Optimization of Fiber Bragg Grating Parameters for Sensing Applications

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ABSTRACT
Fiber Bragg Gratings (FBGs) are increasingly being employed in a novel range of applications, especially in sensing and measurement field. Some of these novel FBG-based sensing applications, especially those requiring high resolution sensing in harsh environments, impose challenges on Bragg gratings and their performance. Additionally, there is a growing list of Fiber Bragg Grating types and manufacturing techniques, each with its own strengths and disadvantages. With the new generation of fiber optic interrogation technologies reaching femtometer-level resolution in Bragg wavelength tracking, the achievable accuracy and stability of the sensing system is becoming limited by the performance of the employed Bragg grating itself. In many cases, correct selection and definition of the FBG parameters can result in defining the success of the sensing system.

Here, we explore the specifications of Bragg gratings that are most relevant to FBG-based sensors, propose their characterization and analysis methodologies and explore their effects for both static and dynamic sensing applications in combination with tunable laser based fiber optic interrogation techniques. Bragg gratings manufactured by several different techniques are compared to demonstrate their suitability for different types of sensing applications. Several application focused examples are also provided to demonstrate the importance of the parameters for detection of strain, pressure, sound, vibration and tilt using fiber optic sensors.

Keywords: Fiber optics, fiber Bragg gratings, fiber sensor, sensor interrogation, birefringence, polarization dependent frequency shift

1. INTRODUCTION
Fiber Bragg Grating (FBG) sensors [1-9] have been demonstrated for different commercial applications especially in the telecom and sensing sector over the past years. Today different companies offer commercial FBGs tailored to customer requirements and specifications. However, in terms of provided FBG specifications and datasheets, there is still ambiguity on how does the specified and un-specified parameters influence the overall system performance which will also depend on the interrogation technique and the packaging of the sensor.

One of the unspecified parameters in current commercial FBGs is the polarization dependency frequency shift (PDFS) which is induced due to birefringence in the fiber/FBG and also depends on the grating inscription technique [5, 10]. Other parameters that could influence overall system performance are: FBG shape distortion and asymmetry, FBG full width at half maximum (FWHM), side lobe suppression ratio (SLSR), reflectivity, coating type and uniformity, etc. In sensing applications, the main performance parameters depend on the application and the time scale of the measurement. For static, long term, low frequency applications (e.g. temperature/pressure measurements), the stability and long term drift of the sensor is an important parameter. For dynamic, short term, high frequency applications (e.g. acceleration/vibration measurements), the noise floor of the measurements which is correlated to the repeatability, resolution (precision/standard deviation) is an important parameter. Other important parameters include the linearity, distortion for the measurement system (combination of the Fiber Bragg Grating, its packaging, the interrogator and even the communication cable and connections). One key differentiator from the different FBG suppliers is the way the grating is inscribed, essentially before coating, through coating or stripping and recoating the fiber.

The standard FBG inscription process involves stripping the polymer coating on the cladding of the fiber, exposing it to a grating pattern using a UV source and phase mask allowing the control of the FBG shape and characteristics, and then recoating the fiber on the location of the grating to protect the glass [2]. However the stripping and re-coating process
often results in damage in the fiber, which results in both limitations in lifetime and the maximum strain that could be applied to the FBG. Additionally, the recoating process often results in a different and non-uniform coating at the location of the grating, which can result in different sensing characteristics. Many of the above limitations are overcome with the Draw tower grating (DTG®) which enable the inscription of the grating during the fiber drawing process, before the coating is applied and as such avoids stripping the coating enabling higher tensile strength for the sensor [7]. However, due to the limited time of exposure during the draw process for this production technique the fibers are required to have considerably higher dopant levels to ensure sufficiently high reflectivity levels for the FBGs, and as such often have different core diameters for the single mode fibers than many of the standard telecom fibers and have higher attenuation losses. Even then, the reflectivity of the Bragg gratings are often more limited in draw tower process in comparison to strip-and-recoat technique. Additionally, the higher dopant levels can result in limitations in temperature resistance of the DTG®s.

More recently techniques have been developed to enable Bragg gratings to be inscribed through the coating. Since this requires considerably more optical power to be exposed, often femtosecond (FS) pulsed lasers are used to avoid coating to be damaged. The grating formation can be achieved either by using point-by-point, line-by-line or phase mask inscription techniques. One specific advantage of the femtosecond written gratings is the ability to form the FBG in various fiber types and dopant levels, even pure silica fibers, which enable FBGs to operate at high temperature and chemically harsh conditions such as high hydrogen levels as encountered in downhole situations in oil and energy applications [7, 8]. However, especially in the point-by-point technique, there exists limitations in the sharpness of the reflection spectral width that can be achieved as well as the polarization effects that can be observed.

