ERBIUM DOPED FLUOROZIRCONATE FIBRE LASER OPERATING AT 1·66 AND 1·72 μm

Indexing terms: Optical fibres, Doping, Lasers and laser applications

Pulsed laser emission at 1·66 and 1·72 μm has been observed in a multimode fluorozirconate fibre doped with erbium under excitation at 514 nm. The threshold absorbed pump power for laser oscillation was measured as 90 mW.

Introduction: The doping of rate-earth ions in the core of optical fibres has become an established technique for obtaining efficient, low threshold active devices. The use of a fluorozirconate host instead of a silica host is attractive as the low phonon energies of the fluorozirconate glass reduce the non-radiative decay rates. This results in much higher radiative quantum efficiencies for transitions between closely spaced energy levels and laser action may be observed for many more transitions in the fluoride host. In erbium doped fluorozirconate fibres laser emission has already been reported at 850 nm, 988 nm, 1·56 μm and 2·7 μm (CW).[1–3] For silica laser emission has only been observed at 1·55 μm. We report an erbium doped fluorozirconate fibre laser pumped at 514 nm and operating at 1·66 and 1·72 μm at room temperature and at 1·60, 1·66, 1·68 and 1·72 μm when cooled to 77 K. The observation of laser action between 1·66 μm and 1·72 μm is interesting as this wavelength region is not currently served by fibre lasers, falling between the ranges presently covered by Er^{3+}-doped and Tm^{3+}-doped silica fibre lasers.[4,5]

Experimental: The fibre used was a ZBLANP fibre with a 40 μm diameter core doped with 977 ppm of Er^{3+} ions. Pump light at 514 nm (corresponding to absorption from the $^4I_{15/2}$ ground state to $^2H_{11/2}$ excited state as shown in Fig. 1) from a

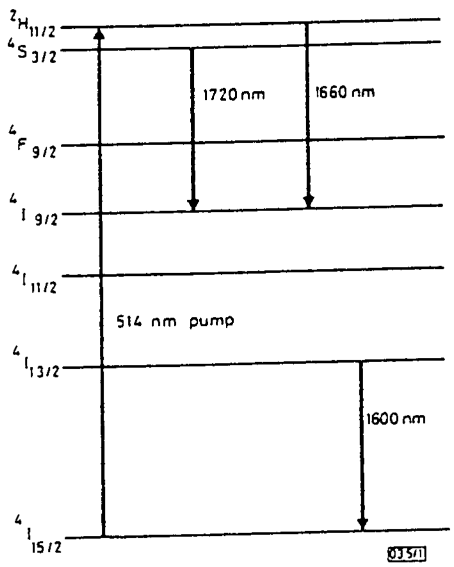

Fig. 1 *Partial energy level diagram*
Er^{3+} doped ZBLANP fibre

CW argon ion laser was mechanically chopped and launched into the fibre with a ×5 microscope objective. As noted by Brierley *et al.*,[2] about 20 separate fluorescence transitions are apparent. A partial fluorescence spectrum under excitation at 514 nm is shown in Fig. 2. Three peaks at 1·56, 1·66 and 1·72 μm are evident corresponding to emission from the $^4I_{13/2}$–$^4I_{15/2}$, $^2H_{11/2}$–$^4I_{9/2}$ and $^4S_{3/2}$–$^4I_{9/2}$ levels, respectively. This spectrum is for light which has been guided down a 40 cm length of fibre and is distorted by reabsorption of short wavelength emission from the $^4I_{13/2}$ to $^4I_{15/2}$ transition. In sidelight fluorescence, the 1·56 μm peak obscures the other peaks. Fluorescence decay measurements have shown the 1·66 μm and 1·72 μm emission to have an exponential decay with a 1/e decay time of approximately 500 μs. The lifetime of the $^4I_{9/2}$ level was found to be about 1 ms by observing the decay of the fluorescence at 784 nm which is caused by decay from this level to the ground state. Laser action between the $^4S_{3/2}$ and $^4I_{9/2}$ can be expected to be self-terminating as the lower level has a longer lifetime than the upper level.

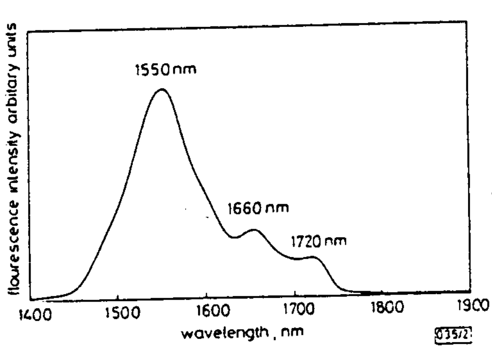

Fig. 2 *Partial fluorescence spectrum*
Er^{3+} doped ZBLANP fibre
Excitation at 514 nm

To investigate laser performance a 40 cm length of fibre with cleaved ends was butted between two mirrors (both >99% reflective from 1·65 to 2·1 μm and 85% transmissive at 514 nm) to form a Fabry–Perot cavity. Liquid paraffin was used as an index matching fluid to improve the quality of the butt. Laser action at 1·72 μm occurred with a threshold pump power of 200 mW incident on the launch optics (corresponding to 150 mW launched and 90 mW absorbed). This transition is from the $^4S_{3/2}$ level to the $^4I_{9/2}$ level and is self terminating. Lasing at 1·66 μm has also been obtained both with and without laser action at 1·72 μm (at a similar threshold to the 1·72 μm operation) and is caused by a transition from the $^2H_{11/2}$ level to the same $^4I_{9/2}$ lower laser level and thus is also self terminating. We suggest that the two upper laser levels ($^2H_{11/2}$ and $^4S_{3/2}$) are in thermal equilibrium. Since there are no wavelength selective elements within the cavity neither transition is favoured over the other at room temperature. The pulsed nature of the 1·66 μm transition is evident in Fig. 3. Pulsed laser emission at 1·72 μm has also been obtained with pumping at 488 nm with a similar threshold to that for 514 nm excitation.

