Femtosecond Laser Writing of Phase-Shifted Bragg Grating Waveguides in Fused Silica

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Abstract: Phase-shifted Bragg Grating Waveguide filters were formed in bulk glass for the first time by femtosecond laser direct writing. A narrow, tunable 0.1-nm transmission window at 1550-nm is demonstrated for tunable π and other phase-shifts.

OCIS codes: (130.3120) Integrated optics devices; **(**140.3390) Laser materials processing

1. Introduction

Davis *et al.* [1] demonstrated in 1996 the possibility of creating refractive index change in bulk glasses by focusing a femtosecond laser to drive multiple photon absorption in a confined focal volume. This technique has given way to direct writing of numerous optical devices such as optical waveguides [1,2] in pure silica glass, opening the possibility of three-dimensional integrated optical circuits. A recent modification of this method [3] to drive burst-trains of pulses enabled the formation of high resolution periodically ($\Lambda \approx 0.5$ μm) segmented waveguides with strong Bragg resonance responses satisfying the Bragg grating equation, $\lambda_B = 2n_{eff}\Lambda$. Here, λ_B, n_{eff}, and Λ are the reflected Bragg wavelength, effective refractive index of the waveguide mode and grating periodicity, respectively.

The integration of such Bragg grating waveguide (BGW) devices bring many important new directions for spectral filtering, forming distributed-feedback Bragg grating lasers [4], temperature and strain gauging [5], and optofluidic sensing in bulk glasses. By introducing a precise phase shift into the grating period, very narrow transmission bands have been tailored into the stop-band of fiber Bragg gratings that offer much higher resolution for applications such as optical communication de-multiplexers, DFB fiber lasers, and fiber sensors [6]. This paper reports, to the best of the author's knowledge, the first demonstration of narrow transmission window spectra formed in BGW devices inside bulk fused silica glass. Precise phase shift control during burst modulation is shown to reproducibly generate 'defect' resonances in controlled positions of the Bragg stop band, opening new directions for high resolution and tailored spectral design of BGW devices in 3D integrated optical circuits.

2. Experimental setup

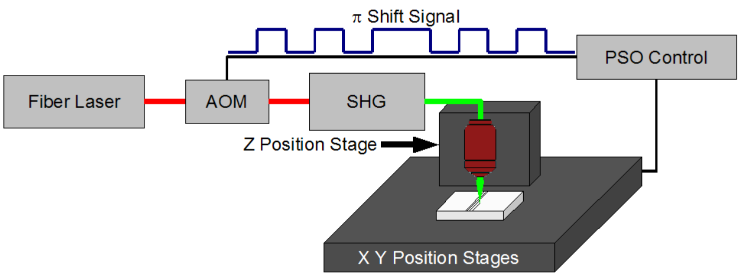

Fig. 1. Femtosecond laser, beam modulation control, and beam delivery arrangement.

To fabricate the phase shifted BGWs, a Yb:fiber chirped pulse amplified system (IMRA America; μJewel D-400-VR), with a centre wavelength of 1044 nm, pulse width of 300 fs, repetition rate of 500 kHz and 150 nJ pulse energy, was used. The laser beam was directed into an acousto-optic modulator (AOM; NEOS 23080-3-1.06-LTD) to create burst trains of laser pulses, which were then focused into a 3-mm thick lithium triborate (LBO) crystal for second harmonic generation to λ = 522 nm of wavelength to drive strong refractive index contrast in fused silica [2]. The beam was focused 75 μm below the surface of the fused silica sample using a 40X, 0.55 NA aspheric lens and scanned on an air-bearing motion stage (Aerotech ABL1000 with 2.5 nm resolution) at constant velocity of 0.26815 mm/s. The AOM was precisely triggered by the position synchronized output (PSO) signal from the Aerotech motion stages to provide 500 Hz burst-trains of laser pulses with an on-duty cycle of 60%. This combination created partially overlapping refractive index voxels with a period of Λ = 536 nm, n_{eff} = 1.446, and Bragg resonance at approximately λ_B = 1550 nm. With appropriate programming, the PSO enable precise phase delays to be introduced in the middle of BGW writing to form a non-segmented waveguide. The experimental setup for the fabrication of the phase shifted BGW is shown in Figure 1.

3. Results

Figure 2a through 2d illustrates the reflection spectrum of relatively weak 5 mm Bragg grating waveguides with $\frac{\pi}{2}$, π, and $\frac{3\pi}{2}$ phase shifts and a regular BGW (0 phase shift), respectively, demonstrating the precise control of this new PSO-AOM modulation technique. A 0.1 nm wide defect line is accurately positioned in the centre of the π-shifted Bragg resonance. The spectra were measured using a swept wavelength system (JDS Uniphase SWS2000) which has a spectral resolution of 3 pm.

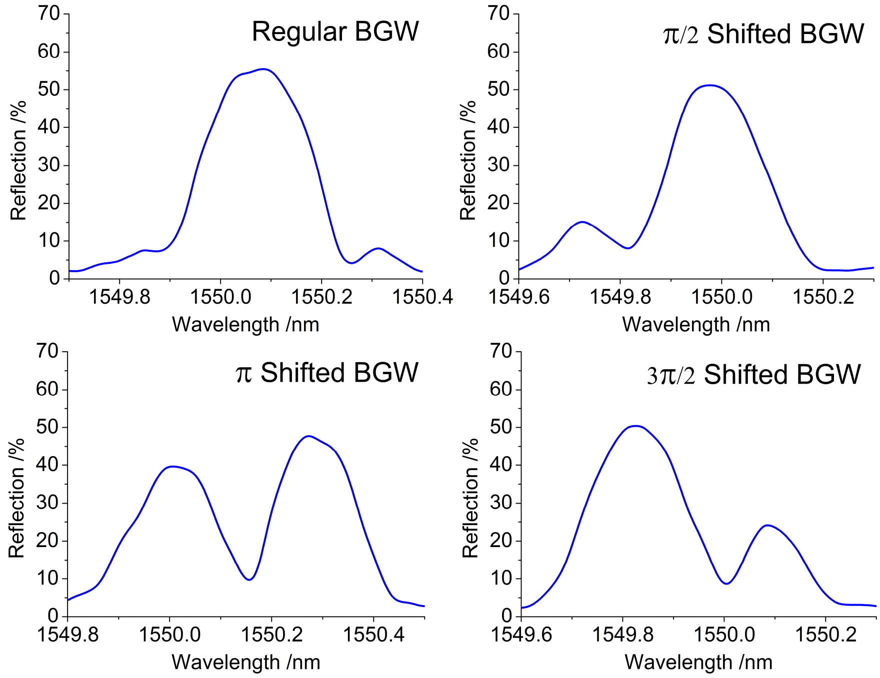

Fig. 2. Reflected spectra of phase shifted Bragg grating waveguides.

4. Conclusion

We reported on the first demonstration of fabricating phase shifted Bragg grating waveguides in fused silica by femtosecond laser direct writing. The phase shifts are controllable and repeatable and have a very narrow bandwidth below 0.1 nm, which may enable the fabrication of very precise optical devices. The present technique further enables apodization, chirping, and multiple defects to be employed for high spectral control of BGWs. Several additional examples of such phase and apodized controlled BGWs will be presented.

5. References

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