Ring-by-Ring Femtosecond Inscription of a Multilayer Single-mode Bragg Grating in Sapphire Optical Fiber

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Abstract: A multilayer Bragg grating was inscribed in sapphire optical fiber using a femtosecond laser. The grating was single-mode at 1550 nm with a ~0.3 nm bandwidth, showing potential for multi-point high-temperature sensing. © 2022 Creative Commons Attribution 4.0 License.

1. Introduction

Fiber Bragg gratings (FBGs) have been widely used in telecommunications and industrial monitoring. Compared to FBGs fabricated on silica optical fibers, sapphire fiber Bragg gratings (SFBGs) have several advantages. They have been demonstrated to survive higher temperatures up to 1900°C [1]. They are also radiation-hard and more chemically resistant. However, sapphire fibers are intrinsically multimode, because of their high refractive index and absence of cladding. This causes SFBGs to have a broad peak, which limits the accuracy of sensing applications and their potential as quasi-distributed sensors. There has been continuous research effort to write a few-mode FBG within a commercial sapphire optical fiber [2]. In this work, we report the inscription of a single-mode multilayer SFBG, written by a femtosecond laser using a ring-by-ring method.

2. Fabrication and Characterization

The laser fabrication was performed using a regenerative femtosecond laser system (Light Conversion, Pharos SP-06-1000-PP), emitting linearly polarized light at a wavelength of 515 nm with a 170 fs pulse duration. A half-waveplate and a polarizer were used to adjust the pulse energy. The sample was a 1-cm long sapphire fiber with a diameter of 425 μm (Photran, Laser Components). It was mounted on a 3-D nano-precision motion stage and translated at a speed of 0.1 to 1 mm/s. The repetition rate was 1 MHz. The beam was tightly focused using a 40× objective (0.75 NA) at a depth between 50 and 100 μm below the fiber top surface. A Spatial Light Modulator (SLM) was used to dynamically compensate for the aberration. A schematic of the SFBG is shown in Fig. 1, written using a ring-by-ring method.

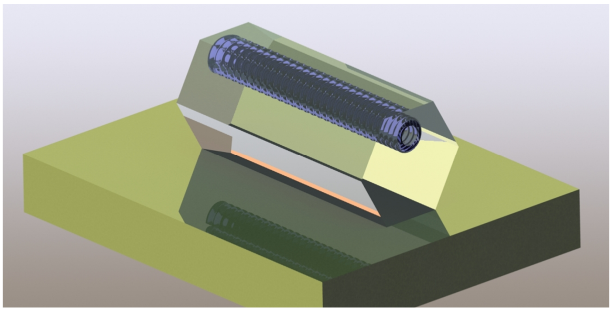

Fig. 1. The schematic of the SFBG.

Waveguides and Bragg gratings were firstly inscribed on planar sapphire substrates to obtain the parameter window for fabrication. This was achieved following a process similar to that described in [3]. These optimized parameters were then used to inscribe the SFBG. As the depressed cladding waveguide propagation loss is dominated by the mode leakage, two outer layers were added outside the SFBG for loss mitigation [4]. The structure was written following a three-step process: firstly, the bottom two layers were written at 1 mm/s translation speed and a pulse energy of 22 nJ; secondly, a second-order FBG was inscribed at 0.1 mm/s with a 30 nJ pulse energy; finally, the top layers were written using the same parameters as the bottom layer. Phase correction was applied on the SLM to compensate for the curvature of the sapphire fiber surface [5]. Figure 2 shows the cross-sectional and top views of the SFBG under a microscope. The dimensions were measured to be ~9 and ~8 μm, respectively, for the major and minor axes of the inner ring, and ~53 and ~26 μm for those of the outer ring.

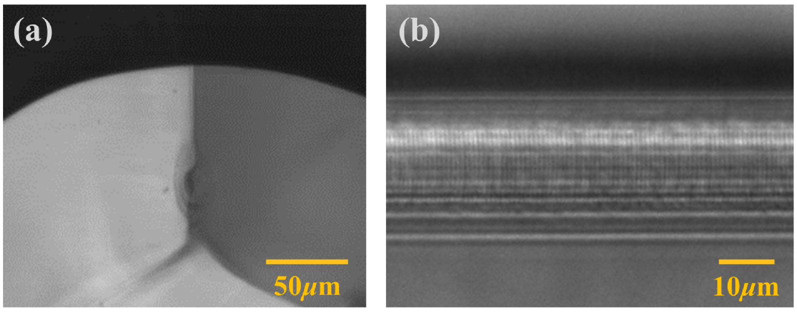

Fig. 2. (a) The cross-sectional view and (b) top view microscope images of a second-order SFBG inside two outer layers.

After fabrication, the SFBG section was polished using silica carbide polishing pads. The transmitted mode field was profiled using a near-infrared waveband imaging system. A 1550 nm laser (ID Photonics, CoBrite) was injected into a single-mode fiber (Corning SMF28e+), and the cleaved fiber tip was butt-coupled to the sapphire fiber. Figure 3(a) shows the mode field measured using an InGaAs camera (Hamamatsu C14041-10U). The measurement shows single-mode operation. However, the mode field was distorted, because of the limited polishing quality and the excessive loss due to the surface inhomogeneities along the sapphire fiber length. The spectral performance of the SFBG was characterized using a tunable laser source and photodetector system (Agilent 8164A) and a 3-dB coupler, as presented in Fig. 3(b). The reflection spectrum exhibits a Bragg resonance wavelength at 1549.04 nm with a bandwidth of ~0.3 nm. We attribute the smaller additional reflection peaks to ripples coming from the light interference of an optical cavity, formed by the front and end facets of the sapphire fiber.

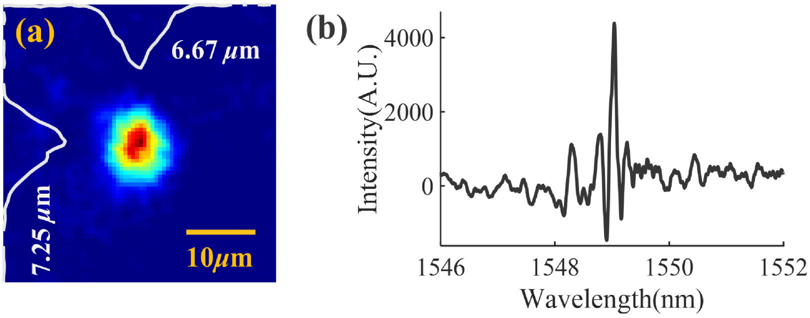

Fig. 3. (a) The measured mode profile at 1550 nm and (b) the reflection spectrum of the SFBG.

3. Conclusion

To conclude, a second-order multilayer FBG was fabricated within a 425 μm diameter sapphire optical fiber. The SFBG was single-mode from experimental observation and has a narrow bandwidth of ~0.3 nm. The result presented here shows great promise for accurate measurement using multi-point quasi-distributed sensing or telecommunication applications under challenging environments.

4. References

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