High-power broadly tunable Ho^{3+}-doped silica fibre laser

S.D. Jackson and Y. Li

Tuning of the 2.1 μm Ho^{3+}-doped silica fibre laser is demonstrated for the first time. The $^5I_7 \rightarrow {}^5I_8$ transition provides tuning over 144 nm, from 2019 to 2163 nm, and a maximum pump-limited output power of 1.58 W at 2100 nm was produced.

Introduction: The relatively large maximum phonon energy of silica glass reduces the optical transparency and limits the quantum efficiency and number of rare earth ions associated laser transitions. As a result, only a restricted number of silica-based fibre lasers and therefore tunable fibre lasers have been demonstrated. These include lasers operating at wavelengths ~1 μm based on Nd^{3+}, Yb^{3+} and Pr^{3+} dopants [1–3], lasers operating at ~1.5 μm based on Er^{3+} dopant [4] and lasers operating at ~2 μm based on Tm^{3+} dopant [5].

Recently, we have shown that the $^5I_7 \rightarrow {}^5I_8$ laser transition of Ho^{3+} can be pumped efficiently and high power output produced when the free running output from a Yb^{3+}-doped silica is used as the pump source [6]. The high beam quality output obtainable from a high power diode-cladding-pumped Yb^{3+}-doped silica fibre laser allows core pumping of the Ho^{3+}-doped silica fibre, which provides the conditions for low threshold and high slope efficiency operation. In an extension to this work, we show that more than 144 nm of tuning is possible on the $^5I_7 \rightarrow {}^5I_8$ laser transition of Ho^{3+} when it is doped into aluminosilicate glass. The current tunable fibre laser demonstration represents, perhaps, the last broadly tunable fibre laser that uses silica glass as the host medium.

Experiment: The Ho^{3+}-doped silica fibre had a Ho^{3+} concentration of ~0.5 wt.% (4×10^{25} m^{-3}), a core diameter of 8.8 μm, a numerical aperture (NA) of 0.17 and therefore provided a modal cut off wavelength of ~1950 nm. The background loss at 1330 nm was 4.6 dB/km. The diode-pumped Yb^{3+}-doped silica fibre laser was an in-house built system. The single-transverse-mode output from the Yb^{3+}-doped silica fibre laser was collimated and focused using a pair of microscope objective lenses; see experimental setup shown in Fig. 1. The focused pump light was steered onto the Ho^{3+}-doped fibre with the use of a 45° dichroic mirror, which was highly reflecting at 1100 nm and highly transmitting at 2100 nm. The output end of the Ho^{3+}-doped silica fibre was cleaved perpendicularly in order to utilise Fresnel reflection for feedback and the distal cleaved at an angle of 10° in order to prevent feedback. The light from the distal end was collimated with an objective lens (~82% transmitting at 2100 nm) and, commensurate with standard arrangements [7], a ruled diffraction grating (300 lines/mm) was used as the tuning element. The wavelength of the fibre laser output was measured using a thermo-electrically-cooled InAs photodiode in conjunction with a lock-in amplifier and a manually controlled monochromator.

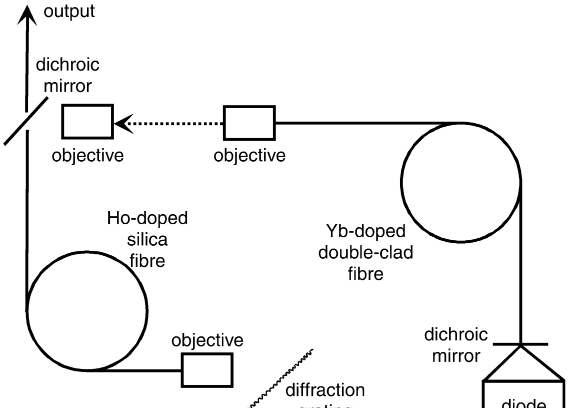

Fig. 1 *Schematic diagram of experimental setup*

Result: The output power measured against wavelength is shown in Fig. 2. The tuning range is observed to extend from 2019 to 2163 nm, i.e. over 144 nm of wavelength tuning was carried out. Over a 43 nm bandwidth, i.e. from 2075 to 2118 nm, more than 1 W was generated and, at the central wavelength of 2100 nm, a maximum output power of 1.58 W was produced (see output power characteristic shown in Fig. 3). The bandwidth of the output was <2 nm. We note that the slope efficiency was 41% and the threshold was ~2.7 W, the latter parameter being somewhat higher than that measured in a previous arrangement [6] because of the loss introduced by the intracavity lens and the lower than 99% reflectivity of the grating in the present setup.

