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Ion-exchanged Er/Yb waveguide laser at 1.5 μm pumped by a laser diode

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Abstract We demonstrate a diode-pumped, planar Er/Yb waveguide laser. The device was fabricated by thallium exchange in a phosphorus-free silicate glass. Lasing was achieved at 1544 nm with a threshold of 5 mW and a slope efficiency of 2%. The low threshold indicates the absence of the severe backtransfer effects previously reported in Er/Yb bulk laser silicate glasses.

Introduction Diode-pumped Er/Yb waveguide lasers are attractive candidates as compact, low-noise, 1.5 μm sources for optical communications. Efficient operation of these devices has already been demonstrated in fibre form using phosphosilicate glasses [1,2]. From the perspective of planar technology, it is of interest to realise similar devices by ion-exchange. Although this technique can be successfully applied to phosphates [3], silicate glasses have superior chemical resistance and are thus more compatible with this fabrication process, and ion-exchanged silicate glass devices are already being deployed in real systems. Historically, the Er/Yb silicate has been deemed as an inefficient energy transfer system due to the backtransfer problems encountered in the realisation of Er/Yb bulk lasers [4]. These laser glasses, originally pumped at 1060 nm, required pump absorption lengths of about 1 mm and thus had high Yb concentrations. The development of 980 nm laser diodes, together with the waveguide geometry, which allows the pump absorption to be distributed over a few centimetres, have made the use of high Yb concentrations unnecessary. Backtransfer problems may not be as severe at lower Yb concentrations. This point has been proven recently with the first demonstration of a planar Er/Yb waveguide laser [5], where the laser was realised in a silicate glass codoped with 1% Er_2O_3 and 5% Yb_2O_3. In this letter, we report on an improved device having threshold of 5 mW, a slope efficiency of 2%, and up to 1mW of output power under laser diode pumping.

Energy Transfer Measurements The silicate glass used in our work was a borosilicate. To study the energy transfer efficiency of the glass, two glass samples were made; one glass was doped with 1% wt Er_2O_3 (8×10^{19} ions/cm^3) and the other one was codoped with 1% Er_2O_3 and 5% Yb_2O_3 (4×10^{20} ions/cm^3). The 1.5 μm fluorescence intensity was measured by pumping samples of equal volume with the same intensity at 977 nm. The energy transfer efficiency, η, was then calculated as $R/\left(\sigma^{Yb}N_o^{Yb}/\sigma^{Er}N_o^{Er}\right)$, where R is the ratio of the measured 1.5 μm fluorescence intensities, $\sigma^{Er(Yb)}$ is the Er (Yb) absorption cross section at 977 nm, and $N_o^{Er(Yb)}$ is the Er (Yb) concentration. The pump absorption cross sections were obtained from spectral transmission measurements performed on the samples with knowledge of the Er and Yb concentrations. From these measurements, we calculated $\sigma^{Yb} = 56 \times 10^{-22}$ cm^2 and $\sigma^{Er} = 6.6 \times 10^{-22}$ cm^2 at 977 nm. Under weak excitation, the fluorescence intensity measurements yielded $\eta = 45$ % for our glasses. Since $\sigma^{Yb}/\sigma^{Er} = 8.4$ at 977 nm, the results showed that the addition of 5% Yb_2O_3 to this glass enhanced the effective erbium small-signal absorption at 977 nm by a factor of 19.

Laser Characteristics Buried waveguides were fabricated in our Er/Yb codoped borosilicate glass by thallium-ion exchange. The resulting waveguide was 2 cm long and had mode dimensions ($1/e^2$ intensity) of 7.1 x 5.4 μm^2 at 1550 nm with a cutoff wavelength of 1580 nm. The waveguide losses at the pump and signal wavelengths were estimated to be approximately 0.26 and 0.2 dB/cm, respectively. Fig. 1 shows the apparatus used for the characterisation of the device. Dielectric mirrors were butted against the waveguide ends. The mirrors had 99% and 91% reflectivities at 1544 nm and 88% transmission at 977 nm. An optical isolator was used to prevent pump feedback ino the laser diode. Fig. 2 shows the lasing characteristics. Lasing was observed at 1544 nm with 15 mW of incident pump power. The coupling efficiency was determined to be 35%, which translated into a threshold of 5 mW and a slope efficiency of 2%.

