Fabrication of Microfiber-Based Bragg Gratings with Ultraviolet-Light Exposure

Xiaocao Yu, Xinwan Li*, Ying Zhang, Linjie Zhou,Wenning Jiang, and Jianping Chen
State Key Laboratory of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200030, P. R. China
**lixinwan@sjtu.edu.cn*

Abstract: We fabricated microfiber-based Bragg gratings with ultraviolet-light exposure. Bragg reflections are observed for gratings with diameters of several micron-meters. The dependence of Bragg grating characteristics on the microfiber diameter is investigated.

OCIS codes: (060.3735) Fiber Bragg gratings; (130.3120) Integrated optics devices; (220.4000) Microstructure fabrication; (230.3990) Micro-optical devices

1. Introduction

Fiber Bragg gratings (FBGs) have been intensively investigated as a basic optical fiber component that is widely utilized in optical communications [1], multi-wavelength fiber lasers [2], and optical fiber sensors [3]. Conventional FBGs are fabricated in standard single mode fibers (SMFs), in which the light energy is strongly confined in the core and the refractive index modulation depth is uniform along the entire length of FBGs. For some applications such as optical fiber sensors, high sensitivity to environmental measurands is needed, for which the conventional FBGs are not good candidates. A possible solution is to fabricate FBGs in microfibers (MFs), where a fraction of guided light leaks outside the fiber core. Thanks to the property of the light leakage varying with the MFs' diameter, the index modulation depth in MF-based FBG (MF-BG) changes with the MFs' diameter. MFs can be easily drawn from conventional fibers by flame-heating [4] or electric strip heating [5]. Moreover, MFs have superior optical wave-guiding properties, including micrometer diameters, small effective area, and large waveguide dispersion [4], which enables many functional devices in applications to optical communication and biochemical sensing [6].

So far, MF-BGs were fabricated using hydrofluoric (HF) etch-erosion [7] and femtosecond laser pulse irradiation [8]. However, these two methods have certain limitations. HF etch-erosion method is complicated and not convenient to use, and laser irradiation method needs accurate alignment of the laser beam to the MF suffering a low production capability. Ultraviolet (UV) light exposure is a common method to fabricate FBGs in industry. If one can fabricate FBGs in MFs by simply using UV light exposure, a mass production capability is estimated.

In this paper, we demonstrate MF-based Bragg gratings (MF-BGs) fabricated using UV light exposure without hydrogen load in the MFs, which is a cost-effective and reliable way to fabricate MF-BGs. The measured 3dB bandwidth of our fabricated MF-BGs can achieve ~0.3 nm which is much narrower than previously demonstrated MF-BGs [8], implying its potential functions as WDM filters and fiber sensors. The integration of MF-BGs with other micro/nano scale devices is also promising in future photonic integrated circuits [9].

2. Fabrication of the MF-BGs

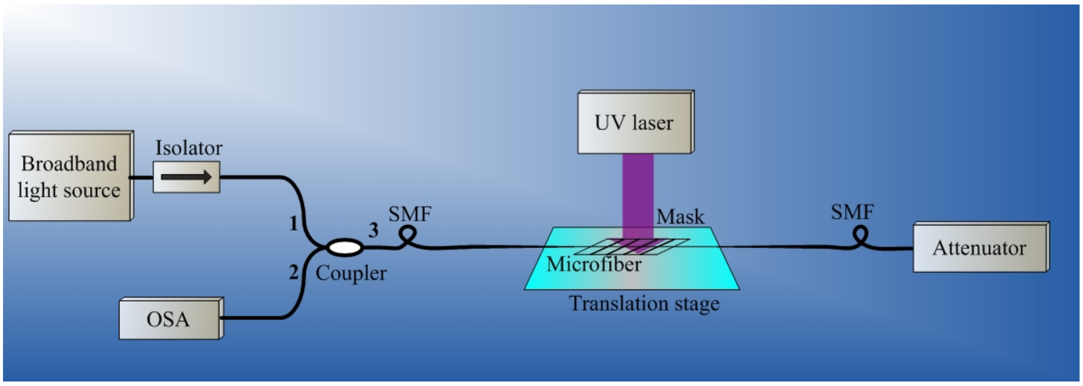

Fig. 1 Schematic setup for MF-BG writing and measurements. SMF: single mode fiber; OSA: optical spectrum analyzer.

