Wavelength-tunable Erbium-doped fiber laser using silicon-on-insulator (SOI) based micro-ring with narrow laser linewidth

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ABSTRACT

We propose and demonstrate a wavelength-tunable and narrow-linewidth erbium-doped fiber (EDF) laser using silicon-on-insulator (SOI) based micro-ring. We discuss the wavelength selection and wavelength-tunable operation of the proposed fiber laser. The SOI based micro-ring is fabricated on a SOI wafer with a 0.22 um thick top silicon layer and a 2 um thick burial oxide (BOX) layer. In order to enhance the coupling efficiency between the SOI based micro-ring and the EDF, a pair of uniform period grating couplers are used. In the experiment, the lasing wavelengths can be tuned in the wavelengths range from 1532 nm to 1567.2 nm with a tuning step of 2 nm. The wavelength range and the tuning step are determined by the EDFA gain-bandwidth and the FSR of the SOI based micro-ring respectively. The OSNR of each lasing wavelength is > 42 dB. By using a double-ring configuration, a narrow laser linewidth of 50 kHz can be achieved.

Keywords: silicon-on-insulator (SOI), micro-ring, optical communication

1. INTRODUCTION

Wavelength-tunable fiber lasers are important light sources for many applications, such as optical-sensing, material processing, spectroscopy, medical diagnostics, imaging, metrology, scientific research and optical communications [1, 2]. In these fiber lasers, tunable band-pass filter, Fabry-Perot etalon or fiber-Bragg-grating (FBG) have been widely used inside the fiber ring cavity to generate the lasing wavelengths. For the gain-media, erbium-doped fiber amplifier (EDFA) or semiconductor-optical-amplifier (SOA) are usually used inside the fiber ring cavity.

Recently, using silicon-on-insulator (SOI) [3-6] based photonic devices in optical networks are attractive since they are complementary-metal–oxide–semiconductor (CMOS) compatible, compact in size and have low-power consumption. The SOI based micro-ring is a promising candidate to act as a wavelength filter offering a high extinct-ratio.

In this work, we propose and demonstrate a wavelength-tunable and narrow-linewidth erbium-doped fiber (EDF) laser using SOI based micro-ring. We first discuss the experimental setup of the proposed fiber laser. The proposed fiber laser is constructed of a C-band EDFA module, polarization controllers (PCs), fiber optical couplers (CPs) and a SOI based micro-ring with uniform period grating couplers. Due to the different birefringent losses in the proposed laser, different lasing wavelengths can be generated. In the experiment, the lasing wavelengths can be tuned in the wavelengths range from 1532 nm to 1567.2 nm with a tuning step of 2 nm. The wavelength range and the tuning step are determined by the EDF gain-bandwidth and the free spectral range (FSR) of the SOI based micro-ring respectively. The output power variations of these tunable wavelengths are ± 1.5 dB over the 30 nm wavelength range of the EDF. The optical single-to-noise ratio (OSNR) of each lasing wavelength is > 42 dB. Finally, we also show that by using a double-ring configuration, a narrow laser linewidth of 50 kHz can be achieved.

2. EXPERIMENT SETUP

Fig. 1 shows the experimental setup of the first proposed fiber laser, which is constructed by a commercially available C-band EDFA, two PCs, a 90:10 CP and a SOI based micro-ring. The amplified spontaneous emission (ASE) from the EDFA is launched into the SOI based micro-ring via a grating coupler. Vertical coupling with a tiling angle of 10^o is

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used. Vertical coupling provides many advantages [7, 8], such as high flexibility to couple the optical signal to and from the SOI devices without dicing the chip, high alignment tolerance, and simpler back-end processing without the requirement of facet polishing. Recently, using "g-Pack" [9] fascinates multiple optical input and output coupling between SMF and grating coupler with high mechanical stability cost effectively. The isolator in the proposed fiber laser maintains the light traveling in single direction.

