Tuning Bragg Wavelength by Writing Gratings on Prestrained Fibers

Qin Zhang, D. A. Brown, L. Reinhart, T. F. Morse, J. Q. Wang, and Gang Xiao

***Abstract*— Bragg gratings at a specific wavelength are made using an Excimer KrF laser and a phase mask. The wavelength can be varied for fine tuning and multiplexing applications by straining the optical fiber during UV illumination. When the strain is removed, the grating formed is at a smaller wavelength than that dictated by the phase mask for the unstrained fiber. This technique was demonstrated by writing two gratings located at the same point in the optical fiber. The transmission from the first grating was used as a means for *in situ* absolute wavelength tuning. The second grating made with approximately 0.2% axial strain was at 1534.54 nm. Once the grating was made, the strain was removed from the fiber leaving the second grating tuned to 1532.04 nm, a wavelength shift of 2.5 nm.**

I. Introduction

A PHASE mask may be used to make Bragg gratings in optical fibers [1]–[3]. This technique first suggested by K. O. Hill [1] requires few optical components and the alignment is simple [4], [5]. The mask is made of UV-grade fused quartz which is etched with periodic grooves having a precisely controlled depth. The UV transmitted light intensity in the near field is spatially modulated according to the pitch-width of the mask. The contrast of the modulated intensity can be adjusted by controlling the depth of the grooves. An efficient phase mask can be made such that the zeroth-order transmission is small ($< 5\%$) and the first order large ($> 35\%$). In such a case, the main spatial frequency component of the near-field intensity is equivalent to twice the periodicity of the mask. Therefore, the grating pitch-width in the fiber is equal to half of the mask pitch-width. The resulting Bragg wavelength is equal to the product of the mask periodicity and the refractive index of the fiber core. The limitation of this scheme is that Bragg wavelength is fixed by the phase mask. To overcome this limitation, one method used a long focus lens to vary the Bragg wavelength [2]. In this letter, we report a technique in which the fiber is strained during UV exposure. The amount of strain determines the grating wavelength with respect to the unstrained condition. The advantage of this method is that it is simple, linear, and absolute, and that *in situ* monitoring of the wavelength shift can performed. We also demonstrate a dual-wavelength grating in which two gratings are written on top of each other using this technique. Upon completion of this work, our attention was called to research in which strain shifting in an internally written Hill grating was studied [7].

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II. Theory

The Bragg condition in an optical fiber is

$$\lambda = 2n\Lambda \tag{1}$$

and the associated fractional phase shift is

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta\Lambda}{\Lambda} + \frac{\Delta n}{n} \tag{2}$$

where n is the index of refraction, λ, Bragg wavelength, and Λ, grating pitch-width. Since Poisson's ratio for glass is less than 0.5, a positive axial strain will produce a density change and corresponding increase in the speed of propagation of light in the fiber core. This strain-optic effect is well known and results in a less-than-unity proportionality factor between axial strain and the resulting wavelength shift. For typical glass properties, we find [6]

$$\frac{\Delta\lambda}{\lambda} = 0.78\frac{\Delta\Lambda}{\Lambda}. \tag{3}$$

If a stress is applied to the fiber as the grating is written, we obtain a Bragg wavelength-shifted grating when the stress is released. Since the strain can be precisely controlled, the Bragg wavelength can be accurately tuned according to (3).

III. Experiment and Discussion

Photosensitive AT&T Accutether^{TM} fiber containing 9 mol% Ge doping in a core diameter of approximately 7 μm and single mode at 1500 nm was used as the host fiber. A 248-nm UV beam generated by a Lambda Physik EMG 201MSC krypton fluoride excimer laser was focused by a cylindrical lens, and the fiber was placed near the focal line. The cylindrical lens was placed such that its focusing line is perpendicular to the longer axis of the rectangular UV beam. The focused UV beam was normally incident on a phase mask. The fiber was placed along the focusing line of the cylindrical lens and orthogonal to the striation of the mask. The period and dimensions of the mask were 1060 nm and 10.0 mm by 0.45 mm, respectively. The zeroth-order transmission at 248 nm measured by a photospectrometer was approximately 65%. The fiber was glued on a translational stage to allow a strain be applied to the fiber.

