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Moving fibre/phase mask-scanning beam technique for writing arbitrary profile fibre gratings with a uniform phase mask

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Abstract

We demonstrate a new technique for writing in-fibre gratings with a uniform phase mask. By moving the fibre/phase mask while the beam is scanning, a range of important grating profiles, such as multi-wavelength gratings, 'pure' apodisation, and chirped structures, have been produced.

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Introduction

Fibre Bragg gratings are by now 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 a subject of considerable research interest. In particular, much of the 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 providing greater repeatability than was previously possible. However, a major drawback has been that the grating wavelength is dictated by the period of the phase mask, and separate masks would be required for different wavelengths. Considerable effort has gone into making the phase mask approach more flexible, e.g. by incorporating a magnifying lens to alter the fibre Bragg wavelength[3]. The introduction of a scanning writing beam was a further advance which enabled the fabrication of long fibre gratings without requiring a large beam magnification. as well as allowing more complex structures to be directly written by modulating the writing beam as it scans across the mask[4,5].

The ability to create more complex structures, such as apodised and/or controllably chirped gratings, is of great importance 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 induced chirp to the grating which is often undesirable. 'Pure' apodisation has recently been reported, but at the expense of either requiring a specially designed phase mask[6], or with double exposure to two different masks[7]. Considerable effort has also gone into writing controllable chirp characteristics into the grating, via a double-exposure technique[8], specially designed 'step-chirp' phase masks[9], or by straining the fibre[10].

In this paper, we demonstrate a simple technique which involves slowly moving the fibre, or alternatively the phase mask, as the writing beam is scanning, and show that this is effective in overcoming many of the limitations which are currently associated with phase masks. With this approach, we can produce multi-wavelength gratings, 'pure' apodisation, as well as a variety of dispersive structures.

Experiment

Fig. 1 shows the experimental setup. The UV writing beam (100 mW cw at 244 nm) from a frequency-doubled argon laser is steadily scanned across a zero-order nulled phase mask, while the fibre is slowly moved relative to the mask, causing 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

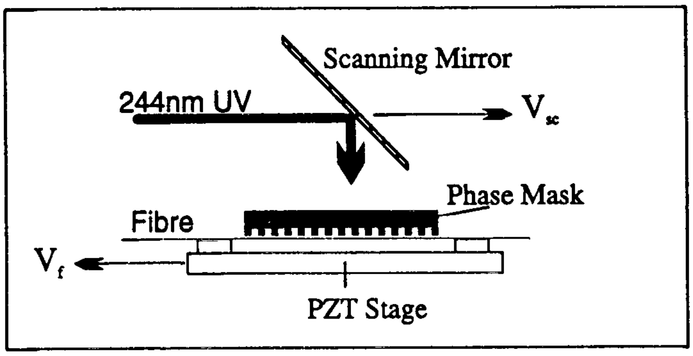

Fig. 1 Experimental configuration

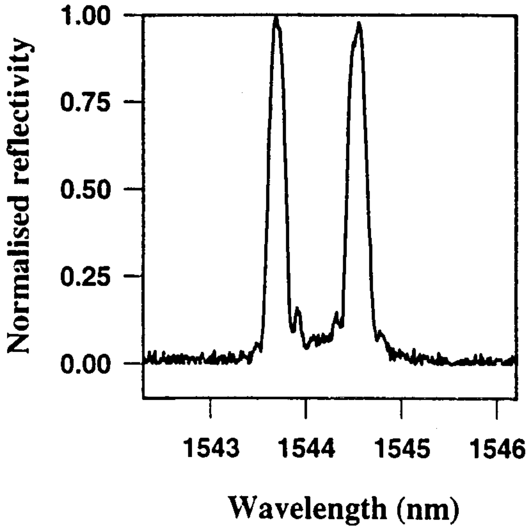

Fig. 2 Reflection spectrum of dual wavelength grating. Peak reflectivity is 67%.

respectively, with $v_f << v_{sc}$ (the case of interest here), it is easy to show that 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. Fig. 2 shows a dual wavelength grating written using a boron-germania photosensitive fibre. The scanning beam speed was 37 μm/s, and the fibre speed was 0.01 μm/s for the first half of the writing time, switching to -0.01 μm/s for the second half (total length of grating was 1 cm).

