Wavelength-tunable mode-locked fiber laser with birefringence-enhanced cavity

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ABSTRACT

A wavelength-tunable Erbium-doped fiber laser with birefringence-enhanced cavity is proposed. A 45° tiled fiber grating (45°TFG) and a section of polarization maintaining (PM) fiber are placed between two two polarization controllers (PCs). Two PCs and PM fiber are employed to enhance the birefringence effect. The 45° TFG plays the role of an in-fiber polarizer. The fiber laser is mode-locked by single walled carbon nanotube polyvinyl alcohol (SWCNTs-PVA) composite film. Central wavelength of the fiber laser can be tuned from 1552.52nm to 1575.28nm with a tuning range of 22.76nm. The demonstrated laser provided the widest tuning range in a high repetition rate all-fiber Erbium doped laser based on SWCNT.

Keywords: *mode locked fiber laser, tilted fiber grating, wavelength tuning, carbon nanotube*

1. INTRODUCTION

During the past decade, wavelength-tunable mode-locked fiber laser have attract a great deal of attention owing to their application in many fields such as spectroscopy, fiber-optic sensors and optical telecommunications, optical instrumentation [1-4]. Up to now, many methods have been proposed to realize wavelength tunable mode-locked laser. The central wavelength can be tuned by adding a Mach–Zehnder interferometer or acousto-optic tunable filter in the laser [5,6] . Fiber gratings such as chirped fiber Bragg grating [7], W-shape long period grating (LPG) [8] are also employed to tune the wavelength of the fiber laser. Commercial mechanically tunable bandpass filter are also shown to be a good device for achieving wavelength tuning of the laser [9,10].Another method is to use the intrinsic birefringence effect of the laser as a birefringent filter to tune the wavelength [11].In order to enhance the birefringence effect of laser, the PM fiber with appropriate length can be incorporated into the laser cavity [12].

In this report, we proposed a wavelength-tunable carbon nanotube mode-locked fiber laser with birefringence-enhanced cavity. Wavelength can be tuned by a birefringent filter formed by two PCs, 45°TFG, PM fiber. The 45°TFG enables the *p*-light to propagate along the fiber core with a small loss, while *s*-light is coupled into the cladding along the direction perpendicular to the fiber core. So 45°TFG plays the role of an in-fiber polarizer [13]. Two PCs are used to optimize the polarization state and adjust the birefringence. PM fiber is used to enhance birefringence.

2. EXPERIMENTAL SETUP

The fiber laser is mode-locked by SWCNTs-PVA composite film with 6.2% modulation depth. Detailed fabrication of SWCNTs-PVA composite film can be found in [14]. 45°TFG used in fiber laser has -7.23dB insertion loss and 19dB polarization dependent loss (PDL) at 1550nm. Fig.1.(a)&(b) shows the measured insertion loss and PDL of the 45°TFG, respectively. The fabrication of 45°TFG is described in detail in ref[15].

Schematic of the wavelength-tunable fiber laser is shown in Fig.2. The fiber laser is pumped by a 980nm benchtop laser (OV LINK) with maximum pump power of 611mW via a WDM with pigtail of 2.47m OFS980 which has normal dispersion β_2 = +4.5 ps2/km. A section of Erbium-doped fiber (EDF Er80-8/125 from Liekki) with length of 1.1m and group velocity dispersion (GVD) of -20 ps^2/km is used as active fiber of the fiber laser. Two PCs are used to adjust the polarization. A 45°TFG and a section of PM fiber with length of 16cm are placed between the two PCs. SWCNTs-PVA composite film is sandwiched between two standard fiber connector ferrules. An optical isolator (OSI) is employed to prevent the reverse light and ensure unidirectional operation of the fiber laser. 40% of the light is coupled out by a 60:40 output coupler. The laser also includes 7.1m single mode fiber (SMF) with anomalous dispersion β_2 = -22.8 ps2/km. Total cavity length is 10.7m and net dispersion is -0.376ps^2, so it is shown that the laser operates in the soliton region. 40% output pulses of the fiber is divided into two parts by a coupler, then an optical spectrum analyzer (OSA, Yokogawa AQ6370C) is employed to analyze the output spectrum and a 1 GHz mixed signal oscilloscope (OSC, Tektronix MSO4104) and a spectrum analyzer (SIGLENT, SSA 3032X) with a 12.5GHz high speed biased photodetector (Newport, 818-BB-51F) are used to record the pulse trains and radio frequency (RF) spectrum of pulses.

