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Moving fibre/phase mask-scanning beam technique for enhanced flexibility in producing fibre gratings with a uniform phase mask

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Abstract

We demonstrate a new and flexible technique for producing photorefractive fibre gratings with a uniform phase mask. By slowly moving the fibre relative to the mask as the writing beam is scanned, wavelength shifts, pure apodisation and phase-shifted gratings can be achieved.

Introduction: Fibre Bragg gratings are well-recognised as key components for many fibre optic and laser systems, but ways for improving their characteristics and ease of fabrication continue to be subjects of strong research interest. In particular, much recent activity has centred on the use of phase masks for grating production[1,2].

The phase mask approach is attractive for it allows fibre gratings to be written with much relaxed tolerances on the coherence of the writing beam, as well as with better repeatability. One drawback, though, has been that the grating wavelength is dictated by the period of the mask, with separate masks required for different wavelengths. Some effort has gone into making the phase mask approach more flexible, e.g. by using a magnifying lens to alter the fibre Bragg wavelength[3]. The use of a scanning writing beam has enabled the fabrication of long fibre gratings, as well as more complex structures through modulation of the scanning beam[4].

The ability to create complex structures, such as apodised and/or controllably chirped gratings, is crucial for many applications. While apodisation can be approximated by modulation of the scanning beam cited above, the accompanying variation in the average refractive index imparts an often undesired induced chirp to the grating. Pure apodisation has just been reported, but requires specially designed masks[5,6]. Considerable effort has also gone into writing controllable chirp characteristics into the grating[7,8].

In this paper, we describe a simple technique[9] whereby the fibre, or alternatively the phase mask, is slowly moved as the writing beam is scanning, and show that this is effective in overcoming many of the limitations currently associated with phase masks. With this approach, we can produce variable wavelength/phase shifted gratings, and pure apodisation.

Experiment and results: The experimental setup is similar to previous scanning writing beam configurations[4], but with the key difference that the fibre is able to move relative to the phase mask while the UV beam (100 mW cw, 244 nm) is scanning, thus enabling a gradual phase shift to be added to the fibre grating being written. For uniform motion, this results in a simple shift of the Bragg wavelength. If λ_0 is the unshifted Bragg wavelength, and v_f and v_{sc} are the fibre and scanning beam velocities respectively, with $v_f << v_{sc}$ (the case of interest here), the wavelength shift is given by $\Delta\lambda=\lambda_0 v_f/v_{sc}$. Thus for a shift of ~1 nm, the fibre has only to move at 0.1% of the scanning speed. For larger wavelength shifts, the grating strength decreases, as the refractive index modulation is averaged out when the fibre moves too quickly across the interference pattern formed by the mask. It can be shown that the index modulation Δn has the following dependence on v_f:

$$\Delta n = \sin(\pi D v_f/\Lambda v_{sc})/(\pi D v_f/\Lambda v_{sc}) = \sin(2n_{eff}\pi D\Delta\lambda/\lambda^2_o)/(2n_{eff}\pi D\Delta\lambda/\lambda^2_o)$$

where D is the writing beam diameter, Λ the fibre grating pitch and n_{eff} the effective refractive index ($2n_{eff}\Lambda = \lambda_o$).

The above relation was verified by writing weak (<20% reflectivity) gratings with different wavelength shifts, and recording their reflectivities, which will have a Δn^2 dependence. Fig. 1 shows that the reflection data fits well to the above relationship for the (measured) beam diameter $D \approx 350$ μm. It is worth noting from the above equation that Δn vanishes when $v_f = \Lambda v_{sc}/D$, or $\Delta\Lambda = \Lambda^2/D$ (where $\Delta\Lambda/\Lambda = \Delta\lambda/\lambda_o$). The maximum wavelength shift is thus only dependent on the beam diameter D. Physically, this limit simply corresponds to the case where a point in the fibre moves by a grating pitch Λ during the time D/v_{sc} that the UV beam scans over it, which obviously results in no net index modulation.

