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A Stable Dual-Wavelength Erbium Doped Fiber Laser Based on Photonic Crystal Fiber and Tapered Optical Fiber

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Abstract: Based on combining of Photonic Crystal Fiber (PCF) and Tapered Optical Fiber (TOF) at room temperature, a dual-wavelength Erbium Doped Fiber (EDF) laser has been proposed and demonstrated. The TOF is fabricated by using fully computerized tapered optical fiber fabrication system. The experimental results showed that the generated dual-wavelength laser at low pumping power of 28.86 mW is highly stable. In addition, single wavelength fiber laser can also be achieved by only the reduction of the input power.

Key words: Fiber laser, dual wavelength, tapered optical fiber, photonic crystal fiber, stable, power

INTRODUCTION

Dual wavelength fiber laser has attracted a great of research interests due to their enormous used in many fields such as optical communication systems, microwave generation and optical fiber sensor (Park *et al*., 2001; Yao *et al*., 2006; Liu *et al*., 2007). Erbium Doped Fiber (EDF) has a uniform gain broadening. So, different techniques for modifying the mode competition have been used to get a stable dual-wavelength lasing spectrum. For example, a Double-Ring Filter (DRF) is incorporated within ring cavity (Yeh *et al*., 2007), a Fiber Bragg Grating (FBG) is inserted into the cavity to increase a suppressant effect for cross-gain saturation and homogenous line broadening produced by deep signal saturation in EDF loop cavity (Liu *et al*., 2006). PCF has been studied broadly for its unique optical features compare with that of single mode fiber which include flexible shape, low optical loss, manageable dispersion, ultrahigh nonlinearity (Wan-Jun *et al*., 2012). Furthermore, PCF was merged with graphene oxide which acts as a saturable absorber to propose multi wavelength (Ahmad *et al*., 2014). PCF was benefited in Sagnac loop and broadband FBG (Chen *et al*., 2009), a tunable band-pass filter (Ahmad *et al*., 2013) and multi-wavelength Brillouin-erbium fiber laser (Nasir *et al*., 2009) to introduce dual-wavelength. On other hand, TOF is widely used to generate dual-wavelength lasing oscillation due to their interesting properties include a high optical nonlinearity, ability of dispersion-tuning, strong evanescent field and easy fabrication of three-dimensional structures with different profile like dual tapered Mach-Zehnder interferometer with ytterbium-doped fiber (Harun *et al*., 2010; Ahmad *et al*., 2015). In this research, we combined between PCF and TOF in one setup to introduce a very stable dual wavelength which operating under room-temperature conditions at around the wavelength 1530 nm at low pumping power of 28.86 mW with wavelength difference spacing of $\Delta\lambda$ = 4.21 nm. TOF was fabricated by using glass fiber processing system (Vytran GPX-3400) and the tapered fiber used in this experiment has a waist diameter 12 μm and a total interference length of 30 mm.

MATERIALS AND METHODS

Tapered fiber fabrication and experimental setup: TOF with a 12 μm waist diameter was fabricated first. Figure 1 illustrates the simple structure of the manufactured tapered fiber for this experiment where a Single Mode Fiber (SMF) is tapered by using the fully automatic tapering machine which was (Vytran GPX-3400). The heat source in this system is a U-shaped microheater (Harun *et al*., 2013). The fabricated TOF shape consist of Transition Length (L_T), Waist Diameter (W_D) and Waist Length (W_L).

The schematic diagram of current dual wavelength fiber laser experiment setup is depicted in Fig. 2. A laser cavity consists of LD 980 nm acting as a pump power, a

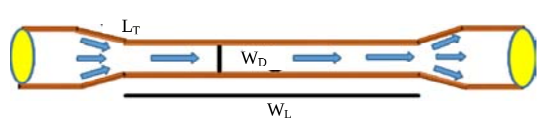

Fig. 1: The structure of TOF

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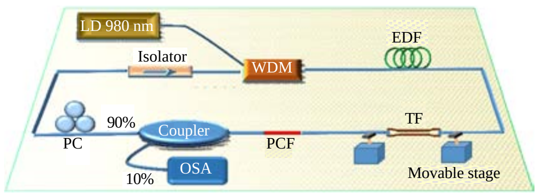