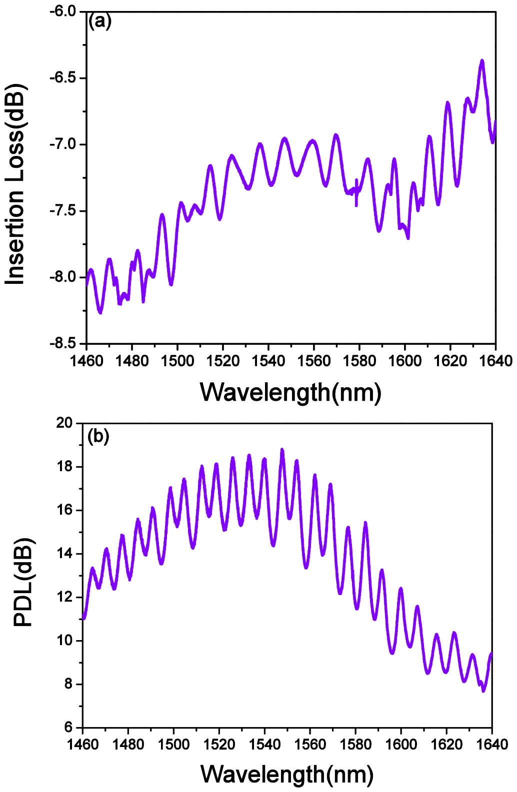

Fig.1. Measured (a) insertion loss, (b) PDL of 45°TFG

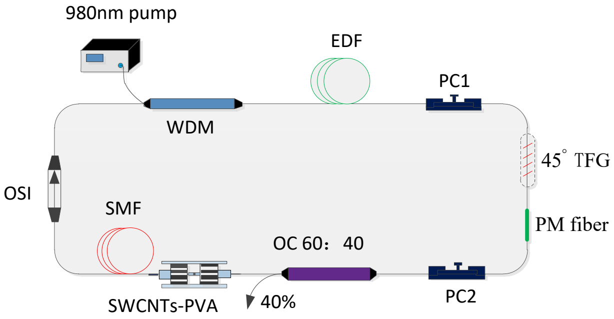

Fig.2. Schematic of the wavelength-tunable fiber laser

3. EXPERIMENTAL RESULTS

The mode-locked threshold of the laser is 220mA. The laser is mode-locked by SWCNTs-PVA composite film without nonlinear polarization evolution (NPE), because only when the pump current is greater than 500mA, NPE will work. When the pump current is increased to 260mA, adjusting the polarization controller slightly, the laser will operate in a very stable mode locking state. Fig.3. (a) shows the pulse trains of the fiber laser with pulse interval of 51.5ns under pump current of 260mA. RF spectrum of pulses is depicted in Fig.3.(b). We can see that the signal to noise ratio (SNR) at 19.4MHz is 50.8dB. Both the pulse trains and RF spectrum indicate that the fiber operates in single pulse state and the pulses is relatively stable. At this point, the central wavelength of the fiber laser can be tuned continuously by adjusting the PCs. From Fig.4.(a), we can see that the central wavelength can be tuned from 1552.52nm to 1575.28nm with a tuning range of 22.76nm. In the wavelength tuning process, the laser has always been working in single pulse state. Pulse duration at different central wavelength are also measured. Fig.4.(b) shows autocorrelation traces of laser output at different central wavelengths. The minimum pulse width is 1.23ps corresponding to central wavelength of 1570.01nm and the maximum pulse width is about 3.48ps corresponding to the central wavelength of 1567.67nm. The minimum spectral width and output power are 1.28nm, 0.22mW respectively. The maximum spectral width and output power are 2.88nm, 0.76mW respectively. Further increasing the pump current, the central wavelength of the laser also can be tuned, but the range is small and laser will become unstable.

