Temperature insensitive long period grating sensors in photonic crystal fibre

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Abstract

A Long Period Grating was fabricated in endlessly single mode photonic crystal fibre using a spatially-periodic electric arc discharge. The sensing characteristics of the grating were studied and it was found to possess an insensitivity to temperature, a bend sensitivity of 3.7 nm.m and a strain sensitivity of -2.0 pm/με.

Introduction: Long period gratings (LPGs) consist of a large scale (hundred's of microns) periodic axial perturbation in the core of a single-mode optical fibre [1]. The effect of an LPG is to couple light of certain well-defined wavelengths from the core of the fibre to various cladding modes; the coupled light is then lost from the fibre, leading to a series of attenuation bands in the transmission spectrum of the device. From a sensing perspective, LPGs are of interest as the positions of the attenuation bands are sensitive to a number of measurands: temperature, strain, external refractive index and curvature.

A feature of LPGs is that the sensitivity to the various measurands is strongly dependent on the dispersion properties of the core and cladding [1]; consequently control of the material or waveguide dispersion can, in principle, be used to increase sensitivity to one measurand while rendering the device insensitive to another. Photonic crystal fibre (PCF) might offer great potential in this regard since the waveguiding properties can be controlled simply by adjusting the air-hole geometry. Recently, it has been shown that LPGs can be produced in non-photosensitive PCF by periodically collapsing the holes by heat treatment with a CO_2 laser [2] or by using an electric arc to modify the fibre structure [3]. In this paper we report the first experimental characterisation of the sensitivity of an electric arc-induced LPG in PCF to temperature, bending and strain.

Experiments and results: The Endlessly Single Mode PCF was supplied by BlazePhotonics and had a pure silica core and cladding. The diameter of the core was 12μm and it was surrounded by 54 air holes, with the space between adjacent holes being 8μm. A stripped section of the PCF was subjected to an electric arc, provided by a commercial splicer. The arc was applied at set intervals, controlled by a translation stage, with the fibre under no tension. The fabricated grating had a period of 500μm and a length of 25.5mm. Fig. 1. shows the LPG transmission spectrum with two attenuation bands present, located at 1239nm and 1409nm. The 1409nm attenuation band was investigated for its spectral sensitivity to external measurands, due to this band being significantly stronger than the other band.

The characterisation of the attenuation band was carried out by illuminating the grating with a broadband light source and observing the resulting transmission spectrum with an optical spectrum analyser (OSA) with an accuracy of 0.08nm.

The temperature sensitivity was investigated by placing the LPG on an insulated Peltier cooler. Varying the Peltier temperature from 20.0 to 90.5 °C produced no measurable change in the centre wavelength of the attenuation band, from which we deduce a temperature sensitivity of $d\lambda/dT = 0.00 \pm 10$ pm/°C. This may be compared with the results of G. Humbert *et al* [4] who quote a temperature sensitivity of 9 pm/°C in the range of 25-160 °C for a similarly structured PCF, which however had different core and hole dimensions. By way of further comparison, the temperature sensitivity of electric arc-induced LPGs in standard single mode fibre is around 70 pm/°C [5].

The bend sensitivity measurements were made by clamping the LPG midway between two blocks, one on a translation stage that was moved inwards, thereby bending the fibre. When the LPG is midway between the two blocks, the resulting curvature, R, of the sensor is given by [6],

$$R = \frac{2d}{d^2 + L^2} \tag{1}$$

where d is the bending displacement and L is half the distance between the fibre clamping points. The resulting changes in the transmission spectrum is shown in Fig. 2. With increasing curvature, a red wavelength shift of the central wavelength was observed.

Fig. 2b shows the relationship between the central wavelength shift and the curvature of the LPG; at a curvature of 1 m^{-1} the bend sensitivity is $d\lambda/dR = 3.7 \pm 0.1$ nm.m.

The strain sensitivity of the 1409 nm attenuation band was determined by fixing one end of the grating on a block and the other to a translation stage. The effect of the strain on the attenuation band is shown in Fig. 3. The resulting wavelength shift gives a strain sensitivity of $d\lambda/d\sigma = -2.0 \pm 0.1$ pm/με. The negative value of the sensitivity indicating a wavelength shift towards the blue with increasing strain.

