Planar Er:Yb glass ion exchanged waveguide laser

G.L. Vossler, C.J. Brooks and K.A. Winik

Indexing terms: Fibre lasers, Ion exchange, Optical waveguides

A planar, single-transverse-mode waveguide laser has been fabricated in erbium-ytterbium codoped silicate glass using potassium ion exchange. The laser operates at 1536.8nm, has a slope efficiency of 5.5%, and exhibits a launched pump power threshold of 14.8mW when pumped at 966.6nm.

Introduction: Er^{3+}:Yb^{3+} codoping has become an effective method for producing short, efficient lasers and amplifiers in the long haul telecommunications wavelength range. Ytterbium codoping increases the pump absorption near 980nm and efficient energy transfer between the Yb^{3+} and the Er^{3+} ions enables the operation of centimetre long lasers with low Er^{3+} concentrations. This mechanism was first demonstrated by Snitzer and Woodcock in bulk glass [1]. More recently, Er^{3+}:Yb^{3+} codoped fibre lasers [2, 3] and planar waveguide amplifiers [4] have been demonstrated.

Ion exchange is a well known method for fabricating integrated optic devices in glass [5]. Ion exchanged devices are inexpensive, robust, and fibre compatible. Monomode planar waveguides lasers have been successfully fabricated in Er^{3+}-doped BK-7 glass [6]. The key to this demonstration was the introduction of rare-earth dopants into an ion exchangeable glass host. We report a short, planar Er^{3+}:Yb^{3+} waveguide laser fabricated by ion exchange.

Fabrication: The glass composition, by weight, consisted of 12.5% Na_2O, 61.3% SiO_2, 3.53% K_2O, 4.08% BaO, 17.0% Yb_2O_3, and 1.5% Er_2O_3. A 150nm thick aluminum layer was evaporated onto one surface of a 25 × 15 × 1mm³ substrate. Standard photolithography and wet etching were used to produce a planar section and 2 – 7µm wide channels in the aluminum mask.

Waveguides were fabricated by ion exchange through the channels by submersion in a potassium salt bath at 400°C for 2.1h. Prism coupling measurements in the planar section indicated two guided modes at 960nm. Effective index method calculations indicated that the channel waveguides would be singlemoded at both the pump and lasing wavelengths for the fabricated channel widths.

The ends of the waveguides were polished normal to the channels. Propagation loss measurements were performed by cutting back the sample and repolishing. The measured losses were ~2.5dBcm⁻¹ at the pump wavelength. These losses are much higher than the 0.5–1.0dB cm⁻¹ typical of potassium ion exchange waveguides. We suspect that glass quality and scattering from the high Yb^{3+} concentration contribute to the increased propagation losses. The resulting waveguides were 8.6mm long. Dielectric minors were butt-coupled to the polished edges of the waveguides using index matching fluid. The mirrors transmitted 87.7% at 966.6nm and reflected 95% at 1536.6nm.

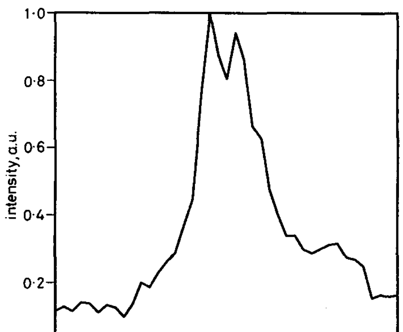

Fig. 1 *Fluorescence spectrum for Er^{3+}:Yb^{3+} waveguide*

Experimental results: Pump light from a Ti:sapphire laser at 966.6nm was end-fire coupled into the waveguides through the end mirror using a ×20 objective. The output of the waveguide was collected with a ×20 objective. All of the waveguides were found carry a single transverse mode at the pump wavelength. The absorption coefficient at 966.6nm, measured with a spectra-photometer in a bulk glass sample, was 15.6dB cm⁻¹. The fluorescence spectrum is shown in Fig. 1. The spectrum was measured using a monochromator with a 2nm resolution by collecting the signal from the 7µm wide channel waveguide. The fluorescence lifetime of a bulk sample was 8.5ms. The level of fluorescence from the Yb^{3+} in the 900–1100nm range was very low, indicating highly efficient energy transfer between the Yb^{3+} and the Er^{3+}. Experiments with another Er^{3+}:Yb^{3+} glass composition produced significant Yb^{3+} fluorescence relative to the Er^{3+} fluorescence and this composition did not lase.

