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High Power (60mW) Single Frequency Erbium:Ytterbium Codoped Fiber Laser

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ABSTRACT: The characteristics of a high power Er^{3+}:Yb^{3+} single frequency fiber laser pumped at 980nm are reported. The device gives 60mW output power with RIN<-168dB/Hz for frequencies>10MHz and linewidth 500kHz. At low output powers (<30mW) the slope efficiency is as high as 25%, falling to 12% at higher powers. The saturation behaviour is related to a bottleneck affect due to the finite Yb- Er transfer rate. Improved performance can be obtained using new fibers with an increased rare-earth concentration which show negligible signs of erbium clustering.

1. INTRODUCTION

Recently, there has been sustained interest towards the development of high performance single frequency fiber grating-based erbium-doped fiber lasers[1-7]. To ensure robust single frequency operation without mode-hopping, these lasers need to be short, a few cm in length at most. Whilst the earlier grating-based fiber lasers relied on conventional erbium-doped germanosilicate fibers, the laser efficiencies and output powers were low - typically 0.1% and in the μW regime respectively[1,2]. This is a direct consequence of the low pump absorption due to the short fiber cavity length. Various configurations have been demonstrated in order to boost the power output, including a MOPA[3] configuration and different pump schemes[4,5]. The potential for efficient devices based on Er:Yb co-doped fibres, although promising[6], suffered due the lack of photosensitivity in these fibers. However, the recent development of photosensitive Er^{3+}:Yb^{3+} codoped fibers[7] has dramatically improved the efficiency and hence output power from these devices, primarily due to the increased 980nm pump absorption. Unfortunately, early DFB fibre lasers made in these fibres were unable to perform at high powers (>10mW) due to thermally induced changes in the grating. These thermal problems are a direct result of the high lasing intensity found at the centre of discrete quarter-wave phase shifted DFB lasers[8], a problem less likely to occur in linear cavity lasers where the lasing intensity is more uniform.

In this paper, we report on the characterisation of a grating-based fibre-laser capable of producing 60mW output power, with single frequency and single polarization mode output. The output power is limited by a bottleneck effect, primarily due to the relatively low Yb to Er transfer rate in the fibre used for this experiment. Such a process is well documented in the literature[9]. The bottleneck occurs when the Yb-ion pump rate is greater than the Yb to Er transfer rate. This can be rectified by an increase in the Yb to Er transfer rate, easily achieved through an increase in the rare earth concentration. However, it is well known that above a critical concentration threshold erbium ion clustering takes place, a feature detrimental to the laser performance[10-12]. In order to quantify this effect we have measured the saturation characteristics of the erbium ions in a Er:Yb co-doped fibre, when pumped directly at 1535nm. In a fibre with 110dB/m absorption at 1535nm, three times the erbium concentration present in the fibre used for our laser experiment, we observe negligible erbium ion clustering. We anticipate these latest fibres will show an increase in output power compared with the present fibre laser.

2. EXPERIMENTAL RESULTS

Fig. 1 shows the configuration of the Er^{3+}:Yb^{3+} fiber Bragg grating laser (FBGL), which has been the subject of recent wavelength tuning experiments[13]. One cavity end reflector consists of a dielectric (TiO_2/SiO_2) high reflecting (99.86% at 1.55 μm) mirror epoxied onto one end of the polished Er^{3+}:Yb^{3+} fiber laser cavity, while the other end is a centimetre long Bragg grating (98% reflectivity at 1536 nm) written directly into the Er:Yb fiber, and situated a few mm away from the dielectric mirror. The entire laser is thus less than 1.5 cm in length. An advantage of this compact configuration is that the 980 nm pump can be efficiently and directly coupled into the laser through the dielectric mirror, which transmits well at 1 μm.

Fig. 2 shows the lasing characteristic of the FBGL, which is pumped by a 980 nm Ti:Sapphire laser. A maximum output power of 58 mW (measured at the output of a pigtailed isolator) is obtained, for a launched pump power of 500 mW. Although this laser is operating at 1535nm, lasing around 1550nm has been demonstrated in these lasers[13]. A scanning Fabry-Perot interferometer confirmed both single frequency as well as single polarisation state operation. In figure 3, the measured RIN is $<$ -168 dB/Hz for frequencies beyond 10 MHz, with a peak RIN value of just -133 dB/Hz at the relaxation oscillation frequency of 2.8 MHz. We have measured the optical linewidth using the delayed self-heterodyne technique to be 500 kHz when operating at high power. Although this value is greater than that obtained in fibre DFB's, albeit at considerably lower powers, it is still considerably less than that obtained from semiconductor devices.