Conclusions: Long period gratings were fabricated in Endlessly Single Mode PCF by exposure to an electric arc and the resulting LPG attenuation bands were found to be sensitive to bending and strain, the bending sensitivity being 3.7 nm.m and the strain sensitivity being –2.0 pm/με. One of the persistent problems of using LPGs as sensors is their cross sensitivity to temperature, which results in discriminatory schemes needing to be employed to separate the effect of temperature from the desired measurands. The electric arc-induced LPGs studied here have been shown to possess an attenuation band with negligible temperature sensitivity eliminating the need for such schemes. Furthermore, since the fabrication process does not involve photoinscription, the cost of the resulting sensing system has the potential to be significantly reduced.

References

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Captions

Fig. 1. Transmission spectrum of LPG with a period of 500μm.

Fig. 2: (a) Spectral response of the LPG to curvature in the range 0 m^{-1} to 1.81m^{-1}, curve in bold corresponds to straight fibre. (b) Wavelength shift as a result of the induced curvature.

Fig. 3: (a) Spectral response of the LPG to strain in the range 0 to 1.98 mε, unstrained curve in bold. (b) Wavelength shift as a result of the applied strain.

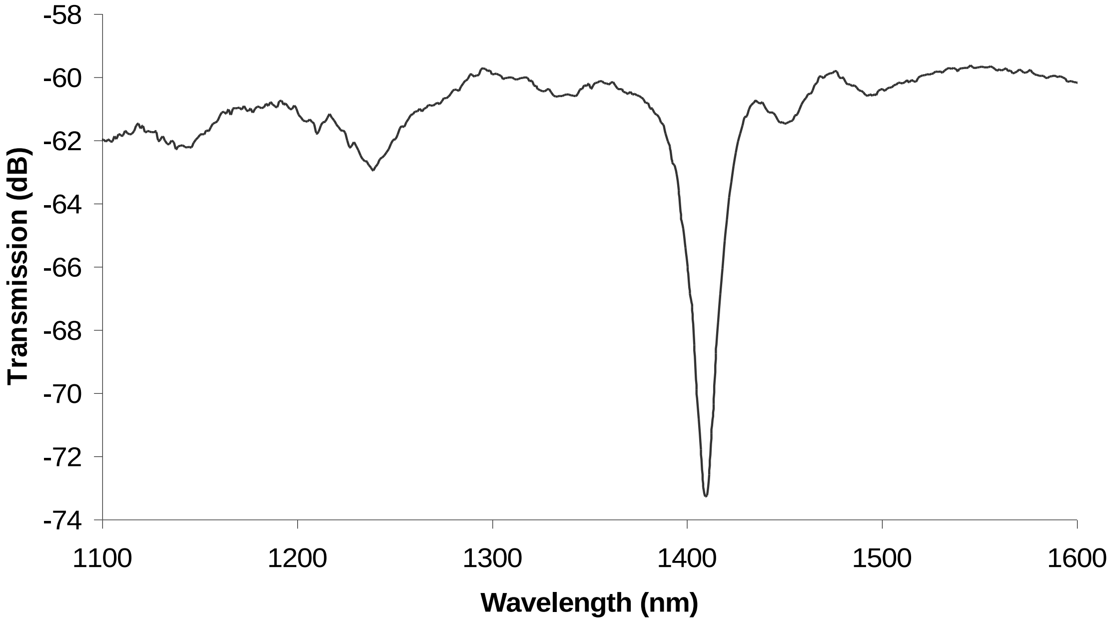
-58
-60
-62
-64
-66
-68
-70
-72
-74
Transmission (dB)
1100
1200
1300
1400
1500
1600
Wavelength (nm)

Fig. 1.

