SAMARIUM^{3+}-DOPED GLASS LASER OPERATING AT 651 nm

Indexing terms: Optical fibres, Lasers, Doping, Glass

Laser emission has been observed in a samarium^{3+}-doped silica optical fibre in a Fabry–Perot-type laser cavity. The emission is centred on 651 nm and corresponds to stimulated transitions from the $^4G_{5/2}$ level to the $^6H_{9/2}$ level. The fluorescence and absorption associated with the metastable level are seen to be unusually narrow (3 nm FWHM) for a trivalent rare earth in a disordered glass structure. The laser has operated in CW and Q-switched modes when pumped with 488 nm light at room temperature.

Introduction: Since the development of rare-earth-doped glass lasers in 1961 by Snitzer[1] a number of glass materials have produced laser emission at a range of wavelengths, the most thoroughly investigated being the 1064 nm transition in Nd : glass. However, up to now, only one tentative report exists of emission in the visible region of the spectrum, this was using terbium-doped glass.[2] We report here continuous-wave (CW) laser emission from a samarium^{3+}-doped silica fibre laser on a transition hitherto unreported in any material. Prior to this work, laser emission has only been observed from samarium^{3+} in a crystalline host.[3] In that case the emission was at a different wavelength (593 nm) and required cooling to 116 K.

Single-mode fibres provide a useful medium for the examination of samarium-doped silica by virtue of the strong confinement of the pump light. This characteristic enables significant gain to be achieved for relatively small amounts of pump input power. In contrast with most other visible lasers, Sm^{3+} in glass has a long fluorescent lifetime and this permits Q-switching.

Optical properties of samarium-doped fibre: A germania-doped silica optical fibre preform was doped with 1000 molar ppm of samarium^{3+} ions using a solution doping process.[4] The preform was characterised by a numerical aperture of 0·18 and was drawn into a fibre with a second-mode cutoff at 620 nm. The fibre loss at 651 nm was measured to be 50 dB/km.

The optical properties of samarium^{3+}-doped silica will be described with reference to the energy level diagram and absorption spectrum shown in Fig. 1. The fibre has a large absorption (1000 dB/km) at the pump wavelength (488 nm) which corresponds to a transition from the $^6H_{5/2}$ ground state to the $^4I_{9/2}$ level. Other wavelengths may be used to pump the laser to levels above the metastable $^4G_{5/2}$ level. It is interesting to note that the absorption band centred at 564 nm, which corresponds to absorption from the ground state directly into the metastable level, has a remarkably narrow linewidth of only 2·2 nm FWHM. This is narrow compared to lines in other more common rare earth dopant materials such as neodymium and erbium (typically > 10 nm). It appears from the symmetrical shape of the absorption line that the transition takes place substantially between just two Stark levels.

When pumped at 488 nm the fluroescence spectrum shows the majority of radiation in the 651 nm band (see Fig. 2). The fluorescence at 651 nm is seen to be only 3 nm wide and appears to take place on a single Stark pair transition. The $1/e$ fluorescence lifetime of the $^4G_{5/2}$ level was measured to be 1·68 ms, although the decay was seen (Fig. 3) to be characteristically nonexponential, indicating an inhomogeneous broadening component in the linewidth. Stimulated emission of 651 nm light occurs between the $^4G_{5/2}$ and $^6H_{9/2}$ levels, which is a four-level transition. Stimulated emission may possibly also occur to the other ^6H levels, although these will be less efficient than the main transition due to the reduced branching ratio components. Samarium^{3+}-doped silica has several characteristics which are advantageous for any laser medium. The long metastable lifetime enables substantial population inversion to be achieved at relatively low amounts of pump input power. This factor, combined with the true four-level nature of the 651 nm transition, should enable very low thresholds to be achieved. The long lifetime also results in good energy storage in the Q-switched mode of operation. The fluorescence spectrum shows most radiation occurring on the 651 nm band, this giving rise to a large stimulated cross-section at 651 nm.

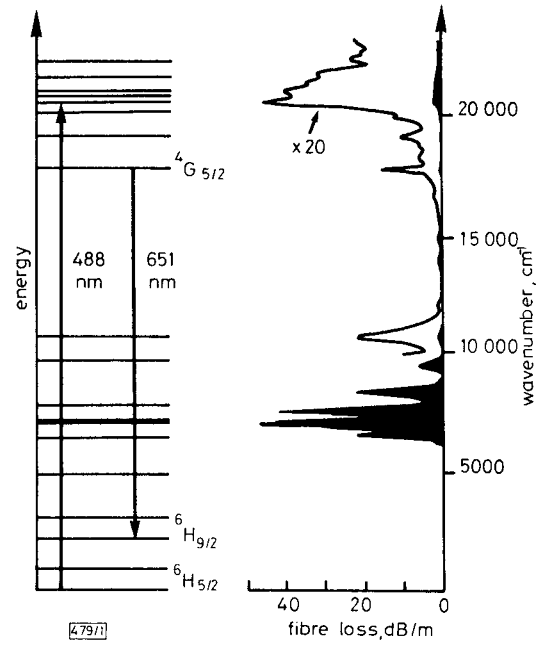

Fig. 1 *Relevant energy levels of Sm^{3+}-doped silica and associated absorption spectrum*

