Liquid-Nitrogen-Cooled High-Concentration Erbium-Doped Fibre Laser

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Erbium-doped fibres suffer from quenching at high Er-concentrations [1, 2]. We have found that cryo-cooling to liquid-nitrogen temperature (LNT) substantially improves both the threshold and slope efficiency of a heavily doped, partly quenched, erbium-doped fibre laser (EDFL). The fibre is fabricated in-house by a heated-frit method, a technique suitable for gas-phase deposition of rare-earth doped fibre. It has an Er-concentration of ~8300 ppm (wt.) in a 10 µm diameter, 0.13 NA aluminosilicate core. It was characterised in a ring laser setup with an outcoupled signal of 3 dB. In the outcoupling we include the loss of an attenuator, two tap couplers, an extra isolator, and a connector pair inserted into the cavity for experimental convenience. The 1 m doped fibre was counter-pumped in the core at 1480 nm with negligible pump leakage. Figure 1 shows the resulting laser power at LNT and RT (room temperature), calculated as the difference between the circulating power after and before amplification in the EDF. The LNT case shows clear improvements in both threshold and slope efficiency, the latter reaching 38.6%. The emission wavelength shifts from 1592 nm at RT to1572 nm at LNT.

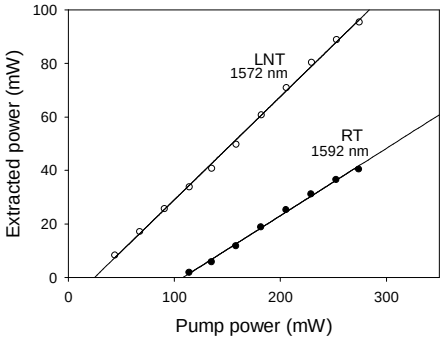

Fig. 1 Fibre output power at different temperatures.

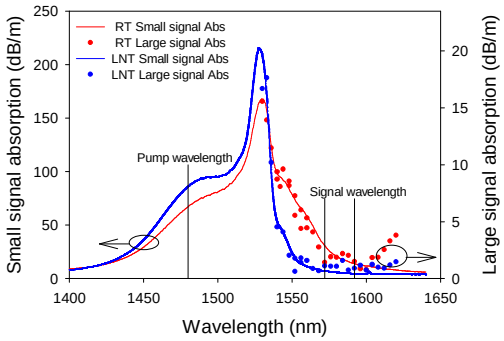

Fig. 2 Small and large signal absorption spectra at different temperatures.

The rich spectroscopy of Er^{3+} offers several possible reasons for these improvements. Figure 2 shows a small-signal and a large-signal absorption spectrum of this fibre at RT and LNT. The small-signal absorption is much lower at LNT than at RT at their respective laser wavelengths, and even though the emission spectrum is also narrower at LNT, the difference between emission and absorption values is larger in LNT. Therefore, fewer Er-ions need to be excited at LNT, which can explain the lower threshold. Furthermore, the narrower LNT linewidths can reduce the propensity for lifetime-shortening upconversion, by reducing the overlap between relevant spectral features [3, 4]. A smaller number of excited Er-ions also reduces the detrimental upconversion.

The difference in slope efficiency may be explained by the large-signal (unsaturable) absorption which, according to Fig. 2, in the LNT case is lower than in the RT case. It must be noted, though, that an offset of 6 and 3 dB/m is subtracted from the RT and LNT unsaturable-loss spectra, respectively. This is not unreasonable, given the large influence of splice loss for the 15 cm long fibre that was used. Still, the good spectral agreement between saturable and unsaturable absorption does add to the confidence in the data. Note that although the higher small-signal pump absorption at LNT suggests that also the unsaturable absorption might be higher for the pump, this is not necessarily a problem, since the ratio of usable (saturable) absorption to unusable (unsaturable) absorption would rather improve at a lower Er excitation, insofar as the small- and large-signal absorption spectral shapes are equal.

In view of the increasing availability of practical cryo-cooling systems, we expect our results to be important for nonlinearly-limited as well as cladding-pumped EDFs, for which a high concentration is important. At LNT, a 7 m length of our fibre would have a core absorption of ~ 1500 dB at 1530 nm. Scaling up our results, the threshold would still be as low as 100 mW of pump power for the same core size, to reach an operating gain of 21 dB. This would be possible in a conventional double-clad geometry with an area ratio of around 100, making cladding-pumping of LNT EDFLs comparable to Yb-doped ones at RT in important respects. Results on cladding-pumping will be reported at the conference.

References

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