1360

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Rare-earth doped chalcogenide glass fibre laser

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Abstract

We report on the first laser action in a rare-earth doped chalcogenide glass fibre. Laser action at 1080nm was obtained in a 22mm long gallium lanthanum sulphide glass fibre with a neodymium doped core, fabricated by the rod-in-tube technique. The laser was pumped continuous wave with a Ti:sapphire laser at 815nm and showed a self-pulsing behaviour.

Introduction: To date, laser action in rare-earth doped chalcogenide glasses has only been reported in bulk glass [1]. Chalcogenide bulk glasses, however, do not turn out to be promising candidates for solid-state lasers due to their poor thermal properties. The full advantages of this family of glasses are obtained when pulled into fibre form. Potential applications of rare-earth doped chalcogenide glass fibres are the 1.3μm praseodymium [2] and dysprosium [3] doped fibre amplifiers for telecommunication and fibre lasers emitting in the mid-infrared wavelength region for trace gas detection [4]. These devices are not feasable in standard silica fibre where the transitions of interest are quenched by strong non-radiative multiphonon decay and multiphonon absorption prevents transmission above 2μm. Even fluoride fibres, which allow infrared transmission to about 4μm, exhibit low efficiencies for fluorescence despite their lower phonon energy. Chalcogenide glasses are currently the only alternative having the lowest phonon energy of these three glass families and consequently low non-radiative decay rates and wide infrared transparency.

Our work focusses on the chalcogenide glass gallium lanthanum sulphide (Ga:La:S) in which laser action has been demonstrated in a neodymium doped bulk glass sample [1].

In this Letter we present the experimental results on a neodymium doped Ga:La:S glass fibre. This, to our knowledge, is the first demonstration of a chalcogenide glass fibre laser.

Experiments and results: The Ga:La:S glasses and fibres were prepared using melt quenching and the rod-in-tube technique as reported in reference [5]. The multimode fibre used in the laser experiments had a 14μm core doped with 0.05mol% Nd_2S_3 with an outer diameter of 230μm. Laser action was obtained in fibres with 21mm, 22mm, and 25mm lengths. The results of the 22mm long fibre laser are presented here.

The absorption and emission spectra of neodymium doped Ga:La:S glass can be found in reference [1]. The neodymium ions are pumped at a wavelength of 815nm into the $^2H_{9/2},{}^4F_{5/2}$ levels. The neodymium concentration in the fibre core is 30 times lower than in the bulk laser sample which leads to an absorption length of 21mm at 815nm as compared to 0.7mm in the bulk sample. That means that about 64% of the launched pump power is absorbed in the 22mm long fibre laser. Multiphonon decay from the $^2H_{9/2},{}^4F_{5/2}$ levels populates the upper laser level $^4F_{3/2}$, which has an exponential lifetime of 75μs in the fibre. As with the bulk laser, room temperature laser action was achieved on the $^4F_{3/2}\rightarrow{}^4I_{11/2}$ transition around 1080nm. A typical laser spectrum measured with an ANDO spectrum analyser with a resolution of 0.1nm is shown in Fig. 1.

For the laser experiments the fibre was held in a V-groove with plane mirrors butted to either end using index matching fluid. The input mirror had a high transmission for the pump wavelength at 815nm and a high reflectivity for the laser wavelength at 1080nm. The 815nm Ti:sapphire laser pump beam was focused into the fibre core with a ×20 microscope objective. Three mirrors with different reflectivities were used as output mirrors. Fig. 2 shows the dependence of the measured output power of the fibre laser on the Ti:sapphire pump power incident on the fibre for the three mirrors. The first output coupler (a) had a high reflectivity of 99.5% at the laser wavelength of 1085nm. The lowest laser threshold of about 100mW incident pump power was obtained with this mirror. The second output coupler (b) had a reflectivity of 93% at 1080nm. The threshold increased to about 200mW and a maximum output power of 1.2mW was measured. The reflectivity of the third output coupler (c) increases from 81% at 1085nm to 92% at 1075nm and forced the laser to operate at the shorter wavelength thereby increasing the threshold to about 380mW and the slope efficiency to a maximum value of 0.7%.

The threshold is higher and the slope efficiency and output power are lower in the fibre laser when compared to the Ga:La:S bulk glass laser and conventional neodymium fibre lasers. In the Ga:La:S bulk glass laser, however, the output power saturated and laser action ceased at higher pump powers due to thermal problems of the glass sample. The thermal problems were reduced in the fibre laser due to the waveguiding geometry and the lower doping concentration, and the output power did not show any saturation effects. The fibre laser also showed good long term stability by operating for several hours without deterioration in performance. This implies that pumping close to the intrinsic glass band edge is possible in Ga:La:S glass.

