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FABRICATION OF FIBER BRAGG GRATINGS IN HIGH GERMANIA BORON CO-DOPED OPTICAL FIBER BY THE PHASE MASK METHOD

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Abstract. A technique to fabricate high reflectivity fiber Bragg gratings (FBGs) with minimal optics is presented. The FBG is written in high germania boron co-doped optical fiber using a phase mask with a 244nm continuous-wave UV light as the printing source. The mol percentage of germania ion in the fiber core is about 20%. We have successfully fabricated FBGs with reflectivity as high as 99.9% in less than 10 minutes of exposure time.

Key words: Optical fiber - fiber Bragg grating – UV laser - Bragg wavelength - phase mask

Abstrak. Kaedah untuk menghasilkan peranti FBG yang mempunyai peratus pantulan yang tinggi diperkenalkan. Peranti FBG telah dicetak dalam gentian optik khas yang mengandungi germanium dan boron yang tinggi. Kandungan germanium ion di dalam gentian optik teras adalah sebanyak mol 20%. Cara yang digunakan ialah cara percetakan topeng fasa dengan menggunakan cahaya ultra ungu ion yang mempunyai panjang gelombang 244 nm sebagai sumber cahaya. Kami telah berjaya menghasilkan FBG yang mempunyai peratus pantulan setinggi 99.9% dan masa yang diambil untuk cetakan adalah kurang daripada 10 minit.

Kata kunci: gentian optik – peranti FBG- laser UV – panjang gelombang Bragg- topeng fasa

1.0 INTRODUCTION

Since the discovery of photosensitivity in optical fiber in 1978 [1] and the ultraviolet side writing technique that opened the door to its practical applications, fiber Bragg gratings (FBGs) have been the subject of intense development at many research centers around the world. FBGs were first used on a large-scale commercial basis about 6 years ago as laser pump stabilizers for erbium-doped fiber amplifiers (EDFAs) and as filters for wavelength division multiplexing (WDM) multiplexers and demultiplexers. Many other applications have been demonstrated and more are under development such as channel add-drop modules, band pass and broadband blocking filters, gain equalizing and gain flattening filters for EDFAs.

FBGs can be photo-imprinted into optical fibers by exposure to UV wavelengths between 240 nm to 260 nm. There are three main techniques for FBG fabrication, of

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which contact printing via phase mask is easiest and fastest. The single photon absorption causes a refractive index increase [2], which is time and intensity dependent. The material characteristic of the fiber, as it is known that the germania content (not limited to only germania though) is directly related to the single photon absorption. Many works have been reported on the use of germanosilicate fiber in fabrication of fiber Bragg grating [3-4]. In this paper, the phase mask technique is used for fabrication of short period grating in conjunction with the use of high germania boron co-doped fiber and a continuous wave UV laser.

2.0 THEORY

The FBG is a grating operating effectively due to a periodic perturbation of the refractive index along the fiber length. Light propagating along a single mode fiber encounters this perturbation and a small amount of light is reflected at each point of the refractive index transition. If each of these reflections is in phase, they will add coherently and produce a large net reflection from the grating. This phase matching occurs at only a specific wavelength called the Bragg resonance wavelength, which is given by:

$$\lambda_B = 2n_{\text{eff}}\ \Lambda / m \tag{1}$$

where, λ_B is the Bragg wavelength, n_{eff} is the effective refractive index of the fiber, Λ is the grating period and m is the diffraction order number. The bandwidth and strength of the reflection depend on the index change per period and the overall length of the grating. The maximum reflection strength is given by

$$R_{\max} = \tanh^2(\kappa L) \tag{2}$$

where, L is grating length and κ is the coupling coefficient.

The full bandwidth to the first zeros of the reflection spectrum $\Delta\lambda$ is given by

$$\Delta\lambda = \lambda_B{}^2\left[(\kappa L)^2 + \pi^2\right]^{1/2} / \pi n_{\text{eff}} L \tag{3}$$

3.0 EXPERIMENT

A schematic of the FBG fabrication set up is shown in Figure 1. The output of a frequency doubled argon ion laser operating at 244 nm is reflected by a mirror, expanded with two circular lenses, focused by a cylindrical lens and then passed through a phase mask before irradiating the bare fiber. The commercial phase mask is used to generate two interfering beams close to the fiber as shown in Figure 2. The phase mask is specially made for this particular wavelength and placed just alongside a bare