For large wavelength shifts, the grating strength would decrease as the index modulation gets averaged or 'washed out' when the fibre moves too quickly through the interference pattern formed by the phase mask. It can be shown that the refractive index modulation Δn has the following dependence on v_f:

$$\Delta n = \sin(\pi D v_f/\Lambda v_{sc})/(\pi D v_f/\Lambda v_{sc}) = \sin(2n_{eff}\pi D\Delta\lambda/\lambda^2_0)/(2n_{eff}\pi D\Delta\lambda/\lambda^2_0)$$

where D is the writing beam diameter, Λ is the fibre grating pitch and n_{eff} is the effective refractive index ($2n_{eff}\Lambda = \lambda_0$).

The above relation was verified by writing weak (<20% reflectivity) gratings with different wavelength shifts, and recording their reflectivities R, which will have a Δn^2 dependence. Fig. 3 shows that the experimental reflection data fits well to the above relationship for the (measured) beam diameter D ≈ 350 μm. It is also worth noting from the above equation that Δn vanishes when $v_f = \Lambda v_{sc}/D$, or $\Delta\Lambda = \Lambda^2/D$ (where $\Delta\Lambda/\Lambda = \Delta\lambda/\lambda_0$). The maximum achievable wavelength shift is thus only dependent on the beam diameter D. Physically, this condition simply corresponds to the case where a point in the fibre moves by one grating pitch during the time D/v_{sc} that the scanning beam passes over it, resulting in a

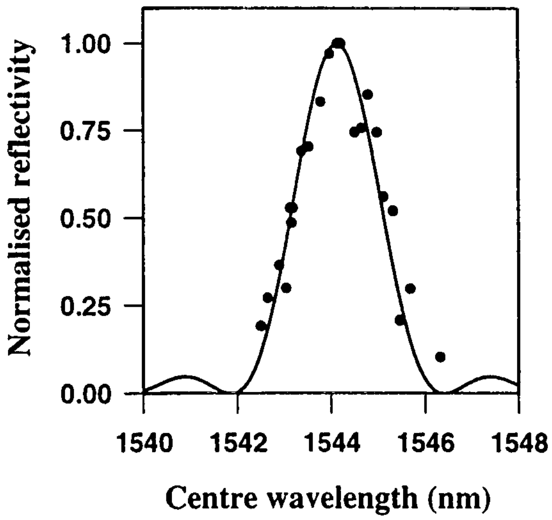

Fig. 3 Dependence of reflectivity with wavelength. Solid trace: sinc^2 function from text.

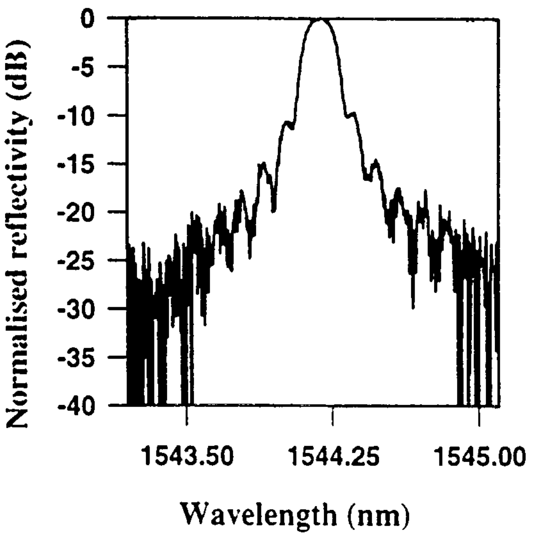

Fig. 4 Reflection spectrum for 1 cm long uniform grating. Peak reflectivity is 82%, bandwidth 0.18 nm.