Although pumped continuous wave the fibre laser did not lase continuous wave but showed a self-pulsing behaviour. This effect was not observed in the bulk laser which showed continuous wave laser action [4]. The fibre laser emitted pulses with about 0.2μs width and regular pulse spacings with repetition rates between 2μs and 3.5μs. A typical train of pulses is shown in Fig. 3. The resolution is limited by the InGaAs diode (ca. 0.1μs response time) used to monitor the laser output. The effect of self-pulsing has been observed in rare-earth doped fibre lasers before [6], and the explanation of the occurrence of the self-pulsing in our fibre laser needs further investigation.

Conclusion: In conclusion we have demonstrated the first rare-earth doped chalcogenide glass fibre laser. The neodymium doped Ga:La:S glass fibre was fabricated using the rod-in-tube technique and showed laser action at room temperature at a wavelength of about 1080nm when pumped with a Ti:sapphire laser at 815nm. This result is a significant step towards the realisation of practical devices in this new class of materials, in particular, efficient 1.3μm amplifiers for telecommunication and new fibre lasers operating at mid-infrared wavelengths.

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Figure captions

Fig. 1 Laser spectrum of the neodymium doped Ga:La:S glass fibre laser

Fig. 2 Output power versus incident pump power of the neodymium doped Ga:La:S glass fibre laser for different output mirrors and laser wavelengths

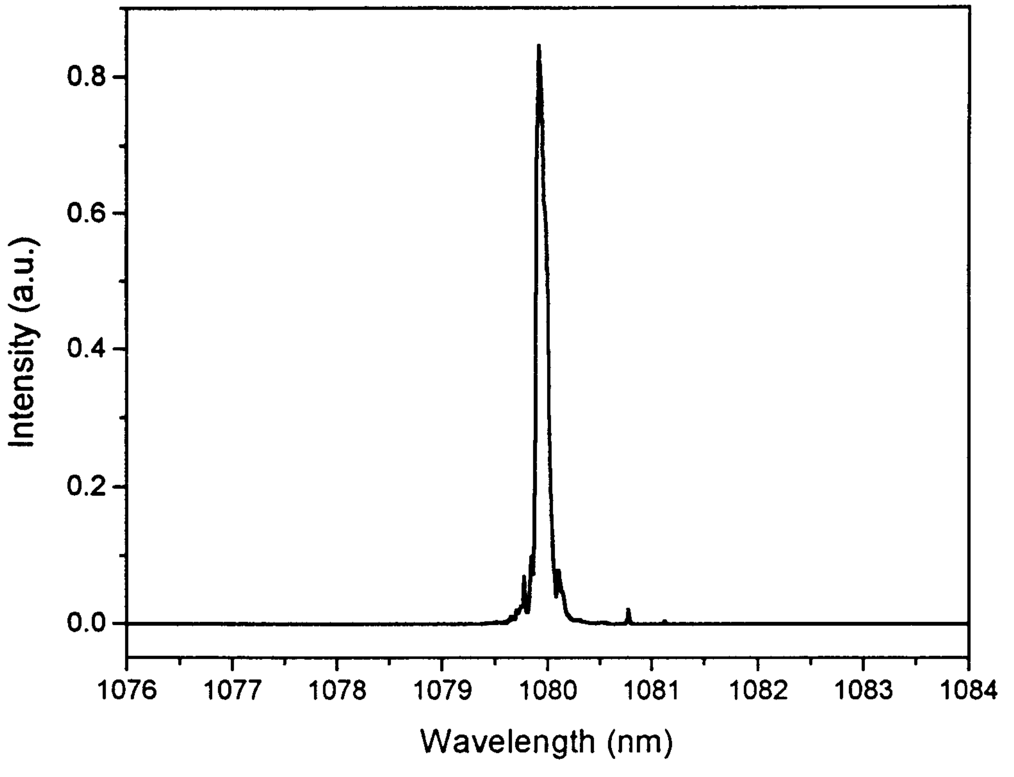
a) 99.5% reflectivity at the laser wavelength of 1085nm

