Photo-thermal Growth of Unsaturated and Saturated Bragg Gratings in Phosphate Glass Fibers

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Abstract: We demonstrate that the strong thermal growth of fiber Bragg gratings in phosphate glass fibers at temperatures between 100 – 250 °C requires the seed gratings written using 193 nm light to be overexposed beyond saturation.

OCIS codes: (060.3735) Fiber Bragg gratings; (060.3738) Fiber Bragg gratings, photosensitivity; (120.6810) Thermal effects; (060.2290) Fiber materials.

1. Introduction

Phosphate glass fiber is a promising choice for building compact and monolithic optical fiber lasers, as the fiber is capable of hosting higher concentration of Erbium and Ytterbium ions without causing cluster formation. However, the lack of photosensitivity in phosphate glass fiber used to prevent the integration of UV-written intra-fiber gratings into the laser cavity. Our group successfully demonstrated the direct writing of gratings in both Erbium-undoped and doped phosphate glass fibers using an ArF excimer laser [1, 2], and we showed that the grating index modulation in phosphate glass fibers can be further strengthened by heating the gratings to temperatures between 100 and 250 °C. This kind of photo-thermal process allows the formation of gratings with high reflectivity and the fabrication of compact distributed feedback (DFB) lasers in active phosphate glass fibers [3, 4]. In this paper, we further investigate the grating fabrication and thermal annealing of Bragg gratings on passive phosphate glass fibers. In particular, we show that it is necessary to irradiate the fiber past the saturation point of the grating writing in order to obtain high-reflectivity gratings during the heating phase.

2. Experiment and Results

Phosphate fibers 5 cm long were spliced to standard telecommunication fiber pigtails. Bragg gratings were written in passive (no rare-earth doping) phosphate glass fibers by using intense UV irradiation from a pulsed excimer laser (PulseMaster 840 series from GSI Lumonics). Operating at wavelength of 193 nm with a gas mixture of ArF, the laser delivered pulses with duration of about 20 ns at repetition rate of 50 Hz. After passing through beam shaping

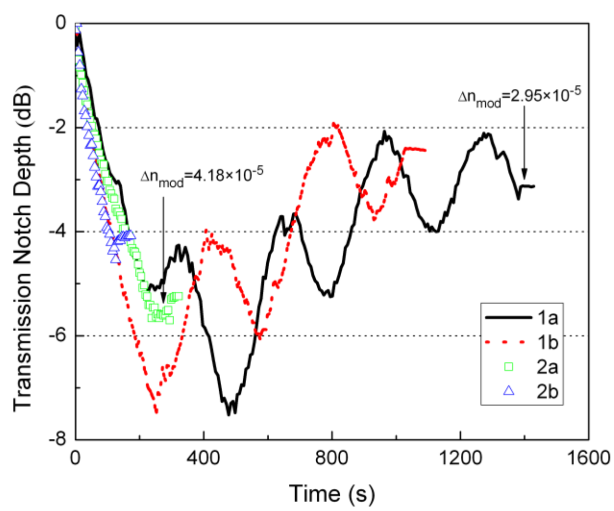

Fig. 1. Growth of 2 cm long FBGs in phosphate glass fiber in 2 groups: Lines represent group 1, which are overexposed gratings beyond saturation; open symbols represent group 2, for which the exposure was stopped at the first sign of saturation.

elements such as apertures and a beam expander, the UV laser beam was focused through a cylindrical lens along the fiber axis to generate a high intensity region with fluence per pulse of ~45 mJ/cm^2. A phase mask with a period of 988.4 μm is placed just in front of the fiber samples to generate fringe patterns on the fiber. During the grating inscription, the grating transmission spectrum was monitored and recorded continually by launching broadband light in the fiber and measuring the transmitted light with an optical spectrum analyzer.

Fig. 1 illustrates the growth of grating transmission notch depths with increasing exposure time for 2 cm long Bragg gratings in phosphate fibers. Gratings 1a and 1b plotted as solid and dash lines in the figure, are saturated gratings which are overexposed and partially erased after the saturation has been reached. Gratings 2a and 2b represented by open symbols are unsaturated gratings, for which the UV exposure is stopped at the first sign of saturation. As shown in the figure, gratings formed in passive phosphate glass fibers typically show a fast growth toward a saturation level with a transmission notch depth around -7.5 dB at the early stage, and then gradually erase in oscillatory fashion upon further exposure. Grating 1a was exposed about 23 min and the grating notch depth was erased to -3.14 dB, which corresponds to an index modulation of 2.95×10^{-5}. In comparison, grating 2a reached a transmission depth of -5.59 dB after a 2.5 min exposure. The index modulation of this grating is about 4.18×10^{-5}.

All of these UV-induced gratings were then subjected to a step-isothermal annealing treatment at temperatures from 100 °C to 250 °C with steps of 50 °C. For each step of isothermal annealing, the gratings were held at the same temperature for duration of about 9 days. The thermal evolution of transmission notch depths of both unsaturated and saturated gratings in phosphate glass fibers is shown in Fig. 2. As shown in the figure, this thermal annealing treatment can increase the strength of the seed gratings significantly. The saturated grating 1a demonstrated a strong growth of transmission notch depth from it initial value down to -16.55 dB, which corresponds to the index modulation of 8.52×10^{-5} (almost 3 times the initial value). In comparison, unsaturated gratings (2a and 2b) grow very little or even decay during the same heating treatment. The spikes on the curves correspond to a reversible grating strength change that occurs when the fibers are returned to room temperature between heating steps.

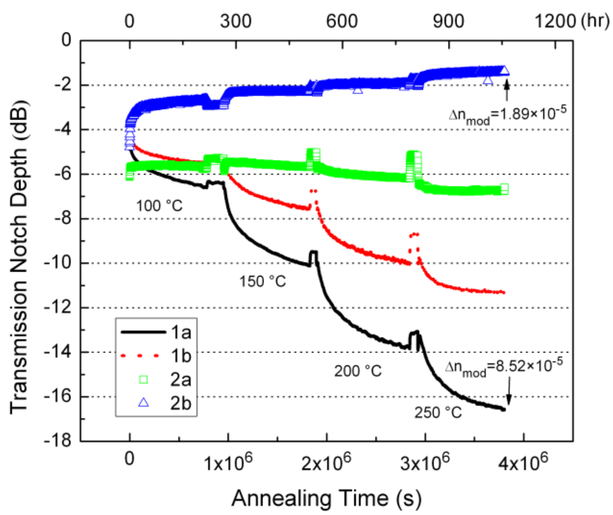

Fig. 2. Thermal evolution of grating transmission notch depth for saturated and unsaturated Bragg gratings in phosphate glass fibers.

3. Conclusion

Both unsaturated and saturated gratings are fabricated in passive phosphate glass fibers by using a 193 nm excimer laser. Thermal annealing experiment on these gratings demonstrated that a strong thermal growth of grating strength requires the UV-induced seed gratings to be overexposed beyond saturation. Possible physical explanations of this behavior will be discussed at the meeting.

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4. References

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