Fiber Bragg Grating using femtosecond laser direct writing

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Abstract*:* Fiber Bragg Grating is an optical structure with a great importance because of the its various applications. The process of inscribing FBG using femtosecond laser direct writing allows a three-dimensional structure with very high precision. In this experiment, it was studied this technique, and it was possible to obtain a reasonable fiber Bragg grating. Due to instabilities in the setup and uncertainties in the certain conditions, the gratings were not perfect and the spectrum obtained was not the expected, but the Bragg reflections were still visible. Since this technique is under development, there are various possibilities to improve it.

I. Introduction

Femtosecond laser micromachining was first demonstrated in 1994, when a femtosecond laser was used to ablate micrometre-sized features on silica and silver surfaces. Since then, microfabrication in transparent materials using femtosecond laser pulses has been receiving a lot of attention. This technique is very versatile, allowing the fabrication of waveguides, couplers, gratings and many other structures, inside a bulk of a transparent material, guaranteeing a three-dimensional (3-D) integration and high resolution of these optical and photonic devices [1][2]

Fiber Bragg grating (FBG) was discovered in a laser setup by Kenneth Hill in 1978 and it's a very important structure. It acts as a wavelength selective mirror, working as narrow band filter, which means that if light from a broadband source is injected in the optical fiber, only light within a very narrow spectral width centered at the Bragg wavelength will be back-reflected by the grating, and the remaining light will continue through the optical fiber to the next Bragg grating without experiencing any loss. For this reason, FGB can be used in sensors, such as temperature or strain. [3][4]

Although, the FBG is usually inscribed by transversely illuminating the fiber with a UV laser beam and using a phase mask to generate an interference pattern in its core (side illumination), in this experiment it was used the femtosecond direct writing, in which, caused by the localized modification in the focal volume, each grating if formed individually inside the core of the fiber.

II. Inscription of fiber grating using femtosecond laser pulses

A. Femtosecond laser pulses and direct writing

The principal idea behind direct writing is the fact that the fiber is mounted on a translation stage and it is illuminated for a fixed time by a focused laser beam. In order to guarantee the required period Λ, the translation pace is controlled by it.

Femtosecond laser pulses are characterize by its short duration in time, but also by its intensity. When focused, with a lens, on a single point inside a glass, the intensity is sufficient to trigger nonlinear absorption within the focal volume, used to modify transparent media permanently, only on the focal area of the laser beam. In this process, the spot where the laser is focused, becomes a plasma but rapidly solidifies, inducing, for example, a refractive-index change to the order of 10^{-2} to 10^{-4}.

There are two types of direct writing: side-writing and parallel writing. In side writing, the sample is translated perpendicularly to the laser beam wheres in parallel writing the sample is translated parallel to the propagation axis of the laser pulses (Figure 1).

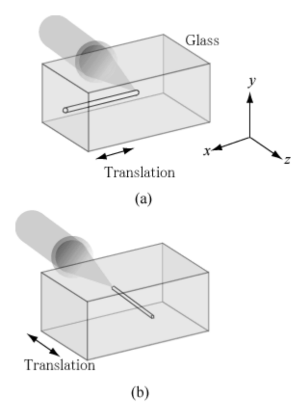

Figure 1. Types of direct writing: (a) side-writing and (b) parallel writing.[2]

For the purposes of this experiment, it was used de side writing, where the direction of the laser beam is antiparallel to the y-axis and the translation is parallel to the z-axis.

In order to have a successful grating inscription, the focusing objective and the fiber have to be positioned so that the intensity is maximal at the core and ensure it during the movement of the fiber.

The two drawbacks of this technique are that the stability of the period Λ depends on the precision of the translation stage in terms of relative positioning, and that the fill factor of the fiber grating is set by the spot size.[3]

B. Fiber Bragg Grating

Fiber Bragg Grating (FBG) is a permanent periodic index modification, that results in a narrow band Bragg reflection by the fiber core. Its central wavelength is given by

$$\lambda = 2n_{eff}\Lambda \tag{1}$$

in which Λ is the grating period (figure 2) and n_{eff} is the effective refractive index of the fiber mode.

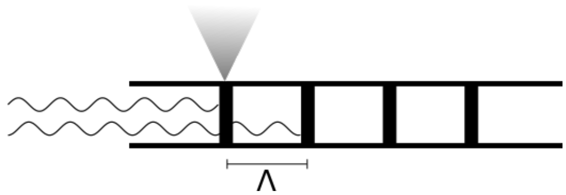

Figure 2. Schematic of the ultrashort-pulse laser-based inscription by direct writing.

When the light reaches a grating, a percentage of the light is reflected and the rest is transmitted, going into the next grating, being also reflected and transmitted. In order to have the total reflection of a small part of the spectrum in the begin of the fiber, the reflected waves must be in phase, and the more layers we have, the narrower it the wavelength interval. Figure 3 represents the spectrum before and after the FBG.

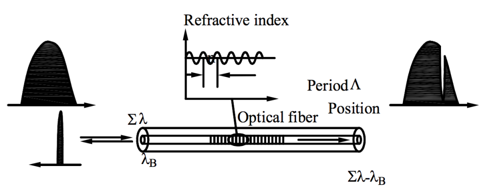

Figure 3. Working principle of the fiber Bragg grating.[5]

Considering a wavelength of 1550 nm, and the refractive index of the glass, the grating period as to be, approximately, 500 nm, which means the distance between gratings is very small, and the size of the gratings has to be even smaller, this being the main difficulty of this technique.

