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A stable multiwavelength SOA ring laser with equalized power spectrum

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We experimentally demonstrate a new structure of a multiwavelength semiconductor optical amplifier (SOA) ring laser based on a fiber Sagnac loop filter that can generate up to 25 stable output lasing wavelengths at room temperature. By varying the length of a polarization-maintaining (PM) fiber within the Sagnac loop filter, the wavelength spacing between the output lasing wavelengths can be changed to a desired value. By tuning a polarization controller (PC) within the Sagnac loop filter, stable multiwavelength 1550-nm operation with up to 17 lasing lines within 3 dB power level variation and with a wavelength spacing of ~ 0.8 nm was achieved. The optical signal-to-noise ratios (OSNRs) of all the lasing wavelengths are greater than 40 dB.

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Keywords: Multiwavelength, fiber laser, Sagnac loop filter, Polarization maintaining, Semiconductor optical amplifier

1. Introduction

Multiwavelength fiber lasers have recently attracted great interest due to their enormous applications in, for example, fiber-optic sensors, test and measurement of wavelength division multiplexing (WDM) components, optical signal processing, and optical communication networks. A number of such lasers exploiting the erbium-doped fiber's (EDF's) broad amplification bandwidth within the 1550-nm window have been demonstrated using various types of comb filters [1-3]. However, due to the EDF's large homogeneous broadening linewidth (>10 nm) at room temperature, it is very difficult to generate stable multiple lasing lines with a small wavelength spacing [4] without taking necessary measures to make the EDF inhomogeneous, such as cooling the EDF down to 77º K with liquid nitrogen [1], using a frequency shifter within the laser cavity [5], exploiting the polarization-hole-burning effect of the PM fiber [6], and utilizing the nonlinear effect of a specialty fiber within the laser cavity [7]. Other gain media such as semiconductor optical amplifiers (SOAs) and fiber Raman amplifiers have also been employed to generate stable multiwavelength emission at room temperature [8,9]. However, the SOA-based multiwavelength laser [8] used two sampled gratings and the number of generated lasing lines was still limited, while the Raman-based multiwavelength fiber laser [9] had a very long cavity length, which easily makes the laser sensitive to environmental changes (e.g. temperature or pressure change). Moreover, these two lasers' output lasing wavelengths had quite uneven peak power levels, which greatly limit their applications in many areas.

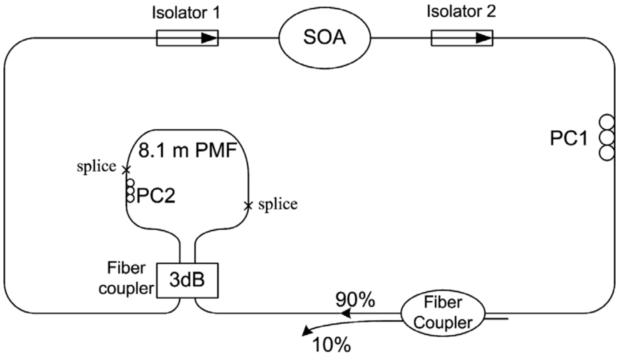

Fig. 1. Schematic of the proposed multiwavelength SOA ring laser using a fiber Sagnac loop filter, where PMF is PM fiber.

In this work, we present a simple structure of a stable multiwavelength SOA ring laser with an equalized power spectrum using a fiber Sagnac loop filter. Up to 17 lasing lines with a wavelength spacing of ~ 100 GHz in the 1550-nm band were obtained under room-temperature conditions. The OSNRs of all the lasing wavelengths are greater than 40 dB. The proposed multiwavelength laser provides such unique advantages as simple structure, low cost, variable wavelength spacing, and stable room-temperature operation.

2. Principle and experimental setup

The experimental setup of the proposed multiwavelength SOA-based ring laser is shown in Fig. 1. The ring laser cavity consists of a SOA (Kamelian OPA), two optical isolators, a fiber Sagnac loop filter, a polarization controller (PC1), and a 10/90 fiber coupler. The two isolators in the cavity are used to achieve the ring's unidirectional operation and reduce the noise of the

SOA. The PC1 within the cavity is used to adjust the state of polarization (SOP) of the light in the cavity, and the PC2 is used to adjust the SOP biasing the fiber loop. The 10/90 fiber coupler is used to extract the multiwavelength emission from the laser cavity for monitoring. The fiber Sagnac loop filter is used to select the lasing wavelengths in the laser cavity [10]. The fiber Sagnac loop filter is formed by a 3-dB fiber coupler, a segment of PM fiber (with a beat length of $L_B \sim 4.3$ mm at 1550 nm) and a PC2 within the fiber loop. The birefringence of the PM fiber generates a wavelength-dependent phase difference, δ, between the fast and slow components of the lightwaves propagating in the fiber loop, which is given by $\delta = (2\pi BL)/\lambda$, where B ($B = \lambda / L_B$) is the modal birefringence of the PM fiber, L ($L = 8.1$ m here) is the length of the PM fiber, and λ is the operating wavelength. This condition can be achieved by adjusting the PC2 in the loop so that the two counter-propagating lightwaves travel along different axes of the PM fiber and by setting the PC2 to generate a 90 degree rotation to the polarization states of the two counter-propagating lightwaves in the cavity. Note that the fiber Sagnac loop filter has the unique advantage that it is robust against any environmental changes (as compared to the Mach-Zehnder interferometers) because the two counter-propagating lightwaves travel through the same optical path (or loop) before they recombine and interfere at the 3 dB coupler. The intensity transfer function of the Sagnac loop filter, $T(\lambda) = \sin^2(\delta/2)$, depends on δ and is periodic in wavelength with a free spectral range (FSR) (or wavelength separation between two spectral peaks) given by $\Delta\lambda = \lambda^2 / BL$ (where $\Delta\lambda \sim 0.8$ nm here). Thus the FSR of the filter can be easily changed by using a different length L of the PM fiber in the loop. Note that, by adjusting the PC2 in the loop, the center wavelengths of the spectral peaks of the filter can also be tuned.

