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1461

High Performance Optical Fibre Polarisers Based on Long Period Gratings in Birefringent Optical Fibres

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Abstract: We have demonstrated the feasibility of achieving high performance fibre polarisers(insertion loss<0.5 dB, extinction ratio>30 dB), based on polarisation mode dispersion in a long period grating. Chirped operation with 100 nm bandwidth has also been achieved, showing the possibility of a broadband device.

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Introduction: Long period gratings have been used widely for gain spectrum flattening in erbium doped fibre amplifiers [1,2] and sensors [3,4]. However, there are other applications for long period gratings. One of them is a fibre polariser based on polarisation mode dispersion in a long period grating first proposed by Kurkov et al [5]. They have demonstrated a polariser having ~12 dB extinction ratio with less than 1 dB of insertion loss. The potential for achieving very high polarisation extinction ratio and low insertion loss combined with the ease of fabrication makes such a scheme very attractive for use in single polarisation fibre lasers and fibre fluorescence sources and anywhere a single polarisation state is required. In this paper, we have demonstrated the feasibility of achieving a high performance fibre polariser, (insertion loss<0.5 dB, extinction ratio>30 dB). Chirped operation with 100 nm bandwidth has also been achieved, showing the possibility of a broadband device.

Theory: In a co-directional mode coupling grating with a pitch Λ, the following resonance condition applies:

$$\beta_1(\lambda) - \beta_2(\lambda) = \frac{2\pi}{\Lambda} \qquad (1)$$

where β_1 and β_2 are the propagation constants of the initial and coupled modes respectively and are both dispersive with a respect to wavelength λ. In our coupling scheme, mode 1 is the guided LP01 mode and 2 is any of the cladding modes. In a birefringent fibre, β_1 is different for the two polarisation modes and consists of $\beta_x = 2\pi n_x/\lambda$ and $\beta_y = 2\pi n_y/\lambda$, This causes the coupling to happen at different wavelengths for the two polarisation modes, introducing a resonant loss to one polarisation but not the other within the resonant bands. In theory, the cladding mode will also show some polarisation dependence, but the effect is relatively small for the fibres used here and is ignored. The splitting of the two polarisation mode coupling peaks is:

$$\Delta\lambda = \Lambda(n_x - n_y) = \frac{n_x - n_y}{n - n_{cl}}\lambda_g \qquad \text{(II)}$$

where $n=(n_x+n_y)/2$, λ_g is the average of the x and y polarisation resonances, λ_x and λ_y, and n_{cl} is the effective index of the appropriate cladding mode. To achieve a large splitting, a lower $n-n_{cl}$ and a large birefringence are preferred. In our implementation where an elliptical core fibre is used, birefringence n_x-n_y is proportional to the square of relative index difference Δ of the fibre while $n-n_{cl}$ is more or less proportional to Δ, therefore $\Delta\lambda$ can be enhanced by having a larger Δ.

Experiments: A photosensitive boron co-doped germanosilicate preform with a NA of 0.11 was used for this work. The circular preform had two sides milled into a quasi-rectangle and the preform was then pulled at different temperatures on a fibre pulling tower . At lower temperature, the preform shape was preserved (see the photo at 1900°C in fig.1), whilst at higher temperatures, the fibre became increasingly circular and at the same time the core became more elliptical (see the photos at 2100°C and 2200°C in fig.1). A desirable birefringence can be achieved by varying the pulling temperature.

The fibres were then H_2 loaded at 60°C at ~100 bar for about three days before grating writing. The grating writing set-up consists of a computer-controlled translation stage and shutter. After the shutter, the ArF excimer beam at 193 nm goes through a 3 mm wide slit and is then focused in the dimension perpendicular to the fibre axis. The beam is finally guided by a mirror to the fibre. The cylindrical lens and the mirror are mounted on the translation stage to ensure equal distance from the fibre to the cylindrical lens during the translation.

To ensure the fibre is not damaged by the 193 nm excimer beam, the pulse intensity is maintained under 0.2 J/cm^2 during the grating writing. The grating is written line by line with ~400 pulses/line. This set-up allows us to change the grating pitch and to introduce chirp easily.

