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Low-threshold Monomode Ion-exchanged Waveguide Lasers in Neodymium-doped BK-7 Glass

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Introduction

The ion-exchange technique has been advanced as method of fabrication of active integrated optic devices in glass substrates[1]. Multimode waveguides have previously been made in rare-earth-doped glasses and optically pumped to provide amplifying media[2] or lasers[3,4]. However lasers fabricated using single-mode waveguides have lower thresholds than multimode devices[5]. In this paper we report the first demonstration of a monomode ion-exchanged laser in neodymium-doped BK-7 glass. The technique is suitable for batch processing of devices at low cost. In addition the waveguide fields can be easily perturbed in the planar geometry enabling a variety of devices such as modulators, ring and coupled-cavities, and wavelength multiplexers to be integrated.

Development of active integrated optic devices in glass has been hampered by lack of rare-earth-doped glasses with suitable ion-exchange chemistry. In our case this drawback has been removed by selecting an ion-exchangeable glass and doping it with the required rare-earth ions. This also allows variation of the dopant concentration to optimise laser performance. BK-7 was chosen as the basic glass because of its good optical quality and excellent ion-exchange properties with silver, potassium and caesium ions which allow waveguides with a wide range of numerical apertures to be easily fabricated[6].

In our studies BK-7 glass was doped with 2 wt% neodymium oxide to form the substrate. Single-transverse-mode waveguide lasers were fabricated in the substrate by potassium ion-exchange.

Fabrication

BK-7 glass pieces were mixed with 2 wt% neodymium oxide in a ceramic crucible and placed in an electric furnace at temperatures which varied between 850°C and 1450°C through the doping process. The melt was kept well mixed to maintain a uniform distribution of neodymium ions in the host. The glass was taken out of the furnace at 1250°C and cast into a stainless steel moult, then annealed at 580°C for thirty minutes and left to cool to room temperature in the annealing furnace.

The doped glass was sliced and polished to dimensions of approximately 20mm × 15mm × 1mm. A 250nm thick aluminium film was deposited on one surface to form a mask and straight channels parallel to a reference edge delineated in it by photolithography and etching. The channels varied in dimensions from 3μm to 5μm in steps of 0.1μm and were 100μm apart.

Waveguides were fabricated through the mask channels by a two-step thermal ion-exchange process. First the substrates were immersed in molten potassium nitrate at 390°C for 230 minutes to form surface channel waveguides. Subsequently the aluminium mask was removed and the waveguides buried by immersing in molten sodium nitrate for 350°C for 30 minutes.

The ends of the substrates were polished normal to the reference edge and multilayer dielectric mirrors, on 2mm thick BK-7 substrates, epoxied on to form a Fabry-Perot cavity. The transmission of the mirrors at 807nm was 90% and their reflectivities at 1060nm were 99.5% for the input and 95% for the output coupler. The device length was typically 17mm.

Experiment

The waveguide loss and absorption coefficient for the pump were measured by observation of the decay characteristics of the light in the waveguides[7] at wavelengths of 850nm and 807nm respectively. The waveguide losses were measured at 850nm because there is very little absorption for light at this wavelength by neodymium ions.

The pump light source was a tunable Ti:Sapphire laser end fire coupled to the waveguides using lenses. The measurements indicated a waveguide loss of 0.8dB cm^{-1} and an absorption coefficient for the pump of 5.6dB cm^{-1}. The relatively high value of waveguide loss is attributed mainly to non-uniformity of the refractive index in the substrate. Work to improve the quality of the substrate is in progress.

Figure 1: Apparatus to measure lasing characteristics

The spectral and temporal characteristics of the Nd^{3+}-ion fluorescence were measured in both the substrate and the waveguide. The peak fluorescence wavelength was 1057nm and the spectrum was found to be asymmetrical. The fluorescence lifetime was found to be 380μs, slightly less than the value of 500μs measured in other samples of BK-7 with lower dopant concentration. This is indicative of concentration quenching, and so improvements in laser performance can be expected with further glass optimisation. An experiment to measure clustering of the Nd^{3+}-ions was carried out using pulses from a frequency doubled, Q-switched, mode-locked Nd:YAG laser operating at $\lambda = 532$nm to excite the dopant ions, however no such clustering was observed.

The apparatus used in the measurement of the laser characteristics is shown in Figure 1. The results presented be-

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*University of Nairobi, PO Box 30197, Nairobi, Kenya low are for a waveguide made through the smallest (3μm) mask opening, though the other twenty waveguides also lased. This waveguide was found to be single mode at both the pump and lasing wavelengths and showed the lowest lasing threshold, which is consistent with it having the highest pump power density.

