EFFICIENT OPERATION OF AN Yb-SENSITISED Er FIBRE LASER AT 1·56 μm

Indexing terms: Lasers and laser applications, Optical fibres, Optical properties of substances, Doping

We report operation of a high-efficiency Yb : Er single-mode fibre laser. Pumping at wavelengths of 1064 nm and at 820 nm has shown low pump power thresholds (< 7 and 4 mW) and high slope efficiencies (4·2 and 7·0%).

Introduction: Erbium-doped glass has long been recognised as an important laser material, particularly for applications in optical fibre communications. The 1·5 μm transition is well matched to the so-called third transmission window in silica-based communications fibres and erbium-based systems are consequently of great interest both as sources and inline amplifiers. Despite its potential usefulness, one drawback of the Er laser is its lack of absorption bands where low cost pump sources, e.g. semiconductor laser diodes or diode-pumped Nd : YAG lasers, emit. Furthermore Er is known to have strong excited-state absorption (ESA) which constrains the choice of useful pump wavelengths.

One way around these problems is to use glass which is codoped, or sensitised, with materials which absorb in desirable spectral bands. Optically pumping a suitable codopant can lead to efficient transfer of excitation to the laser active material. Very early on ytterbium was shown[1] to be a suitable sensitiser for Er, giving efficient energy transfer. Recently operation of the first Yb : Er fibre laser has been reported.[2]

We describe here the operating characteristics of an Yb : Er fibre laser which has produced significant output powers and a high slope efficiency and which can be pumped either at the Nd : YAG wavelength of 1·064 μm (as demonstrated in bulk glass)[3] or at wavelengths and with powers available from commercial laser diodes emitting in the 820–850 nm region.

Details of the energy transfer behaviour in the Yb : Er fibre used in our experiments will be described elsewhere* and only a summary will be provided here. Because of the significant inhomogeneous line broadening in glass and because several levels of the Yb ground state multiplet $^2F_{7/2}$ are thermally populated at room temperature, both Nd : YAG and semiconductor diode lasers can efficiently pump into the Yb $^2F_{5/2}$ doublet, whose lower level has a 0·75 ms intrinsic radiative lifetime.

From the $^2F_{5/2}$ state energy is transferred by multipole interactions to nearby Er ions resulting in population of the $^4I_{11/2}$ level. A fast nonradiative decay from this level prevents significant back-transfer of energy to the Yb and leads to population trapping in the long-lived (14 ms) $^4I_{13/2}$ level. Lasing action subsequently takes place between this level and the ground state manifold $^4I_{15/2}$.

Experimental details: The probability of energy transfer between ions decays rapidly with ion separation. Efficient transfer consequently requires high doping levels. Recent developments of the solution doping technique[4] have made possible the production of low scattering loss, cluster-free fibres with dopant concentrations of several percent. The host glass used in our fibre was silica based with doping levels of 5 mole percent Al_2O_3 (to enhance the solubility of rare-earth ions) and 5 mole percent P_2O_5 and had Yb and Er concentrations of approximately 1·7% and 0·080%, respectively (21 : 1 ratio). The fibre had an NA of 0·25 and a core radius of 2·3 μm. The cutoff wavelength was designed to be 1·5 μm to ensure single-mode operation of the Er laser and a good launch efficiency of the pump light.

A Spectra-Physics CW Nd : YAG laser or a Coherent argon-ion pumped Styryl 9M dye laser provided the pump light. The latter could be tuned with significant power (> 100 mW) over the wavelength range 800–850 nm, thus stimulating the performance of a diode laser. A microscope objective focused the pump light into the fibre and mirrors were butted to both fibre ends to form a low-loss cavity. The input mirror had a reflectivity of 98% at the lasing wavelength and was highly transmitting at the pump. Output couplers with 1·5 μm transmissions of 10% and 27% were used. These had reflectivities of 10% at the pump wavelength.