Fig. 2: The experiment setup to characterized dual-wavelength EDF

980/1550 nm Wavelength Division Multiplexer (WDM) coupler. The out put of WDM was fusion spliced to a piece of EDF that used as a gain medium with length of 3 m to obtain lasing spectrum. The second end of EDF was connected to optical tapered fiber which was fixed on tow holders and then connect to 7 cm length of PCF. A 90/10 coupler used to get the output. Polarization controller and an isolator are connected to control the state of light polarization and to achieve unidirectional of laser, respectively. An Optical Spectrum Analyzer (OSA) (Yokogawa AQ6370B) with a resolution of 0.05 is used to record the output measurements.

RESULTS AND DISCUSSION

Principle and experimental results: When a PCF section is splicing with SMF, the air-holes of the PCF certainly fall down produce in the area of connect. So that, Mach-Zehnder interferometer affect was generated due to the sections of collapsed were positioned in chain. The fundamental mode in SMF start to diffract when it moves in the PCF at the first coupling region and products in higher order mode at the second area of PCF. These high modes of PCF are reuniting with some fundamental modes of standard fiber at next splice region. Refractive index difference Δn_e between fundamental and excited modes can produce a different in optical paths at the same length which lead to get an interferometer. The transmitted power will distribute at wavelength centers more than other regions due to phase difference and phase velocity are wavelength dependent (Chen *et al*., 2009). TOF is mainly consist of three sections: firstly microfiber waist section which has usually a very small and uniform diameter W_D, and two conical transition regions with gradually changed diameter (L_T). The arms of conical transition regions are untapered fibers. As the light wave transmitting through the transition regions, the field distribution fluctuates with the change of core and cladding diameters along the way. Depend on the rate of diameter alteration, the energy transfer from the fundamental mode to closest few higher order modes varies which determines to the loss of the propagating wave power (Jaddoa *et al*., 2016). Figure 3

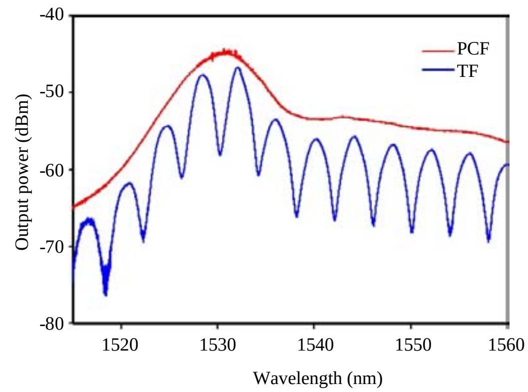

Fig. 3: The output spectra of PCF and TOF

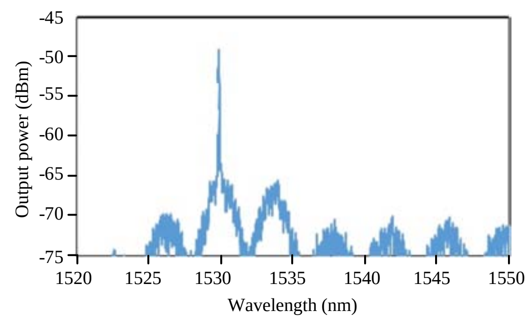

Fig. 4: Output power of single wavelength at pump power 28.86 mW

depicts the output spectra of EDF laser ring when we applied separately the PCF and TF in the cavity at input power of 10.35 mW.

When we carry out our experiment with combined of PCF section and TOF element and with adjustment the PC state to decrease homogeneous linewidth of the EDF, a single wavelength has been obtained at the pumping power (14.93 mW) as depict in Fig. 4. The Side Mode Suppression Ratio (SMSR) for this single pulse was 16 dBm.

