Fibre Bragg gratings tuned and chirped using magnetic fields

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The authors report on the use of magnetic fields in conjunction with magnetostrictive materials for tuning and chirping optical fibre Bragg gratings. The Bragg wavelength shifts as a consequence of the strain induced in the fibre by a magnetostrictive rod when a magnetic field is applied. A tuning range of 1.1nm has been achieved by a magnetic field of 103mT and the grating has been chirped by applying non-uniform magnetic fields.

Introduction: Different techniques have been developed for tuning and chirping fibre Bragg gratings since their discovery just a few years ago. A change in pressure [1], temperature [2] or strain [3] causes a shift in the Bragg wavelength and these magnitudes can potentially be used as tuning and chirping agents. The grating sensitivities to these parameters are -3.0×10^{-3}nm/MP, 1.1×10^{-2}nm/°C, and 1.2×10^{-3} nm/μstrain, respectively, in the 1.5μm telecommunication window; the sensitivity to hydrostatic pressure is too small to be used for practical purposes, only temperature and strain have been used for efficient modification of the Bragg wavelength. Though an excellent control of the grating temperature has been recently demonstrated [4], strain is normally preferred to tune gratings since it is easier to handle than temperature [5, 6].

Rreliable control of the strain applied to the grating often requires the use of electric or magnetic forces combined with appropriate transducers. Excellent control of the grating performances has been achieved by applying an electric field to a piezoelectric stack [7], however, to the best of our knowledge, magnetic fields have not been yet used to chirp fibre Bragg gratings. In this Letter we present the first demonstration of the use of a magnetic field as a straining agent for chirping fibre gratings. The Bragg wavelength is shifted by holding the fibre on a magnetostrictive rod and subjecting the rod to a magnetic field. In this initial experiment, a grating has been tuned in the range of 1.1nm by a magnetic field of 103mT. The grating has been chirped up to 0.7nm by applying a magnetic field gradient of 23mT/cm.

Experiment: When a magnetic field is applied to a magnetostrictive alloy, the magnetic domains in the material tend to align along the field direction and, as a result of the magnetoelastic coupling, the material suffers an elastic lengthening in the direction of the magnetic field. A magnetostrictive rod of composition $Tb_{0.27}Dy_{0.73}Fe_2$ and dimensions 6 × 100mm was used in this experiment as magnetic field transducer. The maximum sensitivity of this alloy, when it operates stress free is of the order of 10ppm/mT, and the maximum strain when the material is magnetised to saturation is about 1000ppm. The application of mechanical prestress will result in significant modification of its performance. The stress reduces the sensitivity to the magnetic field but prevents material saturation and gives a more linear response.

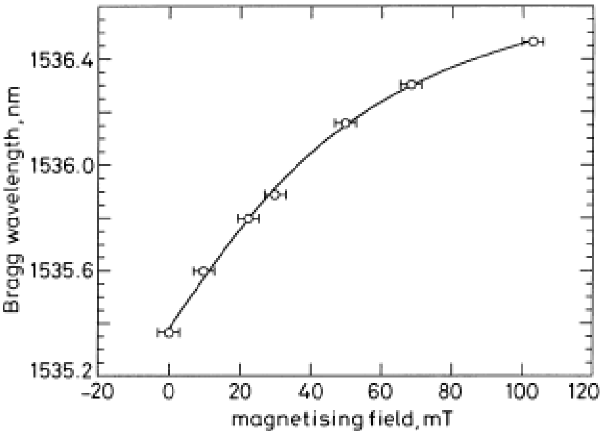

Fig. 1 *Measured displacement Bragg wavelength against magnetising field*

A fibre Bragg grating was held on the magnetostrictive rod and subjected to a uniform magnetic field created by a set of permanent magnets; the rod was rotated with respect to the magnet to vary the magnetic field along its axis. No mechanical pre-stress was applied in order to achieve maximum sensitivity to weak magnetic fields. The measured grating response is shown in Fig. 1. The grating Bragg wavelength shifts as consequence of the rod lengthening; variations of the Bragg wavelength of 1.1nm have been achieved by a magnetic field of 103mT. This wavelength shift corresponds to a strain of 920ppm, which is coherent with the nominal strain of the magnetrostrictive alloy. The calibration curve exhibits a nonlinear response and it has been fitted by the function: $\Delta\lambda_B = \lambda_B - \lambda_{B0} = C_0 \tan^{-1}(C_1 B)$ with $\lambda_{B0} = 1535.380$nm, $C_0 = 0.9595$nm and $C_1 = 0.02082$mT^{-1}. The maximum sensitivity in the linear regime for small magnetising fields is 2.00×10^{-2}nm/mT and the maximum wavelength shift extrapolated from the fitting curve would be 1.51nm. The nonlinear behaviour is due to the saturation of the alloy and a linear response in the range 0–125mT can be obtained by applying a mechanical prestress of 20MPa to the rod. The sensitivity to the magnetic field can be improved by holding the ends of the grating to the ends of the rod with an aluminium bridge.

