Embedding low loss polymer optical fibre Bragg gratings: Two different approaches

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Abstract: In this paper, we present two different ways to embed polymer fibre Bragg gratings (FBGs) into polymer matrices. In the first experiment, we embedded the FBG into a 3D printed polymer structure, whereas in the second experiment, the coating was polymerized around the fibre. In both cases, the response of the grating was unchanged, without any loss or distortion of the FBG signal compared with the bare fibre response. The design of the polymer coating was optimised for the measurement of a single measurand. We highlighted two possible applications: surface bend deformation monitoring and improved-sensitivity temperature sensing.

1. Introduction

Low loss polymer optical fibres, drawn from materials such as CYTOP, are good candidates for the realization of polymer fibre sensors. The usable fibre length can reach tens of metres, without a significant attenuation, even in the telecommunication wavelength band. Compared to other polymer optical fibres (POFs), the optical properties are significantly better, with theoretical losses as low as a few tens of decibels per kilometre. However, precisely because of its high transparency, the photosensitivity of a low-loss polymer is dramatically reduced, and this creates difficulties for the inscription of fibre Bragg gratings (FBGs) made of such material with the usual UV irradiation methods. Fortunately, other methods can be used to overcome this difficulty, for example with very short wavelengths, where CYTOP displays greater optical absorption [1]. Here we use a femtosecond laser setup for Bragg grating inscription, where the index change occurs only in the focus point of the laser and relies on nonlinear electronic effects, which allow for a controlled index change and grating properties [2]. The Bragg response of CYTOP gratings under strain and temperature has also been investigated and showed promising results for sensing applications [2].

Polymers are of great interest as they offer considerable mechanical advantages over glass, especially because they are viscoelastic materials that allow for a greater elasticity and potentially improved strain properties. Nevertheless, embedding POF has attracted serious attention because embedding materials offers the capability of sensing and responding to the surrounding environmental stimulus in a different way compared with the bare fibre [3]. When placed in strategic places, the FBGs can yield crucial information about the material in areas not accessible by other sensors; they are also more robust. All-polymer optical devices, consisting of a polymer fibre embedded in a polymer matrix, are particularly sought after for their mechanical and biocompatible advantages [4]. In the recent past, fibres have been embedded in metal [5,6], between the plies of a glass fibre-reinforced plastic [4,7,6] in epoxy [8], in polydimethylsiloxane (PDMS) [9], however, all polymer devices have not been really considered until recently [10].

2. 3D printed embedment of FBGs

The first embedding method that we highlighted consisted of placing the FBG in a 3D printed structure. The material is deposited layer by layer until the chosen height is reached. The process is then stopped and the fibre placed within the structure and glued to the material. The process is resumed and the material is deposited above the fibre. Depending where the fibre placed in the structure, the FBG will respond differently to bend or temperature. If the fibre is on the neutral axis of a longitudinal beam for example, the FBG can be made bend insensitive [10]. The structure had dimensions of about 1mm x 1mm x 10mm in a shape of a rectangular beam along the fibre length.

First, we characterised the strain response of the embedded structure in strain (Figure 1). Unlike with standard strain tests, where the FBG is strained from two fixed points, here the whole structure is strained, which results

in a homogenous strain along the fibre length. This allowed for a much wider strain excursion – more than six millistrain – compared with our previous experiments with this kind of FBG [2], where we couldn't strain more than two millistrains before the fibre showed signs of deterioration. We measured a typical FBG strain response between 0.71 and 0.76 nm/mε, depending on whether the fibre was strained or unstrained, with a relatively good accuracy (low standard deviation) for strain levels, up to 5 mε.

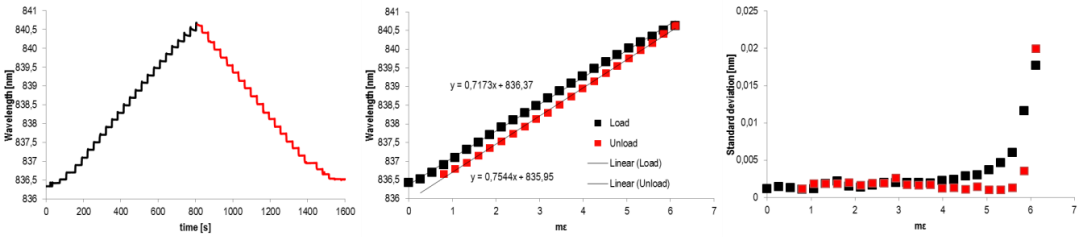

Figure 1. Left. Strain cycle applied to the 3D printing embedded structure. In black the fibre is strained, in red, unstrained
Middle. Position of the resonance wavelength
Right. Standard deviation showing a good response up to strain levels of ~5mε

Figure 2. Bend test on the 3D printing embedded structure. The fibre is embedded near the neutral axis of the fibre

In a second experiment, we placed the fibre at the neutral axis of the beam (exactly in the centre, where the fibre should sense no strain or compression when bent. (Figure 2). Figure 3 shows results where we recorded the position of the FBG peak while the structure was bent. We can see that the fibre was not exactly aligned with the neutral axis, but at a point marginally above the centre; this is apparent because the FBG sensed strain when the structure was bent. Nevertheless, the relatively low wavelength shift indicates that the embedded FBG shows an almost bend-insensitive behaviour, or can be tailored to record selected levels of strain on exposure to bending forces.