Then, the optical signal is launched into the input port of the SOI based micro-ring. The micro-ring is fabricated on a SOI wafer with a 0.22 μm thick top silicon layer and a 2 μm thick burial oxide (BOX) layer. The grating coupler has the length and width of 14μm and 9 μm, respectively. Its period and etch depth are 580 nm and 70 nm, respectively. The length of coupling region between the straight silicon waveguide and the ring region is 6 μm, while the gap between these two regions is 200 nm. Finally, another optical fiber is used to receive the output signal from the drop port of the SOI based micro-ring. A scanning electron microscope (SEM) image of the SOI based micro-ring is included in the inset of Fig. 1. The output signal from the drop port will be input back to the EDFA forming a close loop. As shown in Fig. 1, the output signal from the laser can be obtained at the 10% port of the CP.

Here, we discuss the transmission of the SOI based micro-ring. Eq. (1) illustrates the power transmission characteristics of a micro-ring resonator [10]:

$$T_r = \frac{T_0}{1+(2F/\pi)^2 \sin^2(\beta_r l_r /2)} \tag{1}$$

where T_0 is the transmission satisfying resonance condition (i.e. when $\beta_r l_r = N \times 2\pi$, N is an integer, β_r is the propagation constant in the micro-ring resonator, l_r is the circumference of the micro-ring, and the FSR = $\lambda^2/n_r l_r$, n_r is the effective index of the ring waveguide. F is the finesse of the). For example, if a wavelength λ satisfies the resonance condition, it will couple into the ring waveguide through evanescently side coupling. For other wavelengths not satisfying the resonance condition, it transmits directly to the through port.

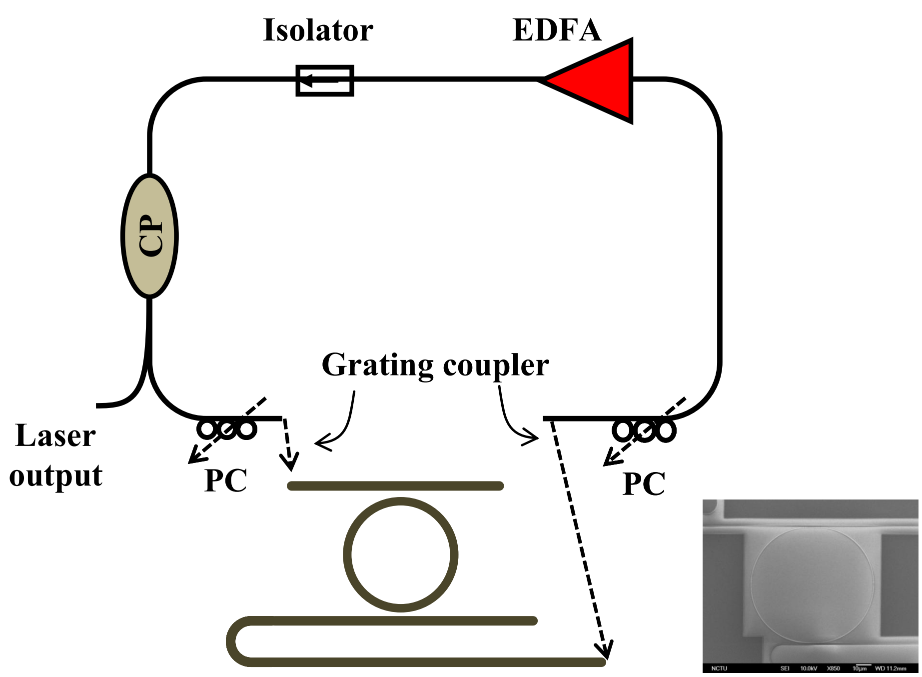

Figure 1. (a) Experimental setup of proposed fiber laser. Inset: the scanning-electron-microscope image of SOI based micro-ring.