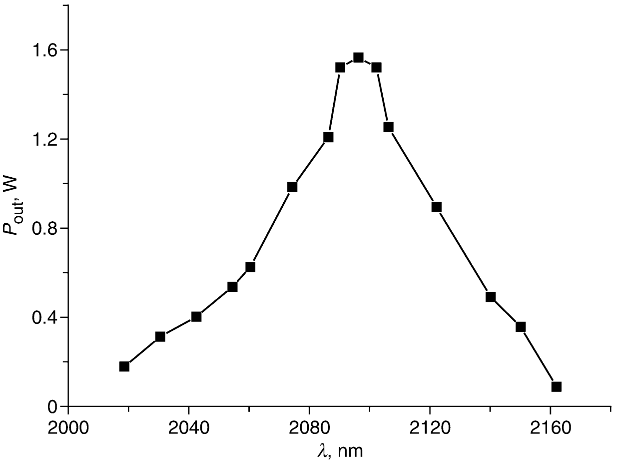

Fig. 2 *Measured output power from Ho^{3+}-doped silica fibre laser against wavelength*

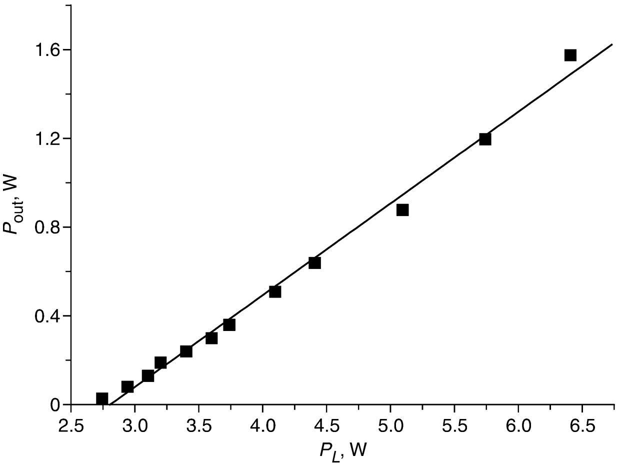

Fig. 3 *Measured output power from Ho^{3+}-doped silica fibre laser against launched pump power when fibre laser operating at 2100 nm*

Discussion: Since the first demonstration of a Ho^{3+}-doped silica fibre laser some time ago [8], there has been very little progress aimed at the further development of this laser. The $^5I_7 \rightarrow {}^5I_8$ laser transition of Ho^{3+} represents perhaps the last exploitable laser transition that is capable of both high power and high efficiency in a silica host. The slope efficiency measured in the current experiment is higher than the slope efficiency measured recently [6] and may indicate an improvement in the quality of the fibre. The tuning range indicates that the $^5I_8$ energy level of Ho^{3+} is Stark split to approximately 330 cm^{-1} which is similar to the $^5I_8$ energy level Stark splitting when Ho^{3+} is doped into $BaYb_2F_8$ crystals [9] but smaller than the Stark splitting relevant to the $^5I_8$ level when Ho^{3+} is doped into YAG [10]. It is clear from the current results, however, that further tuning may be possible on scaling the pump power.

Conclusion: We have produced a broadly tunable Ho^{3+}-doped silica fibre laser that can be tuned over 144 nm and which is capable of high efficiency and high power. The Ho^{3+}-doped silica fibre laser represents conceivably the last high power and tunable fibre laser system that uses silica glass as a host material.

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References

1 Reekie, L., Mears, R.J., Poole, S.B., and Payne, D.N.: 'Tunable single-mode fiber lasers', *J. Lightwave Technol.*, 1986, **4**, pp. 956–960

2 Hanna, D.C., Percival, R.M., Perry, I.R., Smart, R.G., Suni, P.J., and Tropper, A.C.: 'An ytterbium-doped monomode fibre laser: broadly tunable operation from 1.010 μm to 1.162 μm and three-level operation at 974 nm', *J. Mod. Opt.*, 1990, **37**, pp. 517–525

3 Shi, Y., Poulsen, C.V., Sejka, M., Ibsen, M., and Poulsen, O.: 'Tunable Pr^{3+}-doped silica-based fibre laser', *Electron. Lett.*, 1993, **29**, pp. 1426–1427

4 Mears, R.J., Reekie, L., Poole, S.B., and Payne, D.N.: 'Low-threshold tunable CW and Q-switched fibre laser operating at 1.55 μm', *Electron. Lett.*, 1986, **22**, pp. 159–160

5 Hanna, D.C., Percival, R.M., Smart, R.G., and Tropper, A.C.: 'Efficient and tunable operation of a Tm-doped fibre laser', *Opt. Comm.*, 1990, **75**, pp. 283–286

6 Jackson, S.D.: '2.7 W Ho^{3+}-doped silica fibre laser pumped at 1100 nm and operating at 2.1 μm', *Appl. Phys. B*, 2003, **76**, pp. 793–795

7 Wyatt, R.: 'High-power broadly tunable erbium-doped silica fibre laser', *Electron. Lett.*, 1989, **25**, pp. 1498–1499

8 Hanna, D.C., Percival, R.M., Smart, R.G., Townsend, J.E., and Tropper, A.C.: 'Continuous-wave oscillation of holmium-doped silica fibre laser', *Electron. Lett.*, 1989, **25**, pp. 593–594

9 Gilliland, G.D., Powell, R.C., and Esterowitz, L.: 'Spectral and up-conversion dynamics and their relationship to the laser properties of $BaYb_2F_8$: Ho^{3+}', *Phys. Rev. B*, 1988, **38**, pp. 9958–9973

10 Gruber, J.B., Hills, M.E., Seltzer, M.D., Stevens, S.B., Morrison, C.A., Turner, G.A., and Kokta, M.R.: 'Energy levels and crystal quantum states of trivalent holmium in yttrium aluminum garnet', *J. Appl. Phys.*, 1991, **69**, pp. 8183–8204