

# 47-wavelength flat erbium-doped fiber ring laser with reduced operation power

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A 47-wavelength flat erbium-doped fiber ring laser over whole C-band is experimentally achieved with only 21-dBm output power from erbium-doped fiber amplifier (EDFA). The spectrum flatness of the multi-wavelength erbium-doped fiber laser (EDFL) is investigated.

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Multi-wavelength laser generated in a piece of erbium-doped fiber (EDF) is attractive because of its high gain and high efficiency with simple structure, which is very useful in wavelength division multiplexing (WDM) systems or fiber sensors. However, the EDF faces a big problem of intrinsic homogeneous line broadening<sup>[1]</sup> that prevents multi-wavelength oscillation at room temperature. Yamashita *et al.*<sup>[2]</sup> have placed the EDF into liquid nitrogen (77 K) to reduce the homogeneous line width, but it is too expensive for practical application. Several other methods have been proposed, such as active overlapping linear cavities<sup>[3]</sup>, and utilization of EDFs with elliptical core<sup>[4]</sup>. Two novel implemented techniques are inserting an acousto-optic frequency shifter<sup>[5]</sup> or a phase modulator<sup>[6]</sup> into the laser cavity to prevent single wavelength oscillation, however both of these methods need comparatively complicated equipments. Recently, Yamashita *et al.*<sup>[7]</sup> have presented a very simple method by inserting a highly nonlinear fiber (HNLF) into the cavity. As a result, in addition to the erbium gain, the four-wave mixing (FWM) in HNLf provides secondary gain to the lower power wavelength in expense of the higher power peaks, which favors the multi-wavelength lasing. This method is much simple in implementation. However, the experimental result<sup>[7]</sup> is primary and an erbium-doped fiber amplifier (EDFA) with as high as 31-dBm saturation power is used to achieve about 40-nm output bandwidth (1537–1577 nm). In this paper, a 47-wavelength flat EDF ring laser with 8-dBm total output power covering the whole C-band (1528–1565 nm) is achieved with 21-dBm EDFA output power. The relationships of output spectrum flatness versus cavity loss, pump power, and HNLf length are investigated.

Figure 1 shows the scheme of multi-wavelength erbium-

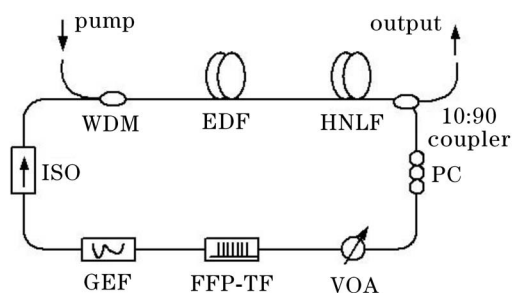


Fig. 1. Experimental setup of multi-wavelength EDFRL.

doped fiber ring laser (EDFRL), which consists of a pumped EDF, a WDM coupler, a gain equalization filter (GEF), and an isolator that forms an EDFA, as well as a HNLf coil, a fiber Fabry-Perot tunable filter (FFP-TF), a polarization controller (PC), and a 10:90 coupler. The difference from the scheme in Ref. [7] is the insertion of GEF and variable optical attenuator (VOA). The VOA is used to adjust the ring cavity loss so that the power entering EDFA could be varied. At a proper power level, the gain spectrum of EDF is flattened over whole C-band by the GEF. The free spectrum range and linewidth of FFP-TF (Micron optics, Inc) are 0.8 and 0.02 nm, respectively. The zero dispersion wavelength of HNLf is at 1548 nm and the dispersion slope is 0.015 ps/nm<sup>2</sup>·km at 1550 nm with the nonlinear coefficient and loss coefficient of 11.8 W<sup>-1</sup>·km<sup>-1</sup> and 0.73 dB/km, respectively. The length of HNLf is 1450 or 500 m. The light in the cavity is monitored at the 10% port of the 10:90 coupler by using an optical spectrum analyzer (OSA).

Setting the pump power of EDF at maximum, and carefully adjusting the VOA and PC to make sure that the output spectrum from 10:90 coupler is the most flat, meanwhile the output power from EDFA is measured to be 21 dBm. Figure 2 is the multi-wavelength output spectrum from the ring cavity. 3-dB bandwidth is 37 nm from 1528 to 1565 nm, covering the whole C-band. All of the peaks within this range have an extinction ratio of 31 dB, higher than that of the FFP-TF (25 dB). The output power of all the wavelengths is totally 8 dBm. The laser linewidth for an arbitrary wavelength is measured with a setup composed of a tunable bandpass filter, a fast

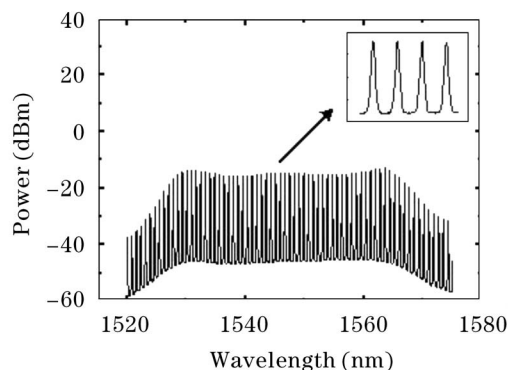


Fig. 2. Output optical spectrum of EDFRL.