3. Experimental results and discussion

The pump current of the SOA was set at 200 mA. 8.1 m of PM fiber was inserted within the fiber Sagnac loop filter. We adjusted the PC1 until an optimum performance of the laser (with the smallest power variations among the output lasing wavelengths) was achieved. Fig. 2(a) shows the measured output of the multiwavelength SOA ring laser using an optical spectrum analyzer (OSA) with a resolution of 0.05 nm. Fig. 2(a) shows that 17 lasing wavelengths with a flat power spectrum (with power variations within 3 dB, i.e. between 0.04 to 2.89 dB) between 1560 nm and 1575 nm was achieved under room temperature conditions. The lasing lines have wavelength spacings of ~ 0.8 nm (which coincides with the FSR or $\Delta\lambda \sim 0.8$ nm of the Sagnac loop filter) and OSNRs of over 40 dB. In [4], there were only 6 lasing lines within the 3 dB power variation. While in [11], the multiwavelength erbium-doped fiber laser with a linear cavity only generated eight lasing lines within the 3 dB power variation.

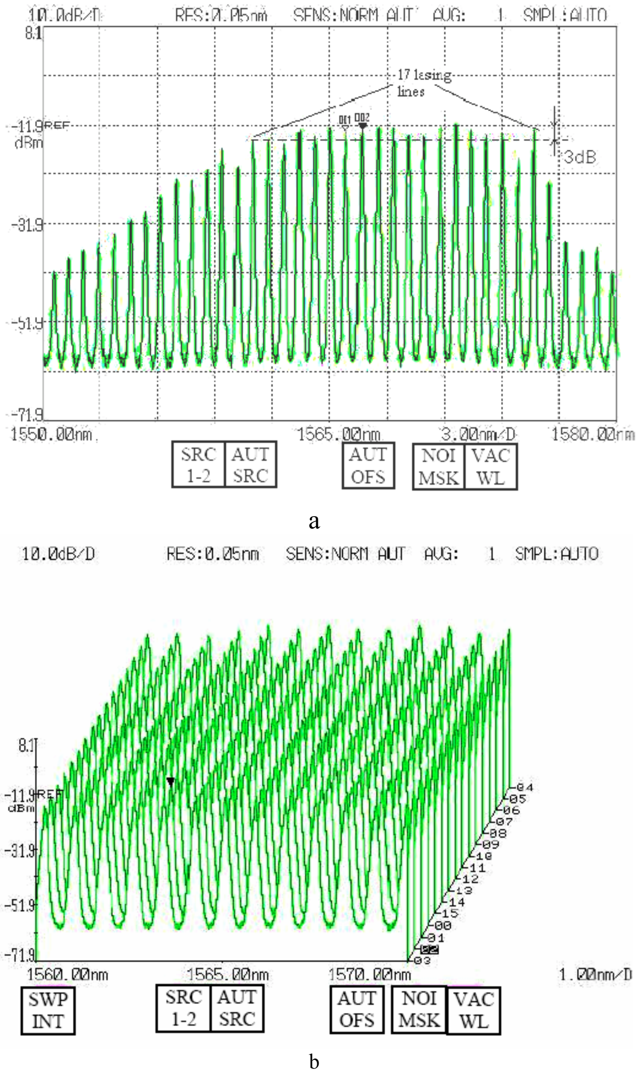

Fig. 2. (a) Measured output lasing wavelengths of the multiwavelength SOA ring laser when the PC1 was adjusted till an optimum performance of the laser was achieved; (b) Repeated scanning of the laser's output with a 5 minutes interval over one hour.

Fig. 2 (b) shows the measured output spectra of the ring laser over 1 hour, where the center frequencies and peak powers of all the lasing lines were almost unchanged during the one hour repeated scan of the laser's output spectra.

