Optical **F**ibre **S**ensors **E**mbedded into technical **T**extile for **H**ealthcare

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D3.2 – Silica FBGs

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Abstract

This deliverable reports on the Fibre Bragg Gratings (FBGs) that have been manufactured for use as respiratory sensors in textile fabrics. The gratings were written into four types of single mode silica fibres with different properties, using a 248nm UV pulsed laser and a phase-mask illuminating technique.

Key word list :
FBG, UV laser, phase mask, photosensitive fibre, hydrogen loading

History :

Version	Date	Modifications/comments	Author
1.0	2007-01-19	Initial document	D. Kinet, A. Grillet
1.1	2007-02-16	First draft finalised and shared with partners	A. Grillet
1.2	2007-03-07	Comments from AOS included New information added on the FBG samples on the Fibre#3	D. Kinet, A. Grillet
1.3	2007-04-02	Comments from BAM included New information added on the FBG samples on the Fibre#5	D. Kinet, A. Grillet

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Content

1 - Introduction

In this project, we will evaluate the capabilities of FBG sensors for sensing purposes into medical textiles. WP3 is in charge of producing a set of silica FBG samples for WP2 (textile integration trials) and WP4 (sensor development).
For a rapid understanding of the principle of FBG sensors and an overview of the state of the art in this domain, the reader is referred to the Annex1 "§1.3: Optical fibre sensors: principle and state of the art" of D1.2[1].

2 - Fabrication of Silica Fibre Bragg Gratings

2.1 - Preparation of the fibre

2.1.1- Increasing the photosensitivity

Photosensitivity of optical fibres may be thought of as a measure of the amount of change that can be induced in the index of refraction in a fibre core following a specific exposure of UV light. Initially, optical fibres that were fabricated with high germanium dopant levels or under reduced oxidizing conditions were proven to be highly photosensitive. Other dopants than Ge were shown to increase the sensitivity as well, including Boron, Nitrogen, Aluminium, Tin and Antimony. Adding more dopants into the fibre core perform has however a negative impact on the transmission properties of the fibre : attenuation can be increased by a factor of up to 100, thereby preventing the use of such fibres for long scale sensing systems.
Standard single-mode (SSM) fibres (like Corning SMF-28e+™), doped with 3 mol% germanium, typically display index changes of ~3x10-5. In case of FBG application however, a higher photosensitivity of the fibre would enable to ease the photo-writing process and lower the laser pulse energy and shorten the illumination time. This in turn would result in more robust gratings, since the mechanical strength of UV induced FBGs has been shown to be degraded by high peak energy and long exposure time[2].

Since the discovery of photosensitivity and the first demonstration of grating formation in germanosilicate fibres, there has been considerable effort in understanding and increasing the photosensitivity in optical fibres. As explained in ref.1, various techniques have been proposed so far, and among others hydrogen loading.
Hydrogen loading is one of the mostly used techniques worldwide for increasing the photosensitivity of optical fibres. Its main advantage is that it is compatible with most standard fibres, thereby allowing producers of FBGs to use fibre available at telecom prices as raw material.
Hydrogen loading allows increasing the photosensitivity of optical fibre by diffusion of H2 molecules through the fibre and eventually to the core, where chemical reactions with oxygen or germanium ions will form hydroxyl and GeH ions, among other effects. The technique requires a specific set-up for maintaining a fibre spool into a confined atmosphere with tight control of the temperature and the pressure in H2.
The equipment available at MUL (see ***Fig. 1***) permits to realise the hydrogenation at ambient temperature and at high temperature (until 300°C, which is required for fibres with very special coating (metallic) for specific applications such as irradiation environment).
Our system can sustain 300bars at 300°C. Adjusting both the pressure and the temperature allows controlling the diffusion of H2 into the core, for a higher photosensitivity, as shown in ***Fig. 2***.

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[1] OFSETH D1.2 : Specification report on optical sensors

[2] C.Y. Wei et al, « The influence of hydrogen loading and the fabrication prcess on the mechanical strength of optical fibre Bragg gratings", Optical Materials 20, 2002

