Reconfigurable Integrated Optics

Diode-Laser induced waveguides for visible wavelengths in $KYb(WO_4)_2$

L. J. McKnight, S. Calvez
Institute of Photonics, University of Strathclyde,
Glasgow, United Kingdom,
loyd.mcknight@strath.ac.uk

Abstract— **We demonstrate the formation of quasi-stable transient fabrication-free waveguides in $KYb(WO_4)_2$ using the electronic index change induced by diode-laser pumping which could lead to reconfigurable integrated optics. Mode profiles and index changes have been measured.**

Fabrication; Waveguide Characterization; Double Tungstates; Diode-Pumping;

I. INTRODUCTION

Optical waveguides typically require complex, time consuming and expensive fabrication techniques including ion-implantation, dry-etching, laser writing and optical or e-beam lithography to define circuits [1]. It is therefore desirable to produce waveguides and devices with a fabrication-free technique to remove the costs and complexities of fabrication. It would also be possible to define and optimize integrated devices during use, in situ. Such a technology would allow for a range of novel reconfigurable devices, circuits with small footprint and the possibility for extended functionality.

The stoichiometric crystal $KYb(WO_4)_2$, referred to as KYbW, differs significantly from typical laser crystals in that the crystal is doped to 100% [2]. KYbW has high active Yb^{3+} density of 6.4×10^{21} cm^{-3}, one of the highest of any available material and as a consequence offers a peak absorption length at 981nm of 13.3µm, one of the shortest of any material [2].

Intense laser pumping of crystals doped with optically active ions causes a refractive index change due to both thermal and athermal causes [3-5]. The cause of athermal index change is due to the linear polarizability of excited ions being different to that of unexcited ions. This athermal index change is known as the electronic index change as it relates to the electronic state of the ion rather than the local crystal temperature.

It has been shown that this electronic refractive index change is not only of significance for wavelengths near the absorption and emission peaks but is also of significant magnitude for wavelengths for which the crystal is transparent [4]. Index changes in Yb^{3+} doped materials for wavelengths far away from the peak 980nm absorption are shown to be due to the existence of strong charge transfer absorption bands in the range from 200-300nm [4].

The electronic refractive index change has been shown to dominate over thermal index changes in a range of materials including Nd^{3+} and Yb^{3+} systems [5]. This index change can create significant guiding effects in laser systems [6,7]. ΔN_e, the electronic refractive index change, depends on the linear polarizability, Δp, of the material and the density of inverted ions ΔN with the following equation [5]:

$$\Delta N_e = 2\pi \frac{n_0^2 + 2}{3} \Delta p \frac{\Delta N}{n_0} \quad (1)$$

where n_0 is the initial refractive index of the material.

From previous work [4] it is possible to estimate the maximum possible electronic refractive index change by assuming that 50% of the Yb^{3+} ions are excited into the $^2F_{7/2}$ energy level and this is shown in Figure 1. These values of refractive index change are significantly larger than that usually achieved by ion-implantation and laser writing fabrication techniques [1].

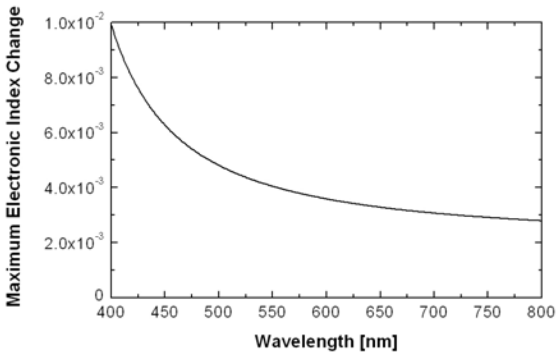

Figure 1. Maximum electronic refractive index change in KYbW assuming 50% of Yb^{3+} ions are excited into the $^2F_{7/2}$ energy level for a range of wavelengths for which the crystal is transparent.

II. EXPERIMENTAL

We orientated a 4 × 4.5 × 5 mm KYbW crystal to allow diode-laser pumping along the a-axis and allow maximum absorption for light polarized parallel to Nm. Pumping was achieved with a diode-laser offering 16W at 980nm. Fast-axis diode-laser light was collimated and focused to a strip with full width half maximum of 23µm on the crystal surface. The slow-axis diode-laser light was focused and apertured to produce a 4.5mm long top-hat strip on the crystal surface. This pumping region defined the refractive index profile and thus the guided mode area of the waveguide.

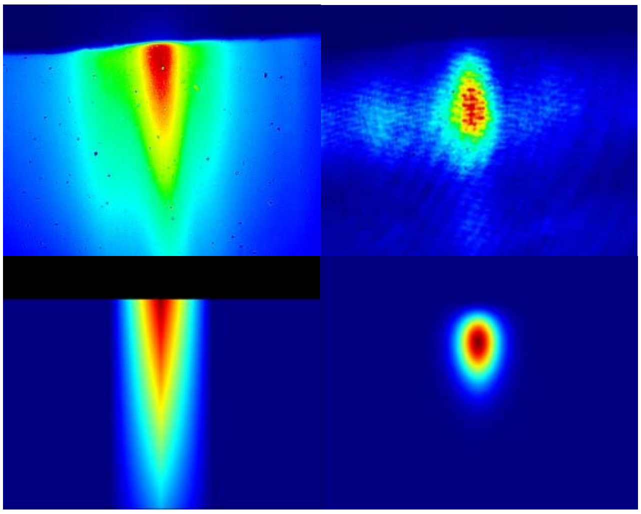

Figure 2. (a) Measured 1000nm+ luminescence due to pumping. (b) Measured guided He-Ne mode profile. (c) Reconstructed refractive index profile chosen to match luminescence. (d) Reconstructed mode profile by optimising the magnitude of refractive index change in c. Individual images sizes are width=153µm, height =123µm.

