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Neodymium and Gadolinium Diffusion in Yttrium Vanadate

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Abstract

The thermal diffusion of Nd^{3+} and Gd^{3+} ions in YVO_4 is characterised in terms of diffusion rates, spectroscopy, and index change in order to fabricate optical waveguides suitable for laser operation.

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Summary

Lasers based on planar waveguides have recently generated interest for use as scalable high-average-power sources, due to a combination of attractive features including good thermal-power handling and compatibility with high-power diode side-pumping [1]. It has recently been demonstrated, in both fibre [2] and planar formats [3], that tapered waveguides can be used to allow high-power diode pumping while still maintaining single-spatial-mode output. The requirement for adiabatic expansion of the fundamental mode from a single-mode channel to a broad planar area limits the maximum width to a few hundred microns for a device a few centimetres long [4]. However, for a strongly absorbing material such as YVO_4 this would still allow high-power side-pumped operation. Here we study the thermal diffusion of Nd^{3+} and Gd^{3+} ions in YVO_4 in order to obtain the essential diffusion characteristics necessary to calculate the conditions required for fabrication of waveguides suitable for laser action at ~1µm. Nd^{3+} is studied both for localised doping as the active laser ion and as a potential refractive index modifier. We also choose to study Gd^{3+} diffusion as an index modifier in order to give the potential for separate control of the index and gain distributions.

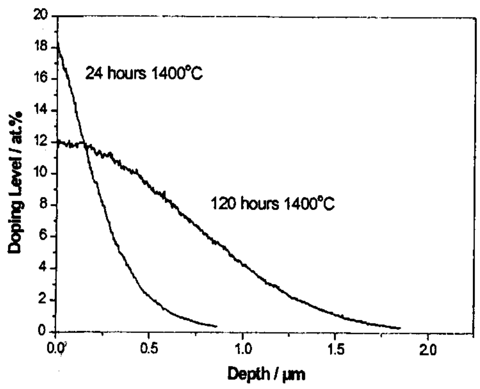

Figure 1 Nd diffusion profiles

In order to characterise this process six undoped YVO_4 substrates from Casix inc. were cut and polished to 18 by 18 by 3 mm in the a, b and c axes respectively. We choose to study diffusion along the c-axis, as this will allow a final device with an orientation such that we have access to both the strongest absorption cross-section for the pump and the highest gain cross-section for the 1.064µm signal, in end or side-pumped configurations. A thermal evaporator was used to coat the 18mm by 18mm polished surface of the substrates with a layer of Nd or Gd, and the samples were then placed in a resistance furnace in a dry oxygen atmosphere. After diffusion the samples were end-polished parallel to the c-axis. Secondary ion mass spectroscopy (SIMS) was used to determine the diffusion profile and hence the doping concentration of the diffused layers. Figure 1 shows typical examples of measured Nd diffusion profiles obtained from the experimental SIMS data. The diffusion coefficients were calculated by fitting to the SIMS results for each sample. The doping level was calibrated using the fact that some of the samples were a close fit to a depleted-source Gaussian distribution, allowing us to assume that all the ions present in the original metal film had been diffused into the substrate. This calibration was confirmed for Nd^{3+} by SIMS analysis of a bulk $Nd:YVO_4$ sample of known dopant concentration (2.2at.%). The temperature variation of the diffusion rate was also investigated.

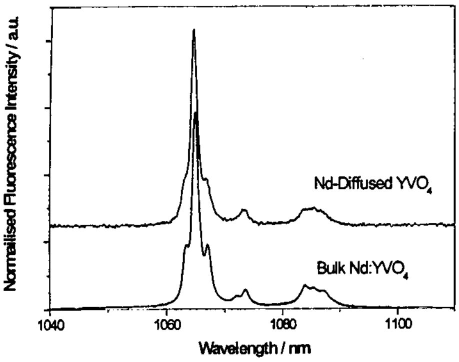

Figure 2 Emission Spectra

The fluorescence spectra of the Nd-diffused samples were obtained by face pumping the samples with a Ti:sapphire laser. The spectrum was recorded using a computer linked to a triple-grating spectrometer. The experiment was then repeated using a 2.2at% bulk doped piece of Nd:YVO$_4$. From Figure 2 we can see that the emission spectrum for the diffused sample is very similar to that of the bulk sample, although a slight degree of broadening is apparent as some side peaks are no longer resolved. The polarised bulk and diffused spectra were also similar.

The optical guiding properties of the samples were tested by end-launching light from a HeNe or argon-ion laser into the diffused layers. The 120-hr Nd-diffused layer shown in figure 1 was the only sample to show waveguide propagation, supporting TM modes at 457nm and 488nm. From the imaged spot sizes measured on a CCD camera, a modal spot size of ~1.8μm was calculated in both cases. These end-launching results were confirmed by dark-line prism coupling measurements that indicated the presence of a single TM waveguide mode in sample 2 at wavelengths up to 514nm but not at 633nm. The lack of an observed mode at 514nm in the end-launching experiments can be attributed to Nd^{3+} absorption at this wavelength

As we were unable to find any published data on the index change in YVO$_4$ due to rare-earth-ion doping we have made rough estimates by assuming that the index change due to Nd^{3+} doping is similar to that found in YAG (0.42x10^{-3} per at.%) and that the index change due to Gd^{3+} doping follows a linear relationship between the index values for YVO$_4$ and GdVO$_4$ (0.24x10^{-3} per at.%). Combining this estimate of the index change with the calculated doping profiles from the SIMS measurements gives a very good fit to the observed waveguide properties, predicting a single mode in sample 2 with cut-off at ~560nm. The predicted mode-size at 457nm and 488nm is also close to the ~1.8μm experimental value.

In summary, we have investigated the thermal diffusion of Nd^{3+} and Gd^{3+} ions in YVO$_4$, finding the essential diffusion characteristics necessary to allow the design of optical waveguides in this important laser material. A Nd^{3+}-diffused waveguide with a cut-off below 633nm was fabricated indicating an index change of ~0.4x10^{-3} per at.%. The observed waveguide supported only TM propagation. Future work will include the fabrication of waveguide lasers and amplifiers at 1.064μm and the investigation of alternative lasing and index modifying ions.

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