The polarization induced frequency shift (PDFS) is a combined effect of the writing process, type of fiber used and the packaging of the sensor which highlights a polarization dependency which could be observed with polarized tunable laser based optical interrogators. Standard FBGs are also sensitive to both strain and temperature. In order to measure one parameter independently from the other, an extra FBG would be required. For absolute strain measurements for example, one FBG will measure simultaneously strain and temperature, while another FBG placed closely to the first one and isolated from strain will be used for temperature measurement and compensation. Differential measurement of two FBGs can also be used for different type of measurements (e.g. pressure). When more than one FBG is used in a measurement system, the un-correlated noise and drift of the sensors will limit the performance of such systems. Therefore it is important to understand and minimize the source of such effects.

In this paper we evaluate the effect of different optical characteristics on the performance of different types of commercial FBGs (standard FBG, DTG®, and FS-FBG using the point-by-point inscription technique) supplied from the different FBG manufacturer companies that are present in the market today in addition to the performance variability from sample to sample of the same kind.

2. EXPERIMENTAL SETUP

In order to characterize and evaluate the performance of different types of FBGs, a FAZ Technology (FAZT) I4 tunable laser based optical interrogator was used for testing the different types of sensors [4-6]. The FAZT I4 interrogator is based on a semiconductor tunable laser diode delivering a high level of repeatability, reliability in addition to power and wavelength referencing to deliver a high level of precision and accuracy.

The main building blocks of the interrogator are shown in figure 1 consisting of the transmitter section, polarization controller (orthogonal polarization switch), passive optics section which interfaces between the fiber sensor array and the receiver section, all connected and controlled by a computer on board (COB) which transfers the data to the end user/client via an Ethernet data communication link. The polarization switch is connected between the laser output and the FBG channels for polarization control and polarization dependent frequency shift (PDFS) mitigation [5].

The FAZT I4 interrogator delivers long term stability and high precision measurements (precision <100fm (1σ) measured by tracking a HCN Gas Cell line P10 [1549.7305] >10 hours [4, 11]). The FAZT I4 long term absolute accuracy specified over the life time of the product (bias/deviation from the true value using a HCN gas cell) over the operating target temperature (0-55°C) and wavelength range (C-band) is <1pm. For dynamic measurements, a repeatability of <50fm (1σ) @1kHz sample rate (<40seconds) is achieved for the I4 which defines the noise floor. The laser in the FAZT I4 interrogator scans the C-band (~40nm) at a sweep rate of 1kHz (tuning rate of 0.1pm/ns). The output of the laser is polarized and the laser signal power is split over four separate FBG channels (typically +3dBm/channel) with the minimum detectable power (noise floor) at the receive end <40dBm.
The received reflected signal is sampled with 1pm resolution and the interrogator can deliver 4Hz spectral data for all four channels at that resolution. The FBG peak tracking is implemented in a field programmable gate array in the I4 to enable tracking of up to 30 FBG peaks per channel @1kHz sample rate (120 sensors tracked at 1kHz simultaneously over 4 channels).

For the sensor testing, the I4 interrogator system was configured to support 3 FBG channels for tracking different FBGs from the same supplier (#n where n=1, 2, 3 is the supplier number all tested in different runs) for short term and long term (7 day) testing. The 4th channel of the interrogator was used to track different absorption lines (troughs) of a 100Torr HCN gas cell as shown in figure 1.

The tracking of these gas cell lines confirmed that the maximum system drift was measured to be in the range of 0.3-0.7pm (p-p) and precision <0.1pm (1σ) was reported over the 7 days for all of the three different runs that were carried out for all the FBGs that were tested for each supplier.

Figure 1. Block diagram of the FAZT I4 tunable laser interrogator

The FBG sensors were supplied from 3 different companies and were made using different inscription techniques (standard FBG using phase mask (strip and recoat), inscription during the fiber drawing process (draw tower grating DTG®), and femto-second laser through coating inscription).

The manufacturer also provided the FBGs with different coating materials (Polyimide (PI), Ormocer®, Acrylate, Carbon-PI), cladding diameters (80 µm, 125µm), grating length and their associated optical characteristics (e.g. FWHM, SLSR, and Reflectivity) as shown in table 1.
Table 1. Different types of commercially available FBGs from different suppliers used in the test.

