Step-index Nd:YAG ceramic buried channel waveguides fabricated by direct laser writing

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Abstract: Multi-scan femtosecond laser writing has been used for the fabrication of high contrast buried channel waveguides in Neodymium doped YAG ceramics. The fabricated structures have been demonstrated to be capable of light confinement in the near infrared. Confocal fluorescence microscopy has been used to elucidate the femtosecond assisted modifications induced in the Nd:YAG network. Based on the obtained fluorescence images the mechanisms leading to the refractive index increment at the modified zone have been discussed. The near infrared laser properties of the fabricated structures have been also investigated.

Since the pioneering work of Davis et al.,[1] direct laser writing (DLW) with subpicosecond pulses has become a well-established and versatile technique for the microprocessing of transparent media for integrated optics applications. Because of its inherent advantage for three dimensional (3D) processing inside the bulk of substrates, ultrafast DLW has already been used for the straightforward demonstration of numerous photonic devices such as 3D photonic crystals,[2] photonic lanterns,[3] integrated gratings,[4] and near-field lenses.[5] Ultrafast DLW has also been proved to be an almost universal technique for waveguide (WG) writing in almost any transparent material.[6-8] Within the field of solid state lasers, Neodymium doped ceramic yttrium aluminum garnet (Nd:cYAG) is of special relevance.[8] So far, the DLW process in Nd:YAG has been based on the direct creation of surface or volume damage,[9,10] and on the use of the collateral strained regions as waveguide cores.[6,8] Indeed, the fabricated structures were found to retain the outstanding spectroscopic properties of Neodymium ions in the as-fabricated YAG ceramics. As a matter of fact the fabricated waveguides were found to be highly efficient laser sources.[11] Most of the structures reported up to now were based on the refractive index changes produced by the combination of lattice damage at focus (refractive index decrease) and lattice compression in the surroundings of damage volumes (this yielding to a refractive index increment). This approach, although demonstrated to provide excellent results, has the main drawback that propagating radiation along the waveguides has a non-negligible overlap with damage volumes leading to residual propagation losses. In addition, the stress based waveguides fabricated in Nd:cYAG were not able of optical confinement for wavelengths longer than 1300 nm.

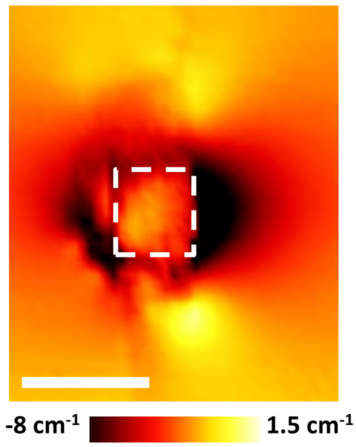

Figure 1.- *Typical fluorescence image (in terms of spectral induced displacements) corresponding to a step-index Nd:YAG ceramic buried channel waveguides fabricated by direct laser writing*. Scale bar is 10 µm.

In this work we have demonstrated the fabrication of buried channel waveguides in Nd:cYAG ceramics by the multiscan direct laser writing method in absence of drastic damage.[12] Waveguiding is provided by the refractive index increment created at focus. The advantage of the waveguides reported here over the typically used Type II stress-induced ones is their capability for light confinement for wavelength longer than 1.3 µm, as well as the ease with which the core parameters, such as size and contrast, can be tailored. Luminescence images of the waveguides have revealed that the writing process causes a complex distortion of the Nd:cYAG network (see **Figure 1**). A great variety of novel and unexpected phenomena have been observed including, as an example, the site-redistribution of Neodymium ions in the YAG network very likely related to the formation of ion pairs during laser writing procedure. The possible physical mechanisms at the origin of the refractive index increment have been discussed and compared to those previously reported for stress based channel waveguides also fabricated in Nd:cYAG waveguides. The potential use of the fabricated structures as integrated laser sources is discussed on the basis of their fluorescence images. We provide on the first, up to the best of our knowledge, laser action demonstration in multi-scan fabricated Nd:cYAG waveguides**.**

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