Femtosecond direct writing of waveguides in optical materials

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Abstract: Waveguiding devices are fabricated in optical materials using a femtosecond pulse train from a Ti:Sapphire laser at a 25 MHz repetition rate. The fabricated structures are characterized through interferometry and Raman spectroscopy.

SUMMARY

Direct laser writing has drawn considerable attention since the development of femtosecond lasers and the recognition of there ability to change the properties of optical materials. This has now emerged in the field as one of the possible routes for the fabrication of optical waveguides. This technique offers the unique advantage of being able to fabricate three dimensional waveguiding structures in transparent materials. A variety of optical devices fabricated by femtosecond direct writing have been reported for optical glasses [1].

It was recently demonstrated that waveguides could be written using femtosecond laser oscillators without the need for amplification [2-4]. This helps reducing the cost, complexity and size of the microfabrication system. In addition, the repetition rate of laser systems using an amplifier stage typically lies in the kHz regime. In contrast, unamplified systems allow repetition rates an order of magnitude higher or more, typically around 100 MHz, enabling fast and efficient processing.

We present and characterize waveguiding structures such as a couplers and an interferometer fabricated with an umamplified femtosecond laser at 800 nm (Figure 1). We developed a special Ti:Sapphire cavity design suitable for this application. This high repetition rate high pulse energy laser was obtained by extending the physical length of the cavity with intracavity mirrors. Pulse energies at the 20 nJ level were obtained at a 25 MHz repetition rate and were sufficient to produce permanent irreversible changes of the optical properties in chalcogenide glass [5].

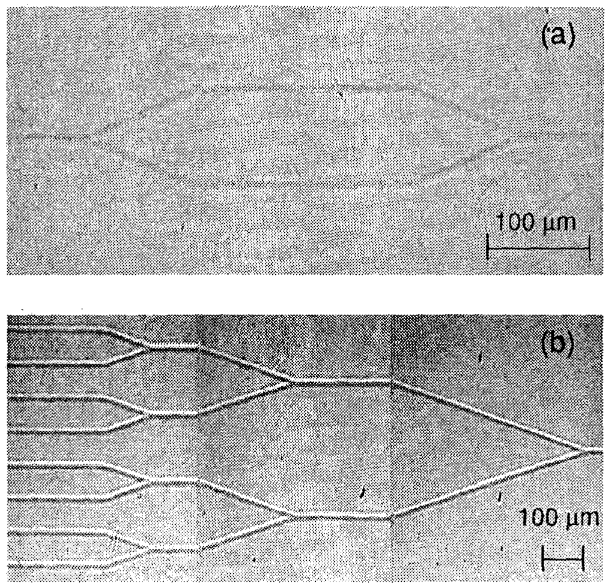

Figure 1 - Optical microscope image of (a) a Mach-Zehnder interferometer and (b) a 1x8 coupler

The fabrication process as well as the waveguide metrology will be described and the coupling efficiency in the waveguides is quantified. The refractive index differential Δn was measured through interferometric techniques to be Δn~0.04 for typical exposure conditions (10^6 pulses per focal spot, 0.25 GW/cm^2 peak intensity). Due to the high photosensitivity of arsenic trisulfide, the Δn value is greater than what has been measured in traditional oxide glasses, even exposed with higher laser intensities [6,7]. The dependence of the refractive index differential on both beam intensity and energy dose (i.e.: number of pulses per focal spot) was studied. The peak intensity was adjusted with a variable metallic neutral density filter and the energy dose was adjusted by varying the translation speed between 0.1 and 20 mm/s. When the peak intensity is kept constant and the energy dose is increased, the Δn value increased following a somewhat logarithmic trend (Figure 2.a.). By contrast, the dependence of Δn on the pulse intensity for a constant energy dose was much sharper (Figure 2.b.). This result confirms that the mechanisms responsible for the photo-induced index change rely on non-linear processes.

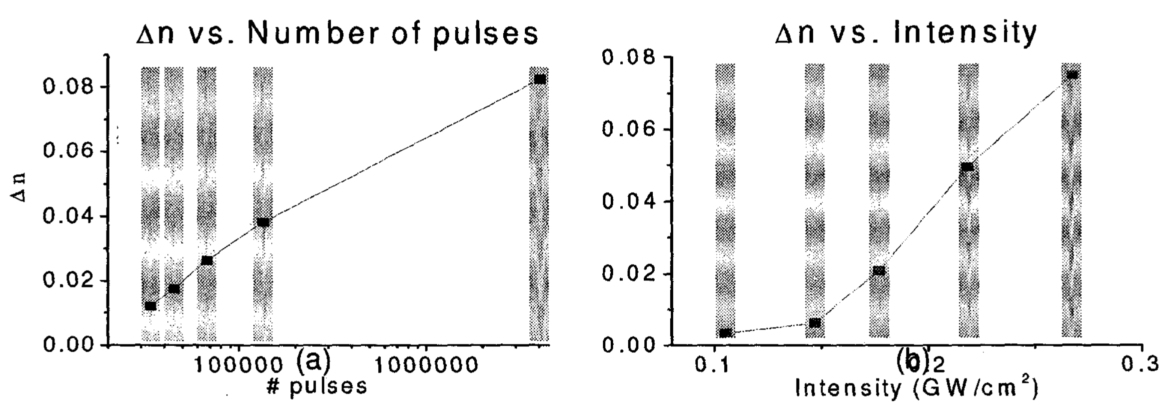

Figure 2 –Dependence of Δn on (a) energy dose and on (b) peak intensity. The background insets show the interferograms corresponding to the measured Δn values.

Finally, the mechanisms at the atomic level underlying the nonlinear photosensitivity of arsenic trisulfide upon femtosecond laser exposure will be assessed from the perspective of Raman Spectroscopy. The photosensitivity of As_2S_3 is linked to the creation of homopolar bonds in the glass network in place of the existing heteropolar bonds, which is in good agreement with previous studies [8].

This approach to waveguide fabrication allows for the rapid production of 3D microstructures without the need of costly and complex laser amplification systems. Combined with our ability to monitor glass structural changes with machining conditions, optimized, stable structures are realized. We expect femtosecond direct writing to play a significant role in the fabrication of integrated optical circuits.

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