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Inscription of narrow-band fibre Bragg gratings with 264 nm femtosecond pulses

Patrick Kelleher, David N. Nikogosyan *

Department of Physics, University College Cork, Cork, Ireland

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ABSTRACT

We fabricated narrow-band fibre Bragg gratings (FBGs) in photosensitive Ge/B codoped fibre by a scanning mask technique with high-intensity (30–60 GW/cm^2) 264 nm 220 fs laser pulses. Comparing with recently reported inscription using 800 nm pulses and same scanning approach, our gratings demonstrate a smaller linewidth down to 0.2 nm and much higher grating strength at shorter length. In addition, the obtained results demonstrate the absence of significant off-band losses.

1. Introduction

For the inscription of fibre Bragg gratings (FBGs) in standard, photosensitive and specialty fibres the phase mask technique is commonly used [1]. The important development of this method, the scanning mask technique, was proposed in 1994 by two independent groups of researchers [2,3]. The schematic of this method is shown in Fig. 1. The fibre is fixed together with the phase mask on the translation stage and they both are moving perpendicular to the direction of inscribing UV beam. As the laser beam diameter is usually an order of 1 mm and the phase mask is of about 1 cm length, such a shift (made continuously or step-by-step) allows the fabrication of longer FBGs than in the original approach with a static phase mask (static phase mask technique). Longer Bragg gratings possess a narrow linewidth and this is the main advantage of this approach. Another advantage is the possibility of inscribing of a complex grating structure [4]. For example, introducing near the FBG geometrical centre an additional ultra-fine shift of phase mask/fibre system for a 267 nm (π-shift or half a period shift) leads to so-called π-phase-shifted FBG, which possesses a sharp dip in the reflection peak at 1550 nm. Finally, the third advantage comes from the installation of an additional slit (slits) in front of the phase mask, leading to a more uniform exposure in the case of non-uniform (in time or in space) laser radiation [5].

Since 2003, high-intensity femtosecond pulses (both IR and UV) have been used for FBG fabrication by a traditional phase mask method [5–8] and the more advanced point-by-point (PbP) technique [9,10]. These studies are motivated by the following reasons:

(1) multi-photon absorption mechanism allows to inscribe FBGs far from the maximum of fibre photosensitivity and even in areas of full transparency, e.g. in the fibre core made of pure fused silica [11] and/or in photonic crystal fibres [12];
(2) due to tight focussing/self-focussing of inscribing laser light the inscribed Bragg gratings demonstrate a very high temperature stability (~1000 °C) [13,14];
(3) using PbP approach, the inscription of very short-period (down to 250 nm) [15] or even non-uniform (chirped) gratings [16] becomes possible.

Recently, a first detailed investigation on FBG inscription by femtosecond IR pulses using a scanning phase mask technique was published [17]. The authors reported the fabrication of FBGs of 20 mm length with a grating strength of 22 dB at 1555 nm and linewidth of 0.4 nm in a standard telecom fibre using tightly-focussed 800 nm pulses with a repetition rate of 1 kHz and energy of 600 μJ, scanned with a continuous speed of 4 mm/min. Due to the uncertainty in focussed beam area, the exact accumulated fluence and the irradiation intensity were not specified. In another publication, the same group reported a 40 mm long FBG in erbium-doped fibre recorded in similar conditions which had an 18 dB reflection peak at 1555 nm and linewidth of about 0.5 nm [18]. It should be noted that both gratings demonstrated a high level of off-band losses (4–7 dB) due to cladding modes originating from multiple beam interference [19].

In the current study, we report the FBG inscription with a scanning mask configuration using femtosecond UV (264 nm) pulses. We show that the inscribed gratings are of better quality (smaller bandwidth and higher grating strength at much shorter lengths) than those inscribed by femtosecond 800 nm pulses. The obtained results demonstrate the absence of significant off-band losses. The comparison with the FBGs inscribed at the same set-up using a static mask configuration was made. Besides, we describe the method

* Corresponding author. Fax: +353 21 4276949.
E-mail address: niko@phys.ucc.ie (D.N. Nikogosyan).

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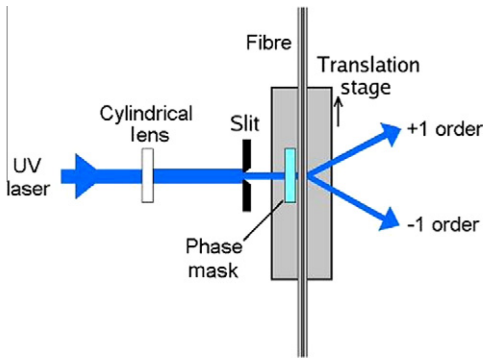

Fig. 1. Schematic of the scanning mask technique.

of accumulated fluence calculation in the case of the scanning mask technique utilizing a slit placed in front of the phase mask.

2. Experimental set-up

In the experiments we used photosensitive Ge/B codoped H_2-free Fibercore PS1250/1500 fibre supplied by Fibercore Ltd., UK. It has a Ge content of about 10 mol.%, a core diameter of 7.1 μm, a cladding diameter of 125 μm, and a numerical aperture of 0.13.

