiency of the generated dual–wavelength laser is measured to be 27.23%. This dual-wavelength TYDF laser operated steadily at room temperature with a 34 dB optical signal-to-noise ratio.

Keywords: *Dual-wavelength fiber laser, nano-engineered glass, silica-based TYDF, NPR effect*

1. Introduction

The dual wavelength fiber lasers (DWFLs) can be used in a variety of applications such as in optical fiber sensors, optical instrument testing for Terahertz generation and iron concentration measurement [1-3]. Likewise, the generation of dual-wavelength Thulium-doped fiber laser (TDFL) is significantly contributes to other applications in the 2 µm wavelength. The strong absorption of 1.8~2 µm radiation in water and biological tissues renders the possibility of development of this laser in a medical field. Two main ingredients of a laser are a gain medium that provides amplification and a suitable cavity that provides positive optical feedback. To date, extensive researches have been done on the gain medium materials such as advanced Thulium-doped fiber (TDF), Thulium-Ytterbium doped fiber and Bismuth based TDF [4-6]. These materials allow modification on a glass network structure to be doped with Thulium ions in order to realize high ion doping concentration. Without such structure, high ion concentration may induce the clustering effects such that ions excitation is prevented. The low phonon energy glass fibers such as flouride and germanate glass are of interest due to its ability to produce high quantum efficiency laser, however, it may also compromise other factors such as mechanical strength and temperature limitations. These issues make the Thulium silica-based host material extremely important to achieve an efficient 2 µm fiber laser. The high phonon energy of silica-based glass matrix can be reduced by incorporating a silica network modifiers like Aluminum (Al) and Germanium (Ge). In addition to that, recently the nano-engineering glass based design has emerged to efficiently modify the intrinsic network glass structure by using nano-particle technology [7, 8].

The 2 µm laser can be explored by utilizing the ion transition $^3F_4$ to $^3H_6$ of Thulium-doped fiber (TDF) when pumped with a variety of pumping scheme such as 800 nm and 1550 nm wavelength by direct pumping or excite the Tm^{3+} ions using 1200 nm wavelength. The latter approach introduces the co-doping element in the Tm^{3+} fiber core with sensitizer ion, Ytterbium (Yb^{3+}) which allows the energy to be transferred from Yb^{3+} to Tm^{3+} due to quasi-resonant energy

Received June 29, 2017; Revised September 5, 2017; Accepted September 23, 2017

levels of Tm^{3+} at $^3H_5$. The high efficiency absorption in the range of 900 nm-1000 nm creates a possible configuration with cheap 980 nm double-clad pumping. Most of the previous work dealing with Thulium-Ytterbium co-doped fiber (TYDF) was confined to a discussion of upconversion in visible and S-band regions. Only a few works have discussed on the lasing performance in 2 µm region using TYDF [9, 10]. Concurrently, dual-wavelength fiber lasers (DWFL) have also gained tremendous interest due to their applications such as optical fiber sensors which can be used in various fiber optic sensor applications [11-12]. The generation of DWFL is quite challenging due to the effect of homogenous line broadening in the gain medium which caused mode competition that prevent the process of getting dual-wavelength output. Various methods have been proposed to achieve a DWFL such as incorporating highly birefringent (Hi-Bi) fibers employing in a fiber Bragg gratings (FBGs) [13], Sagnac loop mirror [14], and cascaded filter structures [15]. Zhou et al. [16] demonstrated a room temperature all-fiber dual-wavelength TDFL based on cascaded fiber Bragg grating (FBG) array. However, the FBG structure requires an expensive UV laser to fabricate and conventional FBG cannot operate at temperature higher than 300 ^{0}C. Despite of effective in solving the mode competition issues, most of the works are difficult to handle and needed a complicated setup in order to generate dual-wavelength output.

In this article, we demonstrated a simple setup for generation of DWFL in a ring cavity configuration constructed with a newly developed octagonal shaped double-clad TYDF as a gain medium operating in 2 µm region. The TYDF is a nano-engineering glass based design which was fabricated using modified chemical vapor deposition (MCVD) process in combination with solution doping technique. The cavity set-up introduced the non-polarization rotation (NPR) effect that lead to a suppression of mode competition in gain medium and results a stable dual-wavelength laser output.

