Implementation of an Automated Fiber Bragg Grating Writing System

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Abstract — This paper reports the implementation of an automated fiber Bragg grating writing system. The main objective is to implement a simple and automatic writing process which allows writing gratings with arbitrary profiles. A theoretical model of the writing method was derived in order to automate the writing process. Preliminary simulation and experimental results of different gratings written with the presented system are shown.

I. Introduction

Advances in photonic technologies are dependent on the development of complex and flexible devices. The significant development of fiber Bragg grating (FBG) technology [1] has ultimately driven the capacity increase at lower cost of modern optical communication systems. In this context, the developed system is planned to write FBGs that respond efficiently and effectively to the demands of flexibility and reproducibility required for such demanding applications.

The system is basically composed by a UV laser and a set of motorized positioners with a resolution of 1 nm. The entire writing process as well the initial alignment is controlled by computer. A phase mask with constant period is used to implement scanning or stitching writing methods. The stitching method allows writing FBGs having arbitrary profiles with high precision. Moreover, it allows a grating length dependent on the positioner size instead of the phase mask length.

II. System Description

The experimental assembly consists on an Excimer high-power pulsed laser with a 248 nm wavelength, high-precision motorized stages, a set of optical beam steering lens and mirrors. An image acquisition system is used to aid in the system alignment. All the control software is developed in LabVIEW ©. Fig. 1 shows the basic scheme of the system. Fig. 2 shows a photograph of the apparatus.

III. Writing Methods

The system supports three writing methods: the phase mask method, scanning and a more complex method, the stitching method.

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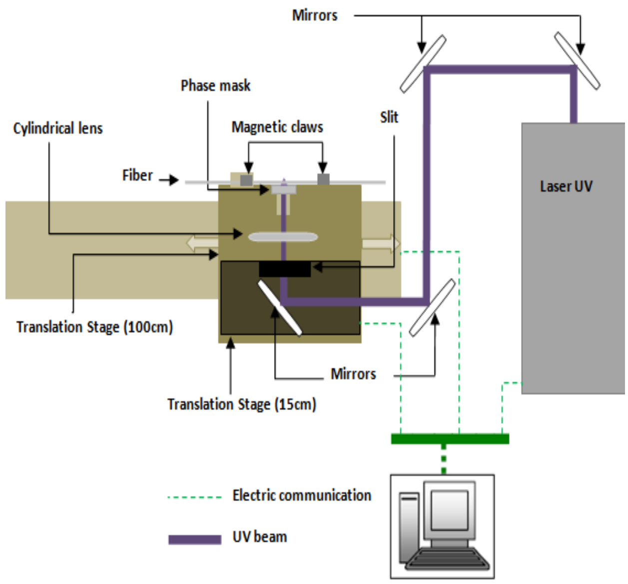

Fig. 1 Scheme of the implemented system

Fig. 2 Experimental apparatus.

A. Phase Mask Method

The phase mask method is the simplest one, and it can be used to write uniform gratings through a single exposure to the laser light. There is no need to use the stage translation, ie, there is no displacement of the phase mask in relation to fiber optics. The length of the grating is limited to the widths of the slit and the laser beam.

B. Phase Mask Scanning Method

Another possible method is to scan the phase mask. The laser, fiber and phase mask stand still. However the translation stage is now needed to sweep the laser beam along the phase mask. This method is more complex relatively to the latter, since a fine adjustment of the slit and mirror alignment is needed. The sweeping speed defines the refractive index variation. Thus, changing the sweeping speed along the phase mask allows defining apodization profiles. The length of the grating is limited to phase mask length.

C. Stitching Method

The stitching method [2] is the most complex and used one. However, it allows the design of complex gratings with arbitrary profiles and long lengths. In this method only the fiber stands still, whereas the phase mask is displaced along the fiber using the translation stage. As such, the mirrors directing the laser light to the phase mask must be carefully aligned. Moreover, the fiber should remain at the same distance from the phase mask during the entire FBG length, otherwise, involuntary variations on the refractive index variations occur. This writing method depends on the exposure length L_{exp} set by the user. A lower exposition length increases the writing precision at the expense of a longer writing time. This method requires an input file that lists the steps that correspond to the values of displacement of the stage. These steps are related to the designed visibility profile. The FBG design begins with software written in Matlab that implements the transfer Matrix method [Erdogan]. Parameters such as apodization, visibility, length and phase shifts can be handled. Afterwards, the visibility is translated to translation steps. The length of each step depends on the exposure length and phase mask period.