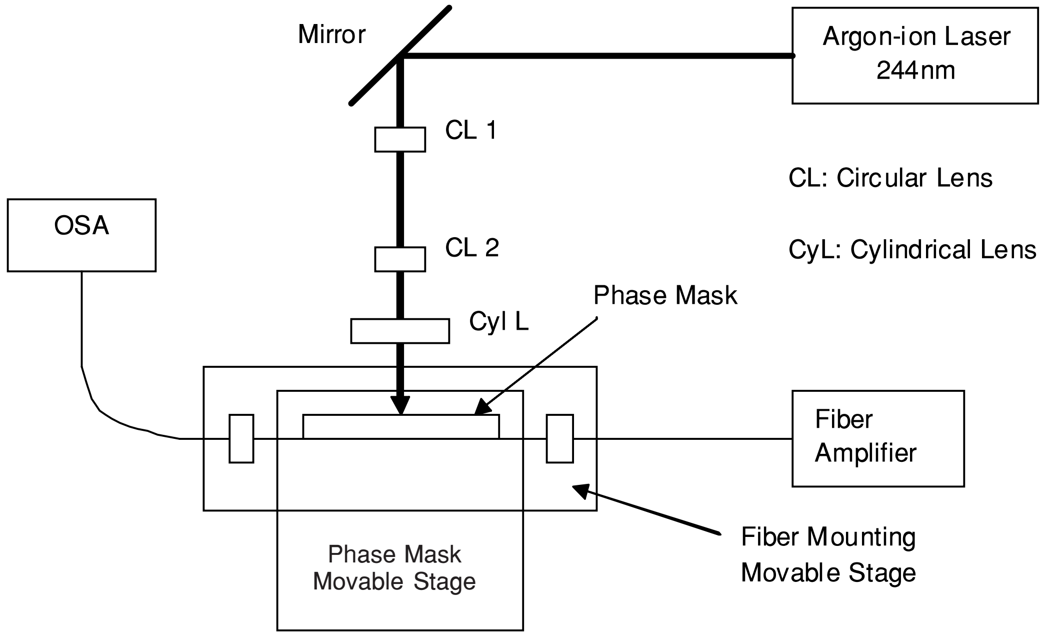

Figure 1 FBG fabrication system set up

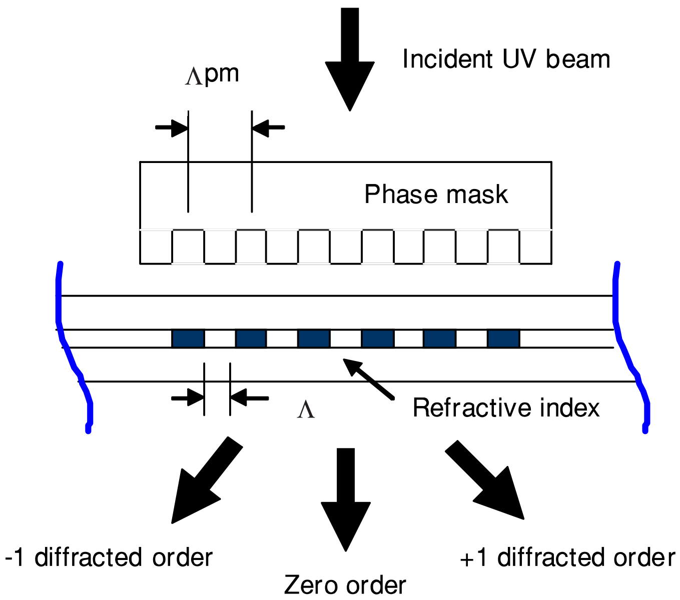

Figure 2 Grating formation using phase mask

fiber with its mask pattern perpendicular to the fiber and the laser. The jacket of the fiber is stripped about 5 cm where the grating will be inscribed. After being aligned perpendicular to the phase mask edge, the fiber is clamped on the two supports placed on each side of the phase mask and separated by 6 cm. The supports are mounted on a precision translation stage that allowed its separation from the phase mask to be adjusted. The fiber should be placed in near contact with the fine corrugations of the phase mask before writing. The separation of the fiber core from phase mask should be less than 0.1 mm. This separation is a critical parameter in producing quality FBGs. However, placing the fiber in contact with the fine corrugations is desirable but not practical due to possible damage to the phase mask. The exposure length is approximately about 2 cm.

The FBGs are inscribed in single mode high-germania boron co-doped fibers. The fiber consists of about mol 20% of germanium. The generated spectral transmission of the FBG was recorded in real time in the course of photoimprinting, using a broadband source from a fiber amplifier and an optical spectrum analyzer. The laser power at its exit shuttle was 76 mW.

