Tunable multiwavelength SOA fiber laser with ultra-narrow wavelength spacing based on nonlinear polarization rotation

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Abstract: A tunable multiwavelength fiber laser with ultra-narrow wavelength spacing and large wavelength number using a semiconductor optical amplifier (SOA) has been demonstrated. Intensity-dependent transmission induced by nonlinear polarization rotation in the SOA accounts for stable multiwavelength operation with wavelength spacing less than the homogenous broadening linewidth of the SOA. Stable multiwavelength lasing with wavelength spacing as small as 0.08 nm and wavelength number up to 126 is achieved at room temperature. Moreover, wavelength tuning of 20.2 nm is implemented via polarization tuning.

OCIS codes: (250.5980) semiconductor optical amplifier; (140.3510) Lasers, Fiber; (060.2320) Fiber optics amplifiers and oscillators.

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1. Introduction

Multiwavelength fiber lasers have been extensively investigated for their potential applications in wavelength-division-multiplexing (WDM) communication systems [1], optical fiber sensors [2], optical instrument testing [3], and microwave photonics [4]. The erbium-doped fiber (EDF) is excellent candidate for the gain medium of the lasers as the EDF can provide large gain, high saturation power and low polarization-dependent gain spectrum. However, due to the homogeneous line broadening of the EDF at room temperature, the fiber lasers based on EDF often suffer from strong mode competition and unstable multiwavelength lasing at room temperature. A range of approaches have been put forward to solve this problem, such as cooling EDF to liquid-nitrogen temperature, utilizing four-wave mixing effect or inhomogeneous loss mechanism by using highly-nonlinear fiber, adding a frequency shifter or phase modulator, using nonlinear gain of cascaded stimulated Brillouin scattering or stimulated Raman scattering, and so on. But all these inevitably add excess complexity and cost to these lasers. In contrast, semiconductor optical amplifier (SOA) possesses the property of primarily inhomogeneous broadening and can support simultaneous oscillation of many lasing wavelengths. Semiconductor multiwavelength fiber lasers with different wavelength number and wavelength spacing have been previously reported. Simultaneous oscillation of 52 lines spaced at 50 GHz was achieved by Pleros *et al.* from a ring cavity including two SOAs and single pass feedback [5]. Baby *et al.* presented a wavelength-tunable lasing operation of 41 wavelengths with 25 GHz (200 pm) spacing [6]. In these two cases, the wavelength spacing is of the same order of magnitude of the SOA homogenous broadening linewidth. Xia et al. shown a lasing with ultra-narrow wavelength spacing of 50 pm [7], but the operation was limited to simultaneous lasing of only three fixed wavelengths. On the other hand, to obtain tunable capability, there have been various experiments that incorporate a Sagnac loop filter, a fiber Lyot filter, and a sampled Hi-Bi fiber grating as a wavelength-selective comb filter [8–10]. However, in all these experiments the tunable range is relatively small. The distinctive characteristics of the SOA-like nonlinear gain compression can also be used to induce the tunability of the lasing wavelength. The lasing wavelength can be controlled by adjusting the feedback optical power into the SOA with a variable optical attenuator (VOA). But this method has a serious impact on the stability of the output power [11].

In this letter, a tunable multiwavelength SOA fiber laser with ultra-narrow wavelength spacing has been proposed and demonstrated. Multiwavelength selection is performed using a Sagnac loop mirror filter consisting of one section of polarization-maintaining fiber. Mode competition within the homogenous broadening linewidth is suppressed by the intensity-dependent transmission induced by nonlinear polarization rotation in the SOA. Stable multiwavelength lasing with multiwavelengths up to 126 and wavelength spacing as small as 0.08 nm is obtained at room temperature. The effect of the SOA driving current on the performance of the multiwavelength laser is also experimentally investigated.

2. Experiment setup and operation principle

The schematic of the experimental setup is shown in Fig. 1. The gain of the fiber laser is provided by a semiconductor optical amplifier (SOA), whose model is SOA-NL-OEC-1550 produced by CIP. The SOA has a 31.4 dB small signal gain at wavelength of 1550 nm and the polarization-dependent saturated gain (PDG) between the transverse electric (TE) and the transverse magnetic (TM) components of the SOA is around 0.5 dB, when the SOA is biased at 200 mA and thermally stabilized at 20 °C.