By carefully adjusting the settings of the PC1 and PC2 within the laser cavity, which effectively change the polarization-dependent loss and the birefringence-induced wavelength-dependent loss in the ring cavity, the center wavelengths of the output lasing lines can be tuned. As shown in Fig. 3, the operating wavelength range of the multiwavelength SOA ring laser was tuned to 1553 nm-to-1565 nm band when PC1 and PC2 were appropriately adjusted, and this is different from the operating wavelength range of 1560 nm to 1570 nm as shown in Fig. 2. It is worthing pointing out that, for multiwavelength fiber lasers based on EDFs, the operating wavelength range can be easily changed by using a different length of EDF as the gain medium in the laser cavity. However, SOA-based multiwavelength lasers normally have a fixed operating wavelength range, which is determined by the

SOA chip during the fabrication process. To overcome this problem of a fixed operating wavelength range, one unique advantage of our proposed SOA-based multiwavelength laser using a fiber a Sagnac loop filter is that the operating wavelength range can be tuned by appropriate setting of PC1 in the ring cavity and PC2 in the Sagnac loop filter.

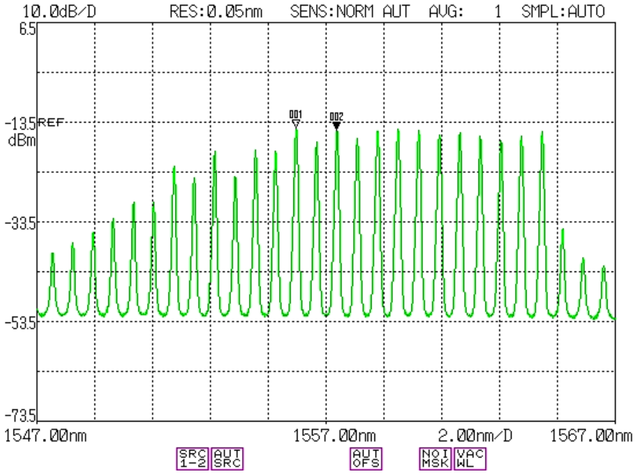

Fig. 3. Measured output spectrum of the multiwavelength SOA ring laser when PC1 and PC2 were adjusted in the laser cavity.

We have also studied the stability of the laser. Fig. 4 shows the output power variations of the six lasing lines with the monitoring time. The monitored wavelengths are 1563.47 nm, 1564.28 nm, 1565.1 nm, 1565.91 nm, 1566.72 nm, and 1567.54 nm. The power fluctuations of the lasing wavelengths over a 3-hour measurement are found to be less than 2.7 dB. These power fluctuations were mainly induced by the environmental changes (e.g. the temperature change of 3~6 degrees) and the fluctuation of the SOA's pump current of 1~ 2 mA.

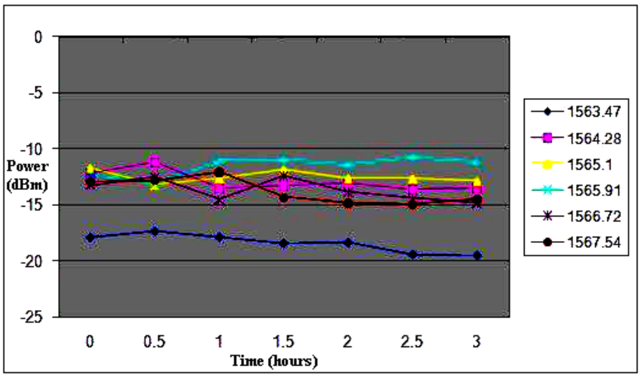

Fig. 4. Measured power fluctuations of the lasing lines as a function of time. The wavelengths of the six lasing lines are 1563.47 nm, 1564.28 nm, 1565.1 nm, 1565.91 nm, 1566.72 nm, and 1567.54 nm.

It is worth noting that the operating wavelength range of the multiwavelength SOA ring laser is from 1560 nm to 1575 nm, which is different from the wavelength ranges of previously reported multiwavelength fiber laser sources such as [4], [8] and [11], where most of the sources operated around the 1530 nm band. Thus the proposed operating band, which is in the longer wavelength range of the C-band and the beginning of the L-band, is especially suitable in optical networks that use non zero-dispersion shifted fibers (NZ-DSFs). In current optical transmission systems, the transmission capacity is limited by the large positive chromatic dispersion value of the single-mode fiber (SMF) in the C-band. However, the NZ-DSF has negative chromatic dispersion value in the C-band and can thus be used as a dispersion compensation component in existing and new generation of high-speed optical networks.

The unique operating bandwidth of the proposed multiwavelength SOA ring laser makes it an excellent candidate for use in the next generation optical networks because the deployment of the NZ-DSF (with a zero-dispersion wavelength at ~1595 nm that is outside the operating C band of the laser) can minimize the build up of unwanted nonlinear fiber effects.

4. Conclusions

We have proposed and demonstrated a simple structure of a stable multiwavelength SOA ring laser with a nearly uniform power spectrum. By changing the state of the PC1 within the cavity to achieve optimum performance of the laser, we have obtained up to 17 stable lasing wavelengths with OSNRs of over 40 dB within the 3-dB power variations at room temperature. All the lasing lines have a wavelength spacing of ~ 0.8 nm, which can be changed by using different length of the PM fiber within the fiber Sagnac loop filter. This laser configuration has a simple topology, is low cost, and can generate stable multiple lasing wavelengths under room temperature conditions.

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