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Tunable Multiwavelength SOA-Based Fiber Laser

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Abstract: Tunable multiwavelength fiber lasers based on semiconductor optical amplifiers (SOA) have received attracting interest due to their wide prospective applications in dense division multiplexing (DWDM) systems and optical sensing. Using an SOA in a nonlinear optical loop mirror (NOLM), we demonstrate up to 13 lasing peaks by controlling the pump current and the polarization controller. At maximum pump current (450 mA), the emitted multiwavelength is between 1550 nm and 1572 nm with a wavelength spacing of 1.87 nm and 3 dB output linewidth of 0.8 nm with an output power of −7 dBm and 27 dB optical signal-to-noise ratio (OSNR). The multiwavelength output power and multiwavelength peak stability are investigated, and it was found that the power fluctuation of each multiwavelength line is less than 0.2 dB. In addition, by adjusting the polarization controllers (PCs) and SOA temperature, we obtained a tunable multiwavelength emission. The proposed fiber laser offers advantages such as simple structure, low loss, and long-time stable and multiwavelength emission.

Keywords: SOA; fiber laser; NOLM; and multiwavelength laser

1. Introduction

Tunable multiwavelength fiber laser has received attractive interest due to their wide prospective applications in optical communication and optical sensing. The broadband, high extinction ratio and fast switching time-like advantages of semiconductor optical amplifier (SOA) make it an attractive lasing source for multiwavelength generations.

Multiwavelength emission has been achieved using different fiber laser sources, including erbium-doped fiber laser (EDFL) [1–5], Raman lasers [6,7], and hybrid Raman and erbium-doped fiber [8,9]. However, the homogeneous line broadening and mode competition were the main challenges for generating a stable dual- and multiwavelength operation at room temperature, even with our recent research work on dual-wavelength lasing for 5G and LiDAR applications [10–13]. In addition, many other techniques have been used for improving the EDFL multiwavelength stability, such as cooling the EDF down to cryogenic temperature [14], using a specially designed twin-core EDF [15], using frequency shift feedback [16], using intensity-dependent loss mechanisms like nonlinear fiber loop mirror (NOLM) [17], nonlinear polarization rotation (NPR) [18], incorporating EDF with SOA [19,20].

However, SOA is considered an alternative approach in the fiber laser for multiwavelength emission due to the advantages of low cost, low insertion loss, broad gain spectrum, heterogeneous spectral broadening, and wavelength versatility via bandgap engineering. Subsequently, some demonstrations like SOA-based multiwavelength fiber laser using a nonlinear polarization rotation NPR [21], high birefringence photonic crystal fiber [22], Mach-Zehnder Interferometer [23], and loop mirror interferometer [24] are also reported.

Achieving multiwavelength laser peaks using SOA fiber lasers has numerous advantages in photonics, electronics, sensing, and quantum optics. For instance, it can be used in the implementation of DWDM systems using a single optical source instead of using multiple lasers, navigation, and surveillance-based applications with high resolution

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and accuracy, like in intelligent transport systems-related industries and smart agriculture sensing systems.

Moreover, this multiwavelength fiber laser is suitable for 5G communication, LiDAR sensing-related applications [10–13], and especially in the field of quantum information processing and quantum communication [25–27].

Furthermore, the obtained results of the demonstrated multiwavelength fiber laser open new windows to extend its application areas in a multiwavelength quantum key distribution (QKD) system that has the advantage of involving and adding multiple wavelengths for different protocols and data exchange [25–27]. It is also an emulated system with a physical unclonable function that eliminates the need to share a subsection of the final key for eavesdropper detection and allows for ternary and quaternary data transmission.

However, the main issue with the SOA is its high sensitivity to the optical reflection from the cavity. It causes the generation of gain ripple, which is dependent on multiwavelength emission.