The MFs used to form MF-BGs were drawn from commercial single mode fibers using hydrogen flame heating [10]. The single mode fiber with its jacket stripped was clipped and attached to two translation stages separately controlled by two piezoelectric actuators. After the fiber was heated and softened by a hydrogen flame, it was gradually pulled longitudinally by the two moving translation stages. With a travel speed of 0.16 mm/s, various microfibers were drawn with diameters ranging from 10's micrometers to sub-micrometers depending on the closeness of the hydrogen flame to the fiber and also the fiber pulling time.

Bragg gratings were then directly written on the prepared MFs by using UV light exposure through a photomask with a 535 nm-period grating pattern on it. Figure 1 sketches the setup for MF-BG writing and in-situ measurements. A KrF laser (248 nm) with a power of 15 mJ was used as the exposure light source. The MFs were in close contact with the photomask during exposure. With a scanning speed of 1 mm/min, ~10 minutes exposure time was used for MF-BG writing. A broadband light source with a wavelength span of 1200-1700 nm provides the light source for the measurements. An isolator followed immediately after the broadband light source to block any back reflection. Light was coupled to the MF-BG through a 1×2 fiber coupler, and the reflection light was then coupled back and collected by an optical spectrum analyzer (OSA) to measure the reflection spectrum. The other end of the MF-BG was connected to an attenuator to prevent the fiber facet reflection. Figure 2 shows the scanning electron microscope (SEM) images of four MF-BGs with various diameters from 25.9 μm to 6.61 μm. The MF-BGs all have very uniform diameters and smooth surfaces covering the whole grating region.

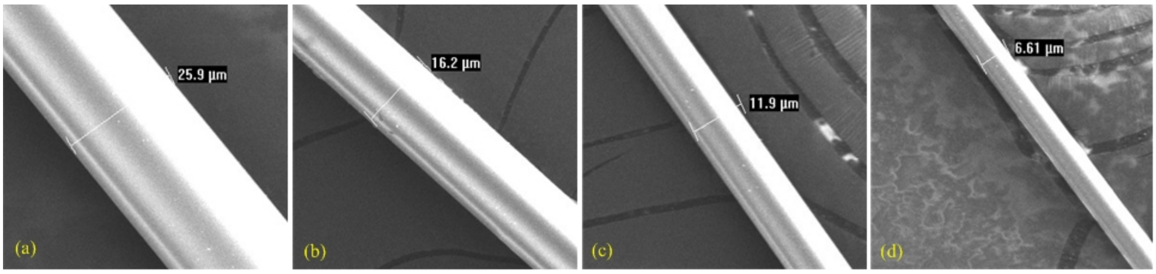

Fig. 2.SEM images of the fabricated MF-BGs with four different diameters.

3. Characterization and Discussion

To investigate the optical performance of the MF-BG and its variation with the microfiber diameter, we measured the reflection spectra of seven MF-BGs (with diameters of 83.9 μm, 60.4 μm, 25.9 μm, 16.2 μm, 14.8 μm, 11.9 μm and 6.61 μm, respectively) and also measured a conventional SMF-based Bragg grating (125 μm diameter) as a reference. Fig. 3(a) shows the reflection spectrum of a typical MF-BG with a diameter of 25.9 μm. The 3-dB bandwidth $\Delta\lambda$ of the reflection window is ~0.3 nm, narrower than previously reported MF-BG [8] due to the small refractive index modulation depth and large grating period (~1 cm). Note that the measured low average power is due to the low output power of the broadband light source that we used. Fig. 3(b) shows the measured Bragg wavelength and the relative reflectivity (ratio between maximum reflection and background power) change as a function of microfiber diameter. Figure 3(c) shows the numerically calculated n_{eff} and microfiber confinement factor η changes as a function of the microfiber diameter. Insets are the fundamental optical mode patterns for two microfibers with diameters of 15 μm and 50 μm, respectively.

