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# Multi-wavelength fiber ring laser based on semiconductor optical amplifier and sampled fiber Bragg grating in a Sagnac loop interferometer

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**Abstract** Multi-wavelength fiber ring laser based on the semiconductor optical amplifier (SOA) with sampled fiber Bragg grating (SFBG) in a Sagnac loop interferometer as the wavelength-selective filter is proposed. Four lasing wavelengths with 1.8 nm spacing have been generated stably at room temperature. The proposed laser has the advantages such as removal of the high-cost circulator, flexibility in channel-spacing tuning, and simple all-optical fiber configuration, which has potential applications in high-capacity wavelength-division-multiplexed (WDM) systems and mechanical sensors.

**Key words** laser technique; fiber laser; multi-wavelength; semiconductor optical amplifier; Sagnac loop interferometer; sampled fiber Bragg grating

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## 1 Introduction

Multi-wavelength fiber lasers have attracted much interest because of their potential applications in wavelength-division-multiplexed (WDM) fiber communication systems, optical fiber sensing, instrument testing, and so on, due to their various advantages, such as multi-wavelength operation, low cost, and low insertion loss. Various techniques have been proposed to realize multi-wavelength oscillations[1~10]. Multi-wavelength fiber lasers based on fiber Bragg gratings (FBGs), including multiple phase shifts in a linear cavity[4] or a ring cavity[5], a superimposed FBG in a ring cavity[6], sampled FBG (SFBG) in a ring cavity[7] and in a linear cavity[8], and a multimode FBG in a linear cavity[9], have been investigated. FBGs have various advantages over other optical devices such as wavelength-selective nature, fiber compatibility, ease of use and fabrication, and low cost. The SFBG is effective in generating multiple wavelengths due to the variable parameters such as sampling period and sampling cycle. The semiconductor optical amplifier (SOA) has a dominant property of inhomogeneous broadening and can support many wavelength lasing oscillations simultaneously in the laser cavity[10], but an erbium-doped fiber would limit the number of lasing modes because of the homogeneous broadening of erbium ions[11].

In this paper, with the removal of the high-cost circulator[7, 10], we demonstrate a room-temperature multi-wavelength fiber ring laser based on the SOA with SFBG in a Sagnac loop interferometer as the wavelength-selective filter. Four lasing wavelengths with 1.8-nm spacing have been generated stably at room temperature. We provide another simple way to obtain the multi-wavelength fiber laser.

## 2 System configuration and principle

Figure 1 shows the configuration of the proposed laser. The laser consists of a SFBG incorporating a Sagnac loop interferometer constructed with a polarization-insensitive 3-dB coupler as the wavelength-selective component of the laser, a SOA (COVEGA 1117) as the gain medium, a polarization

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controller (PC), and two optical isolators (ISOs). The typical output power of the SOA is shown in Fig. 2. The PC is used to introduce the birefringence in the Sagnac loop which convert the reflective spectra of SFBG into transmissive responses and optimize the lasing output spectrum simultaneously by tuning the beam condition. The two ISOs are used to prevent the back-reflection from the FBG band-pass filter without a circulator. The laser power is coupled out using a 95:5 coupler which provides 5% for the output and 95% for feedback inside the cavity.

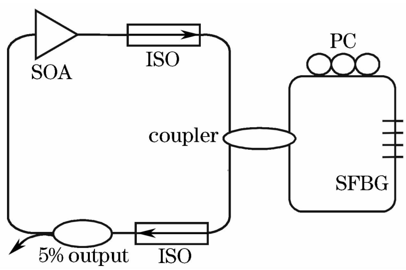


Fig. 1 Schematic diagram of the proposed laser

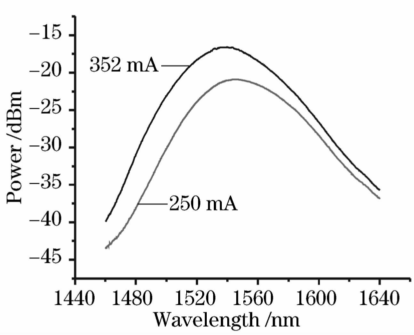


Fig. 2 Typical output power of SOA with different pump currents

The SFBG of about 7 cm was written in the hydrogen-loaded single-mode fiber using KrF excimer laser with a uniform phase mask (with a phase mask period of 1068 nm) and an amplitude mask with uniform rectangular sampling slit (with a period of 451 $\mu$m, which was limited by the laboratory condition) which resulted in the spectrum of sinc-shaped envelope. The fiber was hydrogen loaded at room temperature for two weeks at 100 bars to enhance photosensitivity before grating fabrication. After the fabrication, we annealed the SFBG to remove unreacted hydrogen and stabilize the quality of the SFBG. The transmission spectrum of SFBG with an amplified spontaneous emission (ASE) source is shown in Fig. 3. The value of the sampling period is determined so that the channel spacing in each waveband is 1.8 nm[10] and each wavelength has a 3-dB bandwidth of 0.028 nm. Due to the limit of the phase mask length and the spectrum of sinc-shaped envelope, there are only four reflection peaks at 1548.035, 1549.846, 1551.623, and 1553.446 nm, which have the reflectivity over 75%. The spectral characteristic was measured by using an ANDO AQ6317 optical spectrum analyzer (OSA) with 0.01-nm resolution.