III. Detailed Writing Procedure

In this section the detailed writing procedure is described. They are operated any equipment used in the system. It is connected the computer, amplifier DR500 compressed air system that feeds the optical table and the stage ABL20100, XPS controller, the cooling system of the laser, system purging and laser, the latter being placed in state after 'emission start '. We checked which type of grating to write, if a grating using the method for the phase mask, the method for scanning or the Stitching method, to define the width of the Slit according to the step taken by the file in the case of the Stitching method. It found that the central wavelength desired to the writing system, if necessary, change the mask. The fiber is then placed in the magnetic clutches with some tension, to ensure that the fiber is stretched. The operator runs the software of control and performs the initialization of the system allowing the preparation and initial placement of all motor stages. The imaging system is triggered in real time putting away the mask to the desired fiber, in pixels, allowing the automatic approximation of the phase mask to the desired distance, a distance of about 14 pixels(~70µm). The control of the laser parameters is put the values required for the writing, such as the frequency, the type of shot. The type of shot will depend on the type of method adopted for the grating writing. Then, in the control of position movements will be chosen according to the method adopted for the writing of the grating and the type of movement. If the method is for the phase mask, will focus the window Simple Movement putting the value of the movement. If the method is chosen for scanning, will focus the window Movement scan ILS, putting only the distance and speed to sweep. Finally, if the method is chosen by Stitching, will focus on the window Movement file, only to be selected the data file to record, because the speed is already preset. In the last two methods, the shot is done automatically, because the process is scheduled cyclically move - shot. After the end of the automatic writing of the grating, the next step will be made in the imaging system, the removal of the phase mask in relation to optical fiber, for when the fiber is withdrawn from the clutches magnetic, avoid any contact between them (phase mask and fiber) to avoid damage.To end the spectrum will be stored in reflection and/ or transmission.

IV. Simulation and Experimental Results

A. Uniform gratings

Uniform gratings are the simplest ones. Moreover, the system calibration is done also by writing such gratings.

An uniform grating with 1mm length was written using the phase mask and stitching methods. For the phase mask method the slit aperture was 1mm and there was a single exposure of energy E. For the stitching method he slit

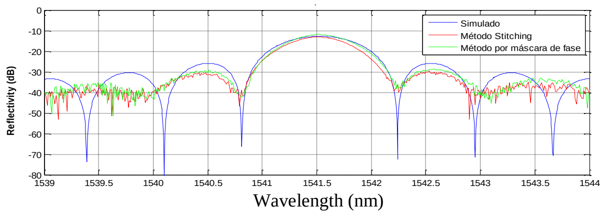

Fig. 3 Reflectivity response of the simulation and written gratings.

aperture was 100µm. It was loaded a file with 10 steps, each step having the same laser energy. Fig. 3 illustrates the extent amplitude of the two cases, and the response of the simulation. It can be seen that there a good approximation of the central peak of the written gratings according to the two methods and the simulation. However, there is a difference in amplitude and period of the lateral lobes of the written gratings on the simulated grating. This difference is originated by the non-uniform profile of the laser beam, inducing a slight apodization.

B. Phase-shifted gratings

This type of grating is characterized by the introduction of a phase shift in the modulation of the refractive index. This shift results in the formation of a cavity, composed by two gratins before and after the phase-shift position.

The stitching method was used to design a phase shift of π in the middle of the grating. The total length of the grating was of 4 mm. Fig. 4 shows that a good match between the simulation and written grating was achieved.

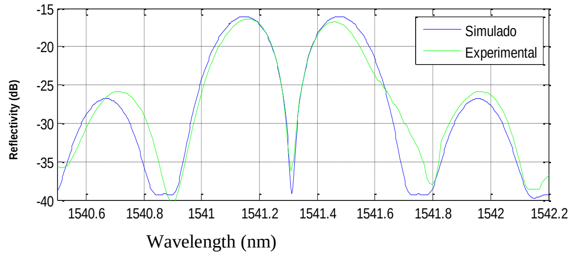

Fig. 4 Reflectivity response of the simulation and written phase-shifted gratings.

C. FBG arrays

Optical code division multiplex access networks use spectral or temporal encoders that can be implemented with an array of FBGs, where each has a different wavelength. As such, if a white light pulse is sent to the grating, the reflected signal consists on several pulses with different wavelengths and time delays. The time delays depend on the spacing between the individual FBGs. The FBG array on the receiver does the opposite process: transforms the pulsed sequence into a single white light pulse. The distance between each FBG is given by

$$d = \frac{cT_{\text{chip}}}{2n}, \qquad (1)$$

where n is the refractive index of the fiber, T_{chip} is the time delay between each chip and c is the speed of light. It was written an array with four gratings delayed by 50ps among them, which corresponds to $d = 5.17789$ mm. The FBG wavelengths were set between 1548.20 nm and 1554.60 nm, spaced by 1.6nm. All gratings were designed to have the same reflectivity. The results are shown in Fig. 5.

The gratings are very close in terms of relative wavelength spacing (see table 2) and delay (se table 3). All gratings have similar reflectivity. A precise central wavelength of the gratings was not achieved since a tension meter device is not available (table 4).

	FBG 1 Spacing |(nm)	FBG 2 Spacing (nm)	FBG 3 Spacing (nm)	FBG 4 Spacing (nm)
Theoretical	--	1.6	4.80	1.6
Experimental	--	1.61	4.79	1.58
Deviation	--	0.01	0.01	0.02

Table 2 Comparison between written gratings in terms of spacing.