To mitigate this issue, we used two ring cavities linked through an optical circulator to design a unidirectional, tunable, and stable SOA-based multiwavelength fiber laser in a nonlinear loop mirror (NOLM) configuration at room temperature. By controlling the pump current and PCs, we attained up to 13 lasing peaks with a wavelength spacing of 1.86 nm, output linewidth of 0.8 nm, output optical power of −7 dBm, and OSNR ~ 27 dB. The attained wavelength spacing of 1.86 nm is convertible to corresponding millimeter waves (mmW) of 230 GHz [10], which ensures the capability of the proposed lasing source to be used for applications like dense wavelength division multiplexing, optical sensors spectroscopy, microwave generation, optical instrument testing, 5G/6G networks, and LiDAR systems.

2. Experimental Setup

The experimental setup of the SOA-based fiber laser for the generation of tunable multiwavelengths consists of two ring cavities, as shown in Figure 1.

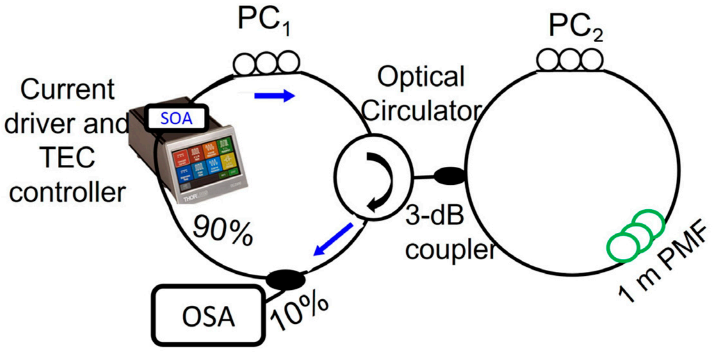

Figure 1. The experimental setup of the multiwavelength SOA fiber laser.

The primary ring cavity comprises the SOA and a polarization controller (PC). The SOA is pumped using a pump current driver and TEC controller; it achieves a peak gain at 1535 nm in this cavity with a spectral bandwidth of 80 nm and a small signal gain of 25 dB at room temperature. The Babinet-Soleil compensator polarization controller (PC1) is used to optimize the polarization state of the cavity.

The second ring cavity (NOLM) consists of 2 × 2 fused couplers with a 55/45 coupling ratio, which splits light into two unequal portions, traveling in opposite directions through the loop mirror. It also contains 1 m of polarization-maintaining fiber (PMF) and 7 m of standard telecom fiber (SMF). An optical circulator connects both cavities and ensures the unidirectional flow of light in the primary cavity. The second polarization controller (PC2) also maintains the polarization state of the second cavity. Further, a 90:10 optical fiber coupler provides an output power of 10% for measurements and analysis using an optical spectrum analyzer (OSA) at a resolution of 0.05 nm, and 90% is redirected to the primary ring.

3. Results and Discussion

The multiwavelength emitted from the proposed fiber laser is analyzed using an optical spectrum analyzer at different pump currents of the SOA device. First, the laser system emitted a single wavelength at an SOA pump current of 88 mA while carefully adjusting the PC_2 in the loop mirror cavity. By slightly increasing the SOA pump current to 89.5 mA, a dual-wavelength laser peak and a triple laser peak at 91.5 mA are observed with OSNR ~ 18 dB, as shown in Figure 2. Additionally, fourth to seventh multiwavelength lasing lines are achieved by gradually increasing the SOA pump current from 96 mA to 150 mA with OSNR ~ 24 dB. We have achieved about 13 lasing peaks (1550 nm–1572 nm) at 450 mA with a wavelength spacing of 1.87 nm, OSNR ~ 27 dB, and a 3-dB bandwidth of 0.8 nm (Figure 2).