<table>
<thead>
<tr>
<th>Type of FBG based on inscription technique and supplier #n</th>
<th>Cladding Diameter, Grating Length, Coating type</th>
<th>Number of Sensors</th>
<th>FWHM (pm)</th>
<th>SLSR (dB)</th>
<th>Reflectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard FBG using phase mask inscription (Strip-Recoat) #1</td>
<td>(80 µm, 10mm, polyimide)¹</td>
<td>3</td>
<td>100</td>
<td>17-20</td>
<td>60-80</td>
</tr>
<tr>
<td></td>
<td>(125µm, 10mm, polyimide)²</td>
<td>4</td>
<td>100</td>
<td>12-15</td>
<td>40-50</td>
</tr>
<tr>
<td>Grating inscribed during fiber drawing process (DTG®) #2</td>
<td>(80µm, 8mm, Ormocer®)²</td>
<td>2</td>
<td>100</td>
<td>8-12</td>
<td>20-25</td>
</tr>
<tr>
<td></td>
<td>(125µm, 8mm, Ormocer®)²</td>
<td>5</td>
<td>100</td>
<td>8-12</td>
<td>20-25</td>
</tr>
<tr>
<td>Femto-Second Inscribed FBG Through Coating (fs-FBG) #3</td>
<td>(80µm, 4.6mm, Acrylate)³</td>
<td>2</td>
<td>290-300</td>
<td>20-23</td>
<td>30-50</td>
</tr>
<tr>
<td></td>
<td>(125µm, 5.2mm, Carbon-Pl)³</td>
<td>4</td>
<td>240-300</td>
<td>12-22</td>
<td>8-50</td>
</tr>
</tbody>
</table>

3. TEST PARAMETERS AND RESULTS

Some of the main parameters used to test the FBG sensors are shown in figure 3 with their definitions described below:

- Bragg wavelength (nominal center wavelength, \( \lambda_c \)) which is defined as the wavelength of highest reflection measured at room temperature (−25°C) and tracked by the optical interrogator with arbitrary input polarization.

- Full width at half maximum (FWHM) which is defined by the FBG width at 50% peak amplitude (-3dB) measured from the FBG reflected spectrum captured using the optical interrogator. In most situations, especially when performing high resolution sensing applications with the new generation tunable laser interrogators, it is highly desired to have the reflection spectra as sharp as possible with the smallest FWHM.

- Side lobe suppression ratio (SLSR) which is defined as the ratio between the FBG main lobe peak and the highest secondary neighbor peak. Ideally, the SLSR level should be as high as possible to ensure only a single reflection peak is present.

- Reflectivity (R) which is defined as the maximum % of power reflected by the FBG peak while laser is at the peak wavelength of the FBG. While it is desirable in most applications to have high reflection peaks, new generation interrogators can handle tracking with reflections as low as -20 dB (1% reflectivity) coming back to the interrogator, including the path losses such as splices and connectors.

- FBG reflection spectra shape asymmetry ratio factor (As) \( (As_{50%/As_{100%}}) \) which is defined as the ratio between \( b/b' \) and \( a/a' \) where \( b/b' \) is defined as the distance from the trailing edge of the FBG reflected response at 50% / 10% of the FBG peak height to \( \lambda_c \) and \( a/a' \) is defined as the distance from the rising edge of the FBG reflected response at 50% / 10% of the FBG peak height to \( \lambda_c \). Ideally, the reflection spectra should be fully symmetric and the As factor should be 1.

- Polarization dependent frequency shift (PDFS) which is defined as the maximum observed peak to peak change in recorded Bragg wavelength due to polarization change which can be emulated by using an external manual or automatic polarization controller placed in the FBG path. Ideally, FBG peak recorded should be independent of the polarization and the PDFS should be minimal to ensure the sensing system is immune to polarization changes in the standard telecommunication fibers due to temperature change and movement of the fiber.

- Residual Polarization dependent frequency shift (RPDFS) which is defined as the remaining PDFS of a tracked FBG peak after polarization mitigation is applied using a polarization switch or polarization scrambler.

- Precision of tracked FBG peak which represents the minimum resolvable change in wavelength. It is also defined as the deviation of a set of measurements over a specified timeframe, reported as peak-to-peak or \( 1\sigma \) standard deviation [4]. Highest possible precision is possible with the lowest standard deviation system, and is often highly dependent on both the FBG type as well as the interrogation system used.
• Accuracy of tracked FBG peak representing a systematic Bias (Trueness) of the measurement which is defined as the deviation of the precision measurement to a true reference value. In the case of an optical interrogator, the reference value is the wavelength of an absorption gas line trough defined by the NIST HCN standard [4, 11].

• Power spectral density noise floor (PSDN) is defined as the noise floor calculated from the mean power spectral density PSD (Px) from 1Hz to 499Hz (~Nyquist frequency). The PSD is often calculated using Welch method, and the results are represented in (nm²/Hz) units. This result is then converted into log units (10LogPx). The window applied to the data is Blackman Harris, selected in this study to be 60 seconds long. For a sensor where the max wavelength deviation is 1nm, the PSDN is correlated to the minimum detectable dynamic signal and the dynamic range (DR) achievable with the sensing system.