	FBG 1 GD (ps)	FBG 2 GD (ps)	FBG 3 GD ps)	FBG 4 GD (ps)
Theoretical	--	50	50	50
Experimental	--	50.11	50.17	50.09
Deviation		0.11	0.17	0.09

Table 3 Comparison between written gratings in terms of group delay.

	FBG 1 λ_{central} (nm)	FBG 2 λ_{central} (nm)	FBG 3 λ_{central} (nm)	FBG 4 λ_{central} (nm)
Theoretical	1553.00	1554.60	1549.80	1548.20
Experimental	1552.86	1554.47	1549.68	1548.10
Deviation	0.14	0.13	0.12	0.10

Table 4 Comparison between written gratings in terms of central wavelength.

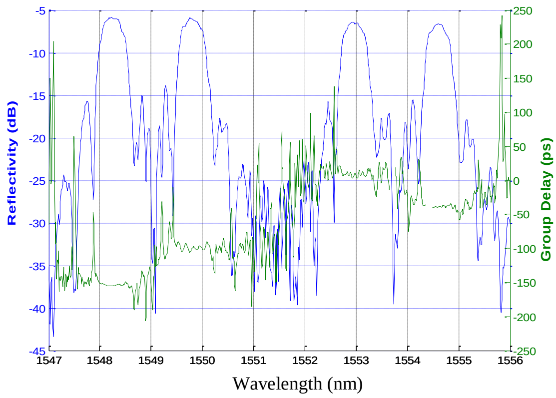

Fig. 5 Reflectivity and group delay response of the written FBG array.

D. Chirped gratings

In the most common form, chirped gratings have a linear increase of the Bragg period along the longitudinal axis. However, in the implemented system it is not possible to write chirped gratings in this way. Another method is used: chirped gratings are written by sampling an uniform FBG. The sampling function consists on a square wave with a period that increases linearly along the longitudinal axis. This type of grating was also recorded with the stitching method. A grating was designed in terms of reflectivity, bandwidth and the group delay. Fig. 6 illustrates the comparison of the grating recorded in terms of reflection and group delay. Table 5 shows the theoretical and experimental results obtained.

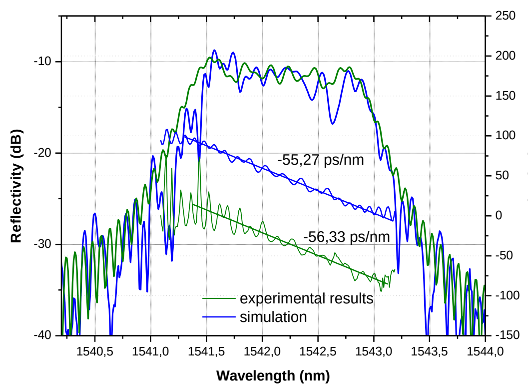

Fig. 6 Reflectivity and group delay response of simulated and written chirped FBG.

	Reflectivity (dB)	Bandwidth (nm)	Dispersion (ps/nm)
Theoretical	28.48	1.63	-55.27
Experimental	28.48	1.49	-56.33

Table 5 Comparison between written gratings and simulation.

The reflectivity, bandwidth and group delay slopes agree very well.

E. Strong FBGs as notch filters

A grating with high reflectivity can be used in transmission to implement a notch filter, where signals with wavelengths that are not the Bragg wavelength pass through the grating. With this technique. Reduced bandwidths can be achieved, which is very usefull for microwave signal filtering. signals. A grating with central transmissivity of -30dB, 40.7pm bandwidth and centered at 1549.744nm was designed. For this purpose, an uniform FBG with 25 mm was written with the stitching method. The exposure length was of 200 µm. The results are shown in Fig. 7.

	$\lambda_{central}$ (nm)	Bandwidth (pm)	Transmission (dB)
Theoretical	1549.744	40.7	-32.1
Experimental	1549.882	44.3	-31.01
Error	0.138	3.6	-1.09

Table 5 Comparison between simulation and experimental results.

The wavelength error is once again due to the lack of tension

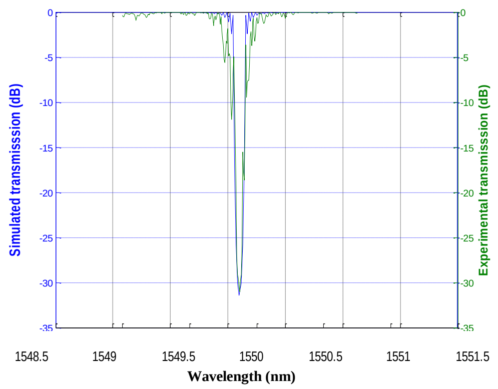

Fig. 7 Reflectivity and group delay response of simulated and written strong FBGs.

control. The bandwidth and transmission agree very well.

V. CONCLUSIONS

An FBG writing system with a purpose of writing long gratings with arbitrary profiles has been implemented. The system is fully automated in order to allow an user without practical knowledge of the system to handle the system. The developed system provides a good reproducibility. Simulation and experimental results show a good match.

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