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Photosensitive Er/Yb Optical Fibres For Efficient Single Frequency Fibre Lasers

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Abstract: Tin co-doping is used for photosensitive Er/Yb/P/Al/Si fibres. A 10 cm long 80% grating was written without hydrogenation to realise a single frequency DFB laser with an efficiency of 11%, the highest reported so far. A boron-co-doped germanosilicate ring next to the fibre core was used in the second approach to achieve 1 cm long high reflectors (>99.9%) and extremely low threshold single frequency DBR fibre lasers with 23% efficiency.

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Summary: The absence of highly photosensitive Er/Yb fibres has been the main obstacle in the implementation of short efficient single frequency fibre lasers. An earlier report of an Er/Yb single frequency DBR laser demonstrated the promising properties of such lasers over their Er doped counterpart due to their very high pump absorption (~0.2 dB/mm at 980 nm) [1]. A fibre grating was spliced onto a short section of Er/Yb fibre and the splice contributed to substantial part of the cavity loss. A highly photosensitive Er/Yb fibre is clearly required for easy implementation of these devices and novel designs.

The first approach that we used is to co-dope Er/Yb/P/Al/Si fibres with tin. Tin doping is known to create photosensitivity in phosphorous-doped silica glass [2]. The fibre has a pump absorption of ~170 dB/m at 980 nm, an Er^{3+} absorption of ~25 dB/m at 1535 nm, a cut off wavelength of 1270 nm and NA of 0.17. A 10 cm long, 0.1 nm bandwidth, 80% reflection grating was written in this fibre using a phase mask technique and a 100 mW frequency doubled Ar laser at 244 nm. The laser was scanned at a speed of 5 μm/s. A 1.5 cm long strong grating (>99.9%) with 1 nm bandwidth fabricated in a boron-co-doped germanosilicate fibre was spliced to the Sn/Er/Yb grating to construct a single output DFB laser (see fig.1). Essentially the same performance shown in fig.1 was achieved whether the laser was pumped from the front or the back. The laser was observed to operate on two polarisation modes spaced 390 MHz apart. The line width was measured to be 25 KHz. We found that, if hydrogenation is used to enhance the photosensitivity, a loss of ~ 0.5 dB/cm is induced at the 980 nm pump, substantially reducing the laser slope efficiency.

To further improve photosensitivity of Er/Yb doped fibres to allow high reflectivity gratings of shorter length to be written for the implementation of much shorter devices, we used the structure shown in fig.2. A highly photosensitive boron-doped germanosilicate (B/Ge/Si) annulus is placed next to the core. By separating the photosensitive region from the Er/Yb core, we avoid perturbing the composition for efficient energy transfer. The refractive index of the B/Ge/Si ring is matched to the cladding so that overlap between the guided optical mode and the rare earth dopants is not affected. The B/Ge/Si glass has a demonstrated photoinduced index change as high as $2X10^{-3}$ [3] which, accounting for the reduced overlap between the guided mode and the photosensitive region, should result in effective index changes much larger than $1X10^{-4}$ for fibres with V value between 1.5 and 2.4. Fig.3 shows the growth of total reflection and final transmission spectrum of a grating written in such a fibre. The grating was written with an interferometer using a line narrowed KrF excimer laser. The bandwidth is ~0.58 nm. The P/Al/Si core has a pump absorption of ~230 dB/m at 980 nm, an Er^{3+}absorption of ~25 dB/m at 1535 nm, a cut off wavelength of 1470 nm, and 0.18 NA.

A DBR laser with configuration shown in Fig.4 is constructed. The high signal reflector R1 (>99.9%) is a dielectric mirror coated on the end face of a standard single mode fibre. Output coupler R2 is a grating with a bandwidth of 0.3 nm and reflectivity of 98%. Due to the high pump absorption, this length of Er/Yb fibre after the grating (L3) is not pumped. A slope efficiency of ~23 % is estimated when including a coupling loss of ~0.5 dB from the standard single mode fibre to the Er/Yb fibre. The laser is both single frequency and single polarisation. A mode change was observed at 25 mW to 30 mW of launched pump power, with a mode spacing of 0.082 nm corresponding to an effective cavity length of 10 mm. The mode change can be eliminated if a more uniform grating with narrower bandwidth is used.