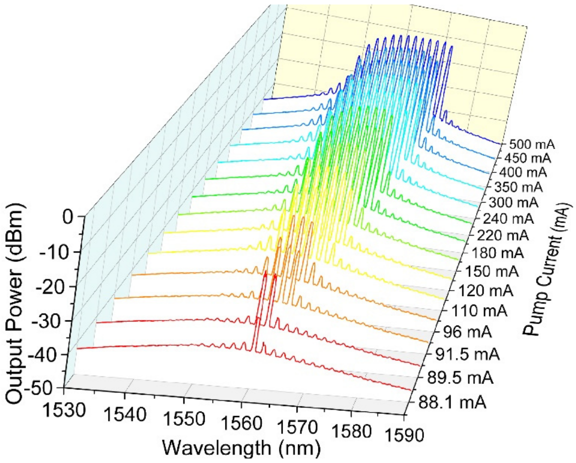

Figure 2. Multiwavelength emission from SOA fiber laser at different pump currents.

Figure 3 shows the central wavelengths of the proposed SOA fiber laser at different pump currents. The attained multiwavelengths are observed, initially on both sides of the central wavelength lasing. However, the peak of the first wavelength laser is shifted to the long wavelength region when the pump current of the SOA increases from 96 mA to 110 mA. This is because the saturated gain peak of SOA lies in the long wavelength region (~1560 nm). SOA signal-gain saturation is caused by a reduction in the population inversion in the active layer due to an increase in stimulated emission (lasing emission).

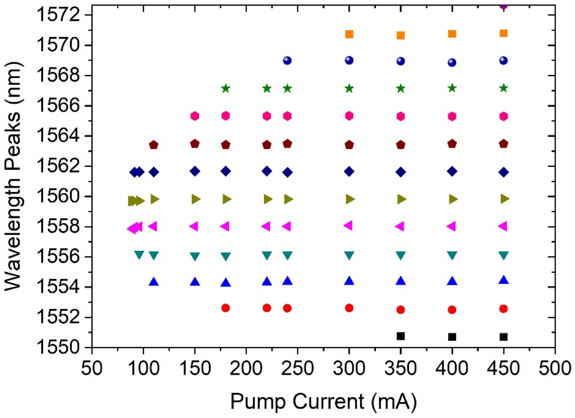

Figure 3. The emitted wavelength peaks vs. the pump current.

Moreover, we keep the pumping below the pumping current of 500 mA in our experiments to avoid any unstable generation of multiwavelength peaks shown in Figure 4.

The SOA lasing threshold is about 70 mA. Then, increased linearly can be seen for up to 150 mA; after that, the output power increased exponentially due to SOA gain saturation at a high pump current. It is also observed that the gain medium of SOA effectively improves the stability of the multiwavelength lasing operation. Moreover, the double-ring structure of the proposed laser reshapes the transmission spectrum and generates lasing peaks with narrow channel spacing.

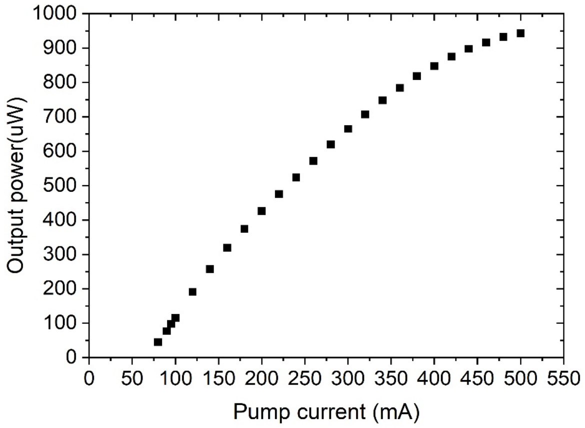

Figure 4. The multiwavelength SOA fiber laser outputs optical power.

As SOA is polarization-dependent, the output spectra are tunable (Figure 5) either to the shorter wavelength by decreasing the temperature of the SOA device to 18 °C or the longer wavelength by increasing the SOA temperature to 23 °C and controlling the state of polarization in the laser cavity and loop mirror. SOA temperature is controlled using a TEC controller (thermoelectric/Peltier module) in the combined laser diode and TEC controllers. The TEC controller first determines the desired temperature setpoint and then applies the appropriate electric current needed to achieve the desired temperature.