b) 93% reflectivity at the laser wavelength of 1080nm

c) 92% reflectivity at the laser wavelength of 1075nm

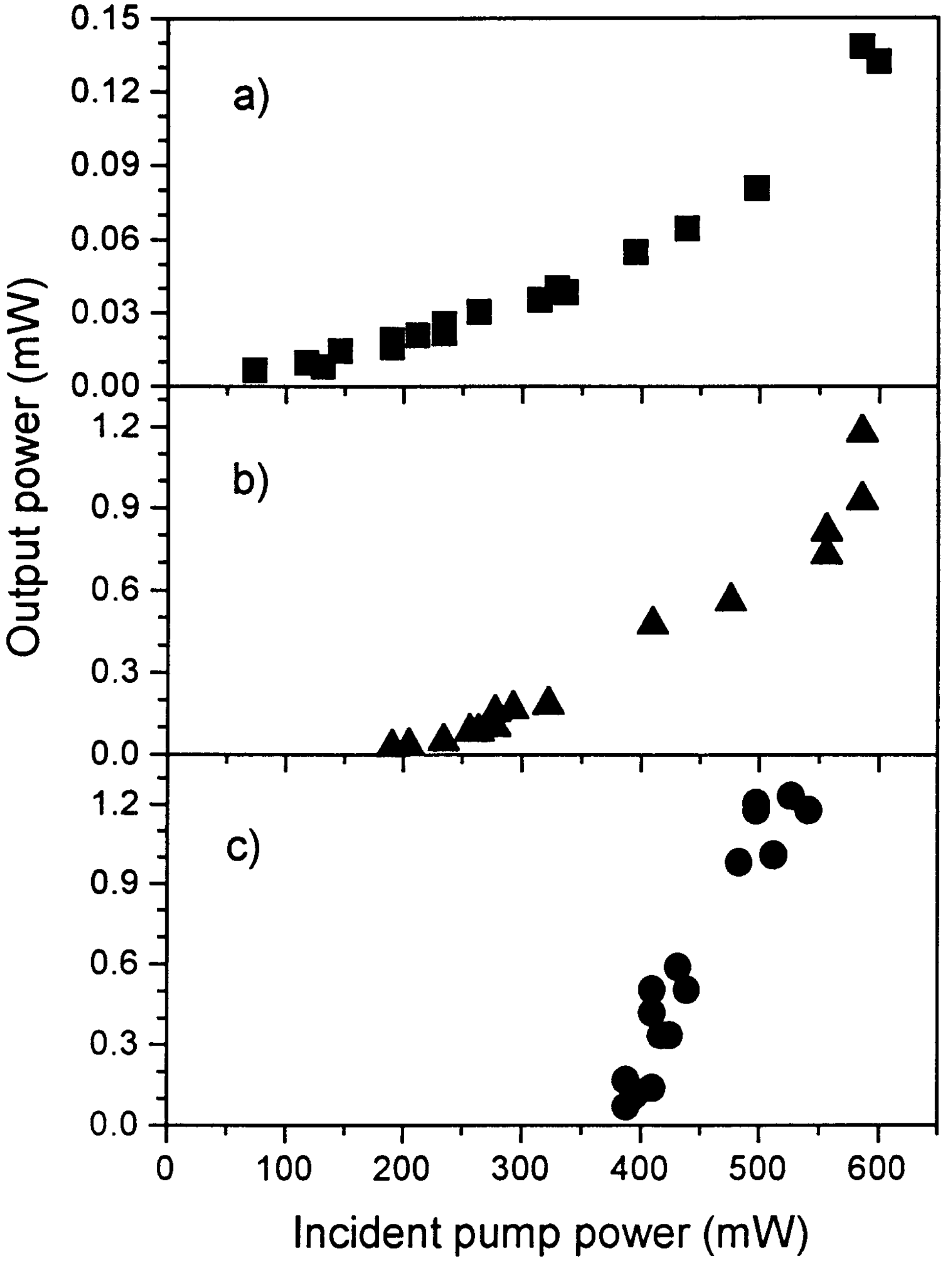
Fig. 3 Temporal behaviour of the output power of the neodymium doped Ga:La:S glass fibre laser

Fig.1



0.8
0.6
0.4
0.2
0.0
Intensity (a.u.)
1076
1077
1078
1079
1080
1081
1082
1083
1084
Wavelength (nm)

Fig. 2



a)
b)
c)
Output power (mW)
Incident pump power (mW)
0.15
0.12
0.09
0.06
0.03
0.00
1.2
0.9
0.6
0.3
0.0
1.2
0.9
0.6
0.3
0.0
0
100
200
300
400
500
600

Fig. 3