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High-Extinction-Ratio Multi-Wavelength Optical Source Based on an On-Chip Nonlinear Micro-Ring Resonator

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Abstract: We present and experimentally demonstrate a stable high-extinction-ratio multi-wavelength optical source with Erbium-dope fiber, which is mainly based on a CMOS-compatible nonlinear micro-ring resonator. Optical spectrum from different output positions are compared and analyzed.

OCIS codes: (060.2320) Fiber optics amplifiers and oscillators; (140.3500) Lasers, erbium; (140.3945) Microcavities; (140.4780) Optical resonators; (190.0190) Nonlinear optics.

1. Introduction

Multi-wavelength optical sources have attracted great attention and been deeply investigated over the last two decades since their potential applications in many fields, such as WDM optical communication systems, spectroscopy, microwave photonics, optical sensing systems, etc. Among different kinds of multi-wavelength optical source, multi-wavelength Erbium-dope fiber laser (M-EDFL) is most attractive and can be easily implemented due to its advantages of low threshold and high power conversion efficiency. However, the intrinsic characteristics of homogeneous line broadening and cross-gain saturation in Erbium-doped fiber (EDF) will make the lasing oscillation unstable at room temperature. In order to suppress this instability from mode competition, several methods have proposed and realized, e.g. employing cavity loss modulation [1-3], utilizing four wave mixing (FWM) effect in a highly nonlinear fiber [4], and mixing EDF and Raman fiber gains [5]. Yet all of these techniques will make the system complex and bulky.

On the other hand, optical micro-ring resonators based on different materials have been developed widely for optical signal processing in recent years [6-11]. Especially for those micro-rings with high nonlinearity and low insertion loss, fiber ring lasers can fully utilize their advantages to generate stable oscillations and also keep compact at the same time [6,7]. In this paper, we present a stable multi-wavelength optical source based on a Hydex high-Q micro-ring resonator and also utilizing the EDF as the gain medium [9-11]. Optical spectrum from different ports of the micro-ring resonator are observed and analyzed. Over 50 dB extinction ratio is achieved from the add port of the micro-ring with channel spacing of 200 GHz from 1540 nm to 1580 nm.

2. Principle and experimental setup

Fig. 1 shows the experimental setup of the proposed multi-wavelength optical source. In this simple configuration, a commercial EDFA with 19 dB gain is used as the power pump in the main ring cavity. The polarization controller and isolator are used to ensure lightwave to propagate in a single polarization mode and clockwise direction. Another two EDFAs with the same gain level are placed at both the through and add ports of the micro-ring resonator respectively. Output spectrum from both ports are observed before and after amplification with high-resolution optical spectrum analyzer (Ando AQ6317), as the four positions shown in Fig. 1.

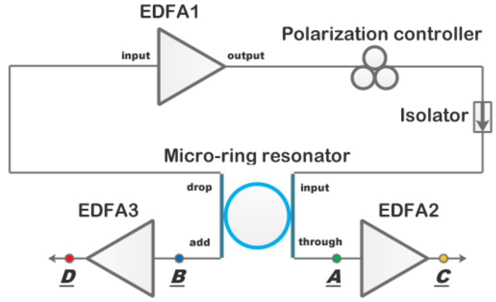


Fig. 1 Experimental setup of the multi-wavelength optical source based on Erbium-doped fiber and nonlinear micro-ring resonator.

The key component, i.e. the micro-ring resonator, is made from high-index doped silica glass with a Q value of more than one million, which has a free spectral range (FSR) of approximately 200 GHz, making the channel spacing of the generated multi-wavelength lasing oscillation also 200 GHz in the C band. Here the micro-ring resonator acts as both roles of a fine filter and nonlinear element in the ring lasing cavity. The induced nonlinear interactions based on 3rd-order nonlinear Kerr effect in the micro-ring resonator, e.g. FWM effect, help stabilize the multi-wavelength lasing output effectively against mode competition in the traditional EDFL [4,9]. Moreover, the on-chip device with low insertion loss can also make the proposed optical source compact in size with lower lasing threshold.