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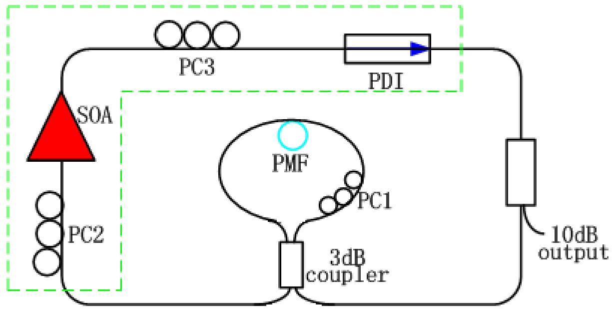

Fig. 1. Experimental setup of our proposed multiwavelength SOA fiber laser. The part surrounded by dashed line is a general configuration of nonlinear polarization rotation based on SOA.

Figure 2 gives the amplified spontaneous emission (ASE) of the SOA at 200 mA driving current. The peak wavelength is 1563.6 nm. The fiber Sagnac loop filter is formed by a 3 dB fiber coupler, a segment of polarization-maintaining fiber (PMF) with birefringence of 3.8×10^{-4} and a polarization controller (PC1) within the fiber loop. The birefringence of the PMF generates a wavelength-dependent phase difference between the fast and slow components of the light propagating in the fiber loop. By adjusting the PC1 in the loop to generate a 90° rotation between the polarization states of the two counter-propagating light in the cavity, the two counter-propagating light travel along different axes of the PMF and accumulate phase difference. They will interfere at the 3 dB coupler and generate a periodic comb-like spectrum. The filter peak spacing is given as $\Delta\lambda = \lambda^2/(\Delta n L)$, where Δn and L are respectively birefringence and length of the PMF. A polarization-dependent isolator (PDI) is used both to ensure the unidirectional cavity and to act as a polarizer. Polarization controllers (PC2 and PC3) are located before the SOA and the PDI, respectively. The laser output is extracted from the cavity by a 10/90 fiber coupler, with which 90% power is fed back into the laser. The part surrounded by dashed lines is a general configuration of nonlinear polarization rotation in a SOA, which has been used for optical signal processing [12] and passive mode-locking [13]. The output is measured by an optical spectrum analyzer (ANDO AQ6317, resolution 0.01nm).

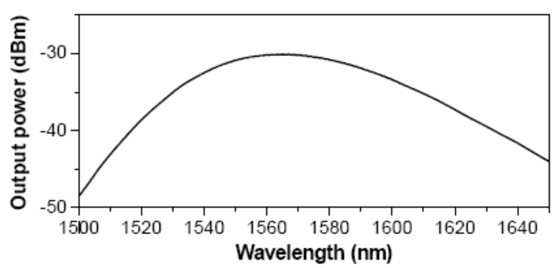

Fig. 2. The ASE from the SOA biased at 200 mA.

The mechanism of multiwavelength generation based on nonlinear polarization rotation in a SOA is described as follows. PC2 is used to adjust the polarization of the input signal with respect to the SOA layers. The light arbitrarily polarized electric field incoming into the SOA can be decomposed as the transverse electric (TE) and transverse magnetic (TM) modes. The modes propagate independently through the SOA, but they have indirect interaction via the carriers. Suppose the optical intensity is high enough to saturate the amplifier. The gain saturation of the TE mode differs from the gain saturation of the TM mode. Hence, the refractive index change of the TE mode also differs from the refractive index change of the TM mode. A phase difference between the two modes builds up as the light propagates

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through the SOA. At the PDI, both modes recombine. PC3 is used to adjust the polarization of the SOA output with respect to the orientation of the PDI. The phase difference and the orientation of the two PCs determine the intensity-dependent switch of the combiner (PC2 + SOA + PC3 + PDI). If the polarizations of the two PCs are set appropriately, the transmission of the combiner will decrease with the increase of the light intensity, which can be utilized to suppress mode competition for multiwavelength generation [14].