The diode-laser was operated quasi-CW with a pulse length of 1ms and variable repetition rate in order to reduce and monitor significant thermal refractive index changes.

The normalized refractive index change profile of the cross-section of the waveguide could be determined by measuring the 1000nm+ luminescence from the crystal surface when pumped with the diode-laser. The crystal surface was imaged with a CCD camera and is shown in Figure 2a). This luminescence is proportional to the number of excited ions and is thus proportional to the electronic index change.

He-Ne probe light was coupled into the waveguide with microscope objectives. Probe light was chopped with a mechanical rotating chopper with a duty cycle of 1% to ensure that the probe pulse arrived at the crystal for a fraction of the pump pulse. The He-Ne chopper was temporally locked to the diode-laser to ensure that the probe pulse arrived after the creation of the waveguide and before removal of the waveguide.

The guided mode of the waveguide is shown in Figure 2b). The measured mode profile has a FWHM width of 20µm and a FWHM height of 31µm. Unguided He-Ne light was measured to diffract to a width of 100µm after 4mm propagation in the crystal making it easy to distinguish between guided and unguided light.

Using finite element analysis software (COMSOL) it was possible to reconstruct the refractive index profile of the waveguide in order to estimate the refractive index change created by diode-laser pumping. Figures 2c) and 2d) show the normalized reconstruction of the refractive index profile and guided mode respectively. Using this technique a peak refractive index change of 1×10^{-4} was calculated. This value is significantly lower than the theoretical maximum due to the low pump absorption of 1.2W used in this experiment.

To confirm that the waveguide is formed by the electronic index change, and not some other mechanism, the temporal

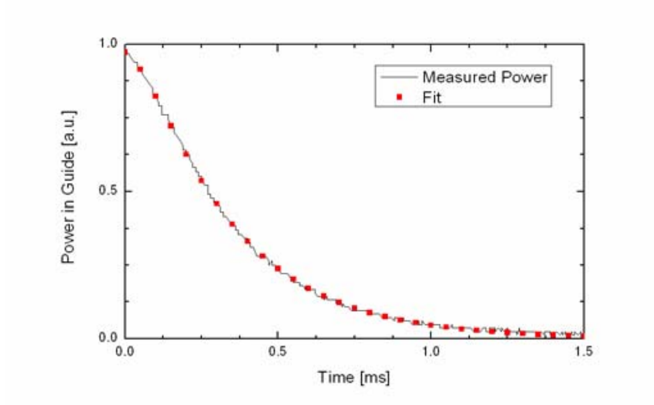

Figure 3. He-Ne power in waveguide after switch off of the diode-laser pump. This power has been shown to be proportional to the refractive index change of the waveguide due to the small index change and large coupling angle. Overlaid is a fit using equation 2.

characteristics of the waveguide were examined. The He-Ne chopper was removed and constant probe light was injected into the waveguide during its creation and removal. Waveguide output light was focused onto a detector to monitor the power in the waveguide as the pump was removed and thus the waveguide was removed.

It was found that the decay is comprised of a small negative thermal component with a lifetime of 75µs and a large positive electronic component with a lifetime of 300µs. This electronic lifetime agrees well with the value available in literature for KYbW (350µs [2]) and the thermal lifetime is similar to that for transient gratings. The negative sign of the thermal component is consistent with the pumping direction as the dN/dT is negative across the waveguide. The orientation of the crystal could be chosen to minimize this thermal component [3].

We propose the formation of a variable directional coupler using the same waveguide formation technique. Suitable design parameters will be presented at the conference.

REFERENCES

[1] J. MacKenzie "Dielectric Solid-State Planar Waveguide Lasers: A Review," IEEE Journal Selected Topics in Quantum Electroncs, vol. 13, no. 3, pp.626-637, 2007.

[2] M. C. Pujol, M. A. Bursukova, F. Guell, X. Mateos, R. Sole, J. Gavalda, et al., "Growth, optical characterization, and laser operation of a stoichiometric crystal KYb(WO4)(2)," Physical Review B, vol. 65, no. 16, pp., 2002.

[3] E. V. Ivakin, A. V. Sukhadolau, O. L. Antipov, and N. V. Kuleshov, "Transient grating measurements of refractive-index changes in intensively pumped Yb-doped laser crystals," Applied Physics B-Lasers and Optics, vol. 86, no. 2, pp. 315-318, 2007.

[4] R. Moncorge, O. N. Eremeykin, J. L. Doualan, and O. L. Antipov, "Origin of athermal refractive index changes observed in Yb3+ doped YAG and KGW," Optics Communications, vol. 281, no. 9, pp. 2526-2530, 2008.

[5] R. C. Powell, S. A. Payne, L. L. Chase, and G. D. Wilke, "Index-of-Refraction Change in Optically Pumped Solid-State Laser Materials," Optics Letters, vol. 14, no. 21, pp. 1204-1206, 1989.

[6] A. M. Prokhorov, V. I. Zhekov, M. I. Studenikin, and V. P. Danilov, "An induced-waveguide YAG : Er3+ laser (lambda=2.9 mu m) using Y1.5Er1.5Al5O12 crystals," Laser Physics, vol. 10, no. 2, pp. 526-531, 2000.

[7] L. J. McKnight, S. Calvez, "Gain-guided KYb(WO4)2 Laser," Europhoton 2010, Hamburg, 29th Aug 2010.