There are two types of FBG: nanogratings and microexplosions. The formation of nanogratings is characterized by the use of intensities above $8 \times 10^{13} W/cm^2$, turning the glass birefringent, and both isotropic and anisotropic index changes are of the order of up to $\Delta n = 10^{-3}$. Microexplosions occur at intensities higher than $30 \times 10^{13} W/cm^2$, resulting in microvoids, that can provide very strong index contrast of the order of $\Delta n = 10^{-1}$. To inscribe the FBG using femtosecond laser direct writing, the pulse energy is chosen high enough to cause a microexplosion with a single shot that leaves a high refractive index contrast microvoid behind.

Fiber Bragg Gratings can be inscribed in almost any fiber material without affecting the surrounding region, being possible to operate at temperatures up to 1000 °C. Grating designs benefit from new structuring possibilities since the modifications can be highly localized within the core or can extend far into the fiber cladding. It can be used as sensing devices, fiber lasers and all optical switches. [3]

III. Experimental

In order to do the inscription of fiber grating it was used the setup represented in figure 4.

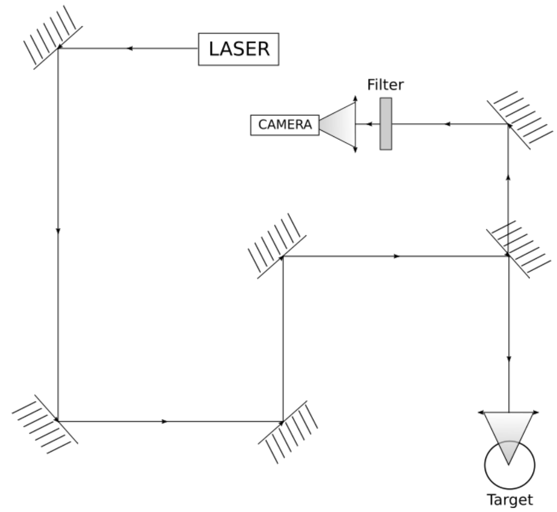

Figure 4. Experimental setup for the inscription of fiber grating

The camera is used to see the position of the fiber's core to make sure that the light is being focused on the right spot. It is placed a filter before the camera so the intensity of the light doesn't damage it.

It is used a cylindrical lens to focus the laser beam into the core of the fiber, in a very small spot where the grating is going to done.

To observe the spectrum of the light that comes out of the fiber during the fabrication of the gratings, the fiber is connected to an Optical Spectrum Analyzer (OSA).

In this configuration, the fiber is under tension and placed in a translation stage that controls its movement along the direction of the fiber. In order to have a very high precision, the tension and the pace of the movement are controlled by computer.

To make sure the laser is focused in the right spot on the fiber, all the equipment has to be correctly aliened.

IV. Results and Discussion

After doing several gratings, it was obtained the spectrum represented in figure 5.

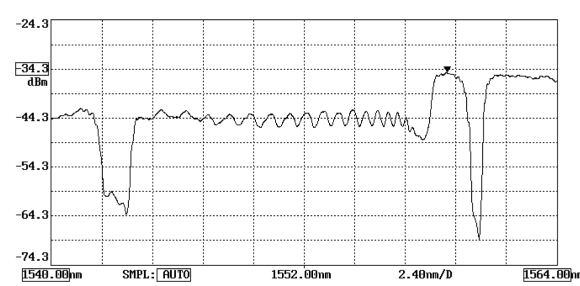

Figure 5. Spectrum of the light after the grating.

The gratings are characterized by the absence of specific wavelengths in the spectrum. Since, during the inscription, the temperature of core can reach very high values, the fiber might have been deformed, causing a diminish in the tension, which leads to a shift of the next grating. These spacing differences between some sections of the fiber altered the wavelengths that are being filtered, which can be seen by the small "drops" in

the spectrum, corresponding to the formation of a new grating. For this reason, the applied tension has to be very small, just enough to keep the fiber in-place.
Since the core of the fiber is extremely narrow, compared with its cladding, it's difficult to center the fiber in order to focus the laser beam in the center of the core, to do the grating. The final result of the FBG is visible in figure 6.

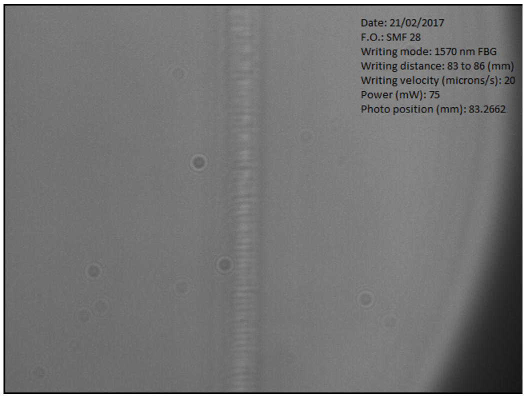

Figure 6. Microscope image of the Fiber Bragg Grating.

V. Conclusions

Femtosecond laser direct writing presents unique capabilities for integration three-dimensional photonic devices in transparent materials, specially inscription of Fiber Bragg Grating. Despite being a technique difficult to master, it has various advantages and the results are promising. Studying more the conditions of the inscription, it's possible to improve a final result and to have a perfect FBG, and even industrialize the process.

References

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