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# Femtosecond-laser writing of photonic structures in zinc phosphate glasses

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**Abstract:** Good quality waveguides can be fabricated in zinc phosphate glasses with O/P ratios of 3.25 using the femtosecond-laser writing technique. Compositional effects, including the addition of $Al_2O_3$ and rare-earth doping, are discussed as well as results on the fabrication of active devices.

## 1. Introduction

Focused femtosecond (fs) laser pulses can be used to permanently modify the refractive index of glasses. If the change in the refractive index of the laser-modified material is positive, the material can be easily used to create optical waveguiding structures. Unfortunately, few materials are known to exhibit this property. Phosphate glasses, which are of interest as host materials for active devices since they allow incorporation of high concentrations of rare earth ions, typically produce negative refractive index changes in the laser-exposed regions. We have recently found that good quality waveguides can be fabricated in zinc polyphosphate glass compositions with an O/P ratio close to 3.25 [1-4]. This paper summarizes the effects of glass composition on fs-laser induced structural modification as well as the fabrication of active devices in zinc phosphate glasses.

## 2. Experimental methods

Glasses were prepared using standard melting techniques. A Spitfire LCX laser (Spectra-Physics) operating at 800 nm with a 1 kHz rep. rate of ~150 fs pulses was used for writing all structures in the glasses reported here. The modifications were written longitudinally through a microscope objective with an NA of 0.25 or 0.40 and a translation speed of 50 μm/s. After fs-laser modification the modified regions were tested for optical guiding and characterized with confocal fluorescence (FL) and Raman spectroscopy. Detailed descriptions about the experimental procedures can be found elsewhere [1-4].

## 2. Results and discussion

Glass compositions that were investigated are listed in Table I. Initially we investigated a number of glasses containing ZnO and $P_2O_5$ with varying composition. Within this series only the glass with an O/P ratio of 3.25 produced good waveguides (see Fig. 1). In order to fabricate optical devices that are practical and reliable, it is important to use glass compositions that are stable and robust. By introducing aluminum in small quantities, <10 mol. % $Al_2O_3$, to the zinc phosphate composition the glass becomes more resilient to moisture naturally present in the atmosphere and also more chemically stable as the aluminum adds rigidity to the phosphate glass network [5, 6]. Waveguide writing experiments in these samples again showed that good waveguides with a positive $\Delta n$ of ~ $3 \times 10^{-4}$ could be produced in the samples with an O/P ratio of 3.25.

Table I. Glass compositions of zinc phosphate glasses

| Sample name | Nominal Composition (mole%) | | | O/P | Sample name | Nominal Composition (mole%) | | | O/P |
|---|---|---|---|---|---|---|---|---|---|
| | ZnO | MgO | $P_2O_5$ | | | ZnO | $Al_2O_3$ | $P_2O_5$ | |
| **ZnP** | 60 | 0 | 40 | 3.25 | **ZnAlP2** | 51 | 5 | 44 | 3.25 |
| ZnP2 | 50 | 0 | 50 | 3.00 | **ZnAlP3** | 42 | 10 | 48 | 3.25 |
| ZnP3 | 55 | 0 | 45 | 3.11 | ZnAlP4 | 30 | 10 | 60 | 3.00 |
| ZnP4 | 65 | 0 | 35 | 3.43 | **ZnPErYb1** | 56 | 0* | 42 | 3.25 |
| **ZnMgP** | 30 | 30 | 40 | 3.25 | ZnPErYb2 | 58.8 | 0* | 39.2 | 3.33 |

* ZnPErYb1 and ZnPErYb2 were co-doped with 0.7 mole% $Er_2O_3$ and 1.3 mole% $Yb_2O_3$.
Samples in bold produce good waveguides.

Other zinc phosphate glasses in which good waveguides can be produced include Er-Yb doped glasses with O/P of 3.25 [ref] as well as 30ZnO ◦ 30MgO ◦ $40P_2O_5$ (ZnMgP). This glass composition is based on the original 60ZnO ◦ $40P_2O_5$ with ½ of the ZnO replaced by MgO, and thus also has O/P of 3.25.