We verified that larger wavelength excursions are achievable by reducing D, the illuminated spot on the fibre, to ~100 μm by focussing with a lens. Fig. 2 shows the transmission spectrum of a comb of 7 gratings obtained with this smaller spot size. The gratings were written one after another on a 1.5 cm length of fibre by changing the fibre velocity at regular intervals. The bandwidth of the comb spectrum is 5 nm.

Apart from varying the Bragg resonance wavelength, pure apodisation can also be accomplished by applying a variable dither to the fibre while the writing beam is scanning. In our case, the magnitude of the dither was simply set to decrease linearly, from ½ grating pitch at the ends to zero at the centre of the grating. It is easy to show that this will produce a cosinusoidal apodisation profile. More importantly, the average UV fluence reaching the fibre will be the same for the entire length of the grating, resulting in a position-independent average refractive index. Thus, only the size of the index modulation will vary, with the local Bragg resonance wavelength the same throughout the whole grating, producing pure apodisation. Fig. 3a shows the reflection spectrum and time delay response for a 1.6 cm long uniform grating, and Fig. 3b the corresponding measurements with the apodisation present, showing its effectiveness in suppressing the side-lobes as well as the ripples in the time delay. The asymmetry of the apodised reflection spectrum with its single side-lobe on the long wavelength side is actually due to the imperfect phase mask, which we have found to be really substantially uniform only over a 1 cm section.

Finally, although only multi-frequency gratings are reported here, it should be clear that continuously chirped gratings can be easily implemented by varying the velocity of the fibre/phase mask accordingly. Furthermore, phase-shifted gratings, such as DFB structures, have also been produced with our technique, just by translating the fibre at the appropriate time by the desired distance. Results of these gratings will be reported elsewhere.

Conclusion: We have shown that the moving fibre/phase mask-scanning beam technique for producing gratings imparts a considerable flexibility to the phase mask approach, enabling more complex grating structures to be written just by moving the fibre relative to the mask in the appropriate manner. The authors acknowledge P. St. J. Russell and D. N. Payne for useful discussions, and L. Dong for fabricating the fibre used in these experiments. This work was funded in part by Pirelli Cavi S.p.A. The Optoelectronics Research Centre is an EPSRC-funded Interdisciplinary Research Centre.

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Figure Captions

Fig. 1 Dependence of reflectivity with wavelength shift. Solid trace: $sinc^2$ function from text.

Fig. 2 Transmission spectrum of grating comb obtained with reduced writing beam size.

Fig. 3 Spectra of (a) uniform grating (reflectivity: 98%, bandwidth: 0.19 nm), and (b) apodised grating (reflectivity: 78%, bandwidth: 0.15 nm).