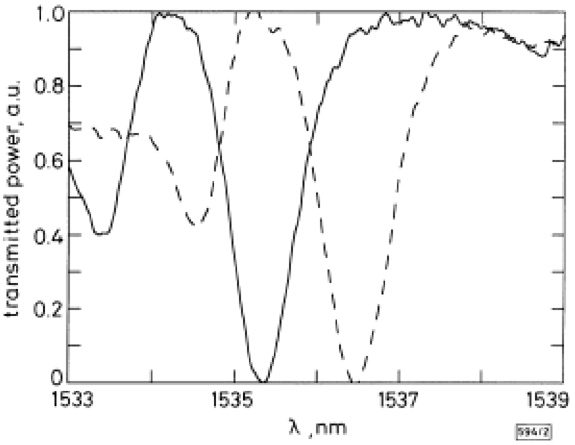

Fig. 2 *Grating spectra at different magnetic fields*

——— B = 0 mT, λ_B = 1535.31, bandwidth = 0.92nm
– – – – B = 103 mT, λ_B = 1536.45, bandwidth = 0.97nm

The grating does not suffer any significant chirp in the tuning process as it is illustrated in Fig. 2. The grating bandwidth variation is 0.05 nm in the whole measured range, this variation is below the spectral resolution of the measurement system. The absence of chirp in the different spectra indicates that the magnetostriction is uniformly distributed on the rod. The strong sidelobe in the grating spectra is due to the coupling of the fundamental mode into cladding modes and it can be reduced by using fibres with depressed claddings [8].

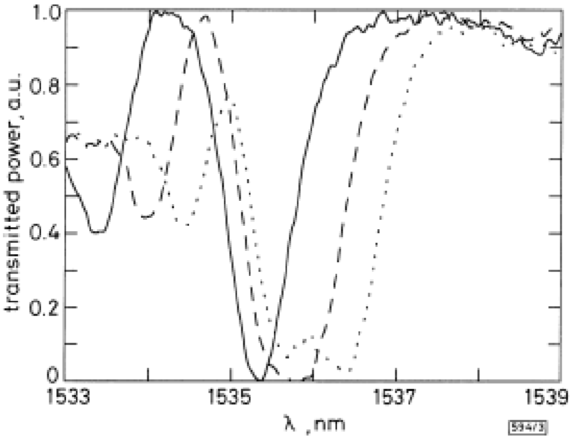

Fig. 3 *Grating spectra at different magnetic field gradients*

——— $\partial B/\partial x$ = 0mT/cm, bandwidth = 0.92nm
– – – – $\partial B/\partial x$ = 12mT/cm, bandwidth = 1.31nm
·········· $\partial B/\partial x$ = 23mT/cm, bandwidth = 1.63nm

To chirp the grating, the fibre was held on the rod and subsequently subjected to a nonuniform magnetic field. The grating chirps as a result of the non-uniform lengthening of the rod. Two permanent magnets with opposite polarities were used to create the non-uniform field. The maximum field gradient was 23 mT/cm and it was modified by rotating the fibre with respect to the field. Fig. 3 shows the grating spectra at different magnetic field gradients. The grating bandwidth broadens and the transmission increases as expected and a chirp of 0.7 nm was reached with a field variation of 56 mT along the 2 cm grating length. Obviously, chirped gratings operating without a magnetic field can be produced with this technique by holding the fibre to the rod while a non-uniform field is applied. The grating would be unchirped in the presence of the field because the fibre is unstressed and will chirp when the field is removed because the different parts of the grating will strain differently owing to the uneven relaxation of the rod; using this method chirped gratings can be packaged without magnets. Chirped gratings in the bare fibre could be fabricated by applying the magnetic field during the grating writing process.

Finally, we believe it may be possible to use magnetostrictive alloys for optical detection of DC and AC currents after solving difficulties arising from the material hysteresis. Experiments are ongoing to characterise these problems.

Conclusions: We have demonstrated a novel method of tuning and chirping fibre Bragg gratings based on the use of a magnetic field as driving force and a magnetostrictive alloy as transducer. In these preliminary experiments the Bragg wavelength has been shifted 1.1 nm with a field of 103 mT. The grating has been chirped by applying a non-uniform field and a bandwidth broadening of 0.7 nm with a field gradient of 23 mT/cm has been measured. The technique can potentially produce chirps of complex profiles.

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