3. Results and discussion

Fig. 2 shows the optical spectrum from 1540 nm to 1580 nm for the four different observing positions as shown in Fig. 1. As can be seen from Fig. 2(a) and Fig. 2(b), output from the through port has larger power than that from the add port of the micro-ring resonator before amplification by the EDFA. But because of the existing amplified spontaneous emission (ASE) noise directly from the EDFA in the fiber ring cavity, the noise level in Fig. 2(a) is up to between 40 dB and 50 dB which dramatically reduces the extinction ratio of the multi-wavelength output. In comparison, the multi-wavelength output from the add port of the micro-ring resonator shows a higher extinction ratio of more than 50 dB (the largest is 70 dB and 60 dB on average in the 40 nm range) and also flatter response, as shown in Fig. 2(b). There are two contributions that can be the explanation. The first one is the lack of ASE noise when it is observed from the add port of the micro-ring resonator. The other one reason is that the multi-wavelength output at the add port actually enjoys twice filtering in the micro-ring resonator, which increases the extinction ratio and also makes the lasing linewidth narrower [11]. Fig. 2(c) and Fig. 2(d) show the optical spectrum after amplification by the EDFA for both the through and add ports respectively. The requirement of the output power of the single wavelength can be as high as 0 dBm in some applications. It can be seen from Fig. 2(c) and Fig. 2(d) that the output from the add port of the micro-ring resonator shows higher power and extinction ratio (the largest is 55 dB and over 40 dB in the 40 nm range) even after the amplification by the EDFA.

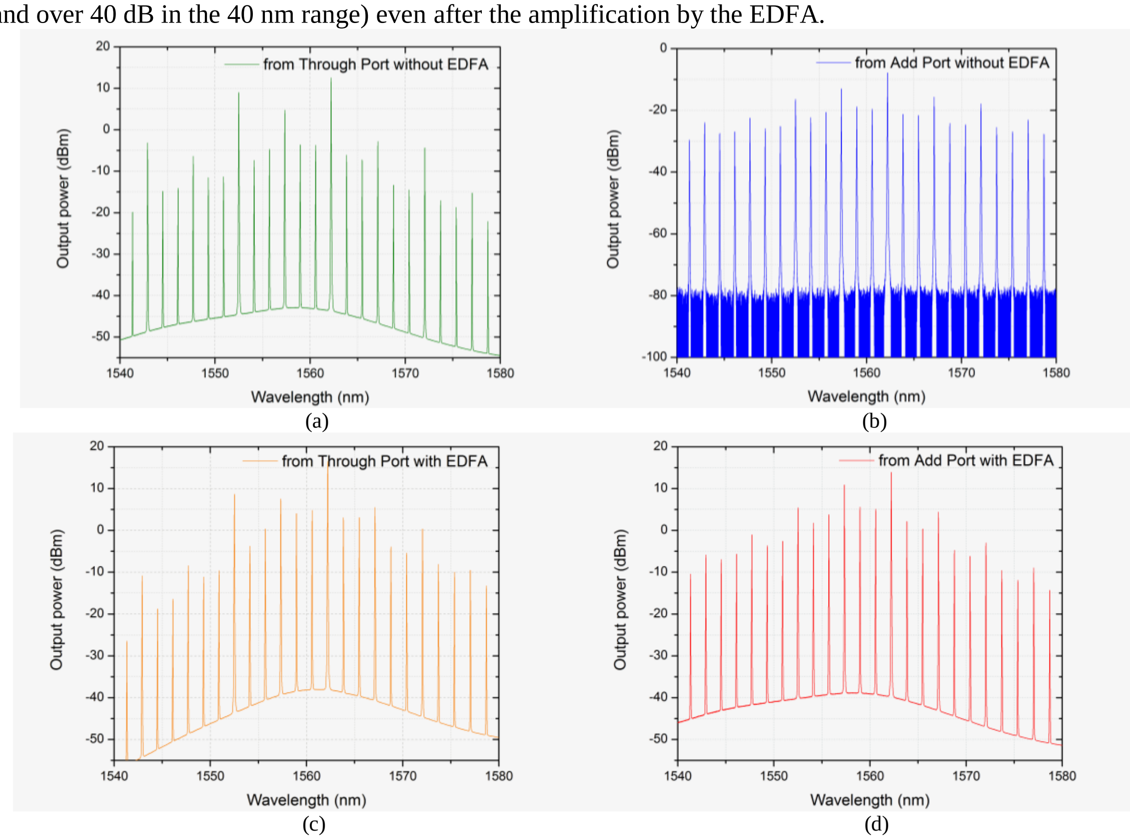
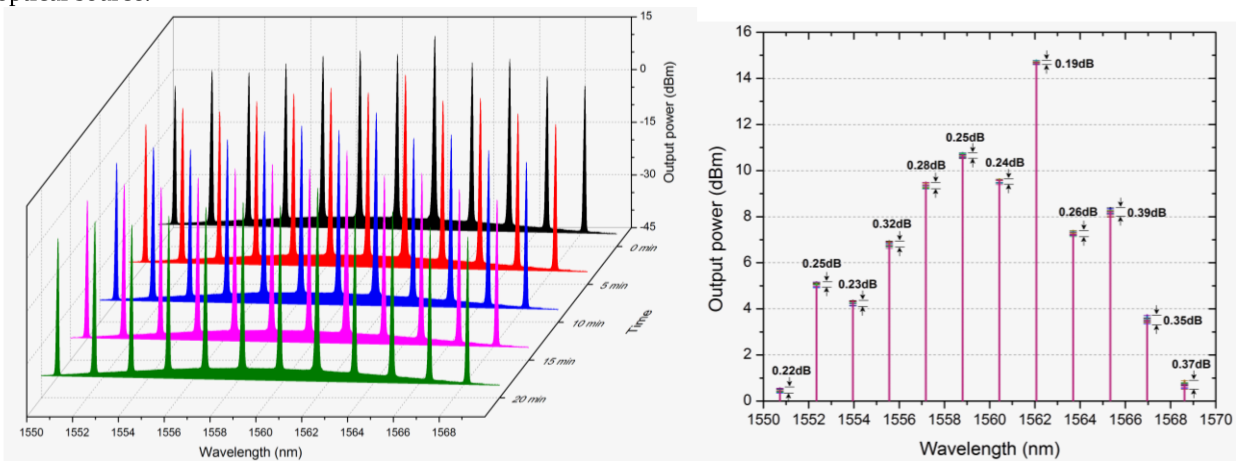


