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Fabrication of a miniature all-glass fibre optic pressure and temperature sensor

K. Bremer[a], E. Lewis[a]*, G. Leen[a], B. Moss[a], S. Lochmann[b] and I. Mueller[b]

[a]*Optical Fibre Sensor Research Centre (OFSRC), University of Limerick, Ireland*
[b]*Department of Electrical Engineering and Computer Science, Hochschule Wismar, Germany*

Abstract

In this paper the fabrication of a miniature all-glass fibre optic pressure and temperature sensor is presented. The sensor combines the functionality of a miniature all-silica diaphragm based Extrinsic Fabry Perot Interferometric (EFPI) Fibre Optic Pressure Sensor (FOPS) and an in-Fibre Bragg Grating (FBG) sensor. The reported fibre optic sensor has several advantages such as being cost-effective, simple to fabricate, miniature in size, mechanically robust and can be designed to withstand high temperatures or/and pressures.

Kewywords: Optical Fibre Sensor; EFPI; FBG; Pressure; Temperature

1. Introduction

Fibre Optic Pressure Sensors (FOPSs) have the advantages of being insensitive to electromagnetic interferences, electrically passive as well as chemically and biological inert, for instance. For low pressure applications FOPSs are often physically constructed using a diaphragm component and air cavity at the endface of an optical fibre. Among others one fabrication technology for these FOPSs is to construct them entirely from fused-silica (i.e. entirely made of glass) e.g.: [1-7]. The so called miniature all-silica diaphragm based EFPI FOPSs have the additional advantages of being cost-effective, simple to fabricate, miniature in size, mechanically robust and are resistant to high temperatures/pressures. However, despite their many advantages, they suffer from the disadvantage of having a high degree of cross-sensitivity to temperature.

* Elfed Lewis Tel.: +353-61-202968; fax: +353-61-338176
E-mail address: Elfed.Lewis@ul.ie.

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Recently our research group has reported an EFPI/FBG hybrid sensor [8] to overcome the traditional temperature cross-sensitivity issue. The EFPI/FBG hybrid sensor consists of a miniature all-silica diaphragm based EFPI FOPS with an incorporated FBG. The FBG is used to measure temperature and additionally to eliminate the temperature cross-sensitivity of the EFPI FOPS. A schematic of the EFPI/FBG hybrid sensor and an appropriate interrogation system is shown in Fig. 1 and Fig. 2, respectively. The reported fibre optic sensor has already been successfully applied to measure accurate high temperature gas flows in an exhaust system of a car [9] and high pressure and temperature in a simulated geothermal well [10]. This paper discusses the fabrication of the EFPI/FBG hybrid sensor for low pressure applications.

2. Fabrication of EFPI/FGB hybrid sensor

At the beginning of this section the fabrication of the miniature all-silica diaphragm based EFPI FOPS is described in general by utilising a standard SM fibre. Following this, the incorporation of the FBG into the EFPI pressure sensor is explained to form the EFPI/FBG hybrid sensor and potential sources of error during the fabrication of the glass diaphragm are outlined.

2.1. Fabrication of miniature all-silica diaphragm based EFPI FOPS

For the fabrication of the miniature all-silica diaphragm based EFPI FOPS a 133/220µm (inner/outer diameter) silica glass capillary, a 200µm diameter core silica glass fibre and a standard 125µm single mode (SM) fibre were used. All three glass components were bonded together during the fabrication by using the BIT MM-40 fusion splicer.

Initially the endfaces of the capillary and 200µm fibre were clamped in the fusion splicer and bonded together - step (a) of Fig. 3. Following this the glass capillary was cleaved away several millimetres from the capillary/200µm fibre splice - step (b) of Fig. 3. Then a SM fibre was cleaved and introduced into the glass capillary to establish the EFPI air cavity. The SM fibre was fed into the glass capillary by means of the fibre alignment of the fusion splicer - step (c) of Fig. 3. The distance between the SM fibre endface and the inner surface of the 200µm fibre form the EFPI air cavity. Following this the SM fibre was spliced to the glass capillary - step (d) of Fig. 3.