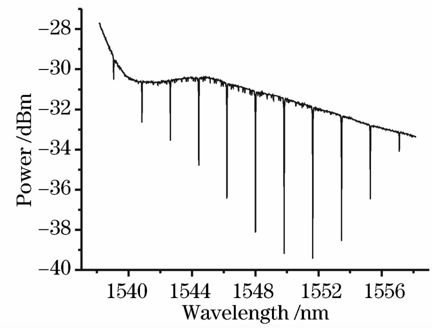


Fig. 3 Transmission spectrum of SFBG

The principle of the Sagnac loop interferometer incorporating an FBG as the wavelength-selective filter is well explained in Refs. [12～13]. The incident beam sent to the 3-dB coupler is split into two counter-propagating beams in the Sagnac loop. When those two beams cross each other at the FBG in the loop, the lightwave of the wavelengths within the FBG resonance bandwidth will be reflected from the FBG, and then those reverse-directed beams will recombine at the 3 dB coupler, which produces Michelson-like interference in the spectrum of the output beam. Simultaneously, the lightwave of the wavelength outside the FBG resonance bandwidth will rotate through the FBG and result in Sagnac interference according to the phase difference, which is proportional to the birefringence between the fast and slow axes of the loop. The path length difference between the SFBG and the 3-dB coupler is quite large and it is almost impossible to observe the fine interference structure within SFBG resonance bandwidth by using an OSA. Thus, the reflective spectra of SFBG can be converted into transmissive responses by adjusting the states of the PC to appropriate combinations without the help of a circulator.

## 3 Experimental results and discussion

Figure 4 shows the output spectrum of the laser when the SOA is driven by 350-mA pump current. There are four lasing wavelengths at 1548.129, 1549.923, 1551.740, and 1553.566 nm with a 3-dB bandwidth of 0.015 nm and signal-to-noise ratio (SNR) of over 40 dB, corresponding to the four reflection peaks that have the reflectivity over 75%. The peak power variations in each wavelength were measured to be less than 0.2 dB. This indicates that they are all very stable at room temperature.

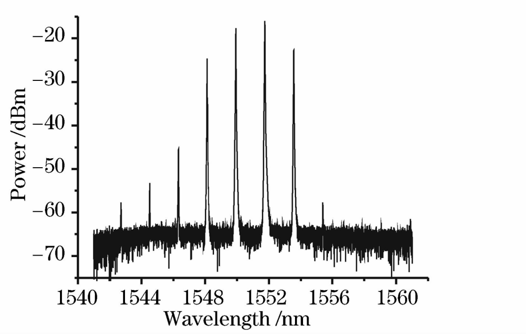


Fig.4 Output spectrum of the laser

The number and power distribution of the lasing wavelengths are determined by the shapes of the SOA gain spectrum and SFBG reflection spectrum, and the polarization state in the cavity. Ideally, it is appropriate to adopt a SFBG that has the spectrum with square overall envelope (i.e., channels of equal power). In the experiment, due to the reflection spectrum of sinc-shaped envelope, the side modes that are corresponding to the reflection peaks with the reflectivity below 75% cannot oscillate, or have negligible powers. And the maximal fluctuations of the four lasing wavelengths are about 7 dB. But more number of lasing wavelengths with WDM ITU-grid spacing and flat output envelope can be obtained by changing the sampling period and a SFBG that has more reflection peaks with equal reflectivity or broad flat-top envelope[14~16]. Actually, we are trying to manufacture a similar experiment setup recently. There is another important advantage in the configuration of the laser for WDM telecommunications: the spectral spaces between adjacent wavelengths are almost uniform because SFBG is formed in a single fabrication process. This is very difficult to achieve in the case of cascaded discrete FBG[13].

## 4 Conclusion

We proposed a room-temperature multi-wavelength fiber ring laser based on SOA with SFBG in a Sagnac loop interferometer as the wavelength-selective filter. Four lasing wavelengths with 1.8-nm spacing have been generated stably at room temperature. We provide another simple way to obtain the multi-wavelength fiber laser. The proposed laser has the advantages such as removal of the high-cost circulator, flexibility in channel-spacing tuning, and simple all-optical fiber configuration. It has potential applications in high-capacity WDM systems and mechanical sensors.

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