To obtain a dual-wavelength, the pumping power is increment to 28.86 mW without variable polarization state by PC. Figure 5 shows the dual-wavelength of EDF laser cavity. The laser is operate at wavelengths 1533.5 and 1529.3 nm with peak power -50.875 and -53.451 dBm, respectively. Moreover, for the dual-wavelength, SMSR is 27 dBm in average. The wavelength spacing at room temperature is 4.2 nm

The output spectrum of dual-wavelength laser was recorded each 2 min over the period of 30 min at increased pumped power of 38.02 mW to notice the stability of the pulses over time as depicts in Fig. 6 and this stability was enhanced by using tapered fiber in our setup.

Figure 7a shows the wavelength shifting for laser 1 and laser 2 and it was just 0.07 nm for both. Besides this,

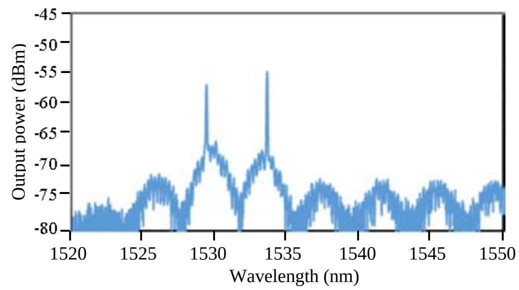

Fig. 5: Output power of dual-wavelength at low pump power 28.86 mW

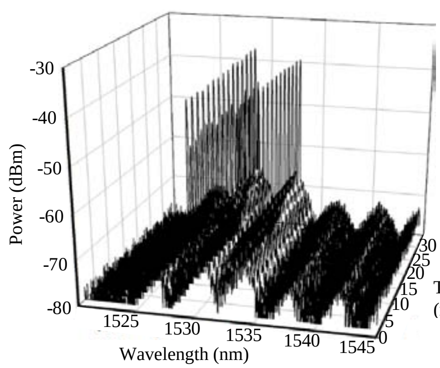

Fig. 6: The dual-wavelength power stability over the time

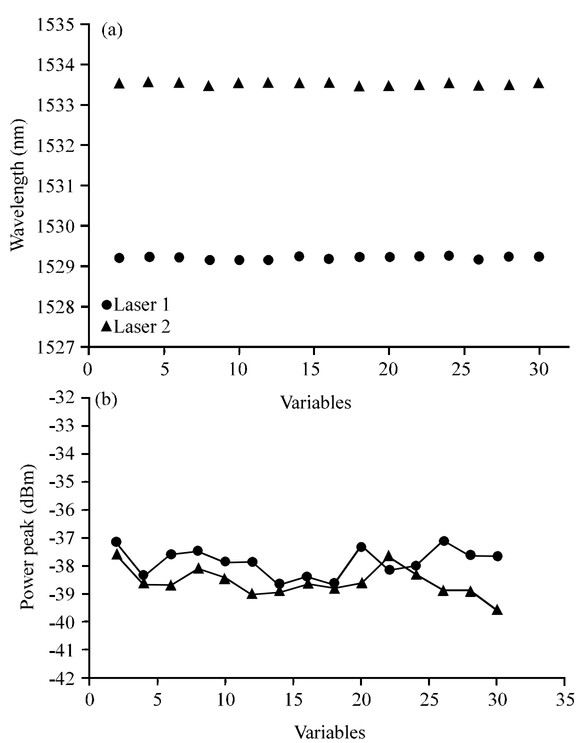

Fig. 7: The dual-wavelength laser stability amount in terms of: a) Wavelength shift and b) Power peak

Fig. 7b depicts the highest power peak oscillation was 1.49 and 1.81 dBm for laser 1 and 2, respectively.

CONCLUSION

In summary, a very stable dual-wavelength EDF is successfully demonstrated by using PCF and tapered fiber as comb filter. The tapered fiber is fabricated by using glass fiber processing system (Vytran GPX-3400). The dual-wavelength is operate at 1533.5 and 1529.3 nm with a stable peak power and low current pumping at 96 mA. A signal-to-noise ratio is 27 dBm. In addition, by decrement the pump current we can get single wavelength at 91 mA current pumping. The tapered fiber has 12 μm waist diameter and 10 mm waist length.

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