Next the glass diaphragm was assembled, as shown in Fig. 4. For this purpose the 200µm core diameter optical fibre of the EFPI air cavity was employed. Initially the 200µm fibre was cleaved away

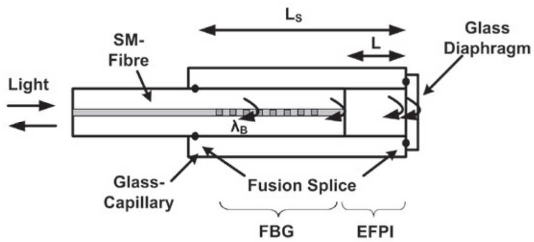

Fig. 1: Schematic of EFPI/FBG hybrid sensor

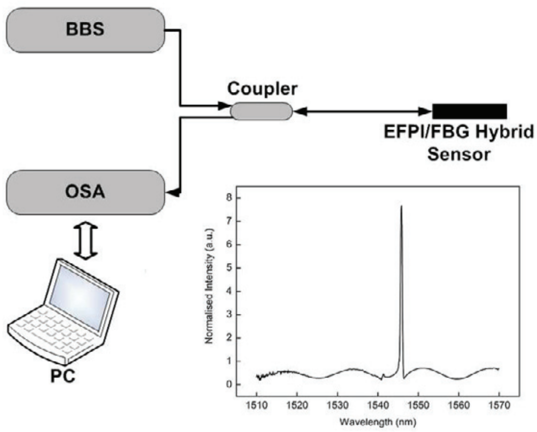

Fig. 2: White Light Interrogation (WLI) system and EFPI/FBG hybrid sensor spectrum

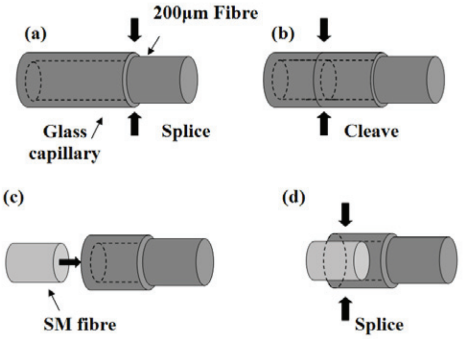

Fig. 3: Fabrication of EFPI cavity

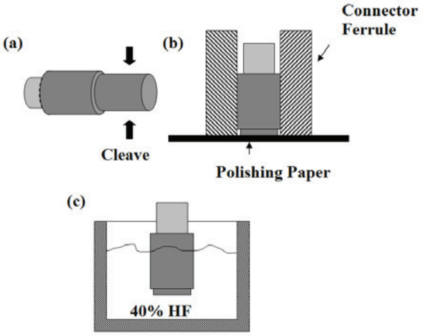

Fig. 4: Fabrication of glass diaphragm

approximately 100-200µm from the splicing point - step (a) of Fig. 4. Following this, the remaining EFPI cavity was clamped into a connector ferrule and the 200µm fibre was polished to a thickness of around 10µm - step (b) of Fig. 4. However, in order to achieve a high pressure sensitivity the glass diaphragm thickness must be very thin. Therefore the glass diaphragm was wet etched after the polishing procedure using 40% HF acid, as shown in step (c) of Fig. 4.

2.2. Incorporating FBG into EFPI FOPS

In order to realise the EFPI/FBG hybrid sensor, a FBG was incorporated into the EFPI pressure sensor. To incorporate the FBG into the EFPI pressure sensor, the whole FBG was recoated and cleaved at the end of the refractive index modulation of the FBG. Fig. 5 illustrates the temperature response of a FBG while the SM fibre of the FBG was fusion spliced to the glass capillary. Each pulse in Fig. 5 represents one splicing cycle with a time duration of about 10s. Overall, five splicing cycles were required to bond the SM fibre to the glass capillary and seal the EFPI cavity. Furthermore, as shown in Fig. 5, the FBG was subject to a change of the Bragg wavelength of approximately $\Delta\lambda_B = 0.8nm$ at each splicing cycle, which corresponds to a temperature change of approximately 80°C. In addition, Fig. 6 illustrates the normalised amplitude of the Bragg wavelength during the splicing procedure. The amplitude of the FBG was attenuated typically by about 3dB after the splicing procedure. The attenuation was due to small misalignments between the FBG SM fibre and glass capillary, which introduced micro bending into the SM fibre during the splicing routine.

