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RARE-EARTH DOPED PLANAR WAVEGUIDE LASERS

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1. Introduction.

Rare-earth doped planar waveguide lasers have been realised in many host materials, using a range of waveguide fabrication techniques. Laser action has been obtained in ion-implanted Nd-doped crystals such as YAG, YAP, $LiNbO_3$ & BGO(1), in proton-exchanged and titanium indiffused waveguides in Nd- and Er-doped $LiNbO_3$(2,3), in Nd- and Er-doped silica waveguides on silicon(4,5), in Nd-doped sputtered glass waveguides(6), and in ion-exchanged Nd-doped glass waveguides(7,8). Each of these materials systems has specific advantages either as a laser host, or because of the potential for increased functionality through use of electro-optic effects, for example. Recent advances in this technology exploit the advantages that planar devices have over fibre devices. In particular, acousto-optic, electro-optic, or thermo-optic modulators may readily be monolithically integrated, complex multiple cavity devices may be defined photolithographically, there is access to the waveguides for surface interactions, and waveguide geometries may be changed along the device for efficient interfacing to external components and optimisation of individual devices. Recently, an FM mode-locked waveguide laser in Nd-doped $LiNbO_3$ with an integral modulator(9), and a waveguide laser in $LiNbO_3$ with locally diffused erbium(3) have been demonstrated. The particular importance of the latter development is that passive waveguide components may be realised on the same substrate as those with gain.

Ion-exchanged glass waveguides have the advantages that they are inexpensive, rugged, and compatible with optical fibres. The demonstration of low-threshold laser-diode pumped waveguide lasers has substantially increased the functionality of this waveguide system. In this paper we report current work on the application of multiple cavities in the planar configuration, for Q-switching, tuning, and line-narrowing ion-exchanged waveguide lasers using thermo-optic modulation(10).

2. Single-channel ion-exchanged waveguide lasers.

Channel waveguides were fabricated by two-step thermal ion-exchange in BK-7 glass doped with 1.5wt% Nd_2O_3(11). The waveguides were 20mm long and had a numerical aperture of approximately 0.13. Laser cavities were made by epoxy-bonding dielectric mirrors on the polished ends of the waveguides. The reflectivities at 1.06μm were >99% for the input mirror and 90% for the output mirror. Laser characteristics were measured by end-fire coupling light from an 810nm laser diode using lenses. Fig.1 shows the characteristic of a waveguide laser made by ion-exchange through a 2.3 μm opening in the Al diffusion mask. The laser threshold measured with respect to pump laser output, which is more significant than launched power from a systems viewpoint, is approximately 6mW and the slope efficiency is approximately 6%. The enhancement in performance compared with previous devices(11) is principally due to improvements in fabrication procedures. These values compare well with other published results, though devices constructed in $LiNbO_3$ have exhibited lower thresholds and higher slope efficiencies, as is expected in a crystalline host.

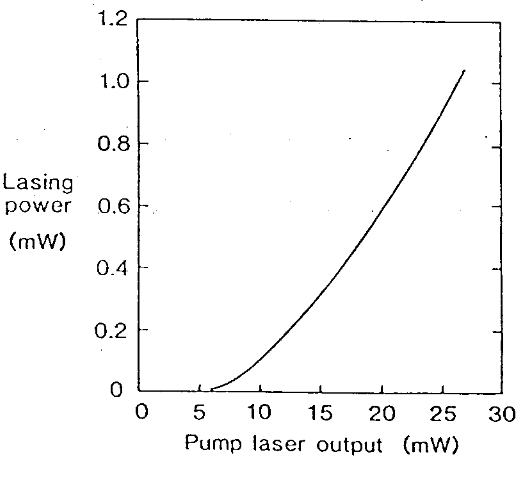

Figure 1. Laser characteristic.

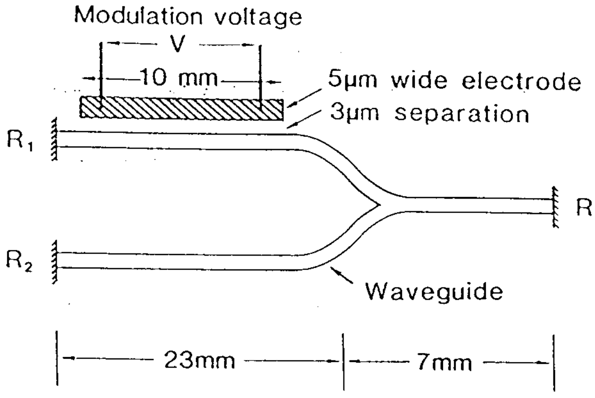

Figure 2. Device structure.

