Record efficiency of a holmium doped silica fibre laser

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Abstract: We present a single-mode, 2.09 µm holmium-doped silica fibre laser resonantly pumped by a 1.95 µm thulium-doped fibre laser. The slope efficiency of 87% versus absorbed power is to our knowledge the highest reported to date.

OCIS codes: (140.3460) Lasers; (140.3510) Lasers, fibre; (140.3070) Infrared and far-infrared lasers.

1. Introduction

Holmium fibre based devices enable the operation of fibre sources in the wavelength region 2.05-2.15 µm. In particular, the spectral region beyond 2.1 µm exhibits excellent atmospheric transmission. These properties make holmium based sources ideal candidates for a number of mid-IR frequency-conversion, remote sensing and defence applications.

Rare earth doped optical fibres have been demonstrated to produce highly efficient lasers and amplifiers. The combination of high purity host materials and low propagation losses, coupled with efficient pump absorption and excellent signal-pump overlap in the core has resulted in near quantum limited efficiencies being demonstrated. Of the rare earth ions, Yb and Tm have been demonstrated to operate with slope efficiencies of 88% [1] and 91% [2] respectively corresponding to ~97% and ~95% of the maximum theoretical efficiency. However holmium doped fibre devices have not previously been demonstrated to operate with such high efficiencies. Holmium doped silica can be pumped at either 1.15 µm or 1.95 µm. In the work of Kurkov et al holmium fibre lasers were pumped at 1.15 µm with efficiencies of 43% being demonstrated, corresponding to operation at ~81% of the maximum theoretical efficiency [3]. In 1.95 µm resonantly pumped demonstrations typical efficiencies of 65-75% have been reported corresponding to ~70-80% of the maximum theoretical efficiency [4, 5]. The low efficiencies reported are typically ascribed to; pair induced quenching, up-conversion, and multi-phonon and OH related quenching processes. As well as these various quenching mechanisms, the holmium operating wavelength is approaching the edge of the multi-phonon absorption of silica. The operating wavelength region beyond 2.1 µm thus results in increased IR-background losses as well as absorption associated with the OH combination mode at 2.2 µm [6].

In this paper we report on the demonstration of a holmium fibre laser operating with a slope efficiency of 87% with respect to absorbed pump power. To our knowledge this is the highest reported efficiency demonstrated from a holmium doped laser and represents operation at ~93% of the maximum theoretical efficiency.

2. Experiment

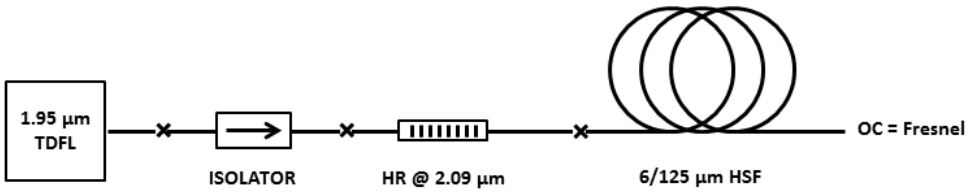

Fig. 1. Schematic diagram of monolithic holmium doped silica fibre laser, HSF – holmium single-clad fibre.

The experimental set up used to investigate the high efficiency holmium-doped silica fibre is depicted schematically in Fig. 1. The fibre under test was a single-clad acrylate coated 0.5 wt% holmium-doped fibre, with a core diameter of 6 µm, a cladding diameter of 125 µm and an NA of 0.22. The fibre was fusion spliced to a HR @ 2.09 µm fibre Bragg grating (FBG) fabricated in-house using matched passive fibre [7]. The splice region was cladding stripped using high-index polymer and any residual pump light from the thulium-doped fibre laser cladding or due to splice loss was attenuated by the cladding stripper region and the high-index acrylate coating of the fibre. The cleaved end of the fibre provided feedback as the output coupler (OC) for the laser. The holmium-doped fibre laser was then

pumped by a thulium-doped fibre laser operating at 1.95 µm which was isolated from any feedback from the holmium-doped fibre laser using a 10 W dual-stage isolator (Shinkosha).

