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A Case Study on Fiber Bragg Gratings for Biomedical Applications

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Abstract
This paperdiscusses the various techniques available for the fabrication of fiber Bragg gratings (FBG) and the most efficient method to fabricate FBGs for biomedical applications. The sensors were fabricated using the phase mask technique and the response was tested.The fabricated bare FBG sensors showed a Bragg wavelength reflectivity around 1547.8nm and the etched FBG sensors showed a Bragg wavelength reflectivity around 1546.5nm when connected to Micron Optics Interrogator. The paper also discusses the further scope of the FBG applications in biomedical and biosensing fields.
Keywords: *Fiber Bragg gratings, fabrication, Phase mask technique, Bragg wavelength, biosensing*

1. INTRODUCTION

Fiber Bragg gratings are sensitive to strain, temperature and various other parameters. FBGs are fabricated by subjecting a length of single mode optical fiber to ultra violet light from an excimer laser, through a phase mask[6]. The gratings make the fiber, a highly-selective mirror. Due to its small size and robustness, ease of fabrication, efficiency in multiplexed sensor networks and immunity to electromagnetic interference FBG sensor has been exploredarduously over the years[7]. Due to its sensitivity to both strain and temperature, measures have to be taken for the independent measurement of either of the parameters.The Bragg wavelength reflected acts as a detection parameter for sensing and is given by

$$\lambda_B=2n_{eff}\Lambda \text{..................Eq. 1.1}$$

where λ_B is the reflected Bragg wavelength, n_{eff} is the effective refractive index of the core, clad and the surrounding medium and Λ is the grating pitch. Fig 1.1 shows the Bragg wavelength reflected in an FBG, when aUV light is incident on it.

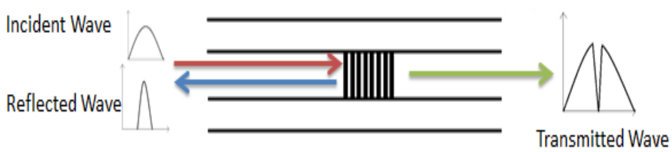

Fig. 1.1 FBG showing the reflected Bragg wavelength

FBG applications are vast in the field of Telecommunication, Aerospace, Mechanical, Civil and Biomedical Engineering. In the recent years, FBGs have found a vast scope for applications in biomedical Engineering. Based on the sensitivity of FBGs to the change in surrounding medium, which brings about a change in effective refractive index, the FBGs can be used in series of applications in biomedical, biomechanics and biosensing fields. The ability of the FBGs to detect stress was used in biomechanics particularly in orthopaedics and dentistry. It was also used to acquire the arterial pulse for blood pressure measurement. Also, a new aspect of sensing biological molecules based on change in refractive indices of FBG and binding these bio molecules on the surface of FBGs lead to a significant shift in the Bragg wavelength, a detection parameter. A new technology of coating carbon nanotubes (CNTs) on FBGs significantly improved its performance for biosensing applications. This gives scope to use FBGs effectively for the detection of various biological elements.

This paper discusses the best method to fabricate theFBG sensors, shows the response of bare and etched fiber Bragg gratings in airand the scope to use FBG for developing biomedical applications.

2. FABRICATION OF FBG

2.1 Fabrication of bare FBG

There are several methods to fabricate an FBG sensor, i.e.Point by point process, interferometric technique and phase mask technique. But the most efficient method is the phase mask technique[8].It is not sensitive to mechanical vibrations as in the other methods used. The phase mask technique involves exposure of photosensitive germanosilicatefiber cores to high energy excimer lasers through an optical phase mask. The fiber used here is a single mode nufern GF1 fiber with a core diameter of 9µm. It is a standard used for biosensing applications. FBGs are produced by exposing a step-index fiber, the core of which is doped with germanium and boron to make it photosensitive, to intense UV light from a KrFexcimer laser at 248nm. Other laser sources like ArF at 193nm or a frequency doubled Argon-ion laser at 244nm can be used. Absorption of this light in the core causes a permanent refractive index change of the fiber, typically $\Delta n=10^{-5}$ to 10^{-3}. To get a high frequency index modulation, there are currently techniques which give accurate results, namely, contact print approach, mask projection technique and transverse holographic method[9].

In the holographic method, a UV source with a high spatial and temporal coherence with a single beam is split and recombined at the fiber core to produce an interference pattern.However the interference fringe spacing and placement is sensitive to optical alignment of the system. Furthermore it requires high mechanical stability and immunity from vibrations. This approach is flexible and allows the change of grating parameters but can also result in non-uniform gratings.

In the mask projection approach, a laser beam is homogenized and passed through a mask. The pattern is then projected at a high reduction ratio onto the fiber.This technique can be used to produce periodic or non-periodic structure but it lacks resolution which produces sub-micron features.