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Figure captions:

Figure 1 The Sn/Er/Yb/P/Al/Si single output DFB laser.

Figure 2 The structure of an Er/Yb fibre with an index matched B/Ge/Si ring.

Figure 3 Grating formation in an Er/Yb fibre with a B/Ge/Si ring.

Figure 4 A DBR laser constructed with an Er/Yb fibre with a B/Ge/Si ring. L1 = 1 cm, L2 = 1 cm, L3 = (a) 1.9 cm, (b) 10 cm.

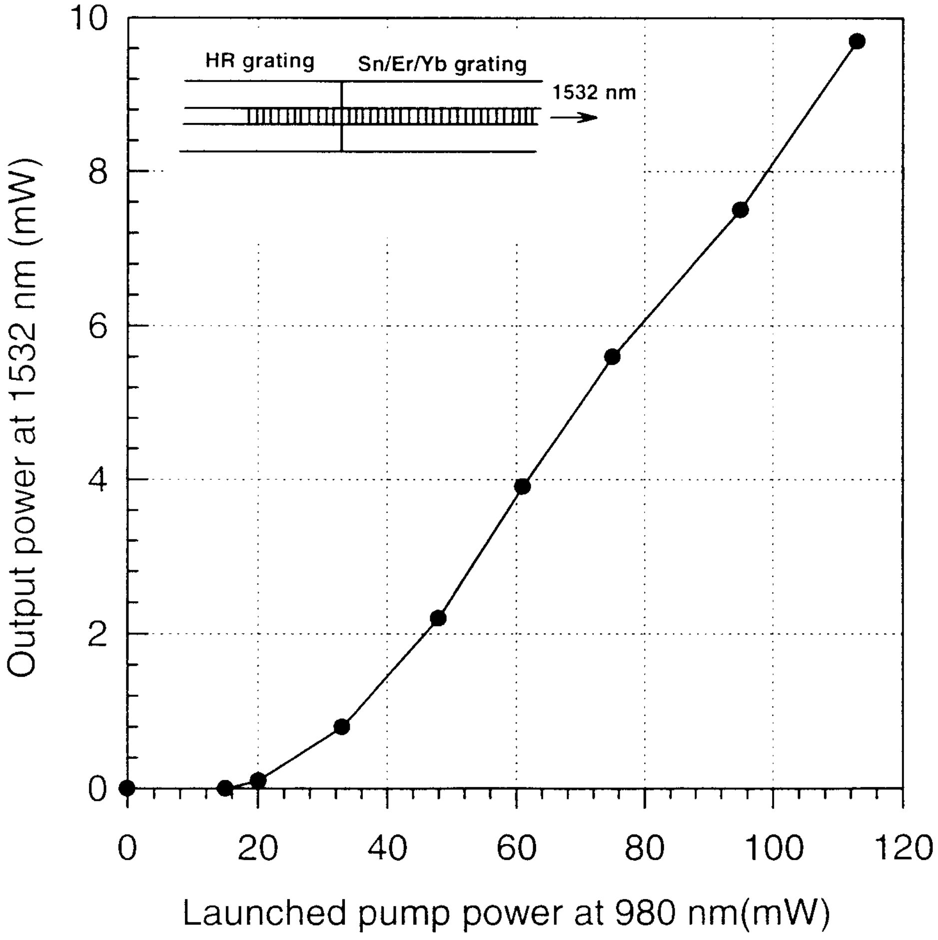

Figure 1 The Sn/Er/Yb/P/Al/Si single output DFB laser.

