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Optics Communications 236 (2004) 75–78

OPTICS COMMUNICATIONS

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Mechanically induced long-period gratings in microstructured polymer fibre

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Received 9 December 2003; received in revised form 19 February 2004; accepted 2 March 2004

Abstract

First results of mechanically induced long-period gratings in a microstructured polymer optical fibre are presented. Grating characteristics were found to be tunable, erasable and reconfigurable, with high transverse strain sensitivity.

PACS: 42.81; 42.79.D; 42.81.P

Keywords: Polymer optical fibres; Photonic crystal fibres; Photonic band gap fibre; Optical sensing

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1. Introduction

Microstructured polymer optical fibres (mPOFs) have been developed recently [1–4]: polymer fibres in which the guiding of light is achieved by a pattern of microscopic air holes that run down the entire length of the fibre, similar to photonic crystal fibres [5]. The combination of this guiding mechanism and the use of a polymeric material offers new, unexplored opportunities to enhance the functionality of polymer fibres and provide specific devices for telecommunication and sensing applications.

Long-period fibre gratings (LPGs) have a range of applications, including gain flattening, band-rejection filters, variable attenuators [5], band-pass filters [6], mode conversion [7], pressure, temperature, and strain sensors [8–10], tunable filters, and dispersion compensators [11]. Most of the work on LPGs has involved silica fibre; LPGs in polymer fibres have not received much attention due to difficulties in fabricating single-mode polymer fibres; one of the issues now overcome by the use of microstructure. LPGs have been incorporated into silica microstructured fibres [5,12–15], and it has been shown that this can lead to qualitatively different behaviour; e.g., the resonant wavelength is decreased by increasing the grating period [15], and there exists an optimal mode loss value that provides sidelobe-free, 100% power transfer from the core to the cladding mode for a uniform LPG

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doi:10.1016/j.optcom.2004.03.004

[16]. Here we report the first experiments of LPGs in microstructured *polymer* optical fibre, which show evidence of such behaviour.

2. Experiment

Different fabrication methods are available for mPOF preform fabrication, including extrusion, drilling, casting, and injection moulding [1]. We have used drilling of an 80 mm diameter preform with a conventional hexagonal structure of four rings of holes surrounding a central core. The material is commercially available extruded polymethylmethacrylate (PMMA) with a T_g of 115 °C and refractive index $n = 1.490$ at 633 nm. This material has a relatively poor optical quality; the scattering losses from impurities are at the level of 2.5 dB/m. However, this loss can be tolerated in the current experiments, as the fibres used are all shorter than 1 m.

The fibre shown in Fig. 1 was drawn to an outer diameter of 270 µm at a rate of 4 m/min at a constant tension of 120 g and a hot-zone temperature of 160 °C. The fibre structure consists of a core, a core-surrounding microstructured cladding and an outer cladding, with no further protective outer coating. Fibre diameter uniformity of ± 1 µm is achieved over tens of metres of fibre by a feedback control loop between the capstan speed and the fibre diameter monitor. The fibre was found to be single moded at a wavelength of 633 nm by noting that the near and far field patterns were insensitive to the launching conditions and to bending [1].

Following the method described in [15,17], a long-period grating is mechanically induced through stress-induced periodic refractive index changes. We press a PMMA rod with 150 triangular grooves of 0.2 mm depth and a period of $\Lambda_{\mathrm{LPG}} = 1$ mm onto the fibre over a length of 15 cm (the overall fibre length used is 24 cm). This method of inducing an LPG allows for shifting of the position of the resonances by changing the angle between the fibre and the grooves, reducing the line width of the resonances by increasing the length of fibre under pressure, and increasing the depth of the resonances by increasing the applied pressure. When the grooved plate is removed, the transmission spectrum returns to its original unperturbed shape. In this manner, a wide range of filter functions can be generated in one fibre in an erasable and tunable manner.

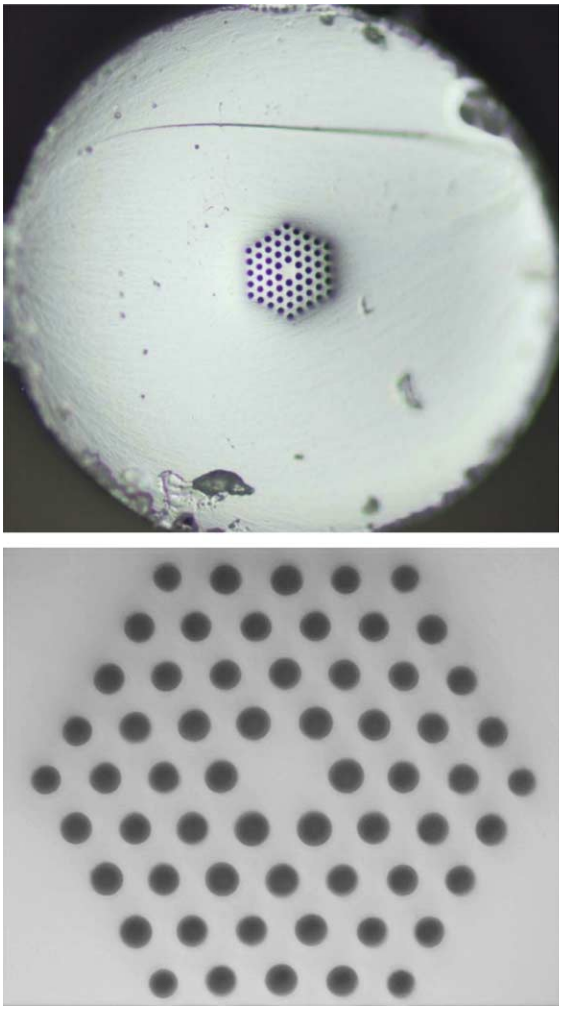

Fig. 1. Optical micrographs of the single-mode microstructured polymer optical fibre (mPOF) with hole diameters of 1.92 µm and spacing of 4.20 µm.

