Annealing Properties of Waveguides and Bragg Gratings Fabricated in a Phosphate Glass Host using the Femtosecond-Laser Direct-Write technique

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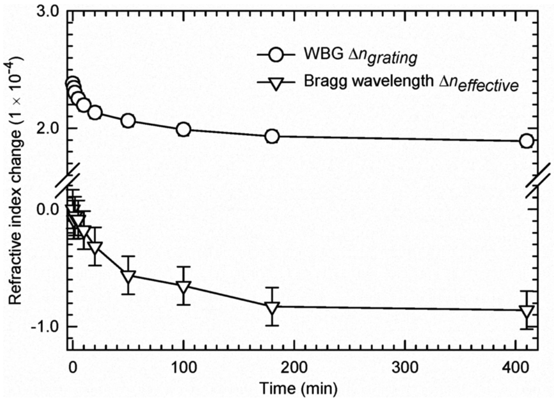
Femtosecond-laser direct-write waveguide lasers are a significantly enabling technology in the fields of sensing, communications, defense and integrated quantum optics. We recently demonstrated distributed feedback (DFB) *monolithic* waveguide lasers with high output powers (of order 100 mW) and optical conversion efficiencies of 17% [1]. However for their general acceptance in the above fields, waveguide lasers need to have proven stability, lifetimes and resilience to changing external environmental conditions. The environmental sensitivity of *integrated* DFB or distributed Bragg reflector (DBR) waveguide-lasers is considerably greater than platforms based on amplifying waveguides and external gratings [2] because changes in the refractive index profile of the waveguide-Bragg grating (WBG) effect both the laser wavelength and the output power due to the changing reflectivity of the grating structures.

In this paper we investigate the refractive index properties of WBGs written in a Ytterbium doped phosphate glass host to determine the effects of pump-laser field and bulk thermal annealing. The use of a WBG written in the *C*-band, outside of the Yb absorption/emission bands, allows detailed studies of the changes in both WBG strength (which reveals the refractive index contrast in the grating) and the Bragg wavelength (which is determined by the effective refractive index, n_{eff}, of the guided mode). We subjected a series of identical ≈ 4 mm long WBG test samples to 976 nm pump light (230 mW absorbed power) and to bulk temperatures up to 200°C. The effect on a WBG of exposure to pump light is shown in Fig. 1. The refractive index contrast of the grating and the waveguide's n_{eff} exhibit a single exponential decay causing a reduction in the reflectivity from 94% to 86% (change in κ from 4.88 to 3.88 cm^{-1}) and a short-wavelength shift of the Bragg resonance by 86 pm. Interestingly, the majority of the material changes occur in the first hour and, as recorded in our laser studies [1], device properties do not alter significantly after that. The evolution of parameters such as these are important considering their effects on laser threshold, output powers and, in the case of DFB based devices, directionality.

Given the natural sensitivity of a Bragg grating to temperature it is important to separate the effects of pump light-field annealing from pump induced thermal annealing. In subsequent bulk thermal annealing studies we determined the $d\lambda/dT$ of the WBG to be 12 pm/°C and the maximum average pump induced heating of the waveguide to be 5°C. Our bulk thermal annealing studies also indicated that temperatures of 100°C and above are necessary for thermal annealing of gratings which leads us to conclude that the thermal influence of the pump on the waveguide is not responsible for the observed decreases in grating contrast and Bragg wavelength.

In this paper we will investigate these effects in detail and assess the relative contributions made by photo- and thermal-annealing on WGL performance.



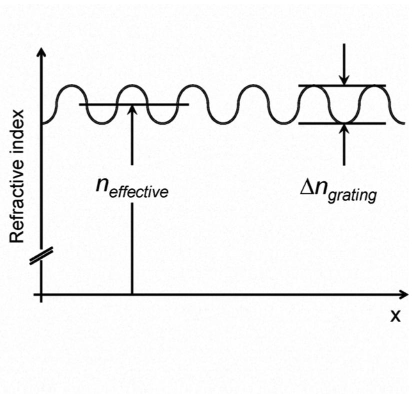


Fig. 1. Pump laser induced waveguide-Bragg grating annealing as a function of time. The pump induced change is measured using the deterioration in grating reflectivity (upper line) and the change in Bragg wavelength (lower line). This is schematically represented in the right-hand cartoon.

References

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[2] G. Della Valle, S. Taccheo, R. Osellame, A. Festa, G. Cerullo, and P. Laporta, "*1.5 μm single longitudinal mode waveguide laser fabricated by femtosecond laser writing,*" Opt. Express, **15**, 3190-3194 (2007).

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