Erbium-doped fibre ring laser based on microfibre coupler

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Abstract. A compact erbium-doped fibre (EDF) laser is demonstrated which uses a microfibre coupler and a highly concentrated EDF loop. The coupler functions to inject the pump light and tap out the output. The EDF laser operates at 1526.3 nm, with a signal-to-noise ratio of about 26 dB. The maximum output power 20 μW is obtained at the pump power 18.6 mW. We have obtained the slope efficiencies of the laser 0.12, 0.06, 0.04 and 0.02% at the EDF lengths fixed at 90, 78, 66 and 51 cm, respectively. The lowest lasing-pump power threshold is achieved at 3.8 mW.

Keywords: microfibre, compact laser, erbium laser

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1. Introduction

Single-frequency lasers emitting light around 1550 nm are among the key components of optical communication systems such as high-capacity wavelength division multiplexing networks and externally modulated high bit-rate links [1–3]. Recently, single-frequency erbium-doped fibre lasers (EDFLs) have been shown to be capable of providing mode-hop-free lasing due to distributed feedback, distributed Bragg reflecting and ring-like construction with embedded narrow-bandwidth filters [4–6]. Many works have also been reported on Brillouin fibre lasers that generate a single-frequency output basing on stimulated Brillouin scattering and provide a spectral filtering effect, selecting out a single longitudinal mode as a laser output [7, 8]. Unfortunately, most of the fibre ring lasers are plagued by longitudinal mode hopping as a result of temperature sensitivity peculiar of long cavities.

Of late, there has been a surge of interest in ultra-compact fibre lasers, which can be built using doped fibres with high concentrations. Micro/nanoscale lasers have also been demonstrated recently using semiconductor nanowires [9] and laser dyes [10] as gain media. In another work, Sulaiman et al. [11] have demonstrated a simple tunable EDFL, using a highly concentrated erbium-doped fibre (EDF) as a gain medium in conjunction with a microfibre knot resonator, which is formed at the end of the gain medium. In this letter, a compact and low-noise EDFL is demonstrated that utilizes an EDF loop attached to a microfibre coupler as a gain medium. The coupler is used for both injecting the pump light and taping out the output.

2. Experimental setup

Fig. 1 shows the configuration of an EDFL suggested by us, which consists of a loop of highly concentrated EDF, where a portion of the loop is fused together with a standard single-mode fibre (Corning SMF-28) to form a microfibre coupler. At first, both ends of the EDF are spliced together to form a loop. The microfibre coupler is made by laterally fusing and tapering a spliced area of the EDF loop and single-mode fibres with the aid of a well-developed single-stage 'flame-brushing' technique. In the fabrication process, two fibres are brought into close proximity after a protective plastic jacket is removed. Then the both fibres are twisted at two different locations to make overlapping contact. Finally, while heated by a torch, the fibres are fused and stretched.

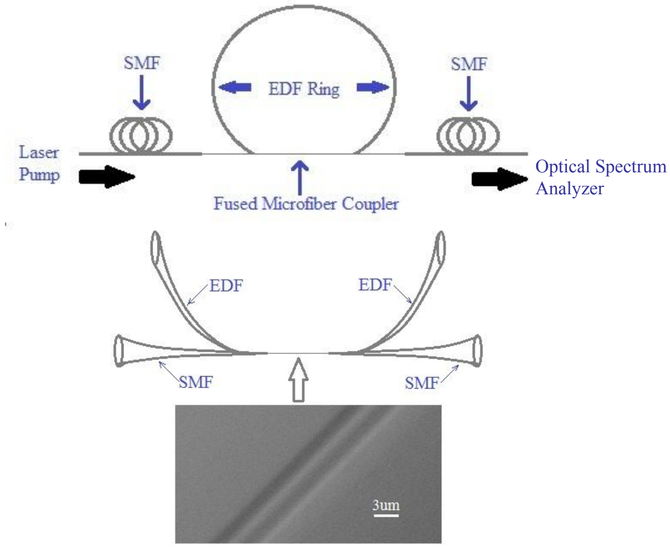

Fig. 1. Schematic diagram of our low-noise ring EDFL based on a microfibre coupler.

Longitudinal profile of the conical transition tapers was achieved by controlling a hot zone and moving precisely translation stages. The diameter of the microfibre coupler waist was equal to about 5 μm and the lengths of the tapered region and the uniform waist were respectively 80 and 40 mm. A 980 nm pumping light was injected into the EDF loop via an input port of the microfibre coupler. The laser output was tapped out from the loop via the output port of the coupler and analyzed with an optical spectrum analyzer having a 0.015 nm resolution. The performance of the laser was investigated for different perimeter lengths of the loop (90, 78, 66, and 51 cm). The EDF built by us had an erbium ion concentration of about 2000 ppm by mole.

3. Result and discussion

As the 980 nm pump light is injected into the EDF loop via the input end of the microfibre coupler, an amplified spontaneous emission is generated. This emission oscillates and is further amplified in the loop to generate laser light. Some fraction of the laser light is tapped out from the loop through the output end of the microfibre coupler. Fig. 2 shows the output spectrum of the EDFL with the open and close loops for a specific case when the loop perimeter length and the 980 nm pump power are fixed at 70 cm and 20 mW, respectively. There is no lasing with the open loop, since the amplified spontaneous emission does not oscillate in the cavity. A comb spectrum is achieved due to multimode interference in the region of the microfibre coupler. The EDFL ope ates at 1526.3 nm with the close loop, which allows the amplified spontaneous emission to oscillate in the ring cavity, thus giving rise to lasing. The operating wavelength is determined mainly by the filtering characteristics of the microfibre coupler, the EDF gain and the loss in the cavity. The lasing peak has a signal-to-noise ratio of about 26 dB, which is comparable with that found in the other works [11, 12].