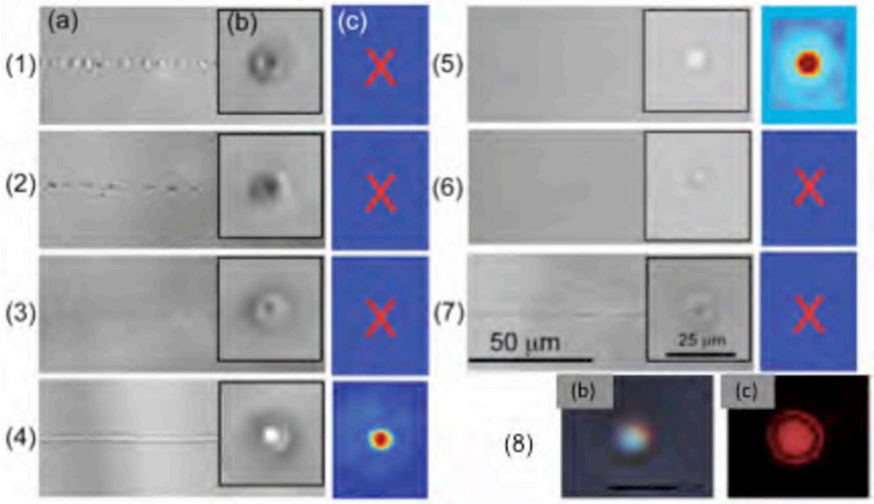


Fig. 1. Microscope images of fs-modified zinc phosphate glass written with fs-laser fluences of 8 J/cm$^2$ (1) ZnAlP4; (2) ZnP2; (3) ZnP3; (4) ZnP; (5) ZnPErYb1; (6) ZnPErYb2; (7) ZnP4; (8) ZnAlP3 (a) white light images of the modification along the waveguide direction (b) Transmission white light images of the modification cross-section (c) 660 nm transmission near field images.

Raman spectroscopy of the laser-modified regions showed that the samples that produced good waveguides exhibited no (or very small) Raman spectral changes with respect to the unmodified glass compared to the samples in which no waveguiding was observed.

In the Er-Yb doped glass we have demonstrated the successful fabrication of subsurface waveguide amplifiers exhibiting internal gain of 1 dB⁄cm at 1.53 µm when pumped with 500 mW at 976 nm [3]. The ZnMgP composition was used to create waveguide Bragg gratings employing a single pass technique in which a waveguide that has a periodic refractive index profile is produced.

## 3. Acknowledgements

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## 4. References

[1] Luke B. Fletcher, Jon J. Witcher, Neil Troy, Signo T. Reis, Richard K. Brow, and Denise M. Krol, “Direct femtosecond laser waveguide writing inside zinc phosphate glass”, Optics Express 19, 7929 (2011).

[2] Luke B. Fletcher, Jonathan J. Witcher, Neil Troy, Signo T. Reis, Richard K. Brow, Rebeca Martinez Vazquez, Roberto Osellame and Denise M. Krol “Femtosecond laser writing of waveguides in zinc phosphate glasses [Invited]”, Optics Materials Express 1, 845 (2011).

[3] Luke B. Fletcher, Jon J. Witcher, Neil Troy, Signo T. Reis, Richard K. Brow, and Denise M. Krol, “Single-pass waveguide amplifiers in Er-Yb doped zinc polyphosphate glass fabricated with femtosecond laser pulses”, Optics Letters 37, 1148 (2012).

[4] Luke B. Fletcher, Jon J. Witcher, Neil Troy, Signo T. Reis, Richard K. Brow, and Denise M. Krol, “Effects of rare-earth doping on femtosecond laser waveguide writing in zinc polyphosphate glass”, J. Applied Physics 112, 023109 (2012).

[5] R. K. Brow, "Nature of alumina in phosphate glass: I, Properties of sodium aluminophosphate glass," Journal of the American Ceramic Society, 76, 913-918 (1993).

[6] R. K. Brow, R. J. Kirkpatrick, and G. L. Turner, "Nature of alumina in phosphate glass: II, Structure of sodium aluminophosphate glass," Journal of the American Ceramic Society, 76, 919-928 (1993).