Discussion The fluorescence measurements and the low laser threshold achieved indicate that backtransfer effects in our glass are not as severe as those reported in Er/Yb bulk laser silicate glasses [4]. We believe this is due to the low Yb/Er ratio used [5]. The measured 45% energy transfer efficiency is lower than the 95% efficiency reported in phosphosilicate fibres [2]. However, this is expected since these fibres had a higher Yb/Er ratio.

The measured 1544 nm lasing wavelength was far from the 1536 nm fluorescence peak. This shift was due to the mirrors used, which had higher reflectivity at 1544 nm (91%) than at 1536 nm (80%). The measured slope efficiency of 2% was five times smaller than the 9.5% predicted from theoretical calculations using the mirror reflectivities and waveguide parameters listed above, together with the 45% energy transfer efficiency obtained from the fluorescence measurements. This discrepancy may be due to pump stimulated emission effects caused by saturation of the $^2F_{5/2}$ level in Yb [6]. This effect, which decreases the transfer efficiency by depleting excited Yb population, was not observed in our fluorescence intensity meaurements because these were made at low pump powers, but may have been present at the pumping intensities used to operate the device. Pump stimulated emission may be reduced by increasing the Yb/Er ratio, which, given the low waveguide losses, may be achieved by reducing the Er concentration.

Conclusion We have demonstrated a diode-pumped, planar Er/Yb waveguide laser in a silicate glass. The device had a threshold of 5 mW and a slope efficiency of 2% with up to 1 mW of output power. Optimisation of the Er concentration and Yb/Er ratio should lead to further improvements in the performance of the device. These results demonstrate that we can potentially achieve efficient operation of diode-pumped waveguide lasers through energy transfer in silicate glasses. Although phosphate glasses may still provide more efficient operation of such devices, the chemical durability of the silicate host may offer many advantages.