3. Results and discussion

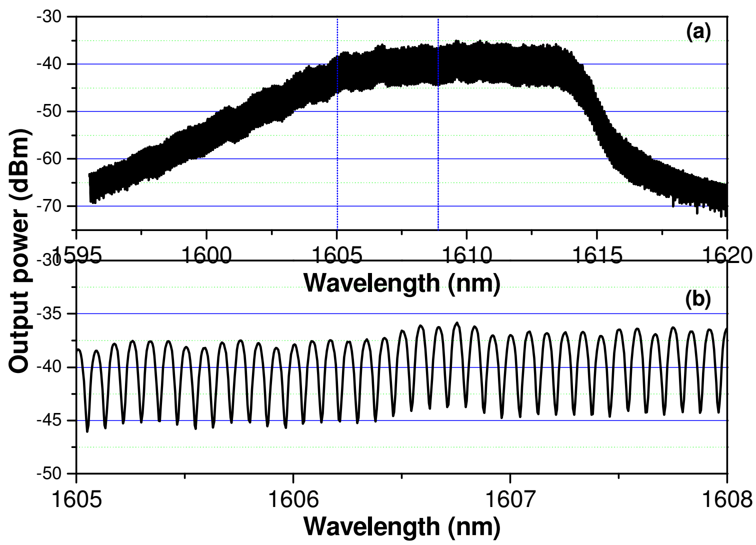

Fig. 3. (a) Mutiwavelength output spetrum with wavelength spacing of 0.08 nm. (b) Zoom-in of the part surrounded by dashed lines in (a).

In the experiment, the driving current of the SOA is first biased at 350 mA, and the length of the used PMF is 79 m. The multiwavelength output is readily obtained just by adjusting the PCs. Figure 3(a) is the typical multiwavelength output spectrum. The wavelength spacing is 0.08nm, which is in agreement with the calculated value. The number of the lasing wavelengths is 126 with 5 dB bandwidth of 10.08 nm, ranging from 1604.67 nm to 1614.75 nm. The zoom-in view of the part surrounded by dashed lines from 1605 nm to 1608 nm is shown in Fig. 3(b). In order to validate the mechanism of the multiwavelength generation, we replace the PDI with a polarization-insensitive isolator. We found that the stable multiwavelength cannot be obtained in any case the polarization is adjusted. The output spectrum of unstable multiwavelength is shown in Fig. 4. It is reasonable because the wavelength spacing of the comb filter is much narrower than the homogenous broadening linewidth of the SOA. The homogenous broadening linewidth of the SOA is deduced to be about 0.6 nm using the technique reported in Refs [10,15]. So the SOA cannot support the multiwavelength geneneration with wavelength spacing as small as 0.08 nm. Note that the self-induced polarization rotation in the SOA has been utilized to mode-lock fiber laser and optical signal processing with nonlinear phase-shift created in the SOA and polarization discriminated in the polarizer [12,13]. In these cases, the output from the combination of a SOA and a polarizer increase with the incoming light intensity. Reversely, if the polarizations of the two PCs are set properly, the transmission of the nonlinear polarization switch based on SOA decreases with the increase of the light intensity, which can be employed to suppress mode competition for multiwavelength generation.

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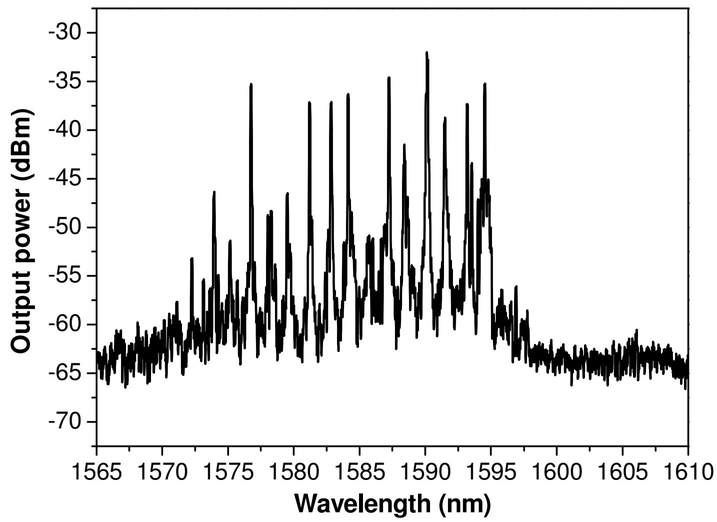

Fig. 4. Output spectrum from the SOA fiber laser with 0.08 nm Sagnac loop filter when the PDI is replaced by a polarization-insensitive isolator.