Fig. 1 Set-up for hydrogenation of the optical fibres

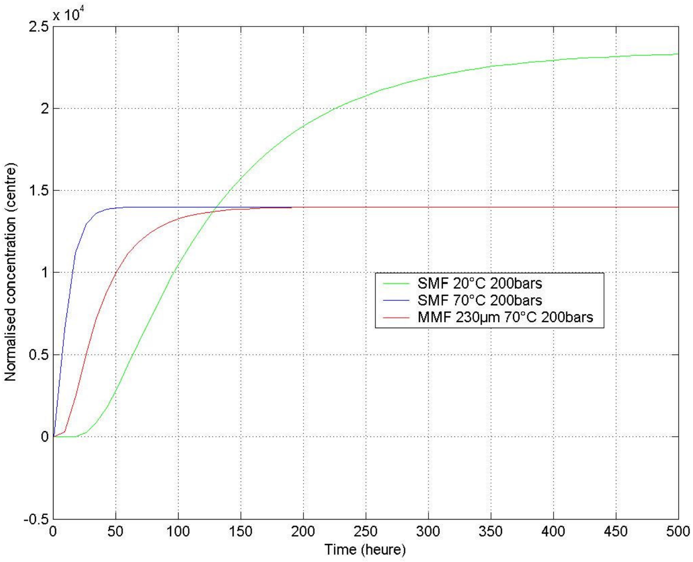


Fig. 2 Influence of temperature and thickness of the fibre coating on the concentration of H2 in the fibre core

After some trials, the following conditions were selected for the hydrogen loading, and the three sets of fibre (Fibre#1, #2, #3) detailed in D3.1 were then processed.

Parameter	Condition
Temperature	70°C
Pressure	200 bars
Duration	24 hours

2.1.2- Stripping

When using 248nm UV laser for writing FBG into SSMF with standard acrylat coating, photo-inscription will fail because of the large attenuation of the coating at this wavelength. Therefore, the coating must be removed before illumination, which is done by stripping.

Both mechanical and chemical stripping techniques can be used. Chemical stripping is usually preferred because of its softer impact on the fibre cladding, whereas mechanical stripping often produces local stress that may cause the breakage of the fibre.
After stripping, the decoated fibre is then cleaned with ethanol so as to remove dust or grease before to be placed on the photo-writing set-up.

2.2 - Photo-writing

The technique used at MUL to write FBG is the phase mask method, which takes advantage of a diffractive element (phase mask) to spatially modulate a UV beam. It is one of the most effective methods for inscribing Bragg gratings in photosensitive fibre.
Our laser is an UV Excimer (KrF) emitting at 248nm (BraggStar S500), and we used a uniform phase mask with a period of 1070 nm and length of 10cm for these gratings.
The principle of photo-writing set-up is shown in ***Fig. 3*** and pictures of the set-up developed at MUL which features in addition a dithering system for apodisation of the gratings are shown in ***Fig. 4***. Apodisation allows reducing the amount of side lobes on both sides of the filter but was not used here.