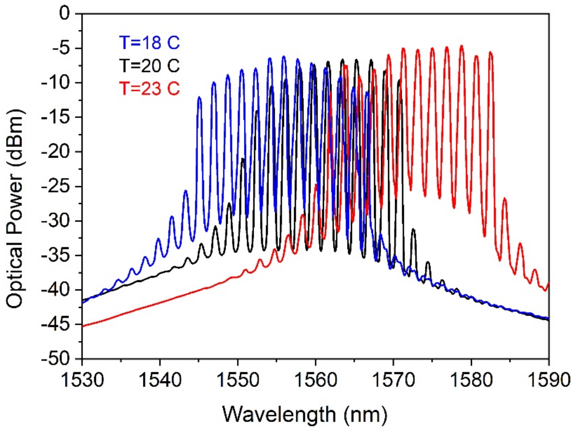

Figure 5. The multiwavelength SOA fiber laser tunability operating regimes at different SOA temperatures.

The stability of the output optical power and wavelength peaks are investigated to the time, as shown in Figures 6 and 7, respectively. The optical power fluctuations of ~0.2 dB are observed after 6 h. Moreover, a shift of 0.059 nm in wavelength peaks is observed after 3 h with the pumping of 300 mA at room temperature. The SOA temperature is controlled by the received feedback from a temperature sensor; accordingly, there is a very small shift (0.059 nm) in wavelength peaks due to the temperature fluctuations in the device over the investigation time (3 h).

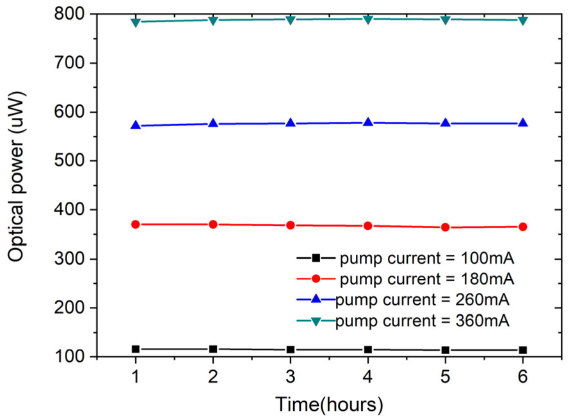

Figure 6. Output optical power stability over 6 h.

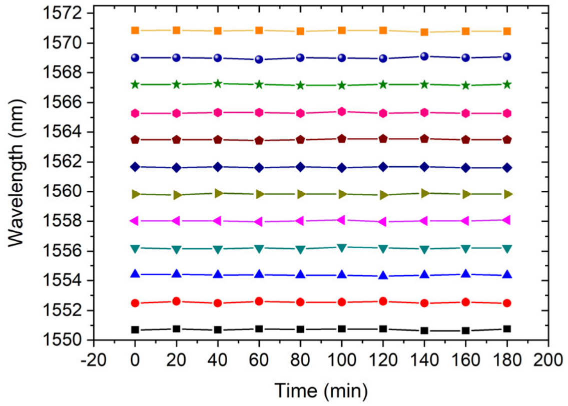

Figure 7. The multiwavelength peaks stability at pump current of 300 mA over 3 h.

4. Conclusions

We have demonstrated a tunable multiwavelength SOA laser based on an NOLM double-ring cavity structure. Multiwavelength lasing with equal channel spacing and 3-dB bandwidth of 1.87 nm and 0.8 nm, respectively, are achieved. The experimental results have also shown that the output optical power and wavelength peaks are flat and quite stable for a long time at room temperature, with a peak power fluctuation of each multiwavelength line of less than 0.2 dB. The source has an average peak power of about −7 dBm and OSNR of about 27 dB at pump current between 220 mA and 450 mA, which makes this source a good choice for dense division multiplexing and low-cost microwave generation.

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