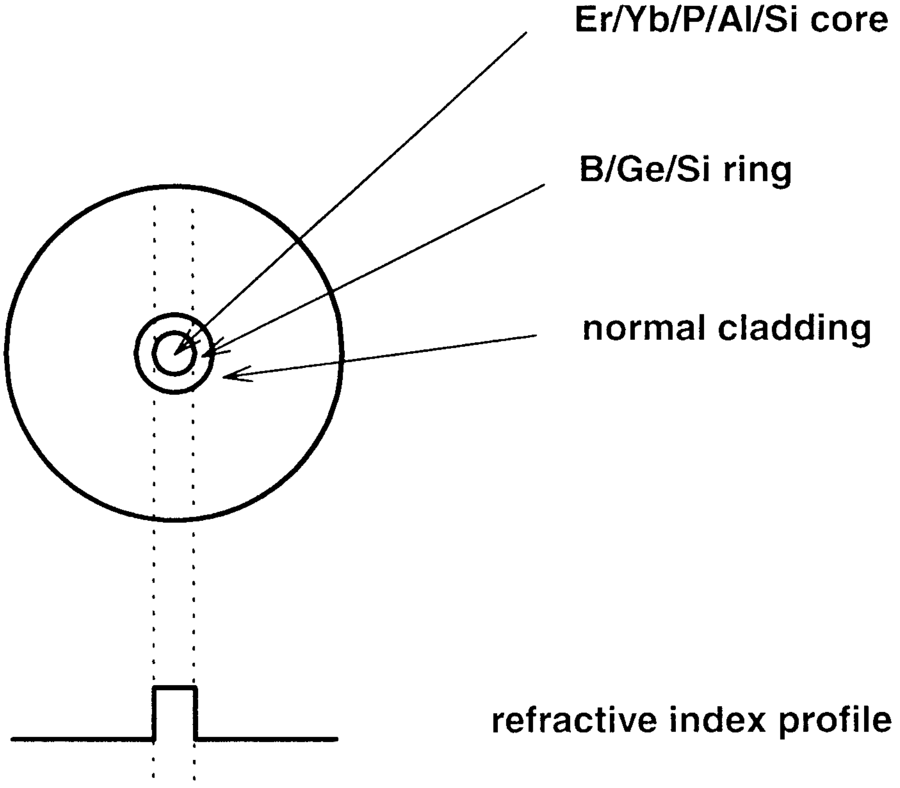

Figure 2 The structure of an Er/Yb fibre with an index matched B/Ge/Si ring.

