Determination of the Recording Profile of Fiber Optic Bragg Gratings

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Abstract—This work presents a method for obtaining the recording profile of fiber optic Bragg gratings. The modulation pattern is obtained with the aid of metallic and dielectric targets (Gold, Nickel, Aluminum and Poly-metil-metacylate) positioned at the focal point of the recording interferometer. For the used 266 nm light the determined profile's envelope is irregular and the modulation period is within the expected 0.5 µm range. The results permit to use the method as an important tool in the optimization of the writing process of Bragg gratings in optical fibers.

Index Terms—Bragg gratings, refractive index profile, optical fibers.

I. INTRODUCTION

The fiber Bragg gratings (FBG) consist of periodic structures with a longitudinal modulation of the refractive index in the core. The electromagnetic field guided in the core has a spectral band reflected by that structure; the frequencies that contribute constructively in the counter-propagating direction add to a reflection band with specific central wavelength close to that given by the Bragg condition.

Those devices have today a widespread application as sensors to measure temperature, pressure, strain and vibration [1]-[2]. Moreover, these devices can also be used in optical communications systems for dispersion compensation, spectral filtering and wavelength division multiplexing (WDM) [2]-[4].

Basically there are two techniques for the writing of FBGs: interferometric and non-interferometric [5]-[6]. In the latter technique, the modulation profile of the refractive index is produced by direct point to point illumination, moving the focalized beam along the fiber, whereas in the former, and most common method, the pattern is obtained by interfering two coherent beams. The interference pattern is obtained directly under a phase mask or using an interferometer in the Talbot configuration with a phase mask to split the wavefront.

Obtaining the writing profile of FBGs is an important indicator for optimization of the recording system. The determination of the periodic profile registered in the gratings is the best way to obtain gratings with better features and to control factors affecting the recording process as, e.g., the laser beam quality; the observed profile can also be used for eventual maintenance and calibration of the imprinting system.
The performance of each produced device depends, basically, of its fabrication parameters, but only a few are really known. The period of modulation, for example, influences directly the Bragg wavelength and it is easily calibrated. However, the quality of the spectral filtering obtained with a FBG depends on the refractive index modulation index and on the envelope of the index modulation along the grating. Such information is very hard to obtain with non-destructive techniques. In practice, the features of the recording system are estimated through spectral analysis of the manufactured device manufactured, without real knowledge of the effective recorded profile. If the desired specification is not reached, adjustments are made to reset the system for a subsequent recording. Therefore this method is slow and laborious.

Bjouklund et al [7] have already obtained the resulting modulation pattern of two-beam interference for grating recording, although their aim was the study of gratings resulting from color centers in a laser active medium, Li:KCl crystals containing F(II) color centers. Distributed feedback (DFB) lasing was demonstrated by preparing the crystals with permanent spatial modulations (i.e., thick gratings) of F(II) center concentrations. These centers in alkali halides have been previously shown to be a practical media for broadly tunable narrow-linewidth laser operation. A specially designed interferometer was used to write the gratings. This interferometer permits the piecewise generation of precisely registered gratings of arbitrary size by sequential exposure of small segments of the photosensitive medium. This is an important advantage for the two-photon coloration process, since for constant laser power the exposure time necessary to produce a certain concentration of F(II) centers is proportional to the square of the beam spot area. To determine the periods of the color center gratings, aluminized flats were exposed in exactly the same way as the crystals. By measuring the auto-collimation angles of the resulting gratings (laser intensity was high enough to remove some of the aluminum in the bright fringes of the interference pattern) the determination of the grating periods was done with an accuracy of about 0.3% [7].

In this work is presented a method to determine the spatial modulation profile of FBGs produced in the Photorefractive Devices Unit, “Núcleo de Dispositivos Fotorrefrativos – NUFOR” at the Federal University of Technology – Paraná through an interferometer with phase mask.

II. METHODOLOGY

A. FBG Recording System

The investigated system for FBG is shown schematically in Fig. 1. It uses the phase mask interferometer to produce the modulation of the refractive index profile. The light source is a Nd:YAG laser operating in the ultra-violet (UV), at 266 nm, by the use of two frequency-doubling crystals, the beam energy can be up to 200 mJ per pulse (4 ns) and the repetition rate can reach 20 Hz. The output laser beam is filtered by an iris with diameter of 2.00 mm. Two fixed mirrors guide the light beam until the phase mask, where it is diffracted. The zeroth order beam is blocked by and opaque screen. The beams of higher order, particularly those with order ±1, are deflected by two
servo-motor controlled rotatory mirrors [8]. These mirrors reflect the incident rays to be interference position in the exit focal point of the interferometer. A cylindrical lens, focal distance of 50.20 mm, helps to increase the laser fluence on the target fiber. In the fiber support were fixed the metallic or dielectric targets used to record the interference pattern.