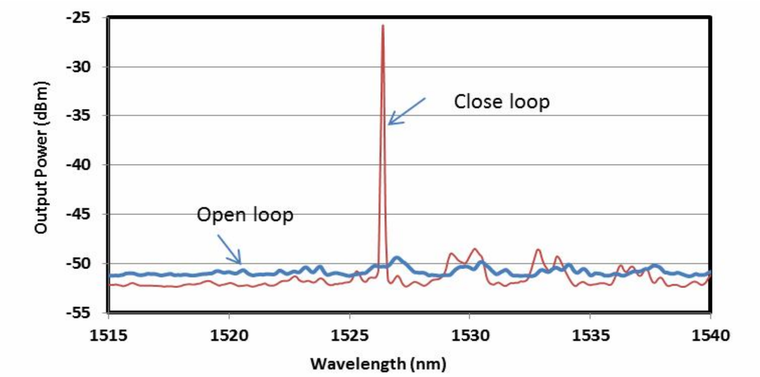

Fig. 2. Output spectra typical for our microfibre-based EDFL for the cases of open and closed loops (the EDF length is equal to 70 cm and the power of the 980 nm pump is 20 mW).

Fig. 3 shows the lasing characteristics of the microfibre-based EDFL at various EDF lengths. It is seen that the peak power of the laser increases linearly with increasing pump power. The slope efficiencies of the laser are obtained as being 0.12, 0.06, 0.04 and 0.02% when the EDF lengths are fixed at 90, 78, 66 and 51 cm, respectively. A low efficiency is mainly due to high losses in the region of the microfibre coupler. As expected, the efficiency of the laser increases for larger EDF lengths. This can be attributed to longer EDF, which consists of more erbium ions to support more population inversion and so produces higher output laser powers. The maximum output power of 20 μW is obtained at the pump power of 18.6 mW for the EDFL configured with the 90 cm long EDF.

The lasing-pump power thresholds for our laser are measured to be 3.8, 4.6, 10.8 and 12.7 mW for the EDFL configured with the 90, 78, 66 and 51 cm long EDFs, respectively (see Fig. 3). The threshold power increases as the EDF length decreases because the cavity loss becomes higher for smaller loops due to a bending effect. Since our cavity lengths may be termed as ultra-short (they are less than 1 m), the output of the laser is expected to correspond to a single longitudinal mode and thus to be characterized with a very small linewidth and low relative intensity noise.

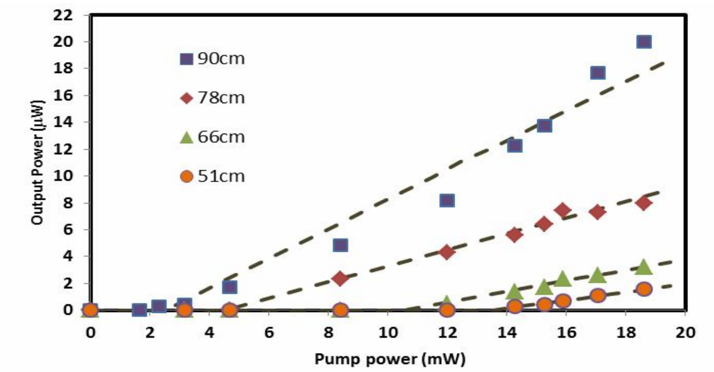

Fig. 3. Output spectrum of the microfibre-based EDFL.

4. Conclusion

We have demonstrated a low-noise EDFL operating at 1526.3 nm, using an EDF loop attached to a microfibre coupler as a gain medium. The slope efficiencies of the laser have been obtained to be equal to 0.12, 0.06, 0.04 and 0.02% as the cavity or EDF lengths are fixed respectively at 90, 78, 66 and 51 cm. For the cavity length of 90 cm, the EDFL starts to lase at the pump power of 3.8 mW and produces the maximum output power of 20 μW. The signal-to-noise ratio 26 dB is achieved at the pump power equal to 18.6 mW.

Finally, we are to notice that the laser of this type operating at around 1.5 μm should have a number of applications, including free-space telecommunications, pump sources for nonlinear frequency conversion in the mid-IR, seed sources for lasers and nonlinear amplifiers, as well as differential wavelength spectroscopy [13].

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Анотація. *З використанням мікроволоконного з'єднувача і високолегованої ербієм волоконної петлі в роботі досліджено легований ербієм компактний волоконний лазер. З'єднувач використовувався для введення та виведення оптичного випромінювання з волокна. Лазер функціонував на довжині хвилі випромінювання 1526,3 нм із відношенням сигнал/шум 26 дБ. Максимальна потужність лазерного випромінювання становила 20 мкВт за потужності випромінювання нагнітання 18,6 мВт. Коефіцієнт корисної дії лазера становив 0,12, 0,06, 0,04 і 0,02 % відповідно для довжин волоконного резонатора 90, 78, 66 і 51 см. Найнижче порогове значення потужності нагнітаючого випромінювання складало 3,8 мВт.*