Mode-locking and Q-switching of a neodymium-doped monomode fibre laser

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Abstract

A cw Nd-doped monomode fibre laser has been actively mode-locked and Q-switched at 1.08 μm and 0.906 μm. Subnanosecond mode-locked pulses of ∿20 pJ and Q-switched pulses of 200 nsec and ∿10W peak power are observed at 1.08 μm.

There has been much recent interest in laser systems using as the gain medium rare earth-doped optical fibres which only support a single waveguide mode at the lasing wavelength[1-8]. The small diameter of the active region, i.e. the fibre core, combined with longitudinal pumping by a laser allows the achievement of low thresholds, high conversion efficiencies[5] and high gain. The small core diameter also eliminates the thermal distortion and thermal birefringence problems that plague bulk glass systems. As an illustration of these benefits of a fibre laser, we note that cw operation has been achieved, with low threshold, even for three-level laser schemes. Thus Er doped fibre, operating at 1.55 μm, ($^4I_{13/2}$ - $^4I_{15/2}$) has been operated as a cw laser[4] and cw operation of a Nd-doped fibre has been achieved[7] on the $^4F_{3/2}$ - $^4I_{9/2}$ transition at ∿0.9 μm. Neither of these transitions has been operated at room temperature in a bulk glass laser with continuous wave output.

A typical configuration for the fibre laser cavity involves a high reflectivity mirror butted against the cleaved fibre end with the pump laser beam launched into the fibre through this reflector using a x10 microscope objective. Pumping has been achieved with an argonion laser, a cw Rhodamine 6G laser and a cw GaAs laser. An intra-cavity microscope objective produces a collimated beam at the output coupler. Acousto-optic devices for loss modulation and tuning elements are introduced in the collimated beam region. The output beam is TEM_{00} by virtue of the monomode propagation enforced by the fibre.

The rare earth transitions have large inhomogeneous linewidths in the glass host and so allow these lasers to be tuned over ranges comparable to those achieved with dye lasers. For example on the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition in a Nd-doped fibre, tuning over the range 1.07 - 1.14 μm has been achieved using a grating as the tuning element[8] and a similar range has also been covered using a birefringent filter[9]. Tuning on the $^4F_{3/2}$ - $^4I_{9/2}$ transition using a birefringent filter covered the range 0.90 - 0.945 μm[9]. Efficiencies reported by Alcock et al[9], where a cw Rhodamine 6G dye laser was used as pump, were ∿6% and did not decrease as a result of the line narrowing (down to 0.06 nm) produced by the birefringent filter, despite the inhomogeneous broadening of the laser transition. It is anticipated that further narrowing, to single frequency operation, should not entail any significant reduction in efficiency. More recently we have seen better efficiencies, ∿30% slope efficiency with dye pumping and ∿50% slope efficiency with diode laser pumping (see also Jauncey et al[5], where 33% slope efficiency is reported using a diode laser pump).

The long lifetime of the ions in the upper laser level (∿470 μsec for Nd and 14 msec for Er)[10] makes these fibre lasers eminently suitable for Q-switching, an advantage that these lasers have over dye lasers. Q-switching has been achieved, either with a simple mechanical chopper, or with an acousto-optic Q-switch[3], in each case inserted into the collimated beam region in the fibre laser resonator. With the latter, a peak power of ∿10w, in a 200 nsec pulse has been achieved at ∿1.08 μm from a Nd doped fibre[3] and similar power but with rather shorter pulses, ∿75 nsec at 0.9 μm on the $^4F_{3/2}$ - $^4I_{9/2}$ transition of Nd. Mode locking has also been demonstrated, using an acousto-optic modulator[6]. Mode locked pulsed durations down to 450 ps have so far been achieved, with energies of ∿20 pJ in an individual mode locked pulse. Both cw mode locking and Q-switched mode locked operation have been observed[6]. The pulse duration of 450 psec is significantly longer than predicted and it is believed that the duration is at present limited by frequency selection arising from etalon effects in the resonator. It is expected that pulse durations of a few picoseconds duration will ultimately be achieved from such fibre lasers.

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