EFFICIENT SINGLE-FREQUENCY ERBIUM:YTTERBIUM FIBRE LASER

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Abstract

We report a 7.6mW single-frequency fibre laser operating at 1545nm, using for the first time an Er^{3+}:Yb^{3+} doped fibre and a fibre grating output coupler. The laser had a linewidth <2.5kHz, and a relative intensity noise (RIN) level below -145dB/Hz above 10MHz.

Introduction

Narrow-linewidth, single-frequency Er^{3+}-doped fibre lasers sources operating at 1.55μm are of interest for use in future high-capacity communications, especially wavelength-division-multiplexed (WDM) and coherent systems. Advantages of single-frequency fibre lasers over DFB lasers for such applications include kHz linewidths, low intensity noise, scalability to high output power and direct fibre compatibility.

Travelling-wave loop or ring fibre lasers [1,2] are relatively complex and are susceptible to mode-hopping owing to the length of fibre employed (a few metres) and the concomitant close spacing of the axial modes. On the other hand, linear-cavity fibre lasers [3,4] using integral fibre grating Bragg reflectors for feedback and mode suppression are simpler, cheaper and potentially more stable. In order to achieve robust single-mode operation they need to be short (a few cm) in order to ensure that only a few axial modes fall within the reflection bandwidth of the grating (~0.2nm). Unfortunately, although considerably easing packaging, the short fibre length leads to inadequate pump absorption at 980nm and low output power (100-200μW). Short fibre lasers are also susceptible to strong relaxation oscillations [4].

We report here the solution to both these problems using Er:Yb-codoped fibre. The presence of Yb^{3+} increases the pump absorption at 980nm by more than an order of magnitude compared to Er^{3+} alone and enables efficient, short Fabry-Perot fibre lasers to be constructed having low thresholds and high output powers. This allows us to operate well above threshold using conventional 980nm laser diodes and drastically reduces the tendency to relaxation oscillations. We are thus able to achieve for the first time a single-frequency Fabry-Perot Er^{3+} fibre laser of a few cm length, having a <2.5kHz linewidth, an output power of 7.6mW and a RIN of -145dB/Hz, which compares well with DFB lasers.

Experiment

The laser configuration is shown in Fig 1. A 7cm-long Er:Yb-doped fibre is fusion spliced (0.6dB loss) to a fibre grating which is written into a highly photosensitive fibre developed in our laboratories. The fibre grating has a peak reflectivity at 1545nm of 40% and a reflection bandwidth of 0.09nm (11.3GHz), which enables us to use cavity lengths up to at least 10cm and still obtain single-frequency operation. We calculate that the single-pass gain required to overcome the total cavity losses is about 2.6dB. The input end of the Er:Yb-doped fibre is butted to a dichroic mirror which reflects nominally 100% of the laser light and transmits 97% of the pump light. The pump source is a 980nm laser diode with 100mW maximum output power.

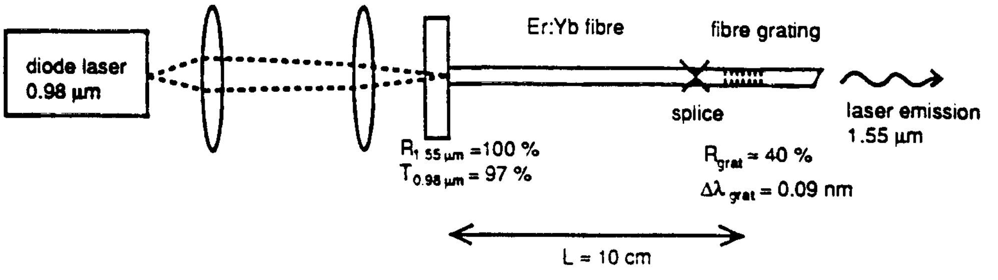

Fig 1 Er:Yb fibre laser configuration

Results

Fig 2 shows the laser output power as a function of the total emitted diode power, ie excluding launch losses which are estimated to be about 50-65%. The threshold pump power is 8mW and the maximum output power is 7.6mW. The slope efficiency relative to the total pump power is 10%, which, taking account of the launching efficiency, compares favourably with the limiting theoretical slope efficiency relative to the absorbed pump power of 49%.