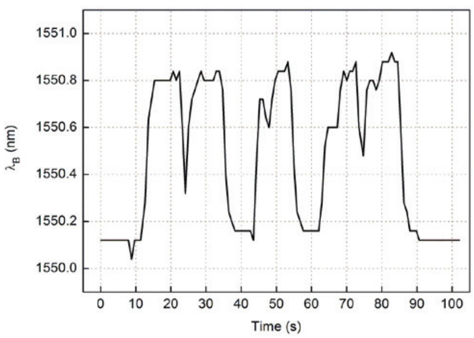

Fig. 5: Temperature induced Bragg wavelength change during the splicing procedure

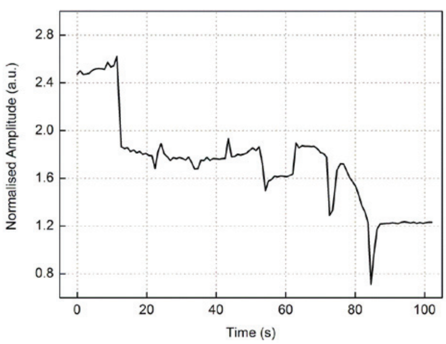

Fig. 6: Normalised amplitude of the Bragg wavelength during the splicing procedure

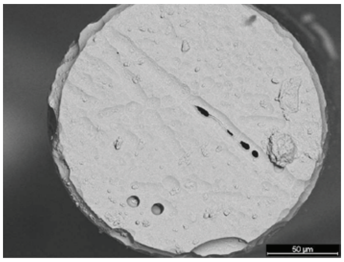

Fig. 7: Rough diaphragm surface after etching

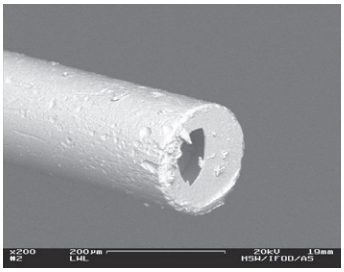

Fig. 8: Broken diaphragm surface after etching

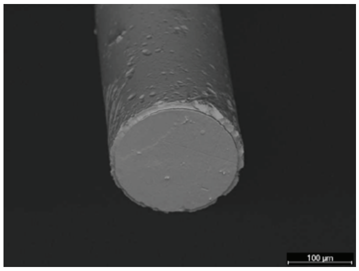

Fig. 9: Good diaphragm surface after etching

2.1. Sources of error during fabrication

The entire fabrication process was analysed in order to increase its repeatability and to enhance the pressure sensitivity of the EFPI FOPS. Several sources of error were found and eliminated during the analysis. For instance, one source of error was a rough diaphragm surface. In Fig. 7 a typical example of a rough surface after etching is shown. In this case the diaphragm polishing process was stopped at 3µm polishing film. The results of this are holes and grooves, which occurred during the etching procedure. An example of another source of error is a broken diaphragm surface due to an uneven etching process, as shown in Fig 8. The uneven etching process was due to misalignment of the 200µm fibre and glass capillary during fusion splicing. In Fig. 9 an example of an ideal diaphragm surface is illustrated. This illustration represents the *status quo* of the fabrication process of the glass diaphragm. The thickness of the diaphragm shown in Fig. 9 was measured to be 2µm.

3. Summary

In this paper the fabrication of a miniature all-glass fibre optic pressure and temperature has been explained. At first the fabrication of the miniature all-silica diaphragm based EFPI FOPS has been described followed by the incorporating of an FBG in the EFPI FOPS to form the EFPI/FBG hybrid sensor. Furthermore, two sources of error during the glass diaphragm fabrication have been characterised.

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