When the microfiber diameter decreases, the Bragg wavelength blueshifts and reflectivity reduces. We can explain the change trend using Bragg reflection theory. The Bragg resonance wavelength is given by $\lambda_B = 2n_{eff}\Lambda$ [11], with n_{eff} the effective refractive index of the microfiber, Λ the period of the MF-BG. Hence, the Bragg wavelength shift follows the n_{eff} change trend. The Bragg grating reflection bandwidth is given by [11]

$$\Delta\lambda = \frac{1}{2}\lambda_B\sqrt{\left(\frac{\Delta n_{eff}}{2n_{eff}}\right)^2 + \left(\frac{1}{N}\right)^2} \quad (1)$$

where Δn_{eff} is effective refractive index change induced by UV light exposure, and N is the number of periods of the MF-BG. When the microfiber becomes < 50 μm, the fiber core can no longer confine optical energy well and as a result, optical mode is expanded to the cladding region, leading to a slight decrease in n_{eff}. When the diameter further reduces to < 15 μm, part of the light begins to extend outside the microfiber, causing a faster decrease in n_{eff}. The reflection bandwidth and reflectivity are determined by the refractive index modulation depth $\Delta n_{eff}/n_{eff}$ and grating period N. For the microfibers with diameters > 15 μm, $\Delta n_{eff}/n_{eff}$ decreases with the reduction of the diameter, as less light is confined in the microfiber core. However, when microfiber diameter is < 15 μm, n_{eff} decease faster which balances the reduction of Δn_{eff}. Thus we see the reflectivity first decreases and then saturates when the microfiber diameter reduces. It should be noted that the reflectivity can be improved by enhancing the index change upon hydrogen loading or by using MFs drawn from multimode fibers with a larger core size instead.

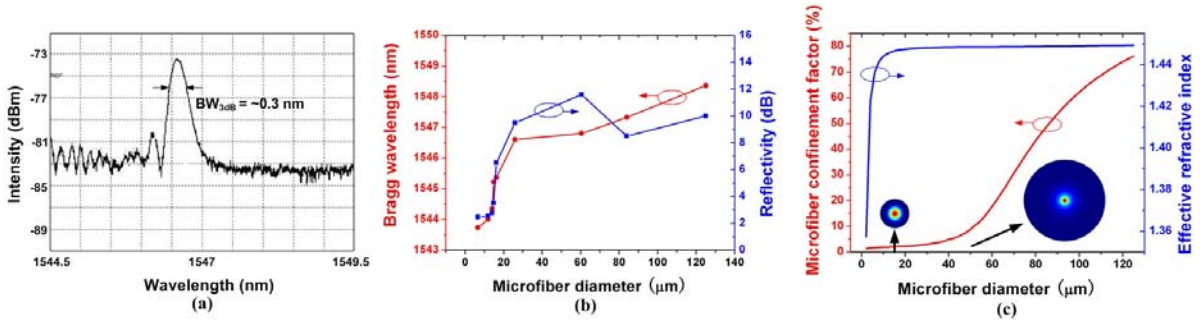

Fig. 3 (a) Reflection spectrum of a typical MF-BG with a diameter of 25.9 μm. (b) Measured Bragg wavelength and reflectivity change as a function of the MF-BG diameter. (c) Simulated microfiber confinement factor η and effective refractive index n_{eff} change as a function of the MF-BG diameter with finite element method. Insets in (c) show the simulated fundamental mode intensity patterns for two microfibers.

4. Conclusion

We demonstrated microfiber-based Bragg gratings fabricated by UV light exposure. We investigated the Bragg wavelength and reflectivity change as a function of microfiber diameter and showed that Bragg grating can be formed on microfibers with a diameter as small as several microns. The narrow 3dB bandwidth of the Bragg reflection peak (~0.3 nm) makes the MF-BGs suitable for WDM channel filtering and biochemical sensing applications.

5. Acknowledgments

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