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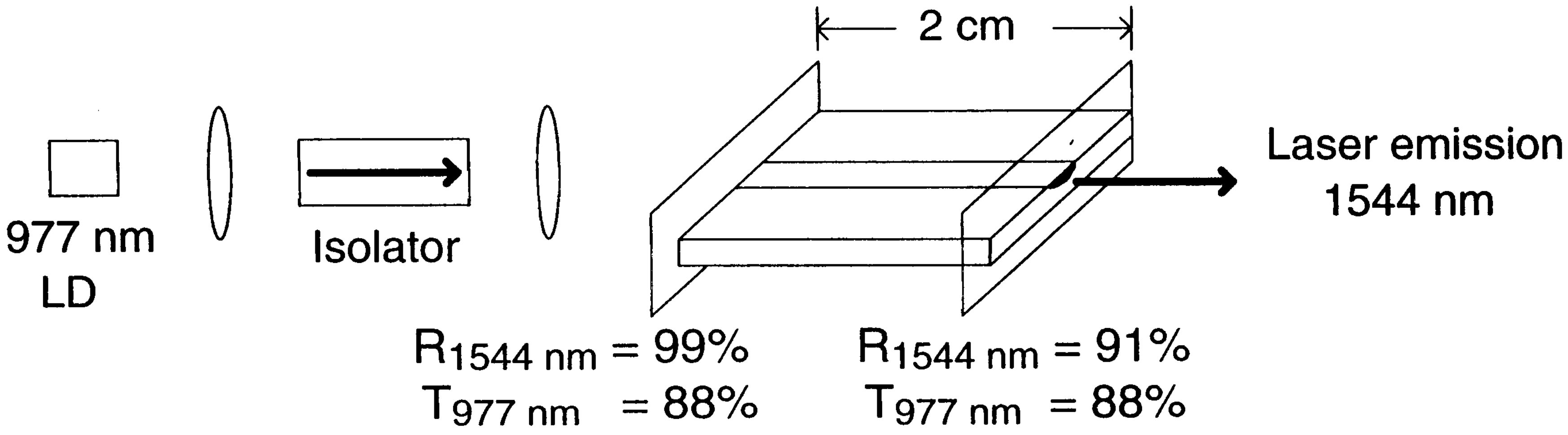
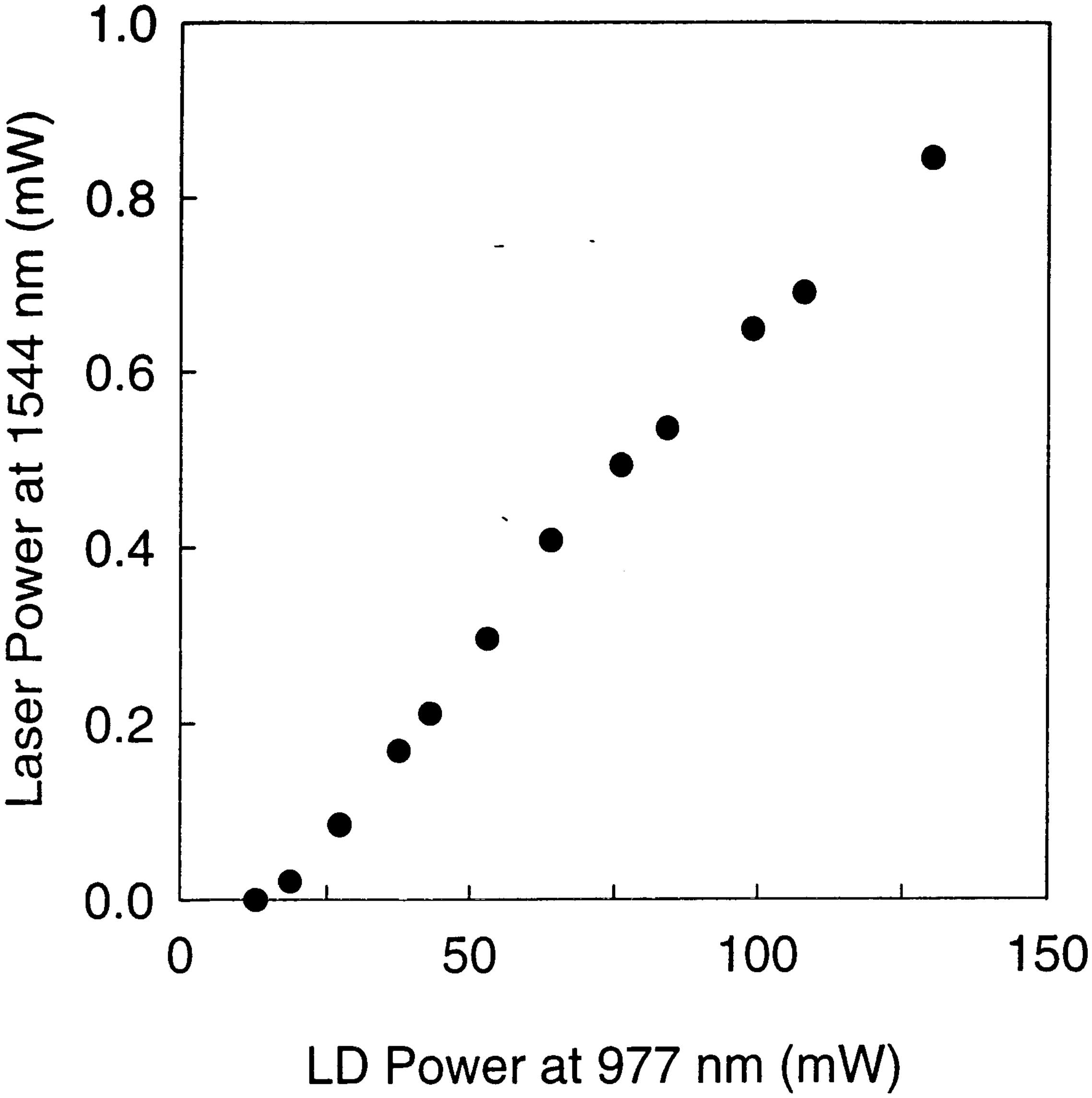
Figure Captions

Figure 1	Er/Yb waveguide laser configuration
Figure 2	Laser characteristics


977 nm
LD
Isolator
2 cm
Laser emission
1544 nm
$R_{1544\text{ nm}} = 99\%$
$T_{977\text{ nm}} = 88\%$
$R_{1544\text{ nm}} = 91\%$
$T_{977\text{ nm}} = 88\%$


1.0
0.8
0.6
0.4
0.2
0.0
Laser Power at 1544 nm (mW)
0
50
100
150
LD Power at 977 nm (mW)