Fig.2 shows a 9 cm long grating (LP01 to LP04) in a fibre with a high birefringence. Using randomly polarised light, two 3 dB loss peaks are seen at the two polarisation resonances (see 45 degree curve in fig.2). This is due to the equal power distribution in the two polarisation modes. When the probe light is alternatively polarised along one of the polarisation axis, ~20 dB extinction is measured for both polarisation modes (see curves at 0 and 90 degree in fig.2) while the loss for the non-resonant polarisation mode stays around 1 dB. The absorption peak at 1250 nm is from molecular H_2 and the ripples on the curves are artefacts from the transmission response of the measurement system. The polarisation splitting in this case is ~38 nm (λ_x=1186 nm, λ_y=1224 nm, λ_g=1205 nm) and the pitch used was 300 μm. From equation II, n-n_2 and the birefringence n_x-n_y can be estimated to be 4X10^{-3} and 1.2X10^{-4} respectively.

In another attempt in a less birefringent fibre, greater than 30 dB extinction for one polarisation mode was achieved while keeping the loss of the non-resonant polarisation mode to ~0.5 dB. The coupling is from the guided LP01 to cladding mode LP03 with a grating length of 9 cm and a pitch of 300 μm. The measurement at the absorption peak was not resolved, limited by the dynamic range of the measurement system. The polarisation splitting in this case is 10.5 nm (λ_x=967.5 nm, λ_y=978 nm, λ_g=972.75 nm), from equation II, the birefringence n_x-n_y is calculated to be 2.6X10^{-5}. A photograph of this fibre is shown in fig.1 (see the photo at 2100 °C). The fibre has a long axis of 125 μm and a short axis of 82 μm. The core was characterised by a fibre geometry measurement set-up (F20 from York Technology) to have an ellipticity of 1:3.33 with the long axis being 9.9 μm and the short axis being 3.0 μm. Using the weakly guided approximation in [6], the form birefringence can be calculated to be ~$2X10^{-5}$, very similar to the measured birefringence.

The device shown in fig.3 has a 30 dB bandwidth of ~ 1 nm, insufficient for many applications. In a practical system, the gratings need to be chirped both to provide a large usable bandwidth and also to reduce the environmental sensitivity of the device.

We have demonstrated chirping of long period gratings in a highly photosensitive boron-co-doped germanosilicate fibres. Such a grating of 10 cm long is shown in fig.4. The LP01 to LP04 mode coupling has been broadened to ~100 nm at 1.3 μm, showing the effectiveness of scheme. The ripples in the coupling band is believed to be due to non-uniformity along the length of the grating, which causes incoherence in the coupled mode and the original mode and leads to interference between the two modes.

Discussion: The ultimate bandwidth achievable is limited by the polarisation splitting. With the achieved splitting of 38 nm, devices with ~30 nm bandwidth can be easily achievable. Larger splitting can be achieved by introducing air holes with a non-circular symmetric distribution in the cladding as has been demonstrated in [5]. These air holes with their large refractive index contrast with that of silica (n_{air}=1, n_{silica}=~1.45), can introduce large birefringence for the cladding modes and therefore enhance the birefringence splitting. To achieve broad band chirped gratings with high peak coupling strength, very highly photosensitive fibres are also required.

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Reference:

1. A.M. Vengsarkar, P.J. Lemaire, J.B. Judkins, V. Bhatia, T. Erdogan and J.E. Sipe: "Long period fibre gratings as band-rejection filters", Journal of Lightwave Technology, **14**, pp.58-65, 1996.

2. A.M. Vengsarkar, J.R. Pedrazzani, J.B. Judkins and P.J. Lemaire, N.S. Bergano and C.R. Davidson: "Long period fibre grating based gain equalisers", Optics Letters, **21**, pp.336-338, 1996.

3. V. Bhatia, and A.M. Vengsarkar: "Optical fibre long period grating sensors", Optics Letters, **21**, pp.692-694, 1996.

4. H.J. Patrick, G.M. Williams, A.D. Kersey, J.R. Pedrazzani and A.M. Vengsarkar: "Hybrid fibre Bragg grating/long period fibre grating sensor for strain/temperature discrimination", IEEE Photonics Technology Letters, **8**, pp.1223-1001, 1996.

5. A.S. Kurkov, M. Douay, O. Duhem, B. Leleu, J.F. Henninot, J.F. Bayon and L. Rivoallan: "Long-period fibre grating as a wavelength selective polarisation element", Electronics Letters, **33**, pp.616-617, 1997.