For Bragg gratings inscription we used the commercial laser Twinkle (Light Conversion Ltd., Lithuania). The experimental set-up (Fig. 2) is similar to that described in [8] with one essential difference, namely, we used a scanning phase mask technique for FBG inscription (in some experiments a static phase mask method was also used for comparison). The femtosecond UV pulses (λ = 264 nm, $\varepsilon_p \approx$ 200 μJ, τ_p = 220 fs (FWHM), $2w$ = 0.31 cm (FWHM), f = 27 Hz) were directed by a 22.3 cm fused silica cylindrical lens onto the fibre (with acrylate coating removed) through a thin (1 mm) phase mask (Ibsen Photonics). The fibre was placed behind the phase mask at a distance of about 100 μm. The lengths of inscribed FBGs were 1 cm and 0.31 cm for scanning and static phase mask methods, respectively. For the narrow-band FBG inscription we used three masks with periods of 1071.2 nm, 1072.6 nm and 1074 nm. For a static mask configuration we used a phase mask with period of 1070 nm.

The phase mask was fixed together with the fibre and moved by a 50 mm long M-405.DG linear positioning stage (Physik Instrumente) with a 0.1 μm resolution. The stage was controlled through

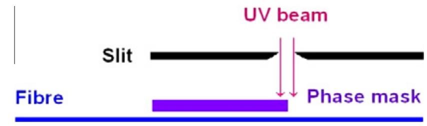

Fig. 3. Step-by-step phase mask illumination procedure by the inscribing UV laser beam.

a Mercury 2 C-862 DC motor controller (Physik Instrumente). In front of the phase mask a vertical slit of 2.3 mm width was placed, the distance between the phase mask and the slit was 7 mm. The focussing by the cylindrical lens was also made in the vertical plane. The movement of the phase mask/fibre system in the direction perpendicular to the inscribing laser beam (Fig. 3) was made in 1.15 mm steps. To ensure that the whole length of the phase mask (10 mm) was scanned by the beam, few initial (and few last) scanning steps were done entirely outside the phase mask. In total, we have used 12–13 steps for one scan. Later during the fluence calculation, in order to exclude the photons passing by the phase mask, we multiplied our total fluence by the parameter

$$\frac{L_{mask}}{L_{step} \times N_{step}} \tag{1}$$

where L_{mask} is the length of phase mask, L_{step} is the length of the single scanning step and N_{step} is the number of steps.

Energy measurements were made using pyroelectric PE-10 heads and LaserStar energy meter (both from Ophir Optronics). The energy meter was connected to the computer through the PCI-GPIB card (National Instruments). The exposure of the fibre to the laser radiation was controlled using a Uniblitz shutter/VMM-D1 shutter driver (Vincent Associates). The fibre exposure, the stage movement and data acquisition were automated using LabView software (National Instruments).

A LabView program allowed the user to choose the certain parameters for the experiment, namely the energy passing through the shutter, the number of steps to be taken and the length of each step. Initially, with the activation of the program the shutter was opened; using the LaserStar energy meter the energy of each laser pulse was measured and the number of pulses counted, that data was summed and recorded by the LabView program. While the accumulated energy was less than the specified amount, the shutter remained open. When the required energy was reached, the shutter was closed. Then the position of the stage was changed for the user-defined distance and then the shutter would open again. This was repeated for the specified number of steps. When the irradiation was completed, the translation stage was returned

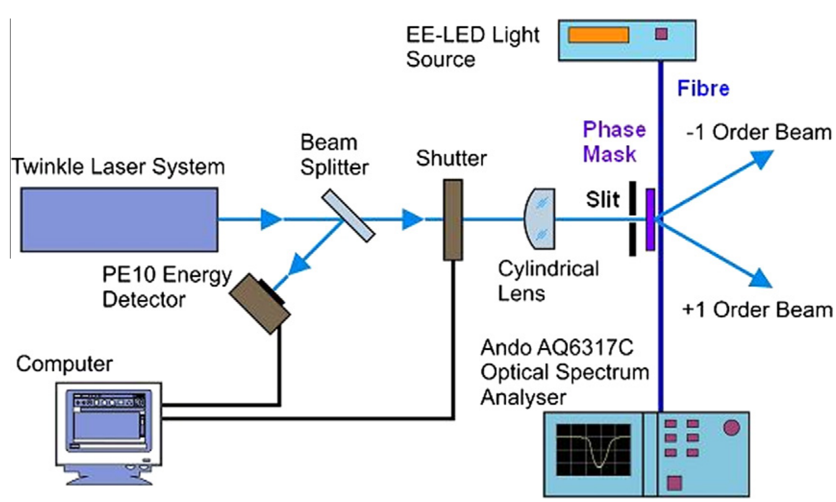

Fig. 2. Experimental set-up for FBG fabrication using femtosecond 264 nm pulses.