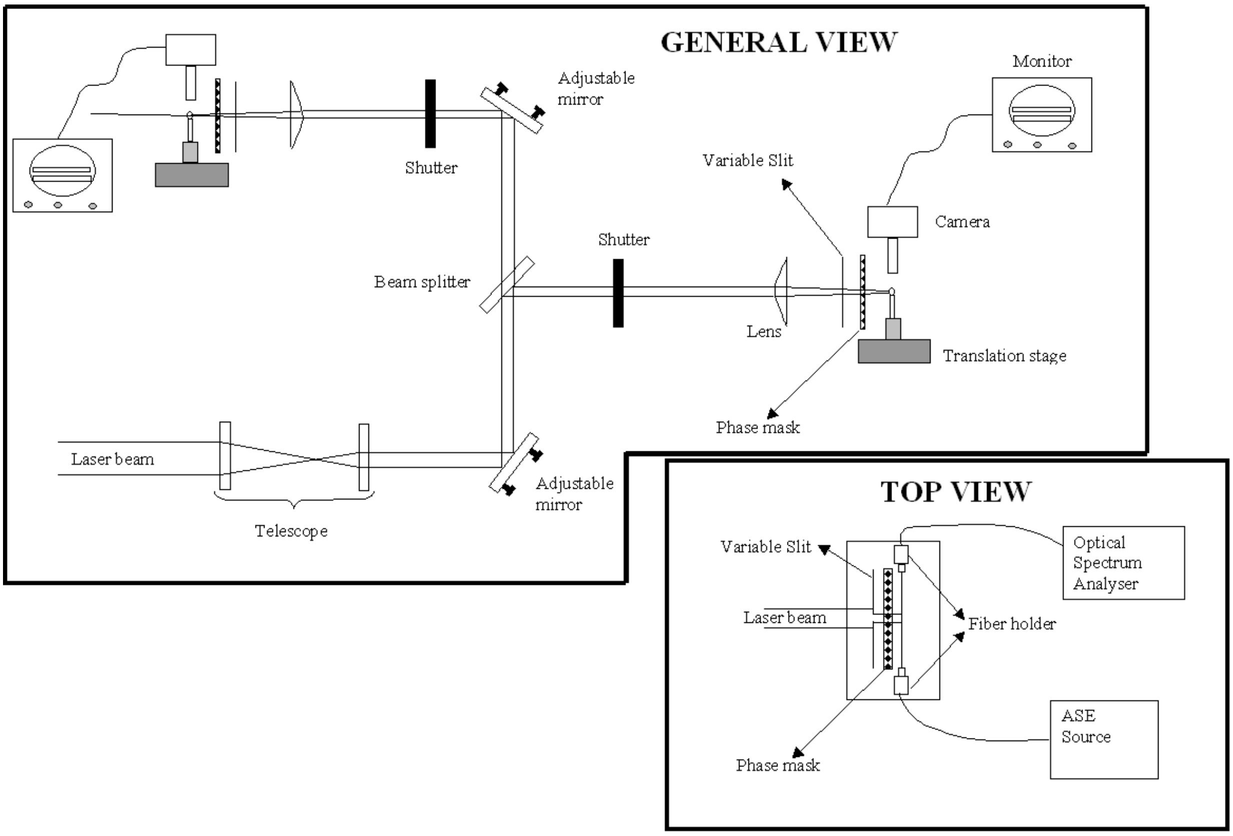


Fig. 3 Schematic description of the photo-writing set-up

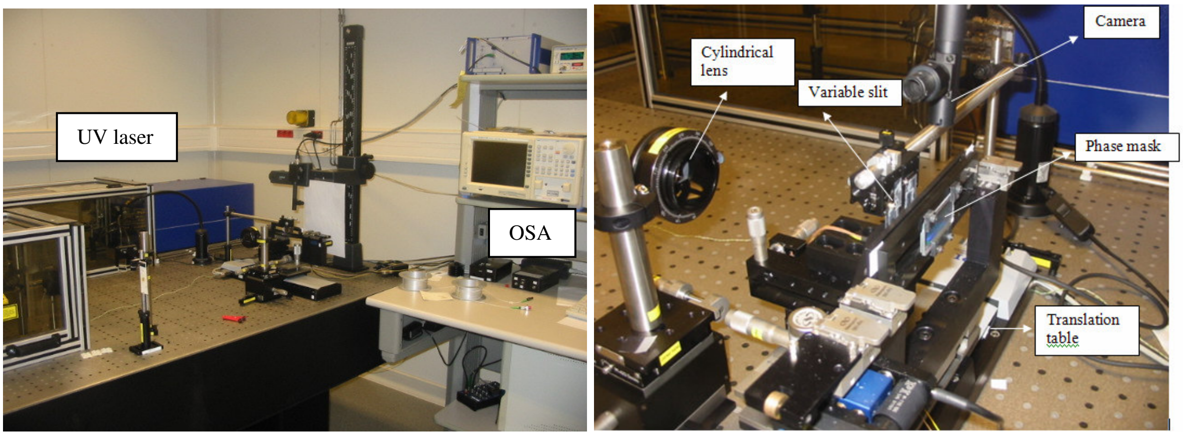


Fig. 4 Photo-writing set-up

The following parameters were used for writing the gratings :

Parameter	**Values**			
	Fibre #1	**Fibre#2**	**Fibre#3**	**Fibre#5**
Pulse energy	8mJ	8mJ	8mJ	8mJ
Frequency	100 Hz	20 Hz	100Hz	100Hz
Duration	7 to 12 min	6 to 10 min	~11min	1.5 to 3min
Grating length	15 to 25mm	15 to 25mm	~20min	10 to 15mm
H2 loaded	Yes	Yes	Yes	No

2.3 - Post process

Recoating of the grating just after the process is required because of the fragility of the bare fibre and especially its sensitivity to dust and humidity. We used a UV curable polymer for recoating the gratings, which were placed in a dedicated groove.
Finally, the annealing process allows to remove hydrogen and any other potential instable defects so as to stabilize the FBG for a long period (typ. 25 years). This was done by placing the gratings during 24 hours into a programmable oven with temperature between 80 and 100°C. During the annealing process, the spectral characteristics of the grating were modified (typically, shift of the position of the Bragg wavelength and slight decrease of the reflectivity) as shown on ***Fig. 6***.