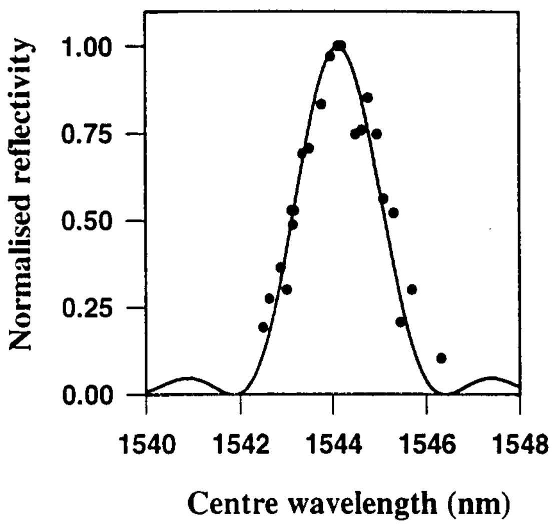
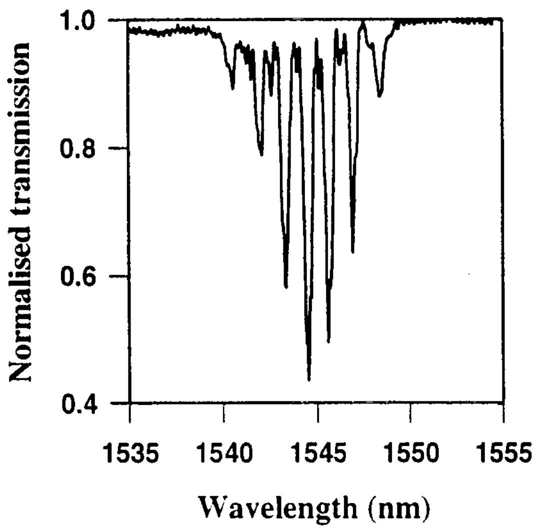
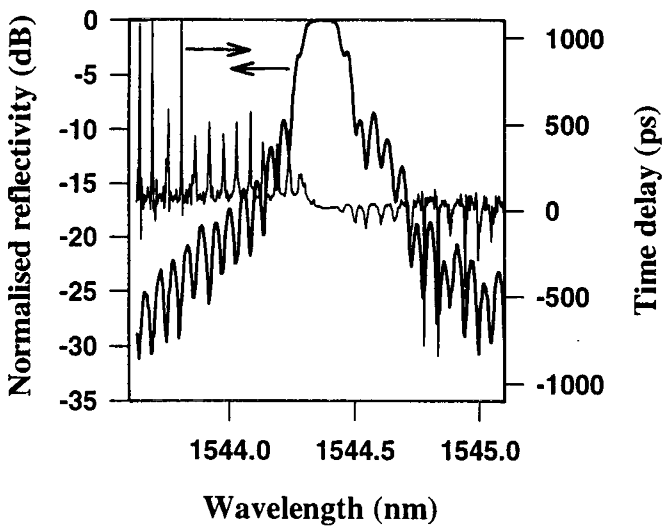

1.00
0.75
0.50
0.25
0.00
Normalised reflectivity
1540
1542
1544
1546
1548
Centre wavelength (nm)

Fig. 1



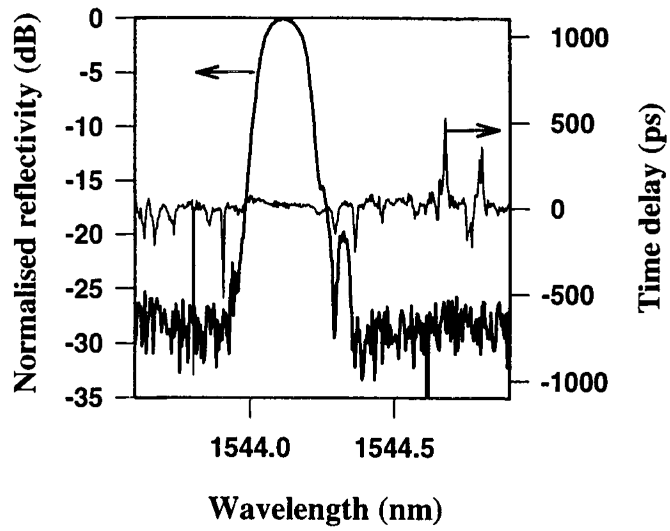
1.0
0.8
0.6
0.4
Normalised transmission
1535
1540
1545
1550
1555
Wavelength (nm)

Fig. 2



Normalised reflectivity (dB)
0
-5
-10
-15
-20
-25
-30
-35
1000
500
0
-500
-1000
Time delay (ps)
1544.0
1544.5
1545.0
Wavelength (nm)

(a)



Normalised reflectivity (dB)
0
-5
-10
-15
-20
-25
-30
-35
1000
500
0
-500
-1000
Time delay (ps)
1544.0
1544.5
Wavelength (nm)

(b)

Fig. 3