To determine the degree to which the laser is indeed operating in a single polarisation state, the laser output was connected to a polarisation controller, and on to a (pigtailed) polarising isolator. By adjusting the polarisation controller, the output from the polarising isolator could be reduced by -50 dB, probably limited by the extinction of the polariser used. The second orthogonally polarised mode of the laser is thus shown to be effectively nonexistent, and the laser output is established to be that of a single polarisation state, with a purity better than 50 dB at high output power.

It should be mentioned that single frequency operation in this laser is not always maintained over the entire pump power range. As the pump power is increased, the lasing wavelength correspondingly increases, and eventually a mode change occurs. It is worth noting that when the pump power is quickly turned on, from zero to full power, the fiber laser correspondingly turns on, but the lasing wavelength is observed to gradually shift longer by 0.3 nm over the course of several minutes before finally stabilising. We thus infer that the associated temperature rise in the fiber laser is ~30°C for the maximum operating power.

The 60 mW FBGL has a reasonable net efficiency of 12% with respect to launched pump power, however, it is clear from Fig. 2 that the efficiency is considerably better at lower pump powers. For this laser the measured slope is around 25% at output powers less than 30mW and clearly the output starts to saturate at higher powers. Unlike the recent measurements on Er:Yb DFB's[5], we believe the origin of this is not thermal but rather a consequence of the bottleneck effect, arising from the finite energy transfer rate from excited Yb^{3+} to ground state Er^{3+} ions. Recent modelling of single frequency Yb:Er fibre lasers[6], has pointed out that fibres with a high concentration of Er and Yb ions should show reduced bottlenecking due to the increased Yb to Er transfer rate in these fibres. However, the theoretically improved performance, of these devices is based upon the assumption that erbium ion clustering is not occurring in heavily co-doped Yb:Er fibres. This assumption is based upon the belief that the Ytterbium ions actually disperse the erbium clusters, thus aiding the homogenous distribution of erbium ions within the glass.

In order to validate this assumption we have studied the saturation characteristics of a heavily doped Yb:Er fibre. The saturation curve for a fibre with 110dB/m absorption at 1535nm, a value 3 times that measured in the FBGL laser fibre, is shown in figure 4. Despite the high concentration of erbium ions in this fibre, the absorption is almost completely bleachable indicating the very low level of clustered erbium ions in this fibre. Based on the pair induced quenching model[8], the measured unbleachable loss corresponds to a clustered ion fraction of less than 3%. We anticipate that single frequency fibre-grating based lasers made from this fibre will give output powers greater than the 60mW already achieved.

3. CONCLUSION

We have demonstrated a high output power (60mW) stable single frequency Er^{3+}:Yb^{3+} fiber laser pumped at 980nm. The laser characteristics, RIN< -168 dB/Hz for frequencies greater than 10MHz, optical SNR > 65 dB and single polarisation state purity > 50 dB, make these lasers highly attractive for CATV applications. The measured slope efficiency at low output power (25% at 30mW) decreases at higher powers due to a bottleneck in the Yb to Er transfer rate. Improved fibre, with increased rare earth concentration, show very little sign of erbium ion clustering, indicating that further increases in the available output power may be possible.

4. ACKNOWLEDGEMENTS

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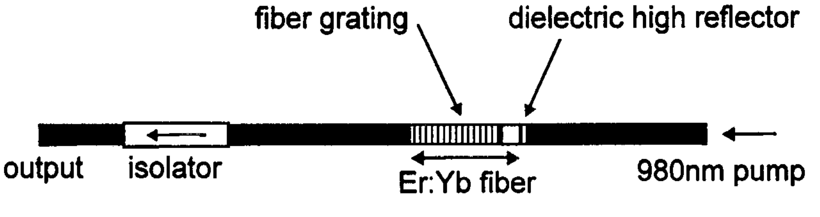