6. A.W. Snyder and J.D. Love: " Optical Waveguide theory", Chapman and Hall,.

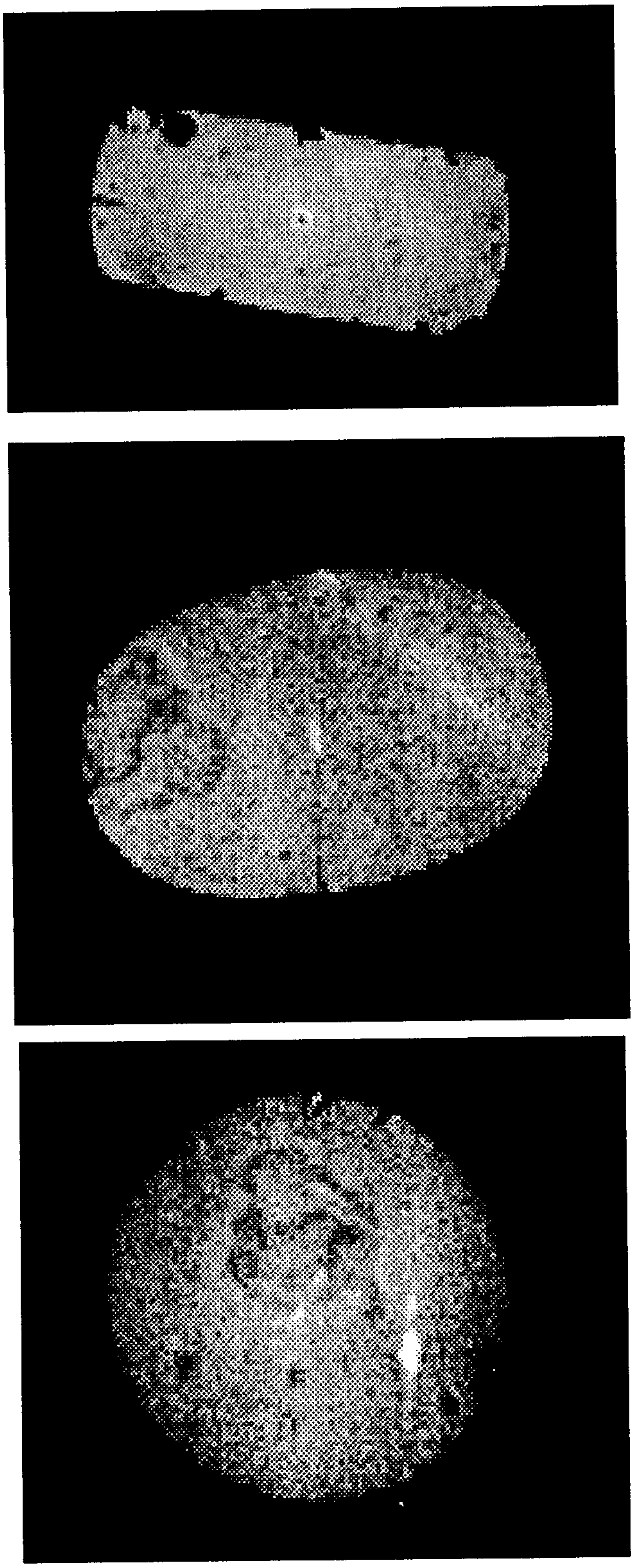
from the same milled preform. Top: 1900°C, middle 2100°C, bottom 2200°C.

Fig.2 The performance of a long period grating in a fibre with a birefringence of $1.2X10^{-4}$ (LP01 to LP04).

Fig3. The performance of a long period grating in a fibre with a birefringence of $2.6X10^{-5}$ (LP01 to LP03)

Fig4. A chirped long period grating in a non-birefringent highly photosensitive boron-co-doped germanosilicate fibre.