Figure 2 shows the output power versus the launched power for this laser. The output power varies linearly with launched power up to 1.1mW and then begins to saturate. The slope efficiency in the linear region is 6% and the threshold of the laser is 7.5mW. The peak lasing wavelength was 1057.8nm. We believe that the saturation of the laser characteristic is due to thermal heating in the waveguide, since when chopped pump light was used the peak lasing power was higher than in the case of continuous pumping. Appropriate heat-sinking should alleviate this problem.

Figure 2: Lasing characteristics

Lasers made in the larger waveguides had a higher value for the saturation output power. The maximum power obtained was 3mW from a laser in a waveguide made through the 4.8μm mask opening. No attempt has been made to optimise the output reflectivity for any of these lasers, and improvements in slope efficiency can therefore be expected.

Conclusion

Neodymium-doped BK-7 glass has been introduced as a substrate suitable for fabrication of active integrated optic devices by ion-exchange. The characteristics of a single-transverse-mode planar glass waveguide laser have been investigated. To the best of our knowledge it has a lower threshold than any other ion- exchanged waveguide laser reported. Saturation, probably due to thermal effects, limits the maximum power available from the device. Making a substrate having greater homogeneity should enable us to reduce waveguide losses, thereby improving laser performance.

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References

1. Najafi, S. I., Wang, W., Currie, J. F., Leonelli, R., Brebner, J. L.: "Fabrication and characterisation of neodymium-dopd glass waveguides", IEEE Photon Tech. Lett., Vol. 1, 1989, pp. 109–110.
2. Babukova, M. V., Berenberg, V. A., Glevov, L. B., Nikon-Orov, N. V., Petrovskii, G. T., Terpugov, V. S.: "Investigation of neodymium silicate diffused waveguides", Sov. J. Quantum. Electron., Vol. 1, 1985, pp. 1304–1305.
3. Aoki, H., Maruyama, O., Asahara, Y.: "Glass waveguide laser", Proc. OFC '90, San Francisco, 1990, p. 201.
4. Sanford, N. A., Malone, K. J., Larson, D. R.: "Integrated-optic laser fabricated by field-assisted ion- exchange in neodymium-doped soda-lime silicate glass", Opt. Lett., Vol. 15, 1990, pp. 366–368.
5. Mears, R. J., Reekie, L., Poole, S. B., Payne, D. N.: "Neodymium-doped silica single-mode fibre lasers", Electron. Lett., Vol. 21, 1985, pp. 738–740.
6. Ramaswamy, R. V., Srivastava, R.: "Ion-exchanged glass waveguides : a review", J. Lightwave Technol., Vol. LT-6, 1988, pp. 984–1002.

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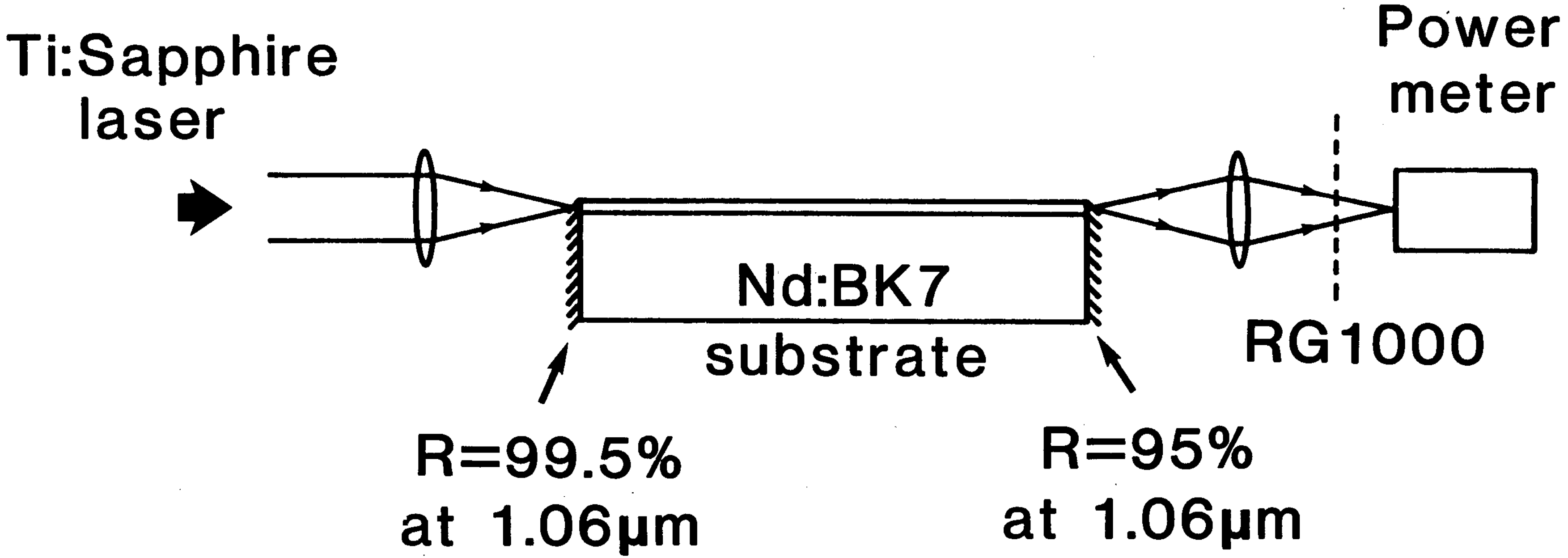