Figure 1
Er:Yb co-doped FBGL laser

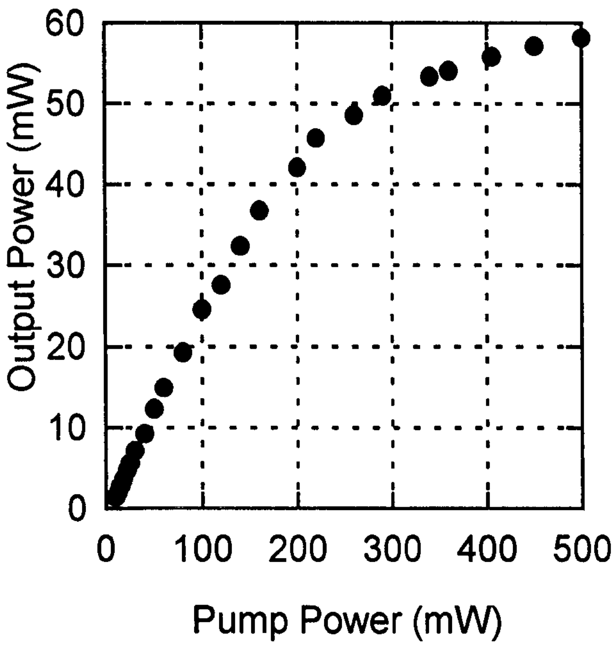
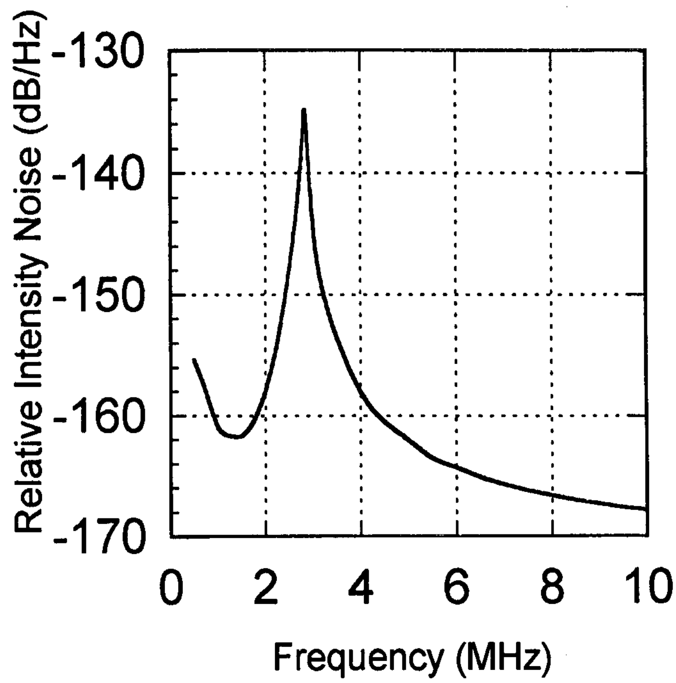


Figure 2
Lasing characteristics of FBGL laser

Figure 3
Measured RIN for FBGL laser
The output power is 50mW



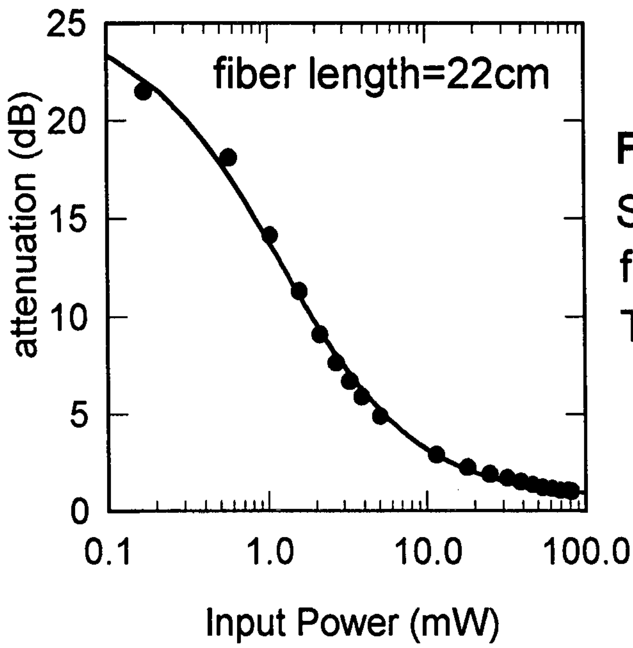


Figure 4
Saturation characteristics for Er:Yb fiber at 1535nm.
The fibre absorption is 110dB/m