DIODE-LASER-PUMPED Nd^{3+}-DOPED FIBRE LASER OPERATING AT 938 nm

Indexing terms: Optical communications, Fibre lasers

We report the efficient diode-laser-pumped operation of an Nd^{3+}-doped single-mode fibre laser at 938 nm on the three-level transition $^4F_{3/2}$–$^4I_{9/2}$. An output power in excess of 3 mW has been obtained with a threshold of 1·9 mW.

The rare-earth-doped single-mode fibre laser has been shown to be a versatile source of laser radiation in the near-infra-red region of the spectrum. CW,[1] tunable,[2] Q-switched[3,4] and bistable operation[5] have all been demonstrated. Efficient operation using a diode laser as a pump source[3] and low-threshold CW operation of three-level transitions[6,7] is also possible. In this letter we report the efficient operation of a diode-laser-pumped Nd^{3+}-doped single-mode fibre laser operating on the three-level $^4F_{3/2}$–$^4I_{9/2}$ transition at 938 nm.

To reach laser threshold using a three-level system, it is necessary to saturate the absorption at the lasing wavelength. This is easily achieved in a single-mode fibre laser[6] owing to the small mode size and consequent high pump light intensity which can be obtained with input powers of only a few milliwatts. Room-temperature CW oscillation on the $^4F_{3/2}$–$^4I_{9/2}$ transition has been reported previously using an Nd^{3+}-doped single-mode fibre laser pumped by a CW Rh6G dye laser.[8]

Miniature Nd : YAG lasers operating at 946 nm have also been reported, pumped either by an Rh6G dye laser[9] or an AlGaAs diode laser.[10] However, careful cavity design of the Nd : YAG laser was required to minimise the intracavity losses and mode volume. In addition, it was found necessary to chop the pump beam to minimise thermal effects which would lead to increased lower-level population and hence higher threshold. The small guided mode volume and lack of thermal effects make these precautions unnecessary with single-mode fibre lasers. It should also be noted that the broad absorption width of the 800 nm pump band greatly relaxes the required wavelength tolerance on the diode laser, especially when pumping a three-level laser.

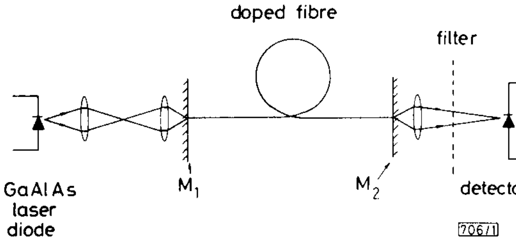

Fig. 1 *Experimental configuration for a diode-laser-pumped, single-mode fibre laser*

The experimental configuration is shown in Fig. 1. The experiment was carried out using a Sharp LT015 AlGaAs laser diode operating at 823 nm. The fibre used in this experiment had an Nd^{3+}-ion concentration of 1200 parts in 10^6, a core diameter of 3·4 μm and a cutoff wavelength of 920 nm. The equivalent step index NA of the fibre was 0·21. The fibre attenuation at 1·1 μm was a remarkable 1·7 dB/km (Fig. 2), despite an absorption of 7·8 dB/m at the pump wavelength of 823 nm. The input mirror (M_1) had high transmission ($T = 85\%$) at the pump wavelength and high reflectivity ($R > 99\%$) at 938 nm, the lasing wavelength. In addition, the input mirror reflectivity was low ($R = 3\%$) at 1·09 μm to suppress the build-up of amplified spontaneous emission and possible lasing on the more common $^4F_{3/2}$–$^4I_{11/2}$ four-level transition. The output mirror (M_2) had a reflectivity of 57% at 938 nm and 40% at 1·09 μm. No attempt was made to optimise the output coupling. The launch efficiency of the pump light into the fibre was limited to 27% by the relatively high numerical aperture of the fibre.

Owing to the three-level nature of the transition, it was necessary to avoid leaving an unsaturated region near the end of the fibre which would lead to unwanted residual absorption

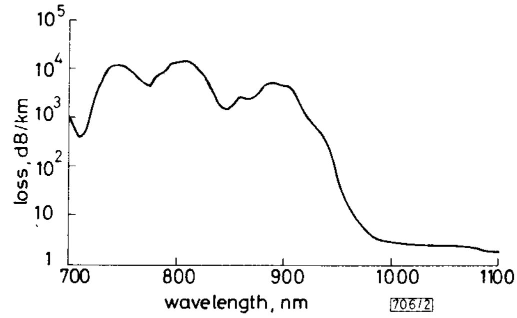

Fig. 2 *Attenuation plot of Nd^{3+}-doped fibre used in experiment*

of the 938 nm emission. The fibre was cut back from an original length of several metres to find the optimum length. The lowest observed threshold was achieved for a fibre length of 110 cm, pump light absorption for this length being 86%. Shorter lengths of fibre in the cavity led to increased threshold due to insufficient pump absorption. The CW lasing characteristic obtained is shown in Fig. 3. A laser threshold of 1·9 mW absorbed pump power was obtained and the slope efficiency was 36%. The maximum output power was limited to approximate 3 mW by the low launch efficiency of the pump light into the fibre. With increased launch efficiency and better matching of the pump laser wavelength to the peak of the absorption curve, submilliwatt thresholds and output powers in excess of 5 mW should be achievable. It should be noted, moreover, that the performance of the laser is similar to that of the same device operated at 1·09 μm, which is remarkable considering the three-level nature of the transition.

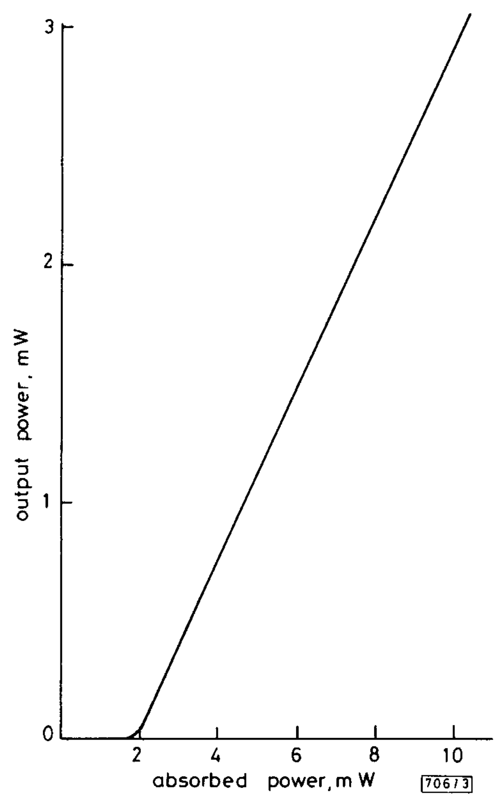

Fig. 3 *Lasing characteristic of fibre laser operating at 938 nm*

In conclusion, efficient diode-laser-pumped operation of an Nd^{3+}-doped single-mode fibre laser has been obtained at 938 nm. A low threshold of 1·9 mW was obtained with an output power of 3 mW and slope efficiency of 36%. Optimisation of the output coupling and matching of the pump wavelength to the peak of the Nd^{3+}-ion absorption should result in submilliwatt thresholds. Although not reported yet, tunable and Q-switched operation of this device is also possible.

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