![Schematic design of the phase-mask interferometer system for FBG recording.](image)

**Fig. 1 – Schematic design of the phase-mask interferometer system for FBG recording.**

**B. Target preparation**

The targets used in the experiment, as shown in the Fig. 2, were thin films of Gold (Au), Nickel (Ni), Aluminum (Al) and Poly-metil-metacrylate (PMMA), deposited on glass substrates (microscopy slides) of about 10 mm width, 10 mm of length and 1 mm of thickness, and commercial Aluminum foil hold on a glass slide. The substrates were cleaned using the standard procedure: 10 min immersed into a sulfuric (H₂SO₄) and nitric (HNO₃) acid solution bath with ultra-sound, rinsed in distilled water, immersion in ultra-pure water during ten minutes with ultra-sound and then dried with air spurt. The thin metallic films were deposited using vacuum thermal evaporation technique [9]. The thin PMMA film was deposited on the substrate using spin coating [10]. The thickness of all films were measured with a DESTAK 3 Profile metering equipment with a diamond tip of 12.5 μm radius and vertical resolution of 10 Å.

Each target was positioned in the system for FBG recording to register the interference illumination pattern. The exposition times and the laser fluence were varied, therefore each imprint was differentiated from the previous one with a vertical displacement of 0.5 mm. The illumination times varied between 5 s and 200 s for metallic targets; and between 600 s and 900 s for dielectric targets. The laser fluence was set between 26 mJ.cm⁻² and 78 mJ.cm⁻².

The resulting patterns on the target films were previewed by optical reflection microscopy, with different magnifications in an optical Olympus BX51M metallographic microscope, calibrated by optical scales.
Fig. 2 – Photography of some targets used to record the interference pattern.

Fig. 3 – Microphotograph with 50x magnification, of the Au target submitted to illumination with laser fluence of 78 mJ.cm\(^{-2}\) during 45 s (a), 60 s (b), 120 s (c) and 180 s (d).

III. RESULTS AND DISCUSSIONS

The Fig. 3 shows the microphotography, with 50x magnification, of some interference patterns obtained with the Au target of 150 nm thickness, when it was submitted to a laser fluence of 78 mJ.cm\(^{-2}\). The indications (a), (b), (c) e (d) in that figure correspond to exposition times of 45 s, 60 s, 120 s e 180 s, respectively. The dark traces are a physical record of the light intensity envelope in the focal line (due to the cylindrical lens used) of the Talbot phase mask interferometer.

It is observed that the pattern envelope is approximately the same independent of the exposition time. However, there is a widening mechanism, both in the transversal and longitudinal directions, that occurs as the exposition time increases, as marked in that figure by the dotted line. This behavior was registered for all the analyzed targets, indicating that it is not a characteristic of a particular material, but really a effect due to the total illuminating dose (fluence × exposure time) over the target. Although not studied in detail, it can be caused by accumulated laser ablation in the target material, which increases as the exposure time increases, coupled to the longitudinal spot-length of the focusing optics and transversal laser profile. As the laser profile is not really Gaussian due to its unstable resonator and phase-matching doubling crystals geometries, that ablation process also explains the irregular borders of the envelope.
Fig. 4 – Microphotographs of the recorded illuminating patterns. Top view: envelope pattern under 50x magnification on one Al target, laser fluence 78 mJ.cm⁻², exposure time 180 s. Bottom view: three chosen regions (position indicated by the dotted lines) under 1000x magnification. False color images.

Fig. 5 – Microphotographs of the recorded patterns in PMMA film. Same conditions and remarks as in Fig. 4, except the exposure time, which is now 600 s.

The recorded interference pattern on the target position, using a metallic Al target with thickness of 120 nm of Al, can be seen in the photographs on Fig. 4. The used exposition time to the UV interference pattern was 180 s with 78 mJ.cm⁻² laser fluence. The 1000x magnification images are obtained at different positions along the recorded profile to verify the longitudinal homogeneity of the exposed pattern. In each one of these segments it is noticed the formation of a periodic structure, as given by the light and dark zones intercalation. The average pitch between two consecutives light or dark zones is approximately 0.5 μm, averaged over a 5 μm length. This measurement is also confirmed in the imprinted interference patterns on other targets, as, e.g., the PMMA film, whose photographs are shown in Fig. 5.

