La-codoped Bismuth-based Erbium-doped Fiber Ring Laser with 106-nm Tuning Range

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Abstract: 106-nm wideband tunable fiber ring laser using 84.6-cm long La-codoped bismuth-based EDF is reported. The laser emits high output power with 35 dB extinction ratio and a second output emits lower power but exhibits 60 dB extinction ratio.

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1. Introduction

Tunable fiber ring lasers (FRL) have attracted tremendous interest because of their many applications in fiber optic test and measurement [1], fiber communications [2] and fiber sensing [3] systems. This is because FRLs exhibit wide tunable range, narrow linewidth and could be tuned at high speed allowing fast component characterization. Silica-based erbium-doped fibers (Si-EDFs) are commonly employed as gain medium in the construction of fiber ring lasers. However, pair-induced quenching and clustering effects [4] limit the concentration of erbium ions that can be doped into silicate fiber and therefore long length of Si-EDF is normally needed in the construction of fiber ring lasers. Fiber ring lasers based on Si-EDF is difficult to tune to wavelength beyond 1610 nm. Furthermore, the long cavity length makes them more susceptible to environmental influence.

In this paper, we report a wideband, short-cavity length tunable FRL that can be tuned from 1520 nm to 1626 nm using one tunable optical filter and a short length of Lanthanum (La) co-doped Bi_2O_3 -based erbium-doped fiber (Bi-EDF). The filter is a micro-electro-mechanical system (MEMS) device that could be tuned over an extremely broad wavelength range from 1510 nm to 1630 nm.

2. Experimental Setup

Figure 1 (a) shows the configuration of the traveling wave tunable FRL. The Bi-EDF is pumped by one 1480 nm laser via port 1 of a four-port optical circulator, which exhibit fairly flat pass-band in the wavelength range of 1460 nm to 1630 nm. The unabsorbed pump power was measured via the 1480 nm port of a WDM constructed with thin-film filter and has flat pass-band in the signal port for wavelength ranges from 1520 nm to 1630 nm. The length of the Bi-EDF was 84.6 cm long. The refractive index of the core and cladding of the Bi-EDF are 2.03 and 2.02, while the diameter of the core and cladding are 4.0 μm and 125.6 μm , respectively. The La concentration is 4.4 %wt and the erbium concentration is 6,470 wt-ppm, which is much higher than that in Si-EDF but without introducing deleterious ion quenching effect [5]. The peak absorption of the Bi-EDF at 1480 nm and 1530 nm are 167 and 267 dB/m. Both ends of the Bi-EDF was angle spliced to high NA fiber (Corning HI980) before splicing to port 2 (SMF-28 fiber) of the circulator and to the signal port (SMF-28 fiber) of the WDM, providing better mode field diameter matching. The splicing loss attained was less than 0.2 dB for the angled splices. The angled splices reduce the reflection in the laser

cavity to less than 60 dB.

Fig.1. Configurations of the Bi-EDF tunable fiber ring lasers: (a) multimode with dual outputs, and (b) single mode laser

A tunable MEMS filter was employed to tune the laser wavelength. The bandwidth of the MEMS is about 20 nm and it can be tuned from 1630 nm to 1510 nm. The insertion loss of the MEMS filter at the peak of the pass-band is less than 1.5 dB. The out-of-band reflection from both ends of the MEMS filter is very high ($> 95\%$). The circulator and the optical isolator prevent any reflection from the MEMS back to the Bi-EDF and ensure unidirectional operation. Reflection from the input end of the MEMS filter was employed as the laser output (port 4 of the circulator). A 20 % fused fiber taper was inserted in the laser cavity to serve as second output.

3. Performance and Discussions

Figure 2 (a) and (b) show the output spectra of the FRL obtained from port 4 of the circulator and taper respectively. The FRL was pumped with 120 mW of optical power. By varying the pass-band of the MEMS filter, the laser wavelength was tuned from 1520 nm to 1626 nm, exhibiting a large tuning range of 106 nm. From output 1 of the FRL, extinction ratio better 45 dB was measured and the output power is greater than +7 dBm over the C-band region. Outside the C-band, both the output power and the extinction ratio decrease. The measured 3-dB linewidth of this multi-longitudinal mode laser using the OSA with 0.01 nm resolution is ~ 0.02 nm. Note that the 106 nm tuning range was achieved without the 20% taper inside the laser cavity. With the inclusion of the 20% taper, the cavity loss was slightly increased and both the output power and wavelength tuning range from output 1 were reduced slightly.

Fig.2. Laser output spectra measured with an OSA: (a) from port 4 of the circulator, and (b) from the 20 % taper

The laser output 2 from the taper exhibits very high extinction ratio of better than 60 dB throughout the entire 104 nm wavelength tuning of the FRL. The improvement in the extinction ratio is because the laser output was taken from the output of the MEMS filter which filters the out-of-band ASE. In the former case, the output was taken from the reflection of the MEMS filter, which reflects both the lasing wavelength and the out-of-band ASE.

FRL with single frequency output can also be achieved by modifying the laser configuration slightly and it is shown in figure 1 (b). Port 3 and port 4 of the optical circulator were reconfigured. A 2.5-m long un-pumped Si-EDF was spliced to port 3 of the circulator and the other end of the Si-EDF was spliced to an FC/PC connector

which was gold coated to serve as a mirror. The purpose of this additional arm in the ring cavity is to produce a periodic spatial hole burning by the light passing into and out of the Si-EDF, thereby generating an intra-cavity narrow-band filter [6]. The RF spectrum of the FRL with and without un-pumped Si-EDF were measured with a 25 GHz photodetector together with an RF spectrum analyzer and they are shown in Fig. 3 (a) and (b), respectively. The absence of the tones in Fig. 3 (b) implies that all the side modes are suppressed. The laser linewidth at this operation condition was also measured by heterodyning the FRL with a tunable external cavity laser. The inset of Fig. 3 (b) shows the beating tone generated by these two lasers, the linewidth of the laser is measured to be less than 300 kHz which was limited by the 300-kHz linewidth of the external cavity laser.

Fig.3. RF spectrum of the fiber ring laser (a) without and (b) with the saturable absorber incorporated into the ring cavity

4. Conclusion

In conclusion, we have demonstrated a short-cavity FRL configuration that exhibits ultra-wide wavelength tuning range by employing only 84.6-cm long Bi-EDF and a tunable MEMS-based filter. The laser configuration permits continuous wavelength tuning over 106 nm and relatively large output power. A second laser output extracted from a 20 % taper in the laser cavity exhibits very high extinction ratio of better than 60 dB but with much lower output power and slightly reduced tuning range of 104 nm. The single longitudinal mode operation is also demonstrated by incorporating a short length of un-pumped erbium doped fiber into the ring cavity as a saturable absorber.

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