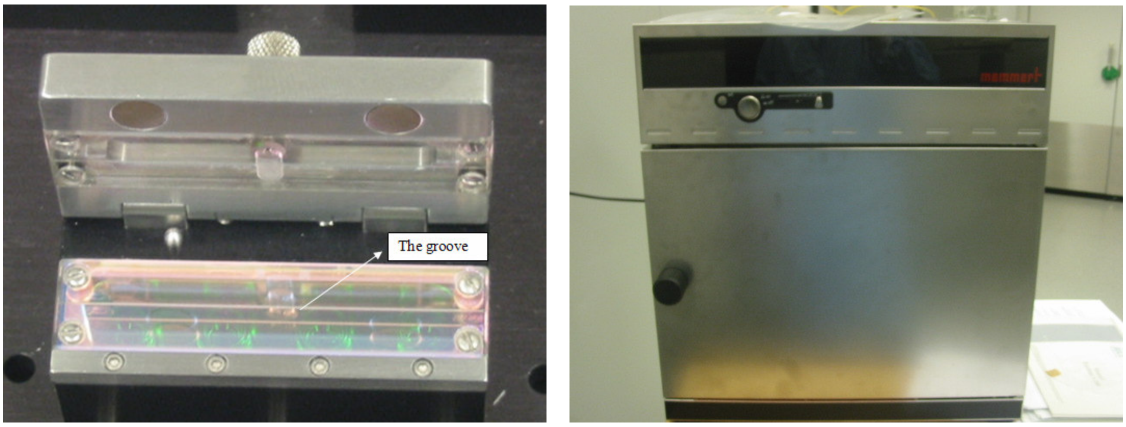


Fig. 5 Equipment for recoating (left) and annealing (right) the fibre gratings

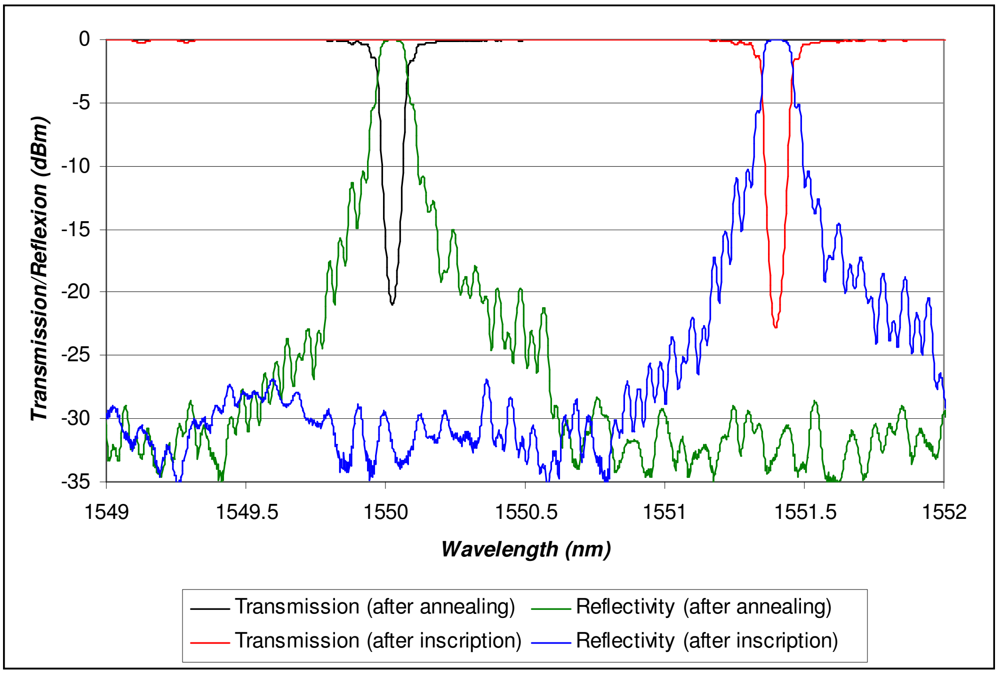


Fig. 6 impact of the annealing process

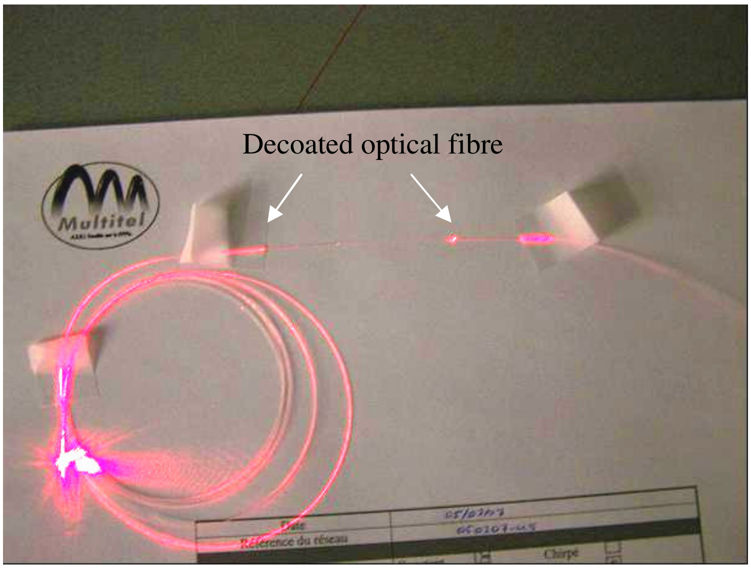
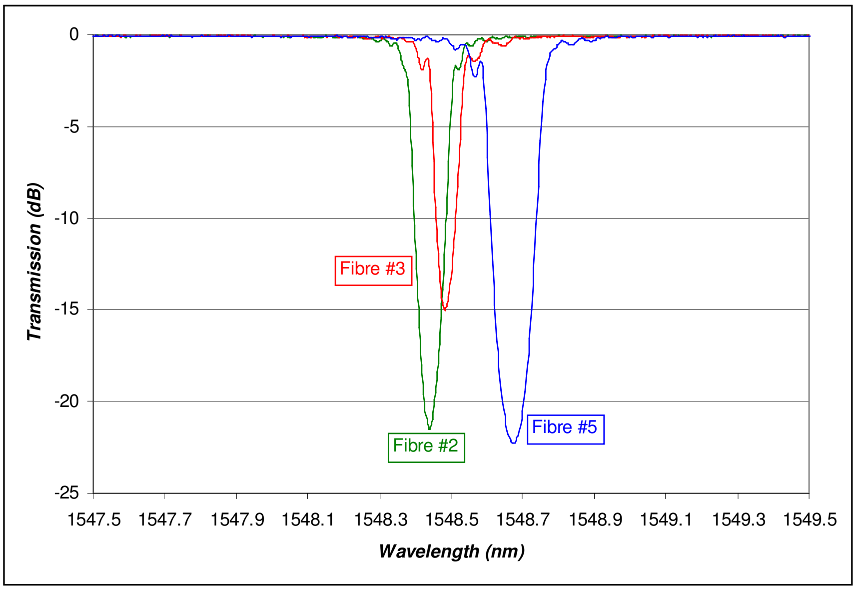


Fig. 7: FBG sample. The optical fibre is illuminated with a red laser to obtain a better image of the fibre. The arrows indicate the place where the coating is removed to realise the photoinscription when the coating is not UV transparent

2.4 - Characterisation

More than 20 samples (see ***Fig. 8***) have been realised using the techniques described in the previous sections. The gratings have been characterised in both reflection and transmission using a broadband ASE source and a spectrum analyser. A typical curve of both spectra is shown in ***Fig. 6***.
As anticipated, FBGs written on Fibre#1showed much higher reflectivity than those written on Fibre#2 and #3, because of the higher photosensitivity of the pristine fibre. This is illustrated on ***Fig. 8***.