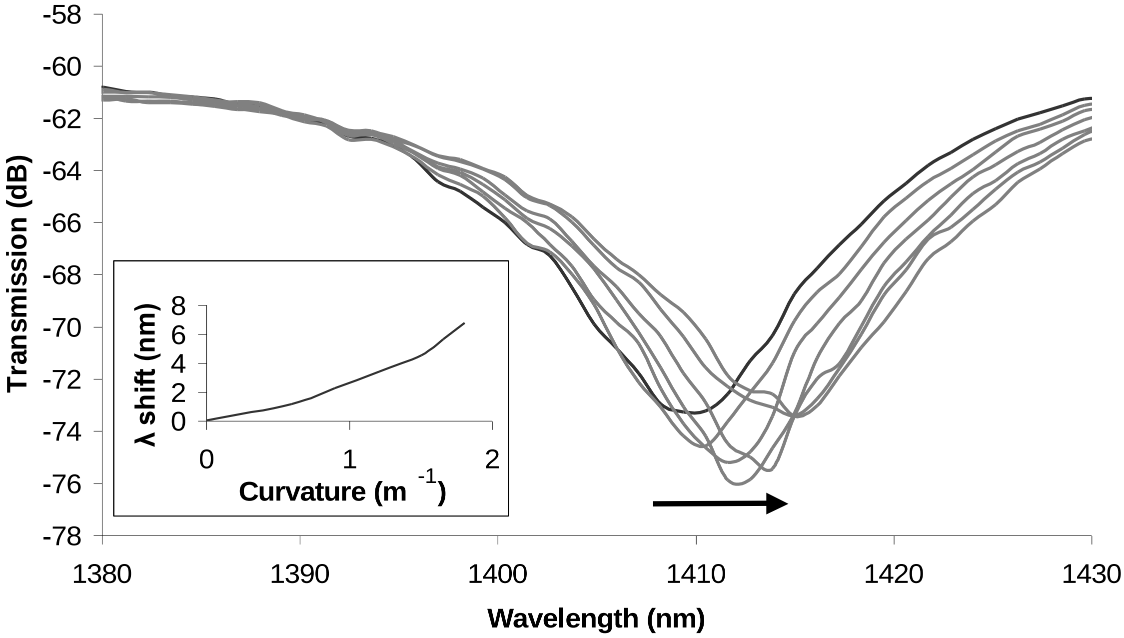
-58
-60
-62
-64
-66
-68
-70
-72
-74
-76
-78
Transmission (dB)
1380
1390
1400
1410
1420
1430
Wavelength (nm)
8
6
4
2
0
λ shift (nm)
0
1
2
Curvature (m -1)

Fig. 2

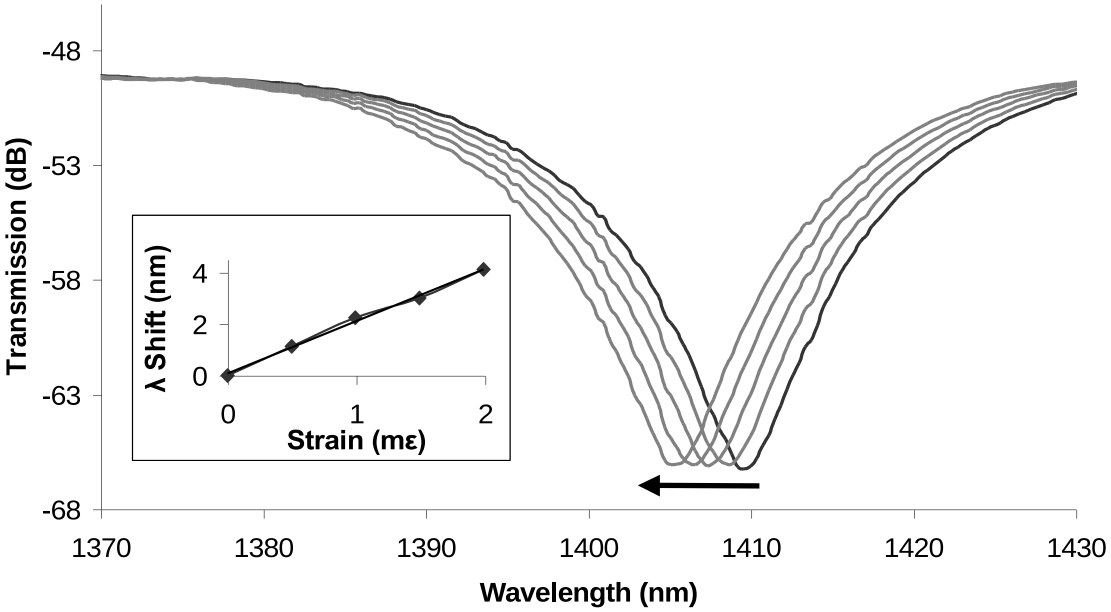
-48
-53
-58
-63
-68
Transmission (dB)
1370
1380
1390
1400
1410
1420
1430
Wavelength (nm)
λ Shift (nm)
4
2
0
0
1
2
Strain (mε)

Fig. 3.