3. Coupled-cavity waveguide lasers.

Laser action has been demonstrated in the dual-cavity branching waveguide device shown in Fig.2. At wavelengths where the cavities are both an integer multiple of $\lambda/2$ long, the device is in resonance and will lase. At other wavelengths light will be radiated into the substrate at the junction, suppressing lasing. The thermo-optic modulator on one cavity may be used to bring the cavities into mutual resonance at the desired wavelength.

The waveguides were made as described above, and aluminium electrodes measuring 5μm x 0.2μm x 10mm, with a resistance of ~200Ω, were placed as shown. Cavities were formed by epoxy-bonding mirrors with reflectivities of $R_1=R_2>99\%$ and $R_3=90\%$ at 1.06μm. The performance of a typical device was investigated by pumping port 3 with a Ti:Sapphire laser at 810nm. The threshold defined as above was 50mW, and the slope efficiency was 4%. The lasing spectrum was measured while applying a voltage to the electrode. Fig.3 shows the spectra obtained for voltages of 0V, 2.5V & 3.6V. It was possible to select lasing wavelengths between 1054nm & 1062nm, or to suppress lasing.

A 105Hz square-wave of 10.4V amplitude was applied to the electrode while monitoring the laser output. Fig.4 shows the input voltage and laser output power as a function of time. Pulses of 5μs duration and 70mW peak power are observed shortly after the falling edge of the input wave. This is explained as follows: Before the input voltage falls, one cavity is at an elevated steady-state temperature. As the cavities are not mutually resonant, the combined cavities have low Q, lasing is suppressed, and population inversion builds up. When the input voltage falls, the temperature of the heated waveguide falls rapidly, and its optical path length passes through that required for mutual cavity resonance. The combined cavities then have high Q and the device emits a Q-switched pulse. The behaviour in the remainder of the cycle is not yet fully understood; however, the device passes through other resonances and it is believed that the rate of change of temperature, and thus of cavity length, is too slow to generate sharp pulses.

4. Conclusion.

Diode-pumped ion-exchanged waveguide lasers in Nd-doped glass, with low thresholds, have been demonstrated in our laboratory, and it is expected that optimisation will lower thresholds further. Attention is now turning to the device advantages that the planar configuration has when compared with fibre. We have demonstrated laser action in a multiple-cavity device, and used thermo-optic control to narrow the spectrum, select the peak lasing wavelength, and Q-switch the device. Further work on this class of laser should allow realisation of tuneable single-longitudinal-mode operation.

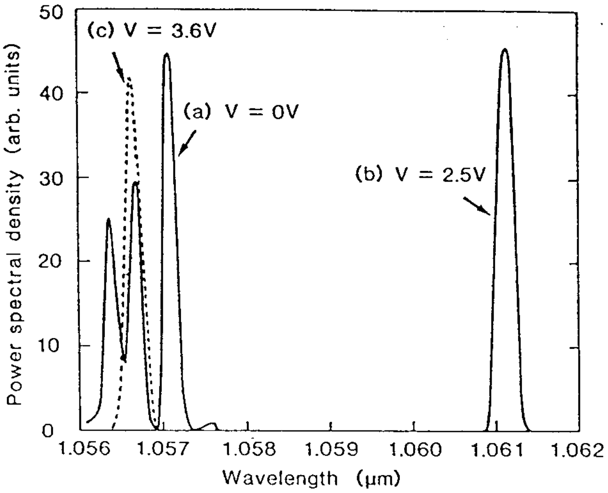

Figure 3. Lasing spectra.

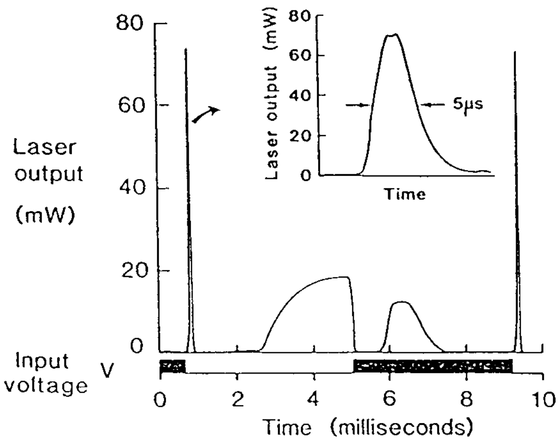

Figure 4. Pulsed operation.

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