Ortega et al, Fig.1

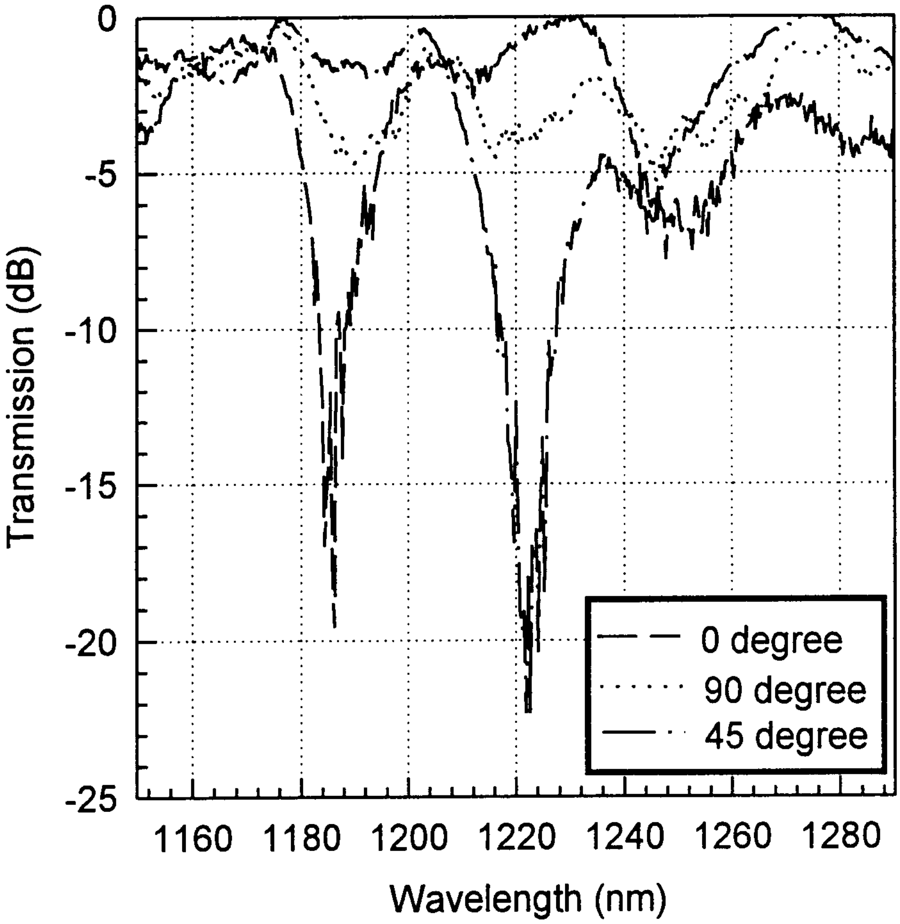


1900 degree

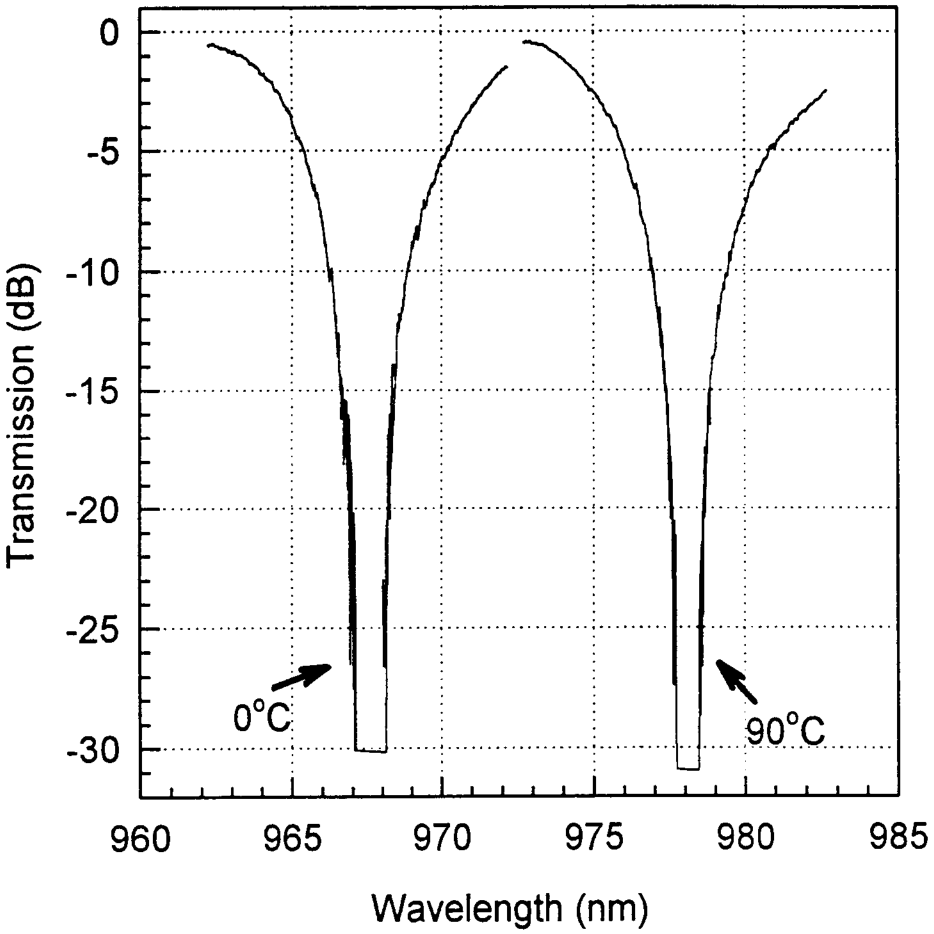
2100 degree

2200 degree

Ortega et al, Fig.2



Ortega et al, Fig.3



Ortega et al, Fig.4