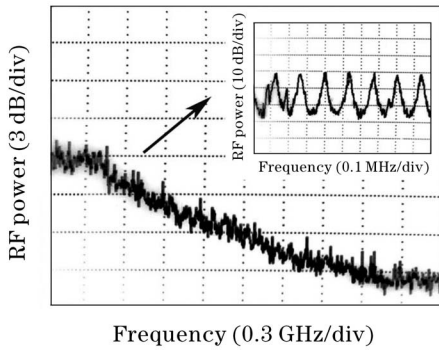


Fig. 3. RF spectrum of the 1545.6-nm wavelength.

photodetector, and a radio frequency (RF) spectrum analyzer. Figure 3 is the RF spectrum of the 1545.6-nm laser line, which has a 3-dB linewidth of 600 MHz and shows multi-mode structure. With higher resolution, the mode interval is observed to be 140 kHz, which corresponds with the cavity modes, as shown in the inset. Similar results are also observed for other wavelengths except that the wavelengths with lower extinction ratio are broader but still narrower than that of the FFP-TF (2500 MHz). The mode structure of output spectrum and the narrower linewidth confirm that the multi-wavelength output from the cavity is really a laser.

Comparing with the result in Ref. [7], we achieve a C-band multi-wavelength EDFRL with similar wide bandwidth of 37 nm (40 nm in Ref. [7]). Moreover, the EDFA operates at much lower output power of 21 dBm (31 dBm in Ref. [7]). The main reason is that a GEF is inserted so that a flat EDFA gain spectrum could be achieved. Without the GEF, the spectrum ripple is increased from 3 to 8 dB. Here the spectrum ripple is defined as the power difference between the highest and the lowest peaks within the considered wavelength range from 1528 to 1565 nm. To give a detailed investigation on the factors affecting the spectrum ripple, two experiments are performed. First, the influence of cavity loss on the flatness of output spectrum is examined. The VOA is set to be 7.88, 6.68, 6.13, 5.21, and 3.07 dB, respectively, while the pump power is set to the maximum. The measured envelopes of output spectra are shown in Fig. 4, where the ripple is varied from 3 to 23 dB. The output spectrum is the flattest when the VOA is 6.13 dB, corresponding to a flat EDFA gain spectrum, which is confirmed by measuring the EDFA gain spectra. When the cavity loss deviates from this value, the gain spectrum of EDFA would be inclined, so the output spectrum ripple becomes larger. Actually, the similar phenomenon has been shown in Ref. [7] where the cavity loss is varied when the two ports of the 1:99 output coupler are exchanged, which makes the gain spectrum proper and the output spectrum becomes more flat. Secondly, the effect of pump power of EDFA on the spectrum flatness is studied. The spectrum ripple is measured at each pump level with 1450- or 500-m HNLf respectively, meanwhile the VOA is adjusted to make the output spectrum as flat as possible. The relations of the spectrum ripple versus the EDFA output power are shown in Fig. 5. It indicates that the spectrum ripple is in negative linear relation to the EDFA output power (in dB unit), and

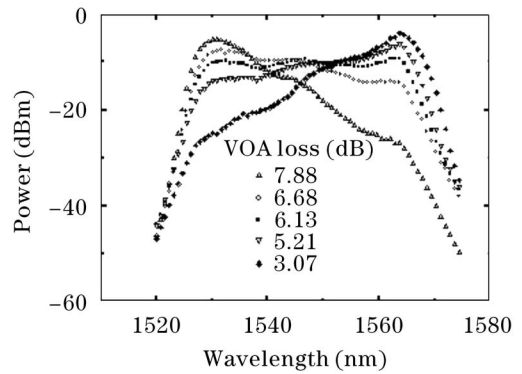


Fig. 4. Spectral envelope with different VOA losses.

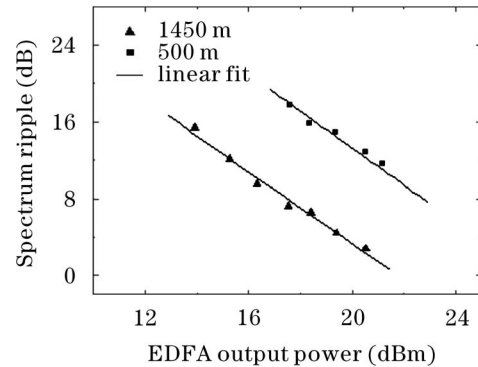


Fig. 5. Spectrum ripple versus the EDFA output power with 1450- and 500-m HNLfs.

increases with the HNLf fiber length decreasing. It is easy to understand that the higher power density or the longer HNLf fiber length favors FWM.

In conclusion, we have achieved a 47-wavelength flat EDF+HNLf ring laser with 8-dBm total output power over the whole C-band (1528—1565 nm), by using 21-dBm EDFA output power. The relationships of output spectrum flatness versus cavity loss, pump power, and HNLf length are investigated. The result shows that a flat gain spectrum of EDFA favors the spectrum flatness, and the spectrum flatness can be improved by increasing the pump power or HNLf length.

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