3. RESULTS AND DISCUSSION

First of all, we will test the performance and the FSR of the SOI based micro-ring. In this case, the ASE signal generated directly from an EDFA is coupled into the SOI based micro-ring, as shown in Fig. 2(a). Then, without constructing a fiber loop, the drop port of the SOI based micro-ring is connected directly to an optical spectrum analyzer (OSA) with resolution of 0.01 nm. As shown in Fig. 2(b), the wavelengths satisfying the resonant conditions of the SOI based micro-ring as described in Eq. (1) can be observed. As also shown in Fig. 2(b), the FSR of the SOI based micro-ring is 2 nm.

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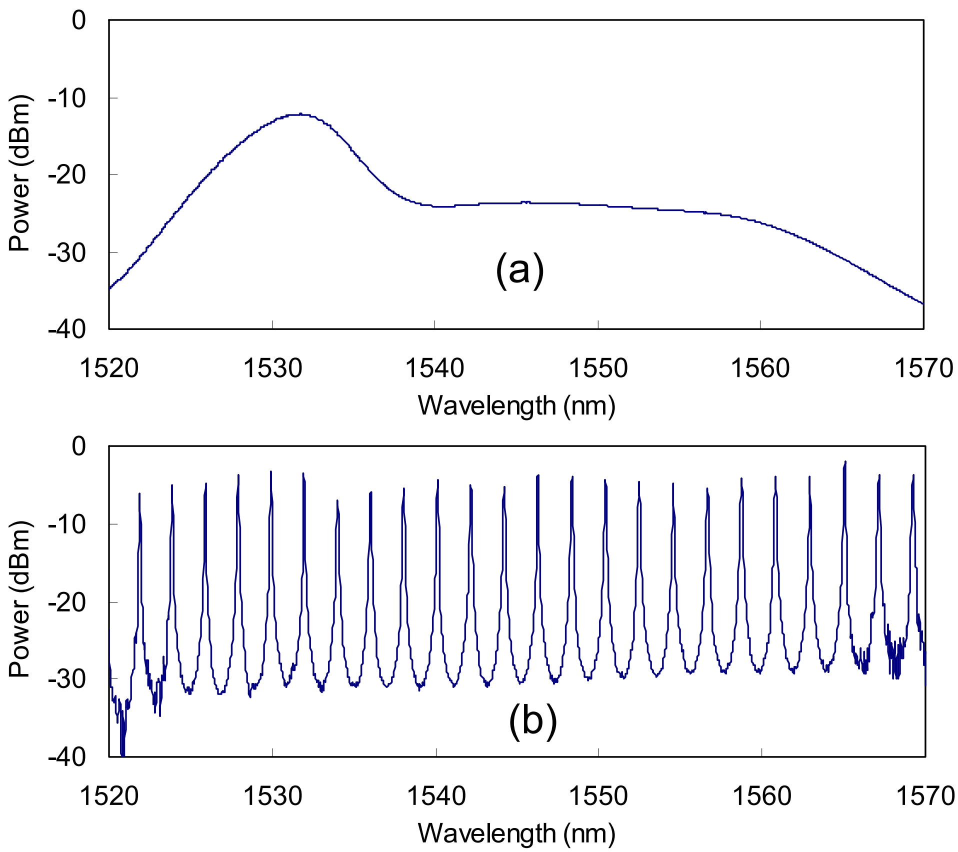

Figure 2. (a) Output ASE spectrum of EDFA. (b) Output spectrum of SOI based micro-ring with ~2 nm mode-spacing.

Then, the fiber laser is constructed as shown in Fig. 1. The EDFA output power is set at 5.8 dBm. Two PCs are used for wavelength tuning, which can be done by controlling the birefringent loss inside the laser system. As the birefringent losses of proposed laser scheme are different inside the fiber cavity, different lasing wavelengths can be generated as shown in Fig. 3. The lasing wavelengths can be tuned in the wavelengths range of 1532.00 to 1567.20 nm with a tuning step of 2.0 nm. As described above, the wavelength tuning range and the tuning step are determined by the EDFA gain bandwidth and the FSR of the SOI based micro-ring respectively. Fig. 3 also illustrates the lasing wavelengths have power fluctuation of ± 1.5 dB over the 30 nm wavelength range of the EDF gain spectrum. The OSNR of each lasing wavelength is > 42 dB.