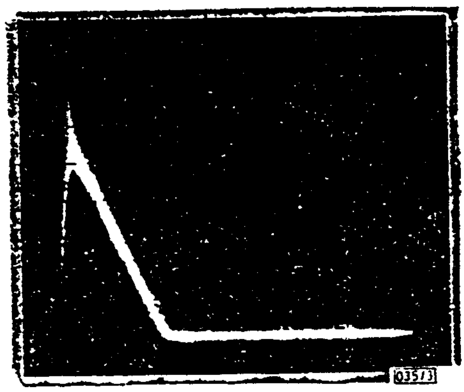

Fig. 3 *Fibre laser emission at 1·72 μm*
Full time scale is 10 ms

By cooling half the length of the fibre in liquid nitrogen to 77 K we were able to obtain laser operation by a cascade process at 1·66, 1·68 and 1·72 μm in pulsed mode and at 1·60 μm continuous wave. The 1·60 μm operation is caused by the long wavelength wing of the three level transition ($^4I_{13/2}$ to $^4I_{15/2}$) at the short wavelength edge of the high reflectivity band of the mirror. The 1·68 μm laser action has the same temporal characteristics as the 1·66 and 1·72 μm operation and we suggest is from the $^2H_{11/2}$ level to another Stark level of $^4I_{9/2}$. The threshold for laser operation on all four wavelengths was about 400 mW incident. The time behaviour of the laser emission from the fibre is shown in Fig. 4. The self

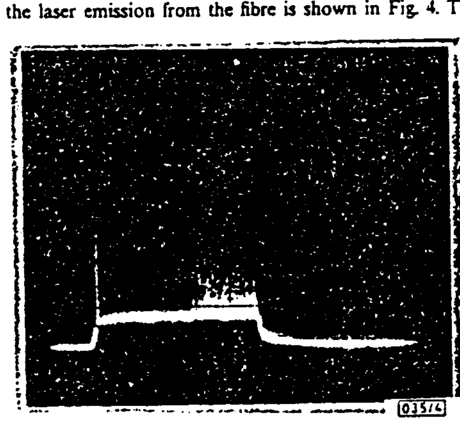

Fig. 4 *Fibre laser emission at 1·66, 1·68 and 1·72 μm and 1·60 μm*
Full time scale in 100 ms

terminating transitions are apparent at the beginning of the pump pulse and are followed by the three level laser operation at 1·60 μm. The time delay between the beginning of the pump pulse and the onset of laser emission at 1·60 μm results from the delay in populating the $^4I_{15/2}$ level by transitions from the long-lived higher levels.

Discussion: We have observed pulsed laser action in an erbium doped fluorozirconate fibre near 1·7 μm using an argon ion laser as the pump source. Interest in a source around this wavelength centres on the possibility of developing a compact sensor for CH_4 gas, exploiting the absorption at around 1·67 μm. Ideally such a device would be pumped by a diode laser. We note that the $^4S_{3/2}$ level can be efficiently populated with the upconversion of pump light at around 800 nm, a wavelength which is readily available from high power AlGaAs diodes. For the fibre used in the experiments described in this letter we note that for an excitation power of 100 mW the efficiency of populating the $^4S_{3/2}$ level with 800 nm light is approximately 20% of that under direct excitation from 514 nm. These figures suggest that for a monomode fibre the threshold power levels for laser operation around 1·7 μm should be available from laser diodes. Clearly it would also be desirable to enforce CW operation rather than pulsed operation. One method of achieving this would be to co-dope with another rare earth ion to increase the decay rate of the long-lived $^4I_{9/2}$ level or using a pump wavelength which causes pump excited state absorption from this level, a technique reported in Reference 1.

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References

1 BRIERLEY, M. C., and FRANCE, P. W.: 'Continuous wave lasing at 2·7 μm in an erbium-doped fluorozirconate fibre', *Electron. Lett.*, 1988, 24, pp. 935–937
2 BRIERLEY, M. C., MILLAR, C. A., and FRANCE, P. W.: 'Laser transitions in erbium doped fluoride fibers'. Technical Digest, Conference on Lasers and Electro-Optics, Baltimore, 1989, Optical Society of America, Washington, D.C., 1989, paper TUJ22
3 ALLAIN, J. Y., MONERIE, M., and POIGNANT, H.: 'Narrow linewidth tunable CW and Q-switched 0·98 μm operation of erbium-doped fluorozirconate fibre laser', *Electron. Lett.*, 1989, 25, pp. 1082–1083
4 SCRIVENER, P. L., TARBOX, E. J., and MATON, P. D.: 'Narrow linewidth tunable operation of Er^{3+}-doped single-mode fibre laser', *Electron. Lett.*, 1989, 25, pp. 549–550
5 HANNA, D. C., PERCIVAL, R. M., SMART, R. G., and TROPPER, A. C.: 'Efficient and tunable operation of a Tm-doped fibre laser', to appear in *Optics Communications*