2. Research Method

Figure 1 shows the experimental setup for DWFL using TYDF with a half-opened linear cavity configuration. In this work, a double-clad octagonal shaped TYDF which was coated with a low refractive index polymer was used as a gain medium. It was drawn by a preform, which was fabricated by the modified chemical vapor deposition (MCVD) process in conjunction with the solution doping technique. The preform was made by deposition of two porous unstinted SiO_2 soot layers inside a pure silica glass tube at temperature around 1550 ± 10 ^{0}C. The porous layers were soaked into an alcoholic solution containing doping elements i.e. Tm, Yb, Y and Al for about 30 minutes to achieve efficient doping. Then, the dehydration and oxidation were performed at the temperature around 900-1000 ^{0}C. Sintering of the un-sintered layers was also done by slowly increasing the temperature from 1500 to 2000 ^{0}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. Based on electron probe micro analyser (EPMA) result, we found out that the fabricated optical preform consists of Al_2O_3, Y_2O_3, Tm_2O_3 and Yb_2O_3 dopants with average weight percentage of 5.5, 3.30, 0.70 and 4.0, respectively. The presence of Al_2O_3 and Y_2O_3 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 normal circular preform is converted to octagonal shaped through grinding followed by polishing method. The geometrically modified preform is then drawn at a temperature of 2050 ^{0}C to obtain an octagonal shaped fiber with outer cladding diameter of 125 µm. The fiber is then coated with a low refractive index polymer to ensure the robustness of the fiber. The doping levels of Tm^{3+} and Yb^{3+} ions in the fabricated TYDF are 4.85 x 10^{19} ions/cc and 27.3 x 10^{19} ions/cc, respectively. The Tm^{3+} and Yb^{3+} cladding absorptions of the fiber are 0.325 and 3.3 dB/m at 790 nm and 976 nm, respectively. The numerical aperture (NA) of the fabricated TYDF is measured to be 0.23. The double-clad fiber allows the injected light to propagate into the inner cladding and get absorbed by the core dopants of the TYDF. The octagonal shaped geometry of the cladding increase the overlapping between the injected pump and the doped core therefore enhances the power transfer which improves the pump absorption efficiency.

The proposed DWFL is constructed using a ring cavity in which a 10 m double-clad octagonal shaped TYDF is used as an active gain medium. It is pumped by a 980 nm multimode laser diode (LD) via a multimode combiner (MMC) to achieve population inversion in an Ytterbium ion, the emitted energy is then transferred to Thulium ions to generate an amplified spontaneous emission (ASE) in 2 µm regions. The ASE oscillates in the ring cavity until it is become larger than the losses in the cavity to generate laser. A 10 dB coupler is used to extract a portion of a laser as an output to be fed into an optical spectrum analyzer (OSA) to observe the output and 90% of the light to oscillate in the laser cavity. The incorporation of isolator is believed to act as a polarizer in order to induce the birefringence effect within the cavity [17]. The laser output is measured by using an OSA with a resolution of 0.05 nm and an optical power meter (OPM).

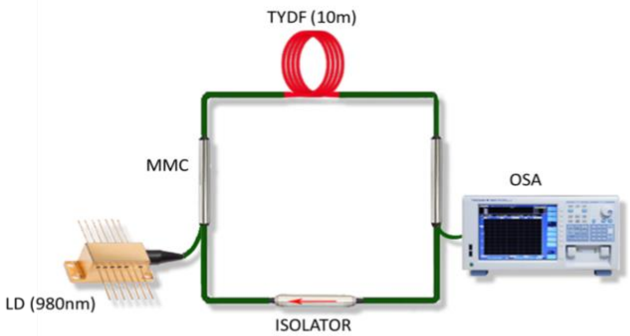

Figure 1. Experimental setup of the proposed dual wavelength TYDFL

3. Results and Analysis

As the TYDF is pumped continuously, a single wavelength laser is successfully generated at a threshold power of 400 mW. As the pump power is further increased, the self-generated DWFL is observed as in Figure 2 at the pump power of 1.5 W. Based on the setup in figure 1, it is believed that stable DWFL is generated due to the nonlinear polarization rotation (NPR) induce intensity dependent loss which alleviate the mode competition caused by homogeneous broadening in the TYDF [18]. The round-trip phase variation in the linear laser cavity has induced due to the birefringence effect in the TYDF fiber and the isolator. Since the TYDF used in the cavity has a reasonably high nonlinearity, it produces sufficient NPR-induced intensity dependent state of polarization in the laser cavity. It does not need any external source or pumps to realize the NPR effect. In this case, the transmission term varies too fast with the power and thus allows at least two wavelengths to oscillate in the linear cavity.

As seen in Figure 2, a dual-wavelength output lines are obtained at 1990.64 and 1998.92 nm with a spacing of 8.28 nm and the optical signal to noise ratio (OSNR) of more than 34 dB. The 3 dB bandwidth of both lasers is measured to be less than 0.2 nm. The power difference between the two peaks is less than 1 dB at around -5 dBm.