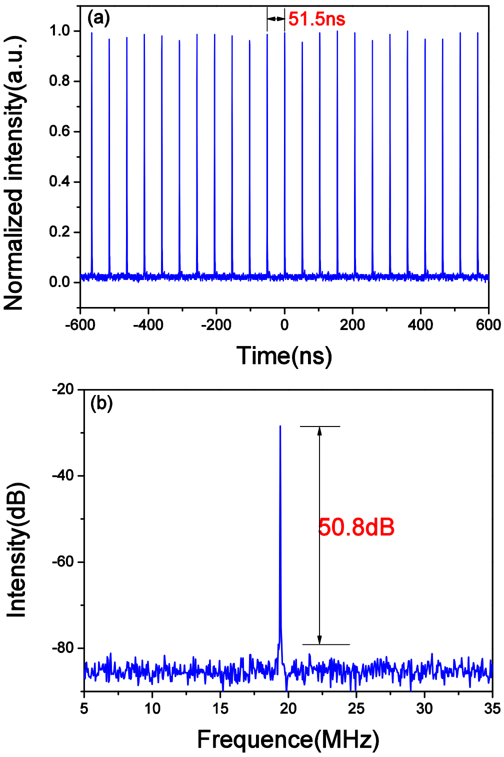

Fig.3. Measured (a) pulse trains, (b) RF spectrum of pulses.

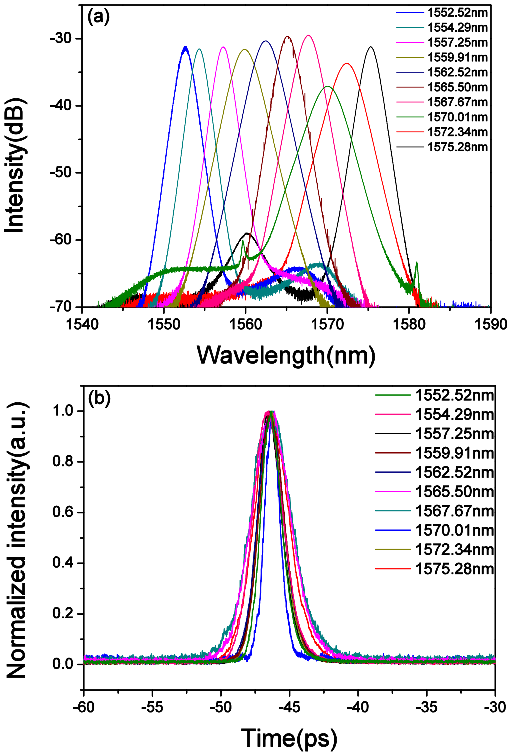

Fig.4. Measured characteristics of tunable mode-locked laser (a) Spectral evolution, (b) Autocorrelation traces of laser output at different central wavelengths.

4. CONCLUSIONS

We propose and demonstrate a wavelength-tunable erbium-doped fiber laser with birefringence-enhanced cavity. The fiber laser is mode-locked by SWCNTs-PVA composite film. Central wavelength of the fiber laser can be tuned from 1552.52nm to 1575.28nm with tunable range of 22.76nm. The minimum pulse width is 1.23ps corresponding central wavelength 1570.01nm. The maximum spectral width and output power are 2.88nm, 0.76mW corresponding central wavelength 1572.34nm, 1567.67nm respectively. The demonstrated laser provided the widest tuning range in a high repetition rate all-fiber Erbium doped laser based on SWCNT.

5. ACKNOWLEDGMENTS

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