4.0 RESULT AND DISCUSSION

The measured transmission spectrum of the fabricated FBG after 524s of exposure is shown in Figure 3. It has a dip of –30.3 dB, which translates to 0.1% transmission of the

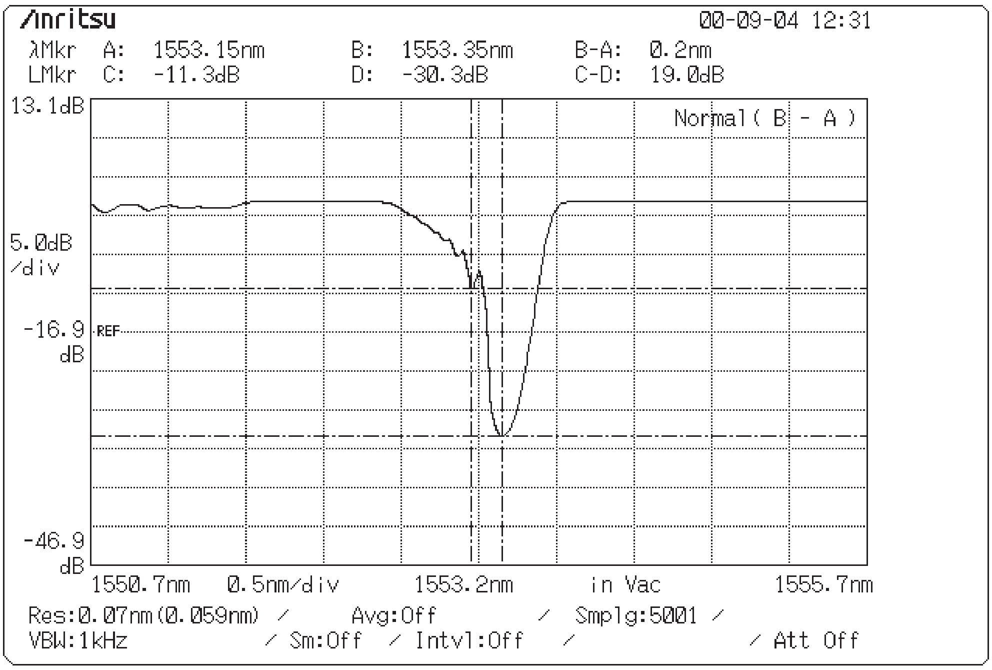

Figure 3 Transmission spectrum of the fabricated FBG

incoming signal at this particular wavelength, will go through, and a bandwidth of 0.16 nm centered at 1553.3 nm. The well-known condition for the Bragg reflection wavelength λ_B is given by equation (1). Using Sellmeier coefficients, n_{eff} at 1553.3 nm is calculated to be 1.444. This then predicts that a first-order reflection at 1553.3 nm should be given by a 538 nm period grating, which is within 1% of the period predicted to be produced by the phase mask period. The phase mask period is 1072.6 nm and the grating period is predicted to be half of the phase mask period. This discrepancy is thought to arise from the measurement error as well as stretching of the fiber.

The FBG growth in the fiber was monitored during the exposure time. For this fabrication method, the growth rate of the FBG measured by an OSA is shown in Figure 4. The measured transmission loss reached 30.3 dB, which translates to a reflectivity of 99.9%. Figure 5 shows the reflectivity as a function of fabrication time.

The growth in back reflected light is explained in terms of a new effect called "photosensitivity" which enables an index grating to be written. The photosensitivity of the optical fiber is due to a defect formation inside the Ge-doped core of silica fiber [5]. The presence of Ge atoms leads to formation of oxygen-deficient bonds (such as Si-Ge, Si-Si, and Ge-Ge) which act as defects in the silica matrix. The most common defect is the so-called GeE' defect. It forms a defect band with an energy gap of about 5 eV (energy required to break the bond). Single photon absorption of 244 nm radiation from a frequency doubled Argon ion laser breaks this defect bonds, and the released electrons are trapped at hole-defect sites to form color centers such as Ge(1) and Ge(2). Resulting changes in the absorption spectrum are accompanied by a corresponding index change through the Kramers-Kronig relation [6]. Since index changes occur