The method used here is contact print or the phase mask approach. It uses a diffraction grating through which the laser beam splits into several diffractive orders and interferes in the core of the fiber creating the required pattern. It is less sensitive to vibrations and the optical alignment as compared to the other methods and requires a low coherence source. It permits the fabrication of several Bragg gratings in a single exposure resulting in low cost per unit Bragg grating.

2.2 Fabrication of etched FBG

The grating area of the sensors fabricated from the above method is marked. The sensor is placed in a glass boat containing 40% concentrated hydrogen fluoride solution such that the grating area is immersed in it completely. The FBG is left in the solution until the cladding around the gratings is removed. This takes about 2 hours. Simultaneously the response of the FBG is monitored by connecting it to the Micron Optics Interrogator sensing module 130(MOI sm130). About 1nm fall in the reflected Bragg wavelength indicates that the cladding is removed[1].

3. RESULTS AND DISCUSSIONS

In this paper we have successfully fabricated FBG sensors using phase mask technique. The bare and etched FBGs fabricated were connected to the MOI and monitored for response. Fig. 3.1 shows the response of bare FBG in air and Fig. 3.2 shows the response of the etched FBGs in air. Table 3.1 shows the values of Bragg wavelengths reflected and the intensity values of the FBGs.

Type of FBG	Bragg wavelength(nm)	Intensity(dB)
Bare	1547.8378	1630
Etched	1546.5412	1018

Table 3.1 Intensity levels of bare and etched FBG in air

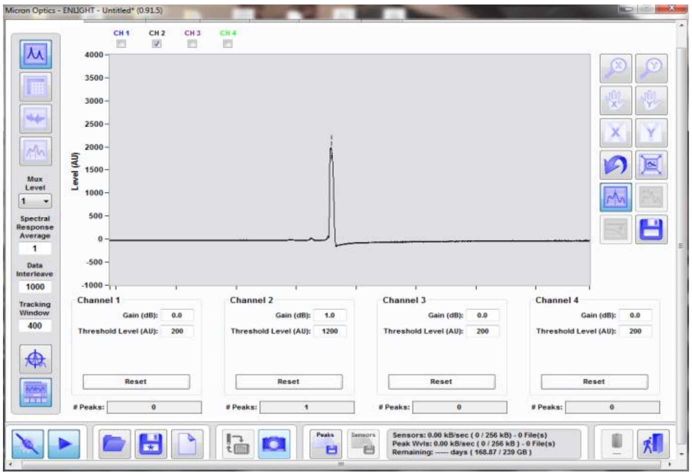

Fig. 3.1 Response of bare FBG in air

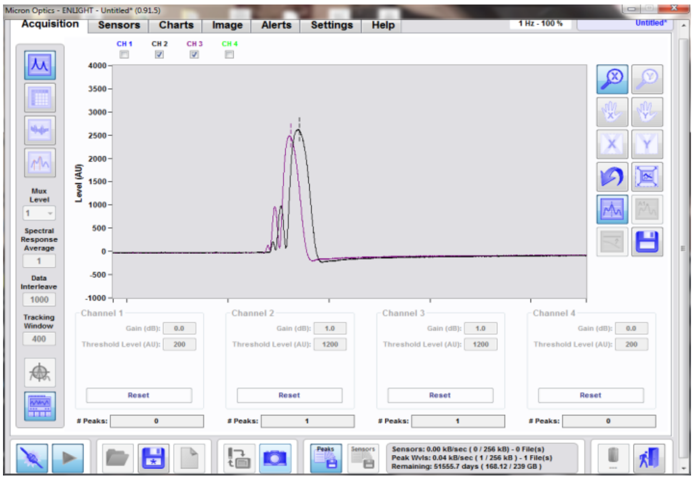

Fig. 3.2 Response of bare and etched FBG in air, Channel 3 shows the etched FBG response

4. CONCLUSION

The above results show the base values of the reflected Bragg wavelength in bare as well as etched FBGs. Eq. 1.1 shows that the Bragg wavelength changes as the refractive index of the surrounding medium changes. With this principle, Bragg reflectivity of the bare and etched FBGs can be tested for various biological elements and solutions of biological elements. Several works carried out show that the etched FBG showed more sensitivity as compared to the etched FBG.Various humidity sensing modules have been developed using FBG where the etched FBGs have been coated with polymers and particles like SiO_2 to further increase the sensitivity of etched FBGs[2-4]. A work carried out recently showed that etched FBGs coated with graphene oxide and CNTs showed more sensitivity to glucose than the bare and etched FBGs[1]. All these factors have given wide open research opportunities for the use of FBGs for various biosensingand biomedical applications.

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