Dense Fiber Bragg Gratings Array Inscription During Fiber Drawing Process

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Abstract: We report in the present paper the manufacturing of dense Fiber Bragg Grating Arrays directly during the fiber drawing with a spacing down to 150µm and global regularity of ± 50µm.

1. Introduction

Optical fiber sensors, and particularly Fiber Bragg Gratings (FBG) based sensors, are really attractive in a lot of applications fields from medicine to structural health monitoring. Most of these applications implies distributed sensing resulting in the need to manufacture Fiber Bragg Grating Arrays (FBGA) [1]. Our inscription process during the drawing fiber process allows us to inscribe a large number of FBG in a short time, making it a cost-effective solution.

2. Single Pulse Inscription Process

The system we developed is based on the phase-mask inscription technique. We inscribe our FBG with a single UV shot using a ©Coherent Excimer Laser (248nm). The laser pulses trigger signal is generated by the drawing fiber tower control unit according to the draw speed.

This allows us to control the spacing between 2 FBGs with respect to the line speed. It means that the pulse generation depends on the line speed so the spacing is much more consistent than if the pulses were generated at a specific frequency since the pulse triggering follows the line speed variations.

But our inscription process also has two main limitations. The first one is related to the phase-mask technique. Indeed, even though it is the simplest way to write gratings during the drawing fiber process, it limits us to a single wavelength since the Bragg resonance wavelength is related to the phase-mask pitch using the well-known equation:

$$\lambda_B = 2 \times n_{eff} \times \frac{\Lambda_{PM}}{2} \qquad (1)$$

Where n_{eff} is the effective index of the guided mode in the fiber, and Λ_{PM} is the phase-mask pitch [2].

The second limitation involved by our process is the maximum reflection we can achieve. Indeed, in order to inscribe uniform gratings, we must write them using a single laser pulse, which means that we can only have a low quantity of UV dose limiting the maximum index variation and so the maximum reflection is limited to only a few percent.

Despite of these limitations, this process is still very interesting because, for most sensor applications, a few percent of reflection is sufficient. In addition, thanks to laser triggering system directly managed by the drawing fiber tower control unit, the spacing between two laser pulses can be controlled very precisely since the triggering will depend on the line speed.

3. Tests and Results

Since we inscribe the gratings with a single UV pulse, the UV dose we can achieve is limited. Moreover, it is not possible to hydrogenate the fiber preform to increase the photosensitivity of the fiber. So, to reach a sufficiently high refractive index change we fabricated a Ge-doped single mode fiber with high germanium concentration to obtain a strong natural photosensitivity. And even with this concentration, we only got a few percent reflection per gratings. But it is not a problem that the reflection of each grating is low, since all our gratings have the same Bragg wavelength: the higher the reflection is, the fewer the number of gratings you can have in an array. Thus, depending on the application a trade-off between reflectivity and the number of gratings within an array has to be found.

Our goal was to obtain a one-meter long array composed of 10mm long FBG with a spacing of a few hundred micrometers. This type of dense array is well suited for shape-sensing applications since the spacing between two successive FBGs will influence the resolution of the sensor [3], and require only a very small amount of reflection, less than 1%, per grating to work well. For this reason, we have decided to limit the energy per pulse of our KrF laser to only 1.5mJ. Another critical criterion is the spacing between two successive gratings which must be very regular, so to improve our repeatability we have reduced our draw speed to 20m/min.

With these settings, we performed several tests to adjust our drawing parameters and finally we were able to fabricate an FBG array of tens of gratings spaced less than 200µm.

As can be seen in figure 1a) which represents the temporal response of the inscribed array, the photo-inscription process (pulse triggering and writing of the gratings) is really stable. The variations in spacing that we observed, thanks to the OBR4600 (©Luna Innovation), were of the order of 50µm.

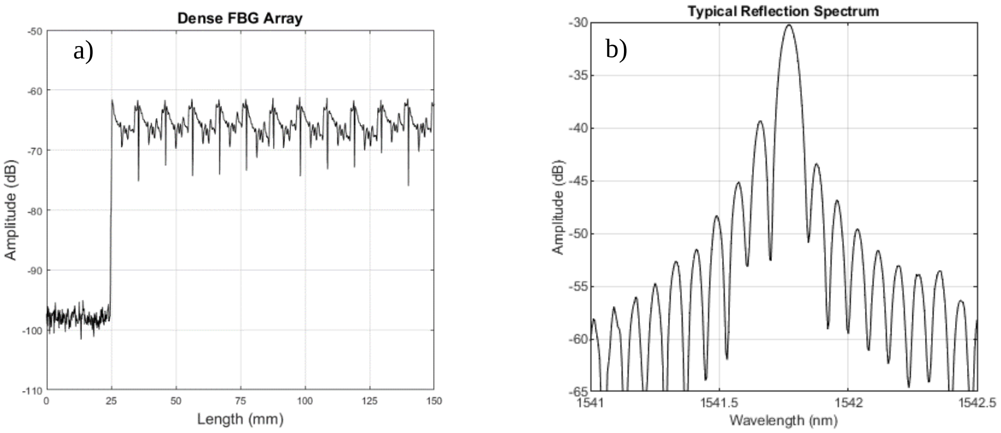

Fig. 1. (a) Temporal response of the FBGA and (b) spectral response of a single FBG of the array measured using the ©Luna Innovation OBR4600

In addition, the gratings individual reflections are quite good with a sidelobe suppression ratio of around 10dB. We can however observe a slight dissymmetry on the short wavelength side of the reflection spectrum. This dissymmetry is directly due to the fact that we inscribe our gratings during the draw fiber process. However, this dissymmetry has no direct influence.

Thanks to our process we successfully produced a one-meter FBG array composed of tens of gratings spaced of 150 ± 50µm with individual reflection of around 0.4%.

4. Outcome and Perspectives

We were able to inscribe FBG arrays of various sorts thanks to our drawing fiber and photo-inscription combined process. The more the spacing is important the easier it is, but by reducing the draw speed FBG arrays with grating spacing as low as 150µm have been achieved.

Thus, some limitations still have to be overcome. One of our main limitation today is related to the phase-mask inscription technique which limits us to a single Bragg wavelength. However, we have several ideas to overcome this limitation. First of all, we could try to develop a Talbot interferometer, but this solution does not seem a promising way. A more viable option would be to have a set of phase-masks that can be interchanged during the fiber drawing.

Another limitation of this process today is related to the coating we use. Today the fiber we produce is coated with a single layer acrylate which is not suitable for harsh environment, especially for high temperature environment. But we are already developing a new drawing process for this type of environment (high temperature and radiation resistive fibers).

We are also working on 7-core multicore fiber with twisted cores, especially for shape sensing applications [4], and manufactured our first FBGA on this kind of fiber with very promising initial results.

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