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Effect of silver nanoparticles on the production of double line waveguide written by fs laser on Nd^{3+} doped GeO_2-PbO glasses

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Abstract: We report the production of double waveguides in Ge_2O-PbO glasses doped with Nd^{3+} and silver nanoparticles by direct femtosecond laser writing. The beam quality measurements and refractive index change are presented.

1. Introduction

Heavy metal oxide glasses appear as excellent candidates for many photonic applications; these glasses normally exhibit large transparency window (400-5000 nm), large polarizability, low cut-off phonon energy (~800 cm^{-1}), high vitreous stability, large mechanical resistance, high chemical durability, and high refractive index (~2.0). Germanate glasses doped with rare-earth ions have been extensively explored, as follows: sensors, lasers, fibers, white-light generation, frequency upconverters, optical amplifiers and non-linear optical devices [1]. In particular, effects of silver (Ag) nanoparticles on the enhancement of luminescent properties of Nd^{3+} doped Ge_2O-PbO glasses were reported [2]; recently, we demonstrated a new configuration of double line waveguides produced directly into Nd^{3+} doped GeO_2-PbO glasses by femtosecond (fs) laser writing for integrated optics application [3]. Motivated by these results, we report the fabrication and passive characterization of double line waveguides written directly into GeO_2-PbO glasses containing Nd^{3+} ions and Ag nanoparticles using a Ti:Sapphire femtosecond (fs) laser operating at 800 nm, delivering 30 fs pulses at 10 kHz repetition rate. The lines, separated by a distance of 10 µm and positioned 0.75 mm beneath the surface, were formed by 4 and 8 overlapping lines, using a writing speed of 0.5 mm/s and pulse energy of 30 µJ. We present results of output mode profile, beam quality factor M^2 (at 632 and 1064 nm) and refractive index.

2. Experimental Procedure

The glasses were fabricated adding Nd_2O_3 (1.0 wt%) and $AgNO_3$ (2.0 wt%) to the original composition GP ($40GeO_2$-60PbO wt.%). The melt-quenching method was used to prepare the samples [2]; the samples were polished, cut, and submitted to additional heat-treatment in order to thermally reduce the Ag^+ ions to Ag^0 and nucleate Ag nanoparticles, as reported previously [1,2].
A pair of parallel lines (each written line is formed by 4-8 overlapping lines) was written with the fs laser system (Ti:sapphire, model PRO 400, Femtolasers GmbH) and using a focusing lens of 200 mm focal length. . The laser beam was incident perpendicular to the polished sample surface, with its linear polarization tilted 45° with respect to the movement direction at a speed of 0.5 mm/s.
An optical coupling system, based on a He-Ne laser (632 nm) and 40 x objective lens was used to couple the light The refractive index change (Δn) was calculated by the measured numerical aperture (NA) of the waveguide, as described in Ref. [4]. The beam quality factor (M^2) at 632 nm was obtained using standard procedures [5].

3. Results and Discussion

The near-field beam image at the output and the top view image of the double line waveguide written with 8 overlapping lines are shown in Fig. 1a and b, respectively. Table 1 summarizes the values obtained for M_x^2 and M_y^2, Δn_x and Δn_y at 632 nm. The refractive index change at 632 nm was $\Delta n_x = 5.47 \times 10^{-3}$; $\Delta n_y = 4.27 \times 10^{-3}$ and $\Delta n_x = 8.09 \times 10^{-3}$; $\Delta n_y = 4.15 \times 10^{-3}$ for double waveguides written with 4 and 8 overlapping lines, respectively, in both horizontal and vertical directions.
Similar values for M_x^2 and M_y^2 are achieved under all conditions showing x,y-symmetrical guiding, mainly for the waveguide with 8 overlapping lines, presented in Table 1.

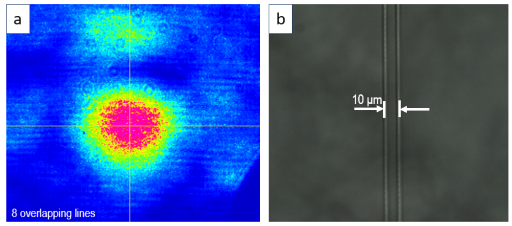

Fig. 1. (a) Near field mode profile (at 632 nm) of the beam transmitted and (b) top view microscope image of double line waveguide with 8 overlapping lines.

Table 1. Results of Δn, M_x^2 and M_y^2

Parameters	4 overlapping lines	8 overlapping lines
M_x^2 (at 632 nm)	5.12	5.22
M_y^2 (at 632 nm)	3.66	5.82
Δn_x	$5.47\text{x}10^{-3}$	$8.09\text{x}10^{-3}$
Δn_y	$4.27\text{x}10^{-3}$	$4.15\text{x}10^{-3}$

Fig. 2 presents the results of M_x^2 and M_y^2 (at 632 nm), respectively for the double waveguide written with 8 overlapping lines.

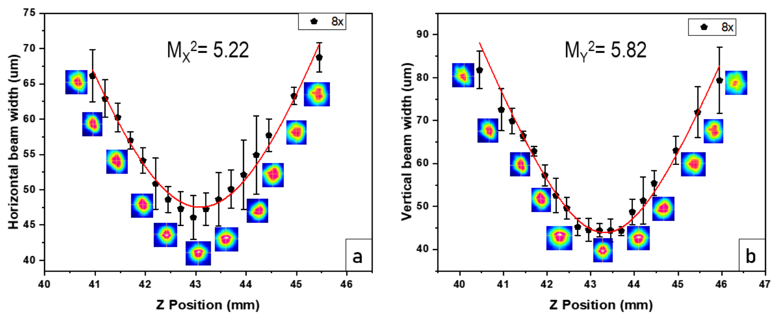

Fig. 2. Results of M_x^2 and M_y^2 at 632 nm of double line waveguide with 8 overlapping lines (30µJ).

4. Conclusions

Compared to previous results (GP with 1.0 wt% of Nd_2O_3) [3], the M^2 values presented in this work (GP with 1.0 wt% of Nd_2O_3 and 2.0 wt% of $AgNO_3$) improved significantly. In the near future we will also investigate the influence of Ag nanoparticles on the relative gain at the near infrared region for optical amplifier applications.

5. Acknowledgments

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