For a best visualization, the microphotograph of written profiles under 1000x magnification are also treated by imaging software, as shown in Fig. 6. The recorded interference pattern with its typical 0.5 μm can be easily observable. In this figure it can also be observed that the recorded pattern has it...
zones slightly tilted to the right of the top border, which indicates a horizontal misalignment of the ±1
diffraction/reflection planes on the recording interferometer during the writing process.

![Image of a 1000x magnification microphotograph of the PMMA film target after software processing. The image corresponds to position (b) shown in Fig. 5.](image)

Fig. 6 – Image of a 1000x magnification microphotograph of the PMMA film target after software processing. The image corresponds to position (b) shown in Fig. 5.

The effectiveness of the chosen target materials to record the resulting interference pattern was also studied as a function of the laser fluence and exposure time. Fig. 7 illustrates the obtained results with microphotographs of imprinted interference patterns in targets of Au (a), Ni (b), Al (c), commercial aluminum foil (d) and PMMA (e) with thicknesses of 150 nm, 130 nm, 120 nm, 40 μm and 230 nm, respectively.

The target of Au was not efficient to register the interference fringes, because in the region of exposition to the UV beam its material was totally removed independent of the used fluence and exposition time. The Ni target allows the visualization of the interference pattern. However, for fluences higher than 26 mJ.cm−2 or exposition times longer than 180 s, independent of fluence value, the material was removed in a chaotic-like process, not allowing the determination of the profile envelope; the observed process characterizes cases of material removal with micro-explosions [11] induced by the focused laser beam.

Although distinct in its electric nature, the targets of Al and PMMA, independent of the thickness, allowed the register of the light and dark zones of the illuminating interference pattern for wide ranges of laser fluence and exposure time. In fact the PMMA, being dielectric, is the material whose characteristics more resemble those of an optical fiber. However, its deposition in the form of regular thin film is complex. As the efficiency of the Al is equivalent of the PMMA, we may affirm that metallic films of Aluminum are the best films for such determination. Of course such conclusion is valid for the laser used in the used interferometer. The process of laser ablation is dependent on the photon energy and material’s optical absorption bands, so another laser can lead to different conclusions. A supporting evidence for the above conclusion is the fact that the previous use of the process to measure the interference pitch in colored crystals by Bjourklund et al [7] also used Aluminum blocks under the same laser wavelength.
IV. CONCLUSION

The results obtained in this work show that it is possible to record the illuminating interference pattern of FBG phase-mask interferometers with a wide variety of materials, both metallic and dielectric. From the studied materials Aluminum films have produced the better results, whereas Au films are easily removed and do not permit to register the desired spatial pitch of the illuminating pattern. This may occur because the gold has large thermal diffusion coefficient than those of the other targets, in consequence the thermal heating due to UV absorption in peak illumination zones is quickly transferred to non-illuminated zones in the interference pattern, and this causes the complete removing of the material inside the exposure envelope.

The exposure times used to obtain the patterns are small or in the same order of magnitude of those used to record Bragg gratings in the same system, so it is not difficult to make periodical measurements to control and calibrate the interferometer alignment.

In spite of the difficulty to register the longitudinal spatial profile, Gold targets allow to better visualize the overall pattern shape, probably because this material has fusion temperature smaller than glass substrate. The absorbed UV energy by the target doesn’t create enough differential pressure between the film and substrate to induce removing of the metal by micro explosions, as occurs with Nickel films on glass.

The modulation average period, along all the obtained interference patterns is approximately 0.5 μm – as expected by the used phase-mask, and it is clearly visualized in Ni, Al and PMMA targets.

In spite of PMMA being a dielectric material as the optical fibers, Aluminum is the material best
indicated to obtain the spatial profile because it is easy for the growing of regular thin films. Moreover, the interference patterns are also registered in commercial aluminum paper.

Future work is planned to use a scanning electron microscope, with resolution better than 100 nm for the measurement of the recording profile. This will allow measuring the shape of the interference fringes, that is a required parameter for the design of special FBG for dispersion compensation in optical communication links.

As the position of the targets in the interferometer is the same as the position of optical fibers when recording Bragg gratings, it is clear that the recorded patterns reproduce those effectively written in the core of the optical fibers. The presented method allows rapid and easy visualization of the light profile produced in phase-mask interferometers for fiber Bragg grating recording. It is a fast and accurate method to obtain gratings with better known features, and it is also an easy method to control the interferometer alignment in sub-micrometric scale and the quality of laser beam profile in the focusing region. Although it uses only classical methods it can be an innovative experimental tool with high potential for the evaluation of more complex gratings, and it may be easily adapted to verify the performance of similar optical devices producing units.

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