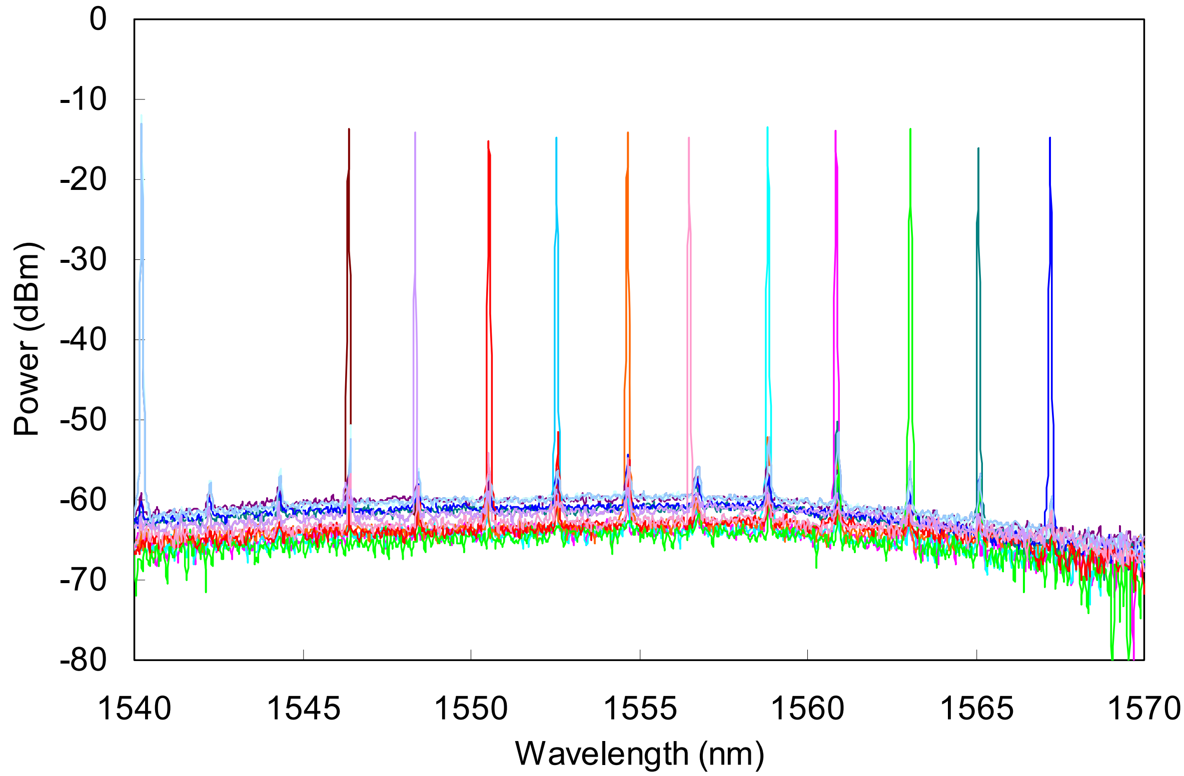

Figure 3. Output spectra of the proposed fiber laser scheme, when two PCs are properly adjusting.

To achieve narrow laser linwidth, a double-ring configuration as shown in Fig. 4(a) has been constructed. The double-ring configuration is based on the experiment setup shown in Fig. 1. A 50:50 CP is used to construct the second fiber ring. Then we use the self-heterodyne method to measure the laser linewidth [11]. In the self-heterodyne measurement, the optical signal from the output of the proposed laser is 3-dB split into 2 paths. One part of the signal is launched into a 20 km standard single mode fiber (SSMF), which is used to destroy the optical coherency between the 2 paths. Another path is composed of a phase modulator, which is electrically driven at 1 GHz. This provides a frequency shift to the optical signal at that path. Finally, the 2 paths are combined and launched into a photo-diode (PD), which is connected to a radio-frequency (RF) spectrum analyzer. Fig. 4(b) shows the measured spectrum after self-heterodyne method. By Lorentian curve fitting of the spectrum, a narrow linewidth of 50 kHz of the proposed laser can be observed.