Fig. 2 Optical spectrum when observed at different output positions.

The stability of the present multi-wavelength optical source based on EDF and micro-ring resonator is also demonstrated, as shown in Fig. 3. Fig. 3(a) shows the repeated scanning spectrum every 5 minutes within 20 minutes for the main 12 lasing wavelengths with the power of above 0 dBm, when it is observed at the add port of the micro-ring resonator after amplification by the EDFA. Fig. 4(b) shows the peak power fluctuation of these 12 wavelengths every two minutes in another 30 minutes. As can be seen from Fig. 3, the maximal fluctuation of each peak power is less than 0.39 dB, which shows stable multi-wavelength output at room temperature for our present optical source.



(a) (b)

Fig. 3 (a) Repeated scanning spectrum every 5 minutes within 20 minutes;
(b) peak power fluctuation for the main 12 lasing channels above 0 dBm in 30 minutes.

4. Conclusion

We have implemented and experimentally demonstrated a multi-wavelength optical source with channel spacing of 200 GHz, which is based on a CMOS-compatible on-chip nonlinear micro-ring resonator and using EDF as the gain medium in the ring cavity. Output spectrum from both through and add ports are observed and analyzed before and after amplification by the EDFA. The extinction ratio of the output from the add port of the micro-ring resonator can be over 50 dB before amplification and larger than 40 dB after amplification. For the 12 wavelength with the power above 0 dBm, the maximal power fluctuation is only 0.39 dB within 30 minutes, which indicates our multi-wavelength optical source can work in a stable condition at room temperature.

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