Femtosecond irradiation induced refractive-index changes and channel waveguiding in bulk Ti^{3+}:sapphire

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Abstract: Femtosecond writing of refractive-index changes in sapphire is demonstrated by doping the crystal with an appropriate ion (here: Ti^{3+}) that reduces the threshold of the process. Passive and active buried channel waveguiding is demonstrated.

OCIS codes: 230.7380 Waveguides, channeled, 130.0130 Integrated optics, 320.2250 Femtosecond phenomena

1. Introduction

Nonlinear absorption of femtosecond laser pulses has been employed in order to induce structural changes by micro-explosions in numerous materials [1] and also for fabrication of waveguide structures [2-4]. Here we report, for the first time, writing of waveguides by femtosecond pulses in a hard crystalline material, Ti^{3+}:sapphire. Around micro-damaged areas induced by femtosecond irradiation, waveguiding is observed. Waveguides in Ti:sapphire are of great importance for application as low-threshold tunable lasers, integrated femtosecond lasers, and as broadband light sources in optical coherence tomography [5].

2. Fabrication and characterization of channel waveguides

A Ti^{3+}:sapphire laser with a pulse duration of 150 fs at a repetition rate of 1 kHz and center wavelength of 790 nm was focused by a 0.3 NA microscope objective into the bulk of the material (100 to 300 µm deep). The pulse energy was varied from 0.5 to 6 µJ and the writing speed from 9 to 17 µm/s. One sample of pure c-cut sapphire and two samples of Ti^{3+}:sapphire with Ti^{3+} concentrations of 0.15 and 0.21 at% were irradiated. Whereas the undoped sapphire did not show any damage or refractive-index modification, channels inside the bulk Ti^{3+}:sapphire approx. 10 mm in length were successfully written by moving the sample perpendicular to the irradiating laser beam. In Fig. 1, a microscope image of the end-face of the 0.15 at% Ti^{3+}:sapphire sample is depicted.

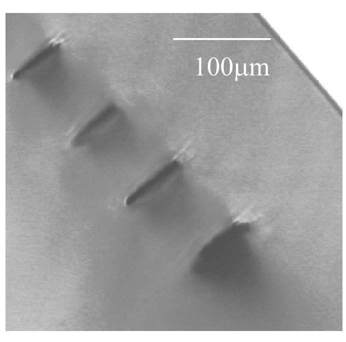

Fig. 1. Microscope image of the end-face of the irradiated Ti^{3+}(0.15 at%):sapphire sample.

In the Ti^{3+}:sapphire samples both the light of a He-Ne laser at 633 nm launched into areas adjacent to the channels as well as infrared fluorescence from Ti^{3+} ions excited by an Ar-ion laser launched into the same areas exhibit channel waveguiding. Mode images of guided light at 633 nm recorded by a CCD camera are shown in Fig. 2. The spectral shapes of fluorescence (Fig. 3) emitted from waveguide and bulk regions of the Ti^{3+}:sapphire sample were compared with an optical spectrum analyzer. Using the technique of digital holography [6], an accumulated refractive-index decrease along the irradiation path was detected. The guiding area is located around the damaged area and is induced by a stress field created by the femtosecond irradiation [2,4].

The fact that irradiation using the same parameters did not show any effect in undoped sapphire indicates that the threshold for creating micro-damage by femtosecond irradiation is greatly decreased when sapphire is doped with Ti^{3+} ions. A probable reason is that two-photon absorption into the dopant's absorption band in the blue-green spectral region has a higher probability than four-photon absorption into the band gap of the host. In addition, the lattice distortion initially introduced to the sapphire lattice by the Ti^{3+} dopant may also support the mechanism that induces the observed micro-damage.

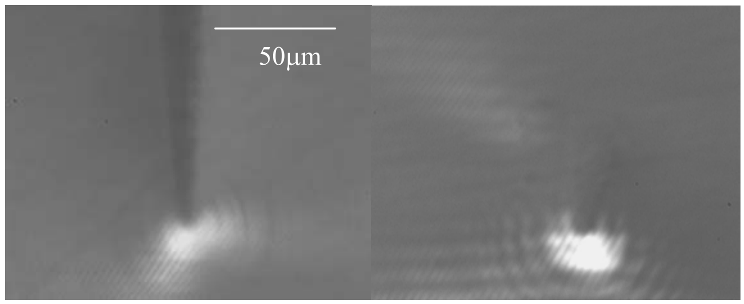

Fig. 2. Mode profiles at 633 nm of two different waveguides written into the bulk of the Ti^{3+}(0.21 at%):sapphire sample. (Visible diagonal fringes are due to a detection artifact)

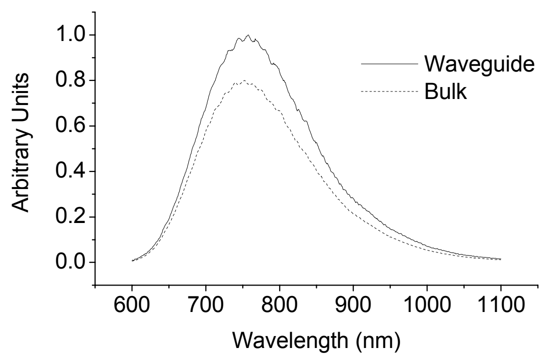

Fig. 3. Fluorescence output signals collected from waveguide and bulk regions of the Ti^{3+}(0.21 at%):sapphire sample

3. Conclusions

It has been shown that refractive-index modifications and channel waveguides can be written in a hard crystalline material by sensitizing the crystal with an appropriate dopant ion. Future work will concentrate on investigating the dependence of the waveguide characteristics on fabrication parameters and on studying the physical origin of the process. Furthermore, femtosecond processing of properly doped samples is expected to lead to 3D optical circuits in various crystalline materials.

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