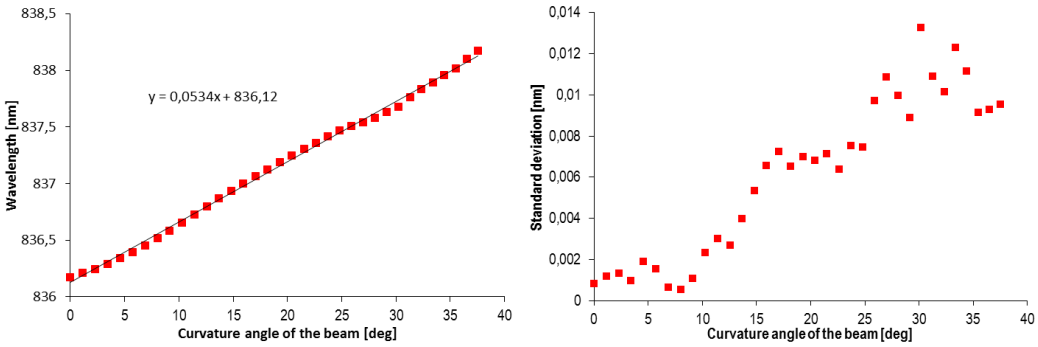

Figure 3. Bend test on the embedded structure
Right. Position of the FBG resonance
Left. Standard deviation

3. Embedding FBGs into polymers

The second embedding method relies on the polymerisation or curing of the coating material around the fibre. To illustrate this method, we coated the FBG with commercial gelatine, a derivative of collagen protein, Figure 4. The polymer in its liquid form at ~60°C was poured into a circular glass mould where the fibre was placed beforehand. The collagen cured at ambient temperature until a solid form was reached. Such simple embedded sensors could find applications for collagen gel contraction assay, a standardized test for the monitoring of the contraction of skin layers during wound healing [11]. We are investigating this application.

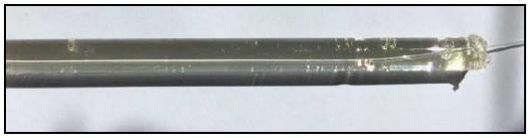

Figure 4. Example of a circular collagen coating around a POF

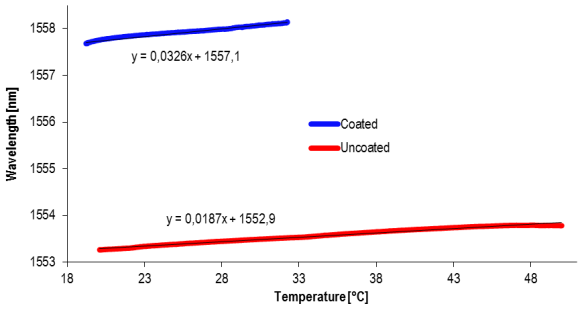

Figure 5. Behaviour of the embedded FBG sensor when PDMS coated and when uncoated

Figure 5 shows the behaviour of the embedded FBG sensor when PDMS coated and its comparison with an uncoated polymer fibre. We observe that there is an increase in the centre FBG wavelength of ~ 4nm, as the grating undergoes compressive strain that results from the embedding process. The coated and uncoated sensors are then exposed to a steady increase in external temperature, from which we observe that both sensors respond

in a linear manner and that the wavelength response to temperature of the coated sensor is almost double that of the uncoated sensor; an increase in response by a factor of 1.7.

4. Conclusion

We have shown that embedding polymer FBGs can be readily realised and offers a means to modify, in a tailored manner, the sensor response to external measurands; this approach can be used to improve the already excellent versatility of FBG sensors. We have used two methods to embed FBG sensors, firstly by embedding via a 3D printing process and secondly by coating the sensor with a polymer gel. The former method enabled the accurate recovery of large strain levels using a robust sensing monolith, whereas the latter showed the advantages of using selective coatings for improved sensor temperature response and the potential for novel applications, e.g. for the process of the PDMS gel contraction assay.

5. Acknowledgements

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6. References

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