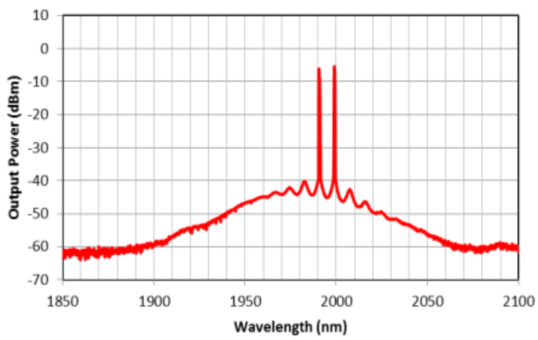

Figure 2. Output spectrum of the proposed dual-wavelength TYDFL at multimode pump power of 1500 mW

Figure 3 shows the output spectrum of the DWFL with a scanning time interval of 10 minutes with the increased in pump power between 2.6 W to 3.4 W. As shown in the figure, stable DWFL can be observed for 2 hours in a room temperature without any perturbation. No other lasing modes have been observed within the 2 μm emission. It is believed that the DWFL generation is governed by the NPR effect contributed by the gain medium, isolator and the octagonal shaped of the double-clad TYDF.

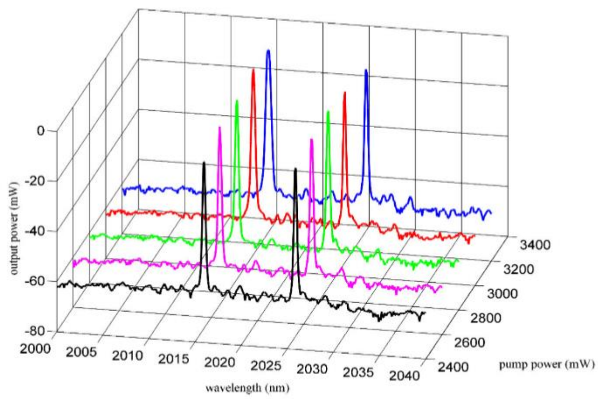

Figure 3. The stability of the output spectra for the DWFL with 10 minutes period of each interval

The TYDF laser (TYDFL) starts to lase at pump power of 400 mW to generate a random laser operating at around 1995 nm region. The output power of the laser is observed to increase linearly with the increment of multimode pump power of up to 1200 mW with a slope efficiency of 12.62%. The output power suddenly drops at pump power of above 1200 mW to enable dual-wavelength laser generation. The relation between the output powers of the DWFL against the multimode pump power is shown in figure 4. The dual-wavelength laser starts to lase at threshold power of 1500 mW and both output peaks power increases linearly with the increment of multimode pump power of 2750 mW. The slope efficiency of the dual–wavelength laser is measured to be around 27.23%, which is comparable to the conventional TDFL pumped by 800 nm single mode pump.

The effect of dual-wavelength can be seen even with an absence of polarization controller in the ring cavity setup. It is believed that if polarization of the light beam can be controlled, the effect of dual-wavelength will be more vibrant and stable. The dual-wavelength laser produces the maximum total output power of 366 mW at the highest multimode pump power of 2750 mW. As the pump power is increased above 2750 mW, the total output power drops and the random lasers have been observed.

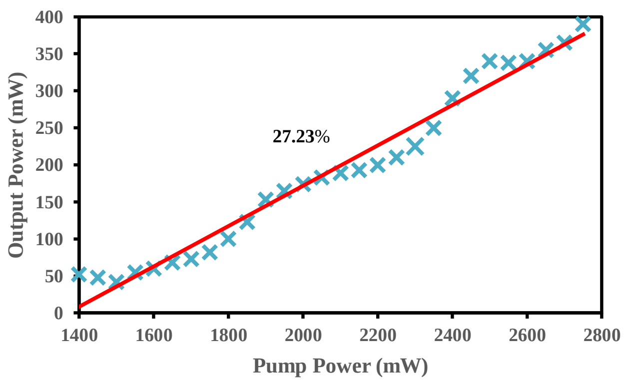

Figure 4. Output power characteristic against the pump power

4. Conclusion

We have demonstrated an all-fiber dual-wavelength TYDFL operating at 2 µm regions based on NPR effect. The newly developed octagonal shaped double-clad TYDF was used as a gain medium. The dual-wavelength output lines at wavelengths of 1990.64 and 1998.92 nm were generated as the 980 nm multimode pump power was increased above a threshold value of 1500 mW. The signal to noise ratios of both laser lines are measured to be more than 34 dB and the slope efficiency is measured to be 27.23%. The performances for both lasing characteristics are not optimized and could be improved by changing the pump wavelength and by optimizing the cavity.