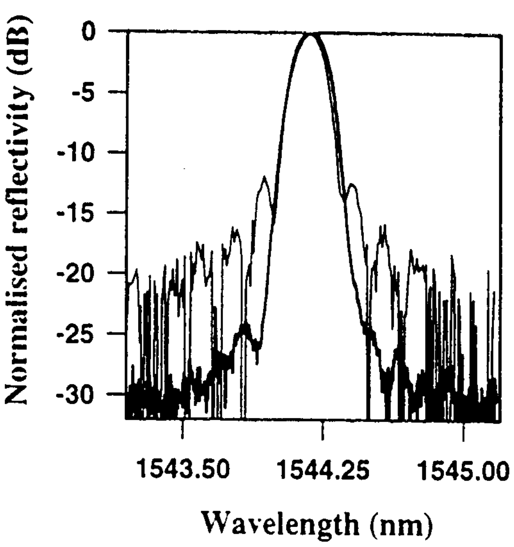

Fig. 5 Reflection spectra for 1 cm long apodised grating (thick trace). Peak reflectivity: 50%, bandwidth: 0.19 nm. Thin trace: uniform grating, same peak reflectivity and bandwidth.

spatial averaging out of the index variation. On the other hand, larger wavelength excursions of several nm should be achievable by simply reducing the writing beam diameter.

Apodisation

Apart from shifting the Bragg resonance wavelength, 'pure' apodisation can also be applied to the grating simply by dithering the fibre back and forth as the writing beam is scanning. In our case, the magnitude of the dither was 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. Since the average UV fluence reaching the fibre is the same for the entire length of the grating, the average refractive index will be independent of length, and only the index modulation will vary, i.e. only Δn is modulated, thus producing a 'pure' apodisation effect. Fig. 4 shows the reflection spectrum for a uniform grating, and Fig. 5 the corresponding spectrum obtained with the apodisation present, showing its effectiveness in reducing the side-lobe levels. With apodisation, the reflectivity is weaker (since the effective grating length is less), so for a fairer comparison, a uniform grating written to have the same peak reflectivity and bandwidth as the apodised one is also shown (Fig. 5, thin trace). It can be seen that the side-lobes of the apodised spectrum are more than 25 dB below the main peak, and 13 dB below those of the uniform grating, comparable to the results by Albert et. al.[6] achieved with a specialised variable diffraction efficiency phase mask.

Chirped Gratings

Finally, instead of applying a constant velocity to the fibre to create a wavelength shift, it is also possible to produce chirped gratings by varying the speed of the fibre relative to the mask. In particular, by simply ramping the velocity of the fibre during the scanning time, a linearly chirped grating can be produced. Fig. 6 shows the reflection spectrum of a 1.5 cm long apodised chirped grating made in this manner. In addition to linearly chirped gratings, it should also be clear that other nonlinear chirp functions can be easily imposed on the grating simply by changing the velocity profile of the fibre during scanning. Indeed, one should in principle be able to compensate for an imperfect phase mask with this method and still produce good quality gratings, provided the imperfections are characterised beforehand. Also, implementing discrete phase shifts for, say, DFB-type structures can be achieved just by shifting the fibre/phase mask by the desired amount at the appropriate time.

In conclusion, we have shown that the moving fibre/phase mask-scanning beam technique for producing gratings from a uniform phase mask imparts a considerable flexibility to the phase mask approach, enabling complex grating structures to be easily written simply by moving the fibre relative to the mask in the appropriate manner. Multiwavelength gratings, 'pure' apodisation and controlled chirp have all been successfully demonstrated.

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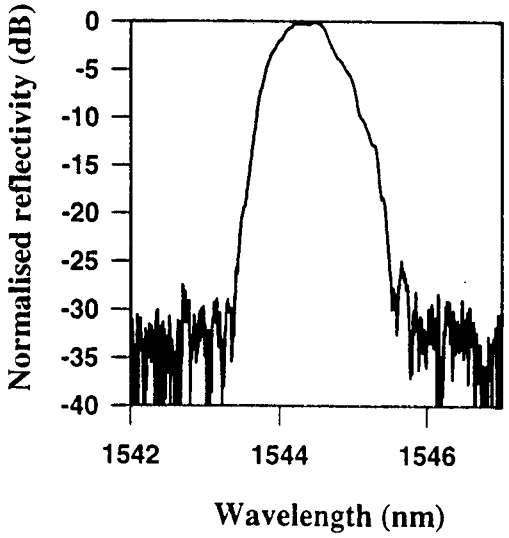

Fig. 6 **Reflection spectrum for apodised chirped grating. Bandwidth: 0.82 nm, peak reflectivity: 40%.**

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