A dichroic mirror (HR @ 1.95 µm, AR @ 2.09 µm) was used to separate the pump and signal wavelengths in the output beam and the power of the transmitted pump and signal was measured using thermal power meters. The efficiency was characterized using a cut-back measurement to investigate the behavior of the slope efficiency and optical-optical efficiency as a function of fibre length. The pump power coupled into the holmium-doped fibre was determined by measuring the transmitted pump power for short lengths, 150mm and 300mm, and extrapolating to 0 mm of holmium fibre to obtain the power coupled into the holmium fibre and an estimate of the splice loss.

3. Results and Discussion

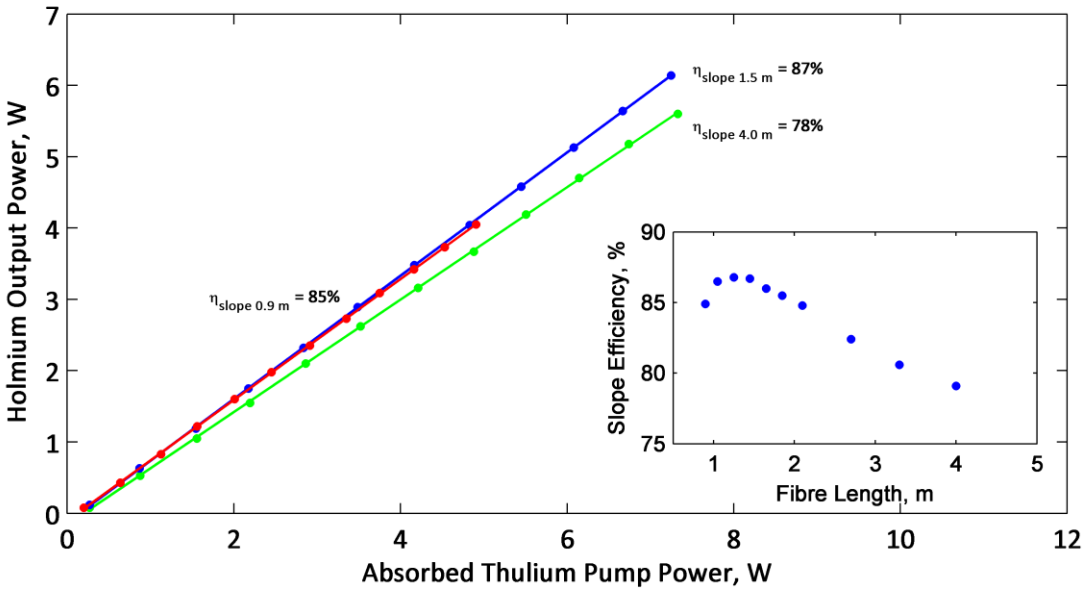

Fig. 2. Holmium fibre laser output power. INSET: Slope efficiency versus absorbed pump power as a function of fibre length.

The output power as a function of pump power for several holmium doped fibre lasers in the cut-back measurement are shown in Fig. 2. The results correspond to a representative long length, short length and near optimum length. The optimum fibre length of ~1.5 m resulted in 6.2 W of output power for a pump power of 7.3 W and an absorbed power of 7.1 W with a corresponding slope efficiency of 87%. The inset graph illustrates the variation of the efficiency as a function of length derived from the cut-back measurement.

4. Conclusion

We have presented results describing to our knowledge the highest slope efficiency achieved from a holmium doped laser of 87% with respect to absorbed pump power. This result represents a significant improvement on previously reported efficiencies. The efficiency corresponds to operation at ~93% of the maximum theoretical efficiency. Future work will focus on transitioning this core composition to a large mode area fibre for cladding pumping demonstrations and subsequent power scaling.

5. References

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