Acknowledgement

Author would like to acknowledge the International Islamic University Malaysia for internal funding by the university under Grant No.: RIGS15-145-0145.

References

[1] Lu G. A dual-wavelength method using the BDJ detector and its application to iron concentration measurement. *Measurement Science and Technology*. 1999; 10(4):312.

[2] Jeon MY, Kim N, Shin J, Jeong JS, Han S-P, Lee CW, et al. Widely tunable dual-wavelength Er 3+-doped fiber laser for tunable continuous-wave terahertz radiation. *Optics express*. 2010; 18(12):12291-7.

[3] Wang S, Liu S, Ni W, Wu S, Lu P. Dual-wavelength Highly-sensitive refractive index sensor. *Optics Express*. 2017; 25(13):14389-96.

[4] Kuan P-W, Li K, Zhang G, Wang X, Zhang L, Bai G, et al. Compact broadband amplified spontaneous emission in Tm 3+-doped tungsten tellurite glass double-cladding single-mode fiber. *Optical materials express*. 2013; 3(6):723-8.

[5] Jetschke S, Unger S, Schwuchow A, Leich M, Fiebrandt J, Jäger M, et al. Evidence of Tm impact in low-photodarkening Yb-doped fibers. *Optics express*. 2013; 21(6):7590-8.

[6] Halder A, Paul MC, Harun S, Ali S, Saidin N, Damanhuri S, et al. 1880-nm broadband ASE generation with Bismuth–Thulium codoped fiber. *IEEE Photonics Journal*. 2012; 4(6):2176-81.

[7] Klimentov D, Dvoyrin VV, Halder A, Paul MC, Das S, Bhadra SK, et al. Emission decay and energy transfer in Yb/Tm Y-codoped fibers based on nano-modified glass. *Optical Materials.* 2015; 42:270-5.

[8] Gorbatikh L, Lomov SV, Verpoest I. Nano-engineered composites: A Multiscale Approach for Adding Toughness to Fibre Reinforced Composites. *Procedia Engineering*. 2011; 10:3252-8.

[9] Damanhuri SSA, Halder A, Paul MC, Ali SMM, Saidin N, Harun SW, et al. Effects of Yb/Tm Concentration and Pump Wavelength on the Performance of Ytterbium-Sensitized Thulium-Doped Fiber Laser. *IEEE Journal of Quantum Electronics*. 2013; 49(1):95-9.

[10] Pal A, Dhar A, Das S, Chen SY, Sun T, Sen R, et al. Ytterbium-sensitized Thulium-doped fiber laser in the near-IR with 980 nm pumping. *Optics express.* 2010; 18(5):5068-74.

[11] Liu D, Ngo NQ, Tjin SC, Dong X. A dual-wavelength fiber laser sensor system for measurement of temperature and strain. *IEEE Photonics Technology Letters*. 2007; 19(13/16):1148.

[12] David G, Miffre A, Thomas B, Rairoux P. Sensitive and accurate dual-wavelength UV-VIS polarization detector for optical remote sensing of tropospheric aerosols. *Applied Physics B*. 2012; 108(1):197-216.

[13] Álvarez-Tamayo R, Durán-Sánchez M, Pottiez O, Ibarra-Escamilla B, Cruz J, Andrés M, et al. A dual-wavelength tunable laser with superimposed fiber Bragg gratings. *Laser Physics*. 2013; 23(5):055104.

[14] Durán-Sánchez M, Flores-Rosas A, Alvarez-Tamayo R, Kuzin E, Pottiez O, Bello-Jimenez M, et al. Fine Adjustment of Cavity Loss by Sagnac Loop for A Dual Wavelength Generation. *Laser Physics*. 2010; 20(5):1270-3.

[15] Wang S, Lu P, Zhao S, Liu D, Yang W, Zhang J. 2-µm switchable dual-wavelength fiber laser with cascaded filter structure based on dual-channel Mach–Zehnder interferometer and spatial mode beating effect. *Applied Physics B*. 2014; 117(2):563-9.

[16] Zhou P, Wang X, Ma Y, Han K, Liu Z. Stable all-fiber dual-wavelength thulium-doped fiber laser and its coherent beam combination. *Laser Physics*. 2011; 21(1):184-7.

[17] Moshe I, Jackel S, Meir A. Production of radially or azimuthally polarized beams in solid-state lasers and the elimination of thermally induced birefringence effects. *Optics letters*. 2003; 28(10):807-9.

[18] Luo Z-C, Luo A-P, Xu W-C, Yin H-S, Liu J-R, Ye Q, et al. Tunable multiwavelength passively mode-locked fiber ring laser using intracavity birefringence-induced comb filter. *IEEE Photonics Journal.* 2010; 2(4):571-7.