MATEC Web of Conferences **8**, 06004 (2013)
DOI: 10.1051/matecconf/20130806004

Ultrafast laser inscribed integrated photonics: material science to device development.

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Abstract: Detailed studies of intense light – material interactions has led to new insights into fs laser induced refractive index change in a range of glass types. This body of knowledge enables the development of advanced processing methodologies, resulting in novel planar and 3D guided wave devices. We will review the chemistry and morphology associated with fs laser induced refractive index change in multi-component glasses such as ZBLAN, phosphates and silicates, and discuss how these material changes inform our research programs developing a range of active and passive lightwave systems.

Keywords: Femtosecond laser inscription, direct-write, refractive index, photonics

Localised refractive index changes, varying in size from a few microns to tens of microns, can be directly written inside bulk glass upon exposure to the tightly focussed output of a femtosecond or picosecond laser. In the seminal papers by Davis *et al* [1] and Glezer *et al* [2], both published in 1996, they were quick to recognize the opportunities of this direct write technique in 2D and 3D guided wave systems and optical storage devices. This field, now 15 years on, has grown dramatically and is now mature enough that devices are produced for real world applications such as spatial multiplexors for optical communications [3], bio-detection [4], quantum logic processing [5, 6] and stellar interferometry [7].

Our understanding into the nature of these changes continues to mature through techniques such as Raman spectrometry, photo-luminescence measurements, refractive index profilometry, annealing, etching, and optical and electron microscopy [8 -11]. Index change is now known to result from a diversity if different effects, depending on the glass composition and irradiation conditions. The underlying factors include modification of the fictive temperature, bond breaking and reformation, generation of colour centres, material migration and internal stress.

The degree to which the index is changed and its sign (ie +ve or –ve) are also dependent on the type of glass irradiated and the irradiation conditions. For example, the index change induced in silica and silicate glasses is commonly positive in sign and falls within the range of 10^{-4} to 5×10^{-3}, a range that is similar to that of conventional optical fibre cores. By comparison, phosphate glasses can manifest in both negative and positive index changes when exposed to fs laser radiation [12, 13]. These insights influence the choice of glass, the engineering of new tailored made glass compositions, and the selection of suitable laser writing parameters. Consequently, ultrafast laser direct writing can be readily exploited to produce a diversity of guided wave components such as splitters, Mach Zehnder interferometers, waveguide arrays, vibration sensors, 3D interconnects and integrated waveguide - microfluidic platforms.

In this presentation our current understanding of ultrafast laser – glass lattice interactions will be reviewed, with a particular focus on ZBLAN, phosphate and silicate glasses. We will discuss how these insights inform our choice of glass and fabrication conditions. Finally, the application of this technology to the development of waveguide lasers and other integrated photonic devices will be highlighted.

Acknowledgments

This research was supported by the Australian Research Council Centre of Excellence for Ultrahigh bandwidth Devices for Optical Systems (project number CE110001018) and performed in part at the OptoFab node of the Australian National Fabrication Facility.

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