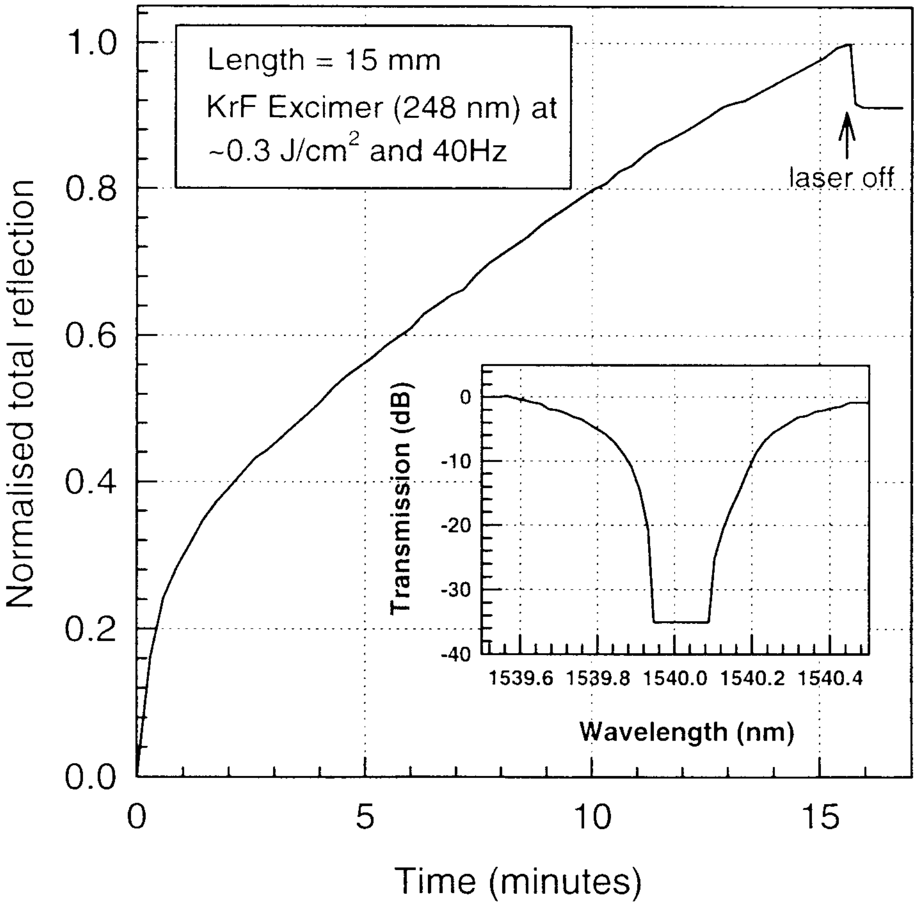

Figure 3 Grating formation in an Er/Yb fibre with a B/Ge/Si ring.

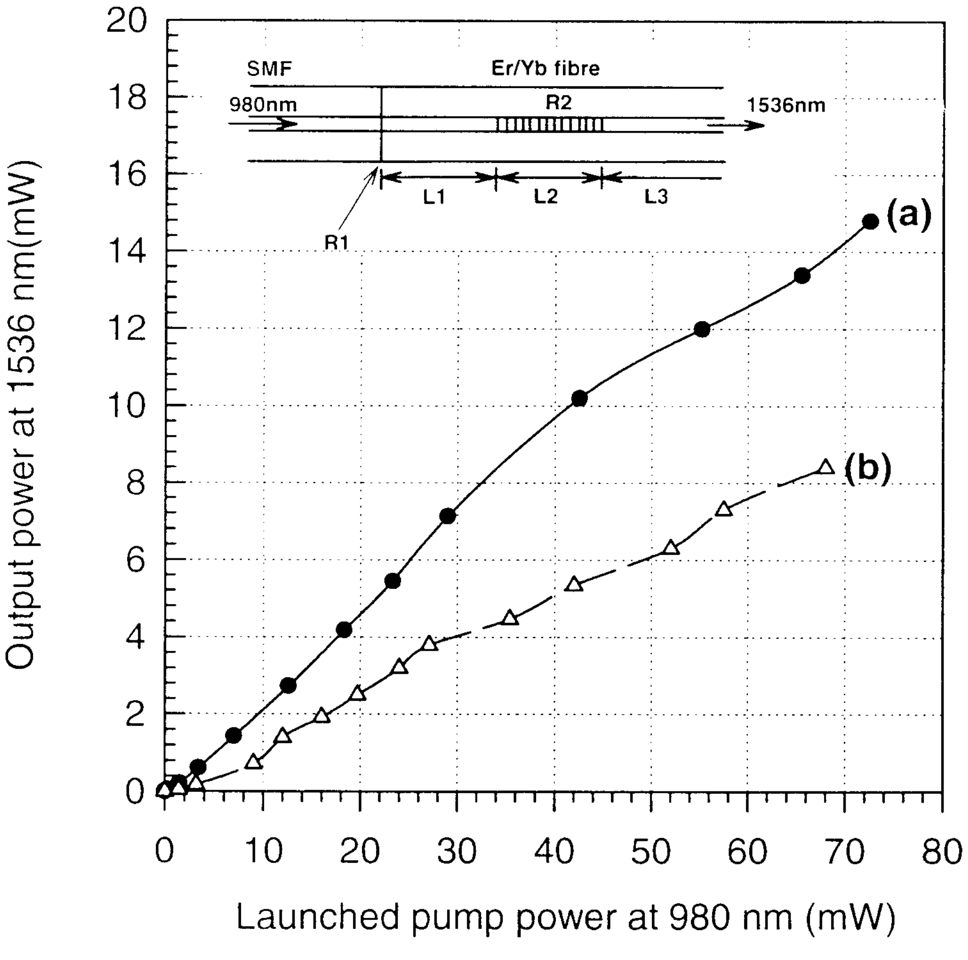

Figure 4 A DBR laser constructed with an Er/Yb fibre with a B/Ge/Si ring. L1 = 1 cm, L2 = 1 cm, L3= (a) 1.9cm, (b) 10 cm.