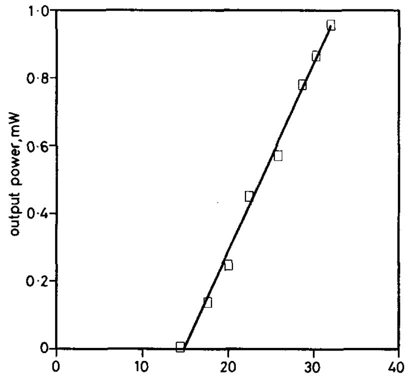

Fig. 2 *Launched pump power at 966.6nm against output power at 1536.6nm*

Lasing was observed in the 7µm wide channel at 1536.6nm. Fig. 2 shows the output power from both ends against launched pump power. The threshold for lasing is 14.8mW and the slope efficiency is 5.54%. The threshold pump power and slope efficiency could be improved by reducing the propagation loss and optimising the mirror characteristics at the pump and lasing wavelengths.

Conclusion: An Er^{3+}:Yb^{3+} codoped glass composition has been demonstrated which is suitable for ion exchange fabrication of active integrated optic devices. A single-transverse-mode planar glass waveguide laser has been fabricated in this glass and has been characterised. The performance of the laser could be improved by reducing the propagation losses and by optimising the mirror reflectivities.

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References

1 SNITZER, E., and WOODCOCK, R.: 'Yb^{3+}-Er^{3+} glass laser', *Appl. Phys. Lett.*, 1965, **6**, (3), pp. 45–46

2 SNITZER, E., PO, H., HAKIMI, F., TUMMINELLI, R., and MCCOLLUM, B.C.: 'Erbium fiber laser amplifier at 1.55µm with pump at 1.49µm and Yb sensitized Er oscillator'. Conf. Optical Fiber Communications - OFC'88, New Orleans, Louisiana, USA, 1988, Paper PD2

3 KRINGLEBOTN, J.T., MORKEL, P.R., REEKIE, L., ARCHAMBAULT, J.-L., and PAYNE, D.N.: 'Efficient doped-pumped single-frequency erbium:ytterbium fiber laser', *IEEE Photonics Technol. Lett.*, 1993, **5**, (10), pp. 1162–1164

4 BARBIER, J.M., DELAVAUX, J.M., KEVORKIAN, A., GASTALDO, P., and JOUANNO, J.M.: 'Yb/Er integrated optics amplifiers on phosphate glass in single and double pass configurations'. Conf. Optical Fiber Communications - OFC'95, San Diego, California, USA, 1995, Paper PD3-1

5 RAMASWAMY, R.V., and SRIVASTAVA, R.: 'Ion-exchanged glass waveguides: A review', *J. Lightwave Technol.*, 1988, **LT-6**, pp. 984–1000

6 FEUCHTER, T., MWARANIA, E.K., WANG, J., REEKIE, L., and WILKINSON, J.S.: 'Erbium-doped ion-exchanged waveguide lasers in BK-7 glass', *IEEE Photonics Technol. Lett.*, 1992, **4**, (6), pp. 542–544

Remote postamplifiers in repeaterless transmission systems

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Indexing terms: Fibre amplifiers, Optical communication

Three schemes for remotely pumping postamplifiers in a repeaterless system are investigated: Raman gain, Raman and EDFA, and separate fibre pumping of an EDFA. Using a dedicated pump fibre, 6dB of budget improvement is predicted for 1000mW of 1485nm pump power. Experiments agree with the theoretical predictions within 0.75dB.

During the past year, the transmission distance of repeaterless transmission systems has increased significantly, from 347 [1] to 529km [2] at a transmission rate of 2.5Gbit/s, i.e. a > 50% increase in transmission distance. The enabling technologies have been the introduction of remotely pumped postamplifiers and preamplifiers based on erbium doped fibres, Raman gain obtained in the transmission fibre owing to the stimulated Raman scattering process, and the availability of high power 1480nm pump sources [3].

We investigate the feasibility of three different scenarios for implementing remotely pumped postamplifiers at the transmitter end of a repeaterless system. The three considered architectures are schematically shown in Fig. 1. Experimentally, we have implemented the scheme using a dedicated pump fibre parallel to the signal transmission fibre.