Since Er operates essentially as a three-level laser, end-pumped fibre laser performance depends strongly on the fibre length. The optimum fibre length can be found by cutting back a long length of fibre while monitoring the laser performance in terms of threshold pump power, slope efficiency and lasing wavelength. When pumping at 1·064 μm, a length of ~1 m showed a good compromise between minimum threshold power and maximum output power. This length corresponds roughly to one absorption length at the pump wavelength. Small fibre length variations do not significantly alter the lasing characteristics. Larger variations increase the pump threshold and lead to a shift in lasing wavelength. This

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shift, from 1·568 μm at 2·8 m to 1·549 μm at 25 cm, results from preferential lasing to lower levels in the Er ground state multiplet.[5]

Laser performance with 1·064 μm pumping was evaluated using a 91 cm length (27% output coupling) and an 84 cm length (7% output coupling) of fibre. The absorbed (launched) power at threshold was found to be 8·0 (16) mW and 6·6 (12) mW for the two cases and slope efficiencies, measured with respect to absorbed (launched) power, were found to be 4·2% (2·0) and 2·8% (1·5), respectively. Fig. 1 shows plots of the output power against launched power for the two output couplers. It is evident that the amount of output coupling is

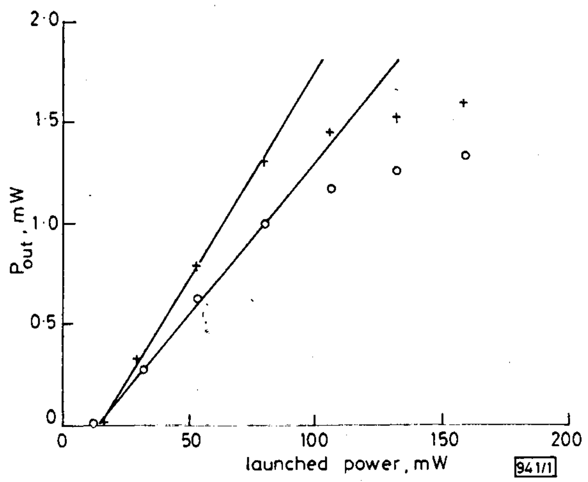

Fig. 1 *Output power against launched power for output mirror transmissions of 27% (+) and 7% (○) when pumped at 1064 nm*

not very critical. The saturation seen at high pump powers is believed to be due to pump saturation of the Yb ions. Higher output powers than those shown can be achieved with higher Yb concentrations or simply by using longer fibre lengths.

Pumping a 70 cm length of the same fibre with the dye laser also showed a low threshold. With a 99% reflector as the input mirror and a 27% transmitting output coupler the threshold with 820 nm pumping was found to be 3·7 mW and a slope efficiency (absorbed power) of 7·0% was measured. More detailed results from the dye laser experiments will be published separately.

Discussion: The results described are significant in a number of ways. First, it has been shown that efficiency energy transfer lasers can be made in fibre form using doping levels of only 1–2%. The only previous mention[2] of such a laser had a significantly lower (0·7%) slope efficiency and produced only small amounts of power (100 μW) using a higher ion doping level (4% Yb). We note that ESA has not strongly impeded the laser performance. Further investigations are aimed at studying the influence of pump-induced ESA. This can conveniently be done using the dye laser since ESA peaks have been identified in its wavelength range at 800 and 840 nm.[6]

Secondly, the Yb : Er system is not unique and many other sensitisation schemes are possible. This opens up new possibilities for fabrication of fibre lasers and amplifiers which can be pumped by convenient and inexpensive sources. As shown here the pump powers required for operation are small enough to be well within the reach of mini-YAGs or diode lasers.

Finally we note that significantly higher output powers for a given pump power can be achieved by feeding the unabsorbed pump light into the output end of the fibre; this is simply a matter of appropriate mirror design. The slope efficiency with respect to launched power can then approach the value calculated with respect to absorbed power.

Acknowledgments: We are grateful to R. M. Percival, I. R. Perry and R. G. Smart for assistance in performing some of the experiments. We thank E. Tarbox of Pirelli General plc for assistance in the development of the fibre design. Funding for this work was provided by the UK SERC, part of the support being provided by JOERS.

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