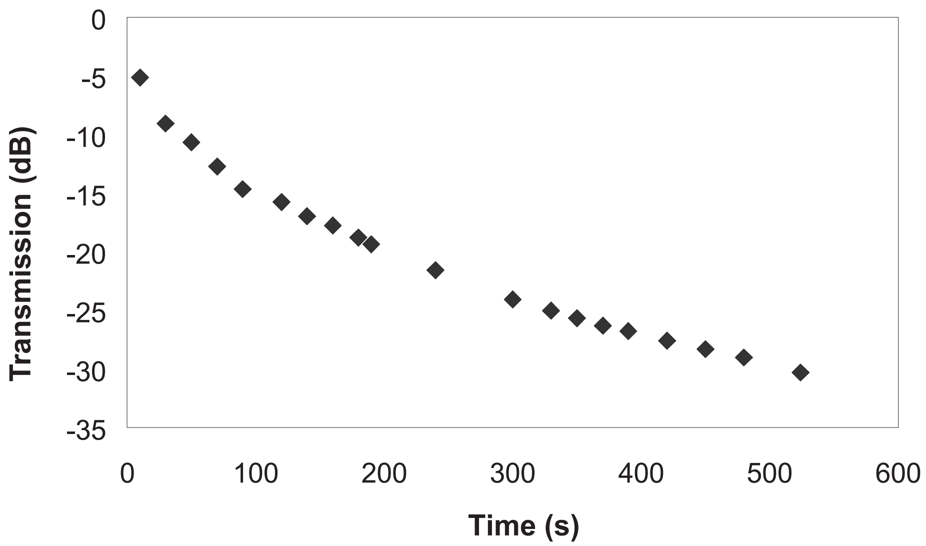

Figure 4 Transmission dip as a function of fabrication time

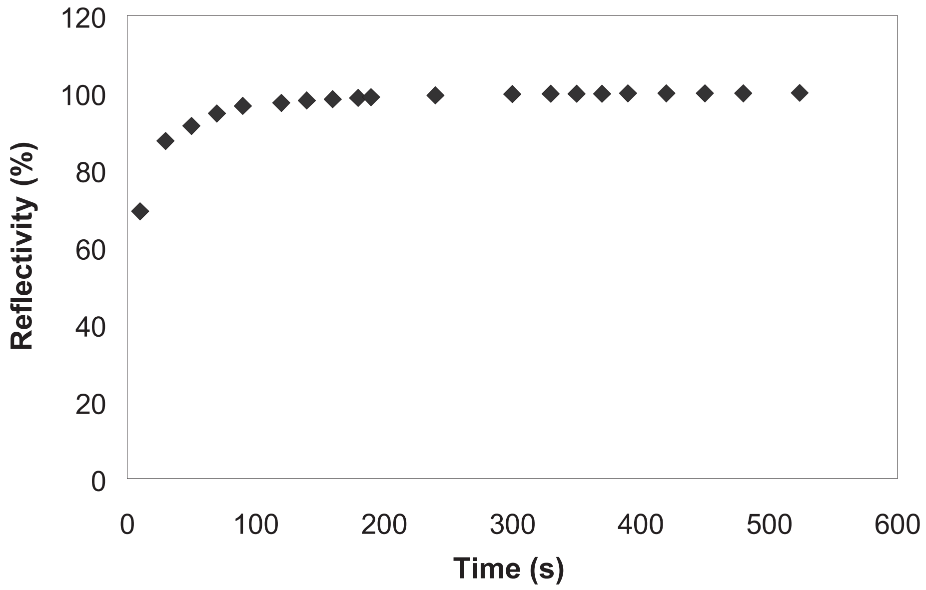

Figure 5 FBG reflectivity as a function of fabrication time

only in the regions of fiber core where the UV light is absorbed, a periodic intensity pattern is transformed into an index grating. The coherent light propagating in the fiber interferes with a small amount of light reflected back from the end of the fiber to set up a standing wave pattern, which through photosensitivity writes an index grating in the core. As the strength of FBG increases, the intensity of back-reflected light increases until it saturates near 100%. The growth rate is related with germanium concentration. Higher concentration of germanium gives a faster growth rate.

5.0 CONCLUSIONS

A FBG operating at 1553.3 nm has been written into high germania co-doped optical fiber with maximum reflectivity of 99.9%. Such gratings can be used not only as passive wavelength filter in WDM systems and sensor systems, but also as frequency selective elements in active fiber devices. This work has shown that high reflectivity FBGs can be produced with an apparatus that is considerably less expensive than the pulsed ultraviolet systems. Presently the grating thermal stability is being investigated.

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