3. Grating measurements

Unpolarised white light was coupled into the mPOF core with a 60× objective and the fibre output was imaged onto the detector of an optical spectrum analyser with a 10× objective. Cladding modes were stripped off before the LPG using an immersion oil ($n = 1.51$). The pressure is controlled by placing weights onto the grooved plate (the fibre remained undamaged even at applied weights up to 12 kg). The LPG transmission spectra for increasing pressures are shown in Fig. 2. Strong resonances up to 34 dB are observed around 530, 577, 811 and 884 nm, indicating efficient coupling between the core mode and co-propagating cladding modes at those wavelengths. Visual inspection showed that the core transmission turned from white to a mix of blue and deep red as the LPG increased in strength, in agreement with the spectra in Fig. 2. Note that the measured transmission spectra show features similar to those described in [16], in terms of the smoothing out of the sidelobes due to the presence of loss. Also, a loss of about 1.5 dB is observed in the passband between 600 and 800 nm (this is a significant improvement over initial experiments, in which a PMMA rod with rectangular grooves was used leading to much larger pass-band loss). When the weight is removed, the transmission spectrum of the fibre returns to the original unperturbed state.

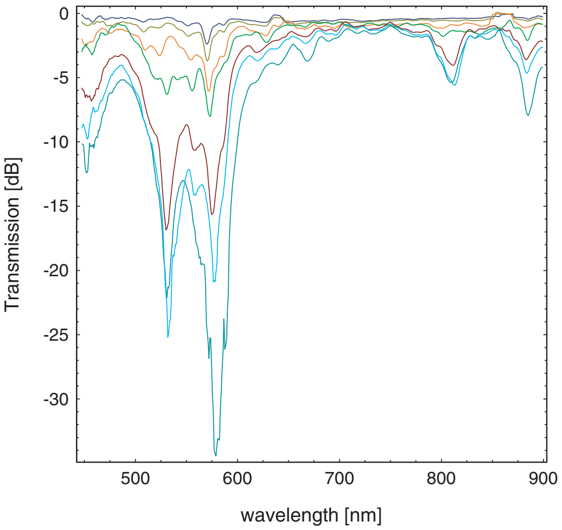

Fig. 2. Transmission spectra of a mechanically induced LPG of 15 cm length in mPOF while increasing the applied weight from 0.33 kg (top curve) to 0.65, 1.75, 2.75, 3.75, 4.75, and 5.85 kg (bottom curve).

The sensitivity of the LPG spectra to the applied load pressure was measured. In our 150 mm long grating, the centre wavelength of the resonance at 577 nm was found to shift by 1.7 nm/kg due to the average index change induced by the pressure (similar values for the other resonances). The strength of this resonance was found to grow on average by 4.8 dB/kg.

LPG-induced mode coupling occurs at the resonant wavelength for which $m\lambda = \Lambda_{\mathrm{LPG}}(n_{\mathrm{co}} - n_{\mathrm{cl}})$, with n_{co} and n_{cl} the effective indices of the core and cladding mode in question and m the order of the interaction. To correlate the transmission spectra with the grating period, calculations of the modes of microstructured fibres were carried out with the recently developed adjustable-boundary condition vector wave expansion method [18], using an average hole diameter of 1.92 μm and an average pitch of 4.20 μm. The wavelength dependence of the refractive index of PMMA is included in the calculations. In addition to the fundamental mode with negligible loss, two pairs of relevant cladding modes were found with losses around 5 dB/m (modes labelled A, B) and 500 dB/m (modes labelled C, D). Using the effective indices of these modes, the resonant wavelengths were calculated in the range of 400–900 nm, and it was confirmed that these decrease with increasing grating period. The results show resonances at 520 nm ($m = 3$ coupling to modes C, D), 590 nm ($m = 3$ coupling to A, B) and 800 nm ($m = 4$ coupling to C, D), which correspond to the major resonances observed at 530, 577 and 811 nm in the experiment. The deviations are attributed to the uncertainty in the fibre parameters (~10%), which the positions of the resonances are sensitive to.

4. Conclusions

Results of mechanically-induced long-period gratings in microstructured polymer optical fibres were presented; a new development in POF research with potential for fibre devices in telecommunication and sensing applications. Gratings of up to 34 dB strength were induced in a microstructured polymer fibre, with major resonances at 530 and 577 nm. The gratings were found to be tunable and erasable. In the next experiments, different grating structures, polarisation properties and temperature sensitivity of the LPGs in mPOF will be studied.

Acknowledgements

The authors thank Prof. Y.-J. Rao for useful discussions, Mr. J. Zagari for fabrication of the fibre, Mr. N. Issa for theoretical discussions and Barry Reed for the fabrication of the grooved rod and preform. The Australian Photonics CRC is acknowledged for funding of this work.

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