Femtosecond Inscription of Superimposed, Non-Overlapping Fibre Bragg Gratings.

A. Martinez, M. Dubov, I. Khrushchev, I. Bennion
Photonics Research Group, Aston University, Birmingham B4 7ET, UK
Email: martinea@aston.ac.uk

Abstract. *A method for direct inscription of fibre Bragg gratings laterally separated by inscription in separate segments of the fibre core is demonstrated for the first time.*

Introduction.

Fabrication of fibre gratings is a new and interesting application of the recently emerged femtosecond inscription technology. The technology is based on modification of transparent dielectrics in the strong field of an ultrafast laser beam. In glasses, exposure at a level below the optical damage threshold produces long-lasting, controlled changes of refractive index. The technique has been successfully employed for fabrication of long period gratings [1, 2] and fibre Bragg gratings (FBG) [3-5]. One of the advantages of femtosecond inscription is a possibility to achieve sub-micron spatial resolution. Tight focusing by high aperture optics, combined with the nonlinear nature of the process, allows to reach the feature size as small as 0.3μm [6]. At the same time, the refractive index modulation can be made significant. As a result, the gratings inscribed in fibres show strong resonant response and yet they can be confined in a relatively small volume.

On the other hand, superimposed gratings represent an interesting type of passive optical device with a number of important applications. Available technologies of inscribing of superimposed gratings inevitably involve repeating modification of the same volume of material during in the process of writing. As a result, the number and the accuracy of the overlapping structures in a single fibre are to some extent limited by the physical interaction between the structures [6].

Femtosecond inscription provides, in principle, a convenient solution. By adjusting the inscription geometry and the regime of exposure, one can control the size and position of the modified volumes of material inside the sample. In particular, it is possible to confine a fibre grating in a fraction of the fibre core cross-section. This way, the interactions mention above can be minimised or eliminated.

In this paper, we make use of the tight confinement of the femto-inscribed FBG and demonstrate a possibility to fabricate superimposed, but physically non-overlapping grating structures by using inscription in different segments of the fibre core. The technique is in principle suitable for inscription of as many as several tens of gratings in the same length of fibre without effects of blurring of the grating pitch caused by overwriting.

Experiment.

Non-photosensitised standard communication fibre (SMF-28) was used in the experiments. All the gratings were designed in order to show the second order resonance at the operating wavelength.

A femtosecond, Ti:sapphire laser operating at a wavelength of 0.8μm was used for inscription. A 100X microscope objective with a numerical aperture NA = 0.65 focused the laser beam in a spot size smaller than 1μm. The pulse energy incident on the fibre was adjusted by an attenuator and was close to a value of 0.5μJ.

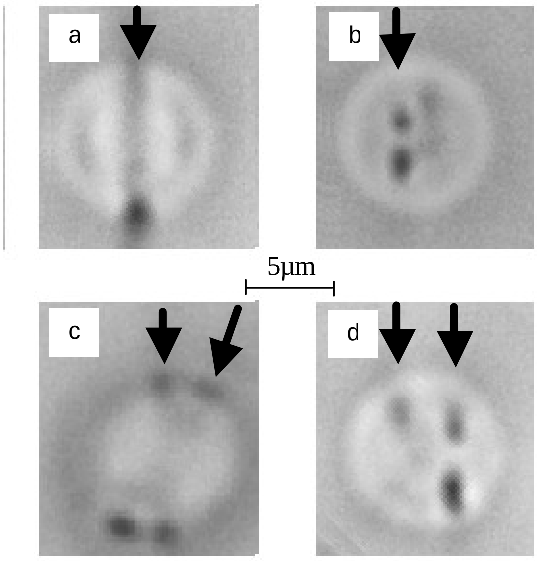

Figure 1. Grating design examples. (a) Single grating inscribed off-centre in the fibre core; (b) two gratings separated by translation along the laser beam; (c) rotational displacement; (d) translation along and across the laser beam.

During the inscription, the grating reflection and transmission were monitored in-situ by using two monochromators and a broadband source. Standard telecommunication fibre was used; no photosensitisation procedure was carried out prior to the exposure. The fibre was placed on a high-precision, two-coordinate translation stage. The stage moved at a constant speed along the focal point of the beam, so that each pulse produced a grating pitch in the fibre core.

Location of the grating structure inside the core was determined by focusing the highly-attenuated laser beam in the appropriate volume. The position of the focal spot was monitored from the top and from the side of the fibre by two microscopes.

A typical cross-section size of an inscribed grating structure was 1µm by 2µm approximately, as shown in Fig.1a. Hence, the area of a grating cross section was only 2µm^2, making it possible, in principle, to inscribe several tens of non-overlapping gratings in the core of a typical telecommunication fibre with the mode area of the order of 70µm^2.

We produced several pairs of non-overlapping gratings by writing one grating after another in each pair. The spatial separation in transverse plane between the elements of the pair was achieved either by a parallel translation of the fibre in lateral direction, or by rotating the fibre with respect to the axis. Figs.1b,c,d show cross sections of several grating pairs produced using different separation techniques.

In each case, the grating structures in the pair were distinctly separate. Note, that the gratings in Fig.1a,c have been formed on the opposite, to the laser, side of the fibre core.

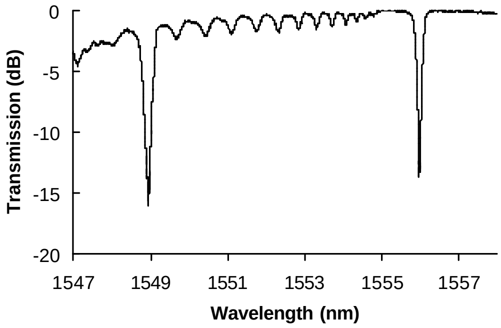

Figure 2: Reflection and transmission spectra of a grating pair. Grating periods are 1.07mm and 1.075mm. Gratings are laterally separated as shown in fig.1b.

Fig.2 presents the transmission spectra measured in a double grating structure of the type shown in Fig.1b. Both gratings in the structure show strong resonances with linewidth of 0.25nm approximately. Importantly, the spectral features of the grating that was inscribed first remained unchanged during and after inscription of the second grating in the same length of fibre.

In this, non-optimised, focusing geometry, additional features were sometimes formed along the path of the laser beam in the areas of cross-section, adjacent to the grating area. These appear in Fig.1a and Fig.1c as slightly darkened spots close to the points where the laser beam enters the core, as shown by arrows. Tighter focusing of the laser beam by an optimised optical system is expected to eliminate this parasitic effect. When optimising the optics, the main challenge will be in compensation for the effect of a strong cylindrical lens formed by a side surface of the fibre. Focusing the laser beam into a smaller spot will of course reduce the lateral size of the grating, thus allowing the inscription of a larger number of non-overlapping, superimposed gratings in a single fibre core. Assuming the spatial resolution of 0.3µm approximately, already achieved in bulk glass samples, estimated number in excess of a hundred of non-overlapping gratings can be in principle superimposed in a single length of fibre. Gratings of this type would be of course important for a number of applications in WDM data transmission, sensors and microwave photonics.

Conclusion.

Fibre Bragg gratings, laterally confined in a small fraction of the fibre core, have been produced for the first time. The technique is suitable for inscription of arrays of superimposed, non-overlapping gratings in standard optical fibre.

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