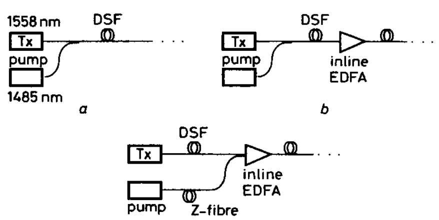

Fig. 1 *Remote postamplifier schemes*

a Pure Raman gain
b Inline EDFA and Raman gain
c Inline EDFA pumped via a separate fibre

The Raman gain process is modelled by two coupled differential equations [4]:

$$\frac{dP_s}{dz} = g_R \frac{P_p}{bA_{eff}} P_s - \alpha_s P_s \qquad (1a)$$

$$\frac{dP_p}{dz} = -\frac{\omega_p}{\omega_s} g_R P_s \frac{P_p}{bA_{eff}} - \alpha_p P_p \qquad (1b)$$

where subscripts s and p denote quantities related to the signal and pump light, respectively. P is the propagating power, g_R is the Raman gain coefficient, b the polarisation preservation factor, A_{eff} is the effective area of the transmission fibre, α is the background loss, and ω is the angular frequency of the light. In these equations, we have included pump depletion since the signal launched in a repeaterless system can be quite high, limited only by the fibre nonlinearities and stimulated Brillouin scattering. For the erbium doped fibre, we use a numerical implementation of the theoretical model as described in [5].

The transmission fibre is assumed to be dispersion-shifted fibre with background losses of 0.204 and 0.235dB/km at the signal and pump wavelengths, respectively. The Raman gain coefficient g_R/b = 1.8×10^{-14}m/W and the effective area A_{eff} = 50µm². For separate pumping via a pure silica-core fibre (Z-fibre), we assume a background loss of 0.198dB/km at the pump wavelength. These numbers represent typical measured values for our fibres.

In our calculations, we have included the influence of fibre nonlinearities by requiring that the signal power integrated over the length of the fibre remains the same in all cases [6]. In our experiments, this limit is reached for a transmitter power of ~24dBm and, consequently, we are investigating the improvements that can be obtained relative to this launch power level. For the schemes involving the remote EDFA, we have optimised the gain of the amplifier since the dominant noise contribution is generated in the optically preamplified receiver. The signal wavelength is 1558nm and the pump wavelength is 1485nm.

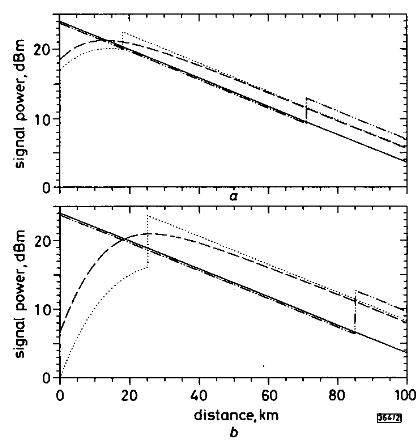

Fig. 2 *Remote postamplifier performance*

——— 24dBm reference transmitter
– – – – Raman, 2.0dB (*a*), 4.4dB (*b*)
········ Raman and EDFA, 2.1dB (*a*), 4.7 (*b*)
–··–··– EDFA only, 3.4dB (*a*), 6.0dB (*b*)

Fig. 2*a* shows the calculated evolution of signal power for the three configurations with pump power of 450mW. The signal launch power has been adjusted to give the same fibre nonlinearities for all cases. The solid line represents our +24dBm reference transmitter. The improvements are 2.0, 2.1 and 3.4dB, respectively, with the separately pumped EDFA being most advantageous. Fig. 2*b* shows the results obtained with 1000mW of pump power. Again the separately pumped EDFA gives the highest improvement of 6.0dB, resulting in an effective transmitter power of +30dBm.

To experimentally verify the benefit of remote postamplifiers, we have built a setup having a dedicated pure silica-core fibre to remotely pump an EDFA located 75km from the transmitter. By varying the launched signal power we have measured the performance of the remote EDFA, shown in Fig. 3. Here, the launched signal power is 23.3dBm and the gain (and system improvement) is 2.95dB. At this input power level, the theoretical model overestimates the gain by ~0.75dB for both pump power levels.

In summary, we have discussed three different configurations for implementing remote postamplifiers for repeaterless systems. The pumping of an EDFA via a dedicated pump fibre parallel to the transmission fibre is found to be more beneficial than for a copropagating signal and pump power in the transmission fibre.