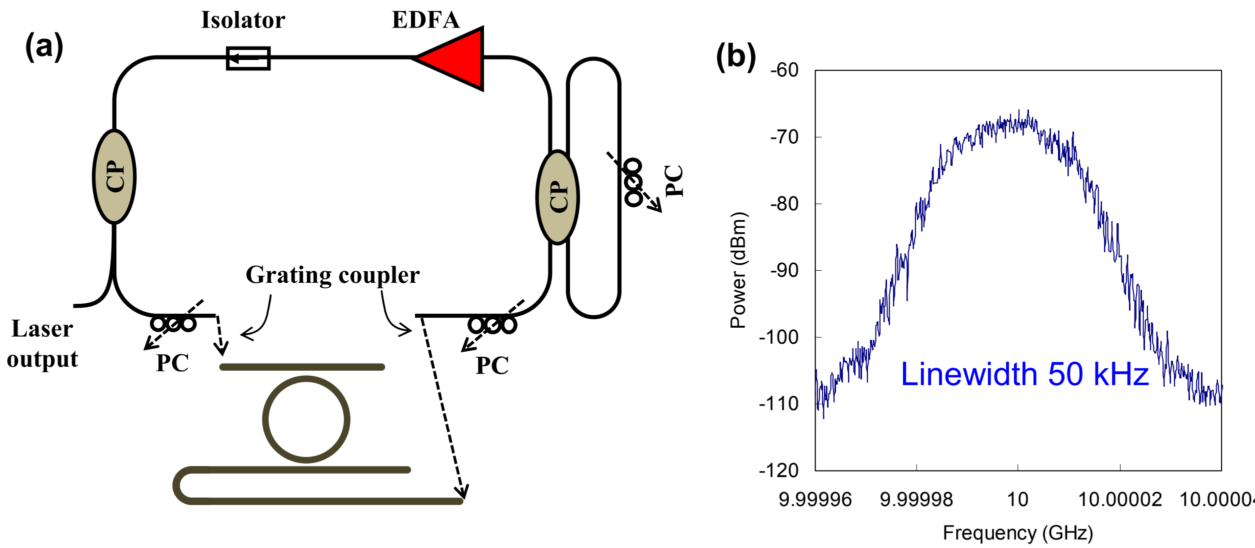

Figure 4. (a) Experimental setup of proposed fiber laser using double-ring configuration. (b) Measured laser linewidth using self-heterodyne method.

4. CONCLUSION

In this work, we proposed and demonstrated a wavelength-tunable and narrow-linewidth EDF laser using SOI based micro-ring. We discussed the wavelength selection and wavelength-tunable operation of the proposed fiber laser. The proposed fiber laser was constructed of a C-band EDFA, PCs, CPs and a SOI based micro-ring with uniform period grating couplers. The SOI based micro-ring was fabricated on a SOI wafer with a 0.22 um thick top silicon layer and a 2 um thick BOX layer. The length of micro-ring straight coupling region and the circumference were 6 um and 232 um respectively. The gap between the ring and the straight waveguide structures was 200 nm in the coupling region. The total length of straight waveguide structure was less than 1 cm. In order to enhance the coupling efficiency between the SOI based micro-ring and the EDF, a pair of uniform period grating couplers were used. The uniform period grating coupler had the length and width of 14 um and 9 um respectively, and its period and etch depth were 580 nm and 70 nm, respectively. Due to the different birefringent losses in the proposed laser, different lasing wavelengths can be generated. In the experiment, the lasing wavelengths can be tuned in the wavelengths range from 1532 nm to 1567.2 nm with a tuning step of 2 nm. The wavelength range and the tuning step were determined by the EDFA gain-bandwidth and the FSR of the SOI based micro-ring respectively. The OSNR of each lasing wavelength was > 42 dB. By using a double-ring configuration, a narrow laser linewidth of 50 kHz can be achieved.

5. ACKNOWLEDGMENT

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