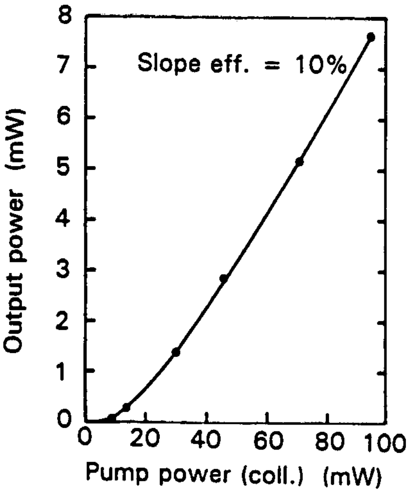

Fig 2 Laser output power as a function of collimated diode pump power

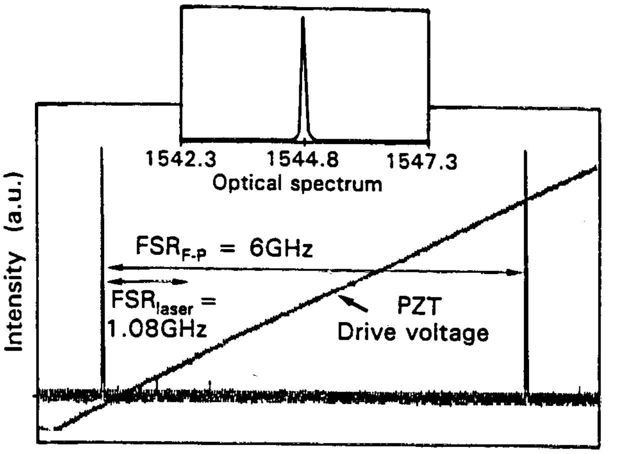

Fig 3 Single-frequency operation verified using a scanning Fabry-Perot interferometer with FSR = 6GHz. The FSR of the laser is 1.08GHz. The inset shows the optical spectrum measured with an optical spectrum analyser with 0.1nm resolution.

Single-frequency operation of the laser was verified with a Newport Supercavity scanning Fabry-Perot interferometer, which has a free spectral range (FSR) of 6GHz and a resolution of 1.2MHz. Fig 3 shows a scan over one FSR and confirms that only one longitudinal laser mode is present. Mode-hopping occasionally occurred on a time scale of one minute owing to environmental perturbations and should be relatively straightforward to eliminate. The mode-spacing (FSR) of the laser was observed to be 1.08GHz, corresponding to a total cavity length of 9.6cm. This length was found to be the maximum length for reliable single-frequency operation, and was chosen to achieve maximum output power with the grating available. Results obtained with shorter laser cavities were essentially unaffected by mode-hopping, but at the expense of somewhat lower output powers, a compromise which could be alleviated by reducing the laser intra-cavity splice losses and optimising the output coupling. The inset in Fig 3 shows the optical spectrum of the laser output at a wavelength of 1544.8nm.

The linewidth of the laser was measured with a self-heterodyne delay-line setup, using a Mach-Zehnder interferometer with a length difference between the two arms of 50km. The frequency shift was 100MHz. The half-width of the output electrical beat-spectrum in Fig 4 is about 2.5kHz, which is smaller than the inverse of the transit time of our delay line (4kHz), causing coherent interference at the output of the interferometer. From this we can conclude that the linewidth of the laser is narrower than 2.5kHz [6]. Note that the Schawlow-Townes limit of the laser is about 5Hz.

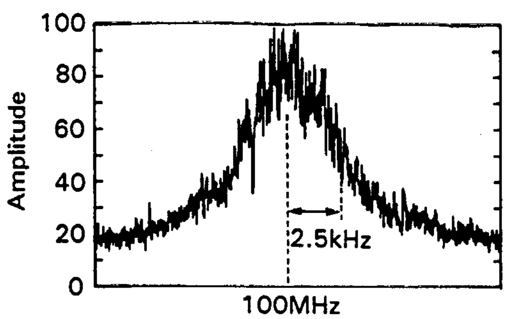

Fig 4 Self-heterodyne measurement of laser linewidth using a 50km delay line (inverse delay time 4kHz). The measured linewidth is less than 2.5kHz. The measurement time is 44s, and the resolution bandwidth is 300Hz. The span is 2kHz/division.

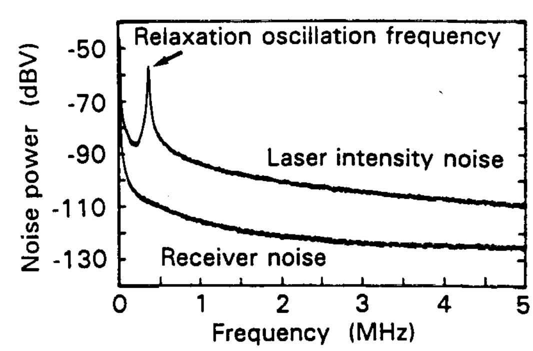

Fig 5 Laser intensity noise spectrum between 0 and 5MHz. The resolution bandwidth is 10kHz. The receiver noise spectrum is shown for comparison.

Finally, we measured the RIN of our laser source. The intensity noise was measured using an Epitaxx ETX-300 detector with 50Ω load, and a bandwidth of around 250MHz. Fig 5 shows the laser intensity noise spectrum from 0 to 5MHz. The spectrum has a peak at 350kHz, which is the relaxation oscillation frequency of the laser. With maximum laser output power, the RIN at this frequency is measured to be around -99dB/Hz. Above this frequency the RIN decreases to -143dB/Hz at 5MHz and -145.5dB/Hz at 10MHz. Above 100MHz the measured noise is dominated by the receiver noise, which corresponds to a RIN of -157dB/Hz. The self pulsation effect reported by Zyskind et al [2] was absent in our laser.

Conclusion

We have demonstrated single-frequency operation of a 10cm-long Er:Yb fibre laser. The linewidth of the laser was <2.5kHz, which is comparable with the narrowest linewidth reported for fibre lasers [1]. The maximum output power was 7.6mW, almost two orders of magnitude higher than previously reported for short erbium-doped fibre lasers. The slope efficiency relative to the collimated pump power was 10%. Improved performance is expected if fibre gratings can be written directly into the Er:Yb fibre so as to avoid splices inside the cavity, and if the input mirror is replaced with a high reflectivity fibre grating. The measured RIN was smaller than -145dB/Hz above 10MHz, which compares favourable with commercially-available DFB lasers.

Acknowledgement

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