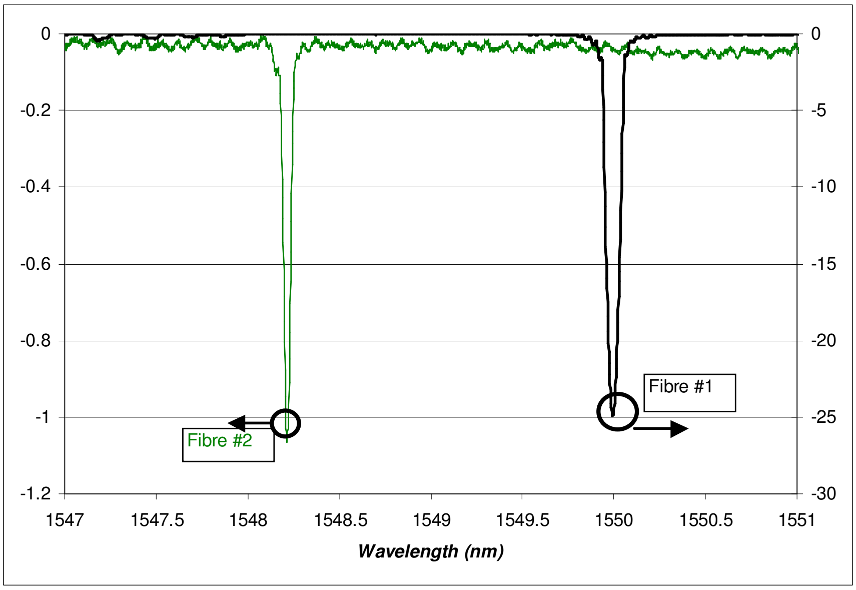


Fig. 8 Transmission spectra of the FBG samples made on the 4 different fibres detailed in D3.1. Top: comparison of FGB strength on Fibre#2, Fibre3 and Fibre#5 using same photo-writing conditions. Bottom: comparison of FBG strength on Fibre#1 and Fibre#2 using same photo-writing conditions, but at a lower pulse repetition rate.

2.5 - Samples distribution to OFSETH consortium

Integration into textile fabrics was then considered, in collaboration with WP2, and according to the distribution shown in ***Fig. 9***. Details of these trials are given in D2.1, where various techniques such as weaving and knitting as well as various fabrics (elastic and non-elastic) have been employed.

Concerning recoated SSM fiber, numerous attempts were necessary in order not to break the fibre, which tent to break at splice or FBG locations.
FBGs that were not stripped showed better robustness to the weaving process, as anticipated. But in that case, the fibre often used to break at the splice location.

N°	Dispatch date	Fibre	Reference	Sent to	Use
1	06/2006	Fibre#2	120506-u2	CEN	Textile integration trials (weaving)
2	06/2006	Fibre#2	120506-u3	CEN	Textile integration trials (weaving)
3	06/2006	Fibre#2	120506-u4	CEN	Textile integration trials (weaving)
4	06/2006	Fibre#2	120506-u5	CEN	Textile integration trials (weaving)
5	06/2006	Fibre#2	120506-u6	CEN	Textile integration trials (weaving)
6	08/2006	Fibre#2	131204-a3	TYT/SHI	Textile integration trials
7	08/2006	Fibre#2	131204-a5	TYT/SHI	Textile integration trials
8	08/2006	Fibre#2	131204-a6	TYT/SHI	Textile integration trials
9	08/2006	Fibre#2	181004-a3	TYT/SHI	Textile integration trials
10	08/2006	Fibre#2	181004a-5	TYT/SHI	Textile integration trials
11	08/2006	Fibre#2	181004a-6	TYT/SHI	Textile integration trials
12	11/2006	Fibre#2	161006-u3	CEN	Textile integration trials (stitching – pattern 1)
13	11/2006	Fibre#2	161006-u1	CEN	Textile integration trials (stitching – pattern 1)
14	11/2006	Fibre#1	271006-u1	CEN	Textile integration trials (stitching – pattern 2)
15	12/2006	Fibre#1	271006-u2	CEN	Textile integration trials (stitching – pattern 2)
16	12/2006	Fibre#1	161006-u2	CEN	Textile integration trials (stitching – pattern 1)
17	01/2007	Fibre#2	231006-u6	ELA	Textile integration trials (weaving)
18	01/2007	Fibre#2	231006-u7	ELA	Textile integration trials (weaving)
19	02/2007	Fibre#4 (FBG not written at MUL)	PR2007_04_02_07	BAM	Sensor caracterisation
20	02/2007	Fibre#1	131006-u2	BAM	Sensor caracterisation
21	02/2007	Fibre#2	231006-u5	BAM	Sensor caracterisation
22	03/2007	Fibre#3	020307-u5	BAM	Sensor caracterisation
23	03/2007	Fibre#2	231006-u2	BAM	Sensor caracterisation
24	03/2007	Fibre#3	200307-c1	BAM	Sensor caracterisation
25	03/2007	Fibre#5	150307-c5	BAM	Sensor caracterisation

Fig. 9 Silica FBGs produced by MUL

3 - Summary

Samples of FBG sensors were produced on three different fibres using the phase mask technique and a 248nm UV laser.
More than 20 prototypes were delivered to WP2 and WP4 partners for textile integration trials (WP2) and sensing characterisation (WP4).
Preliminary trials of textile integration showed very high fragility of fibre zones having been stripped, either for splicing or writing purposes. Therefore, this point deserves further investigation.

List of Abbreviations

FBG	Fibre Bragg Grating
SMF	Single mode fibre
SSMF	Standard single mode fibre
UV	Ultra Violet