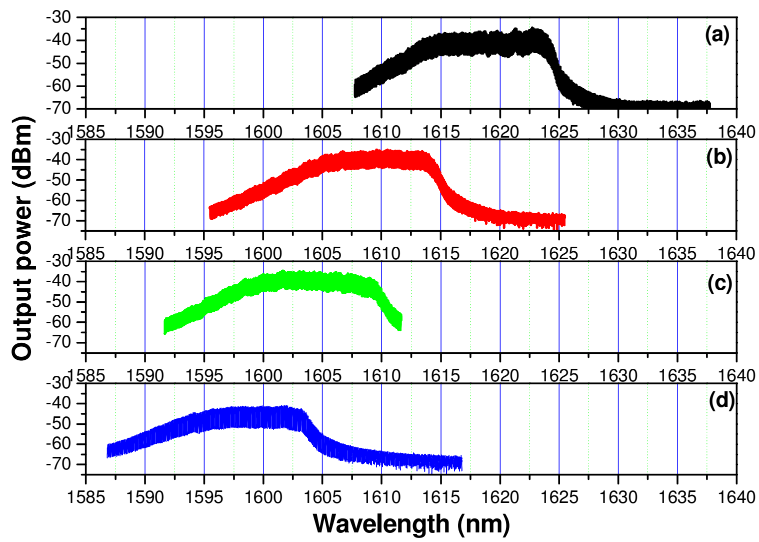

Fig. 5. Tunable multiwavelength generation through adjusting polarization.

Then, to demonstrate tunability of the multiwavelength comb, we adjust the polarization controllers in the main laser cavity to modifying the polarization-dependent cavity characteristic. Figure 5 shows the multiwavelength spectra with wavelength spacing of 0.08 nm under four different polarization states. In Fig. 5(a), multiwavelength spectrum ranges from 1614.25 nm to 1624.01 nm with 5 dB bandwidth of 9.76 nm and wavelength number of 124. In Fig. 5(d), multiwavelength ranges form 1594.02 nm to 1603.46 with bandwidth of 9.44 nm and wavelength number of 118. Therefore, 20.2 nm tuning has been implemented without distinct variation of the wavelength number. The tunability can be attributed to the

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polarization-dependent gain of the SOA and the polarization-dependent transmission induced by nonlinear polarization rotation in the SOA.

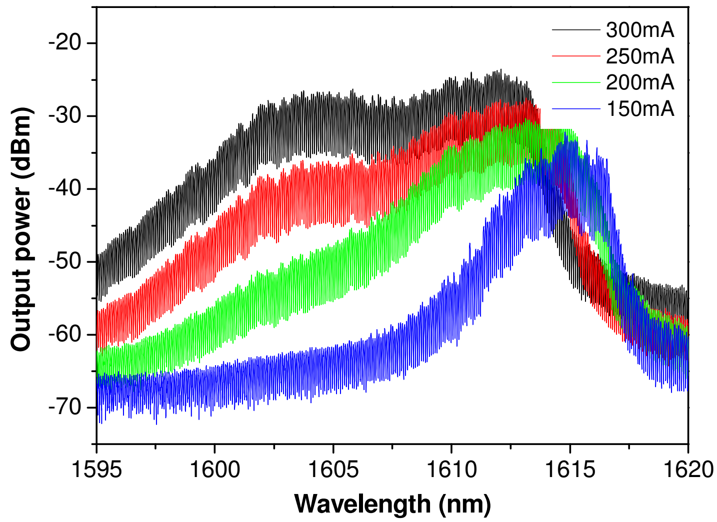

Fig. 6. Output spectra under different SOA driving currents.

Additionally, we have checked the effect of the SOA driving current on the multiwavelength generation. After the multiwavelength comb with wavelength-spacing of 0.08 nm generates at current of 350 mA (See Fig. 3(a)), decrease the current step by step with the polarization kept fixed. Figure 6 presents the results under the currents of 300, 250, 200, and 150 mA. For clarity, the spectrum under 300, 250, 200 mA are respectively offset upward by 8, 5, 2 dB, while their horizontal coordinates kept unchanged. With the decrease of the current the multiwavelength combs become more and more narrow. The bandwidth of the output spectrum under 150 mA driving current is only 2.3 nm.

4. Conclusion

In conclusion, we have demonstrated a tunable multiwavelength SOA fiber laser with ultra-narrow wavelength spacing and large wavelength number. Multiwavelength generation is the results of the intensity-dependent transmission induced by nonlinear polarization rotation in the SOA. Wavelength tuning is realized through polarization-tuning the cavity characteristic. Stable multiwavelength lasing with multiwavelengths up to 126 and wavelength spacing as small as 0.08 nm is achieved at room temperature. The effect of current on the performance of the multiwavelength laser has been also experimentally investigated.

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