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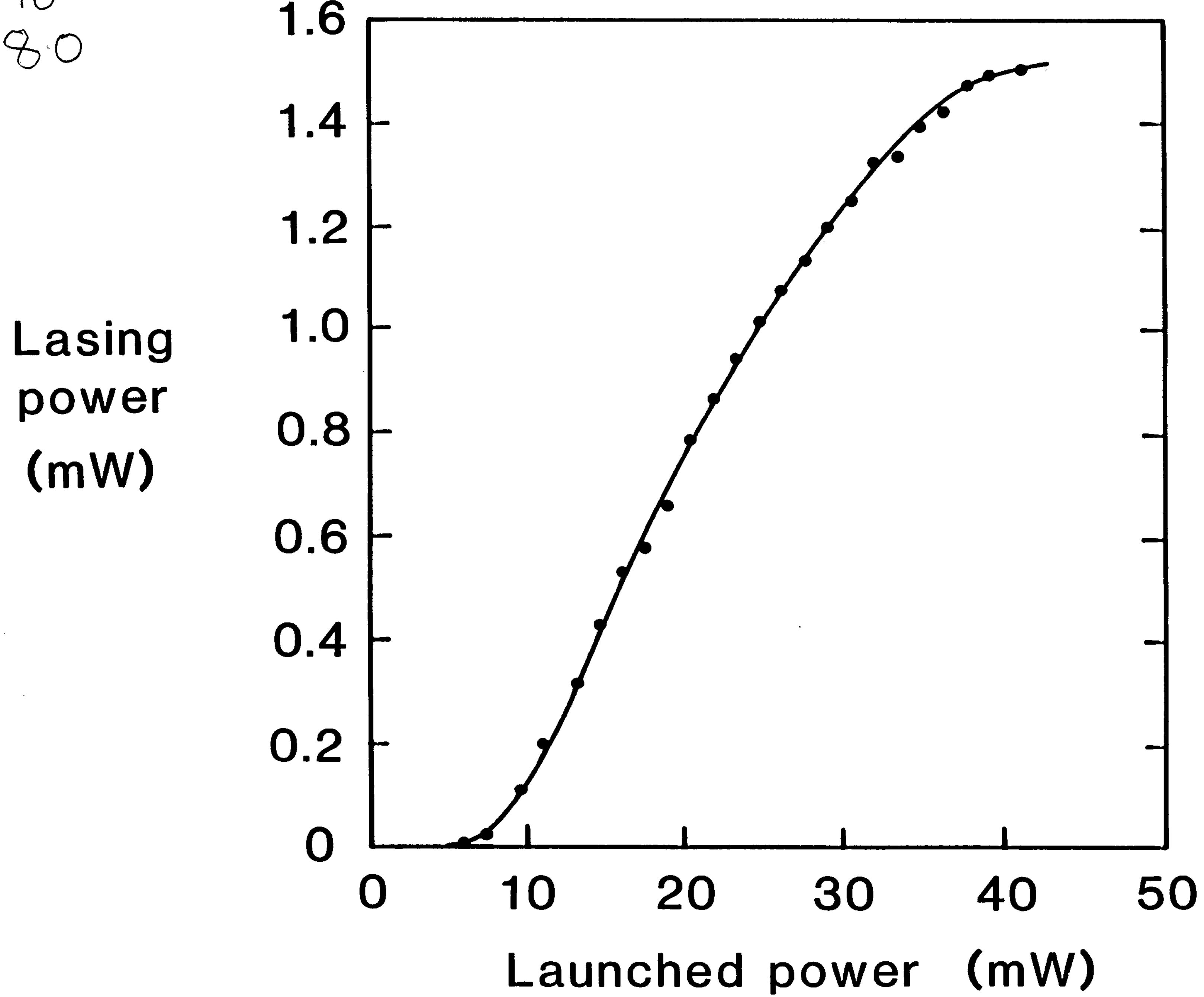

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