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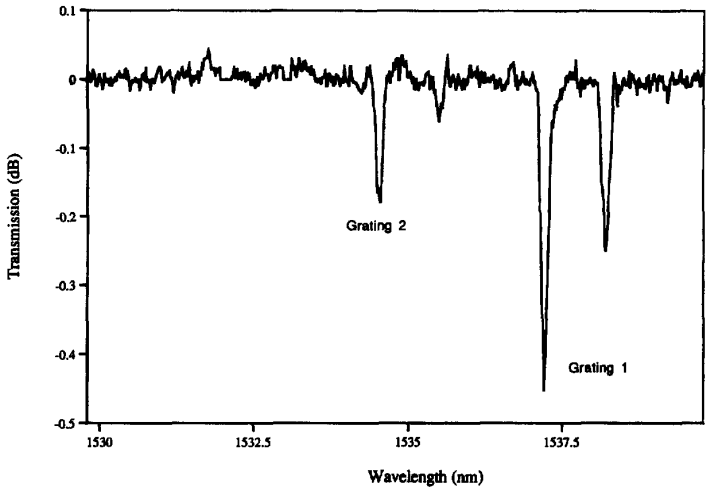

Fig. 1. The transmission spectrum for two optical fiber Bragg gratings with fiber under 0.2% axial strain. The first was made under unstrained conditions; the second with an axial strain of 0.2%. The center wavelengths under 0.2% strain are 1537.23 nm and 1534.54 nm, respectively.

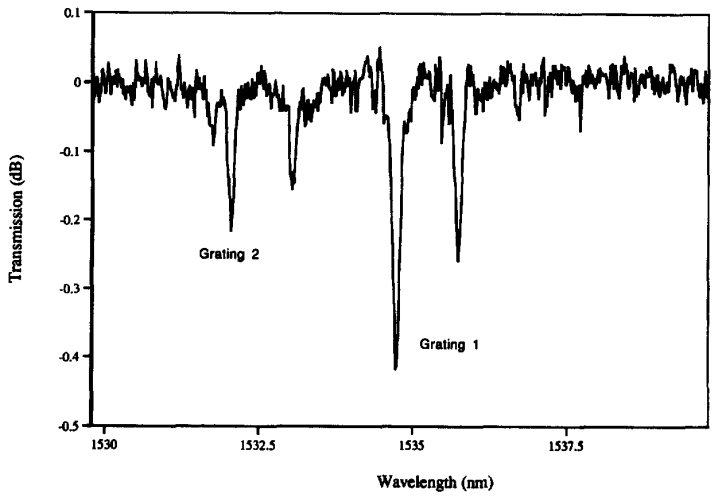

Fig. 2. The transmission spectrum of the strain-released fiber with two gratings at center wavelengths of 1534.74 nm and 1532.04 nm, respectively.

In our experiment we chose to write the two gratings at the same physical location of a fiber. Each grating was 7 mm in length. The exposure was 200 mJ/cm^2/pulse at a repetition rate 10 Hz for 60 min. The use of a more-efficient grating would have resulted in a shorter exposure time. The first grating was made on a unstrained fiber (actually, a small tension needs to be applied to keep the fiber straight) with Bragg wavelength centered at 1534.84 nm. The fiber was then strained approximately 0.2%. A wavelength shift to 1537.23 nm was observed using a spectrum analyzer, which agrees with 2.39 nm shift in wavelength predicted by (3). The strained fiber was then exposed to the same UV light to produce a second grating. The transmission spectrum of the two gratings for strained fiber is shown in Fig. 1. As shown in the figure, the first grating was stretched toward the longer wavelength at 1537.23 nm and the second one written on the strained fiber at approximately 1534.54 nm, the center wavelength of the mask. The lower reflectivity of the second grating is ascribed to saturation of the photo-induced index change. It can be reduced by increasing the second exposure time or eliminated by writing the second grating in a different location. Fig. 2 shows the transmission spectrum of the two gratings after the fiber was released from strain. The second grating was tuned to 1532.04 nm, which was downshifted 2.5 nm. The first grating returned to 1534.74 nm, which proves that the making of the first grating was indeed under slight tension, corresponding to a strain of 83.5 micro-strains. The tuning range of this method is limited by the mechanical strength of a fiber. Typically, a fiber cannot survive more than 3% strain.

IV. Conclusion

Bragg gratings at different wavelengths may be made with a phase mask by writing the gratings on a fiber in a strained state. A dual-grating method was introduced to monitor the tuning magnitude *in situ* so that an accurate Bragg wavelength can be obtained by precisely controlling mechanical translation. This

method is simple, linear, versatile and can be readily applied to various existing grating-writing schemes.

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