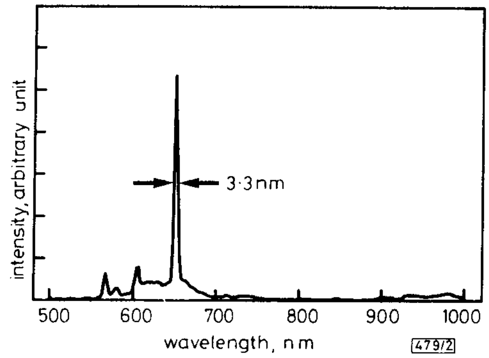

Fig. 2 *Fluorescence spectrum of Sm^{3+}-doped silica when pumped at 488 nm*

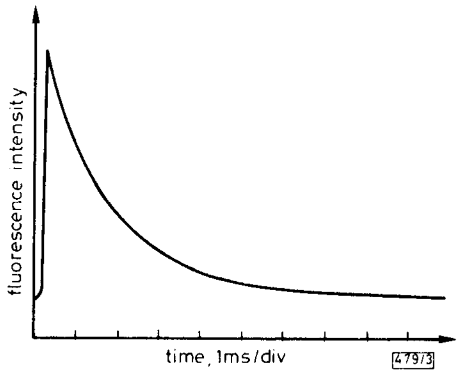

Fig. 3 *Nonexponential fluorescence decay at 651 nm*

Pulsed, pumped at 488 nm

$1/e$ = 1·57 ms; $(1/e) - (1/2e)$ = 1·67 ms; $(1/2e) - (1/3e)$ = 1·78 ms

Characteristics of visible fibre laser: A Fabry–Perot resonator was constructed, consisting of dielectric mirrors butted to the fibre ends. The mirror reflectances at the laser wavelength (651 nm) were 99% and 60%. The input mirror had a transmission of greater than 90% at the pump wavelength (488 nm). Optical pumping is achieved by coupling in up to 1 W of optical power at 488 nm from an argon-ion laser with a

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microscope objective.

The lasing characteristic of this fibre laser is shown in Fig. 4. Lasing thresholds of 20 mW absorbed pump power with a slope efficiency of 12·7% are obtained in this configuration. The threshold has been reduced to 2 mW by increasing the output mirror reflectivity to 93%. The performance of the laser was limited by the fibre loss at the lasing wavelength, which was 1 dB/round-trip.

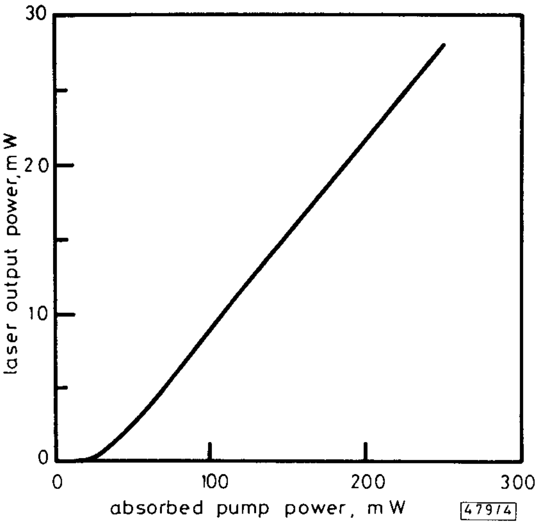

Fig. 4 *Lasing characteristic for 651 nm visible fibre laser*

Pulsed Q-switched operation of the laser is achieved by inserting a lens and a rotating chopper or a Bragg cell into the laser cavity. In this way pulses of peak power 8 W and width 144 ns have been achieved. Peak Q-switched powers are limited by mode competition in the laser, the long (4 m) cavity length and the switching time of the modulator. However, it is anticipated that improvements to the Q-switching will produce a useful high-power visible pulsed laser source.

Conclusions: Samarium^{3+} in silica glass is particularly interesting because the linewidths of absorption to and fluorescence from the $^4G_{5/2}$ level are much narrower than seen in other rare-earth-doped glasses. This appears partly to be due to the $^4G_{5/2}$ level having only one Stark component.

Examination of the fluorescence decay under pulsed pumping suggests the residual line has an inhomogeneous component.

We have demonstrated laser action in samarium-doped silica optical fibres. We believe this to be the first report of laser action in a samarium^{3+}-doped glass. In addition, to our knowledge laser emission due to the $^4G_{5/2}$ to $^6H_{9/2}$ transition in samarium^{3+} has not been observed in any material prior to this work. Samarium^{3+}-doped silica fibre lasers are expected to provide a useful source of high-power pulsed red laser light.

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