Figure 2. Typical FBG reflected spectrum (linear normalized amplitude) with the main parameters (Center wavelength λc, Asymmetry ratio (As), FWHM, SLSR) (left), λ peak tracking and probability distribution of values (right)

Several FBG samples were from different suppliers (using different inscription techniques) were characterized using the FAZT I4 interrogator as shown in Table 2 which shows the main optical characteristics measured from the reflected spectral response of the FBG as shown in figure 2.

Table 2. Measured results for the different sample FBGs characterized optically using the FAZT I4 interrogator

<table>
<thead>
<tr>
<th>Type of FBG based on inscription technique and supplier #n</th>
<th>Cladding Diameter, Grating Length, Coating type</th>
<th>Sensor ID</th>
<th>λc @25°C</th>
<th>FWHM (pm)</th>
<th>SLSR (dB)</th>
<th>As (50%)</th>
<th>As (10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard FBG using phase mask inscription (Strip-Recoat) Run #1 (7 days)</td>
<td>80 µm, 10mm, PI</td>
<td>FBG 80 a</td>
<td>1553.671</td>
<td>87.66</td>
<td>13.15</td>
<td>1.03</td>
<td>0.551</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FBG 80 b</td>
<td>1549.97</td>
<td>100.39</td>
<td>12.51</td>
<td>1.076</td>
<td>1.016</td>
</tr>
<tr>
<td></td>
<td>125µm, 10mm, PI</td>
<td>FBG 125 a</td>
<td>1529.594</td>
<td>96.35</td>
<td>12.44</td>
<td>0.975</td>
<td>1.079</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FBG 125 b</td>
<td>1532.533</td>
<td>96.95</td>
<td>11.44</td>
<td>1.092</td>
<td>1.189</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FBG 125 c</td>
<td>1558.617</td>
<td>96.5</td>
<td>14.7</td>
<td>1.007</td>
<td>1.113</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FBG 125 d</td>
<td>1561.145</td>
<td>95.21</td>
<td>14.99</td>
<td>1.004</td>
<td>1.125</td>
</tr>
<tr>
<td>Grating inscribed during fiber drawing process (DTG®) Run #2 (7 days)</td>
<td>80µm, 8mm, Ormocer</td>
<td>DTG 80 a</td>
<td>1539.53</td>
<td>95.28</td>
<td>8.73</td>
<td>1.014</td>
<td>0.996</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTG 80 b</td>
<td>1544.321</td>
<td>97.86</td>
<td>9.44</td>
<td>1.06</td>
<td>1.043</td>
</tr>
<tr>
<td></td>
<td>125µm, 8mm, Ormocer</td>
<td>DTG 125 a</td>
<td>1537.976</td>
<td>98.83</td>
<td>8.67</td>
<td>1.081</td>
<td>1.075</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTG 125 b</td>
<td>1542.428</td>
<td>97.04</td>
<td>8.83</td>
<td>0.968</td>
<td>1.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTG 125 c</td>
<td>1532.965</td>
<td>96.42</td>
<td>9.41</td>
<td>0.976</td>
<td>0.961</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTG 125 d</td>
<td>1547.362</td>
<td>95.92</td>
<td>11.43</td>
<td>1.004</td>
<td>0.981</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DTG 125 e</td>
<td>1551.67</td>
<td>98.47</td>
<td>10.35</td>
<td>1.034</td>
<td>1.016</td>
</tr>
<tr>
<td>Femto-Second Inscribed FBG Through Coating (fs-FBG) Run #3 (7 days)</td>
<td>125µm, 5.2mm, Carbon-PI</td>
<td>FS-FBG 125 a</td>
<td>1546.052</td>
<td>234.92</td>
<td>11.51</td>
<td>0.964</td>
<td>0.802</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS-FBG 125 b</td>
<td>1547.911</td>
<td>310.71</td>
<td>17.17</td>
<td>0.895</td>
<td>0.821</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS-FBG 125 c</td>
<td>1547.965</td>
<td>299.43</td>
<td>23.53</td>
<td>0.968</td>
<td>0.944</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS-FBG 125 d</td>
<td>1546.037</td>
<td>317.92</td>
<td>21.59</td>
<td>0.912</td>
<td>0.886</td>
</tr>
<tr>
<td></td>
<td>80µm, 4.6mm, Acrylate</td>
<td>FS-FBG 80 a</td>
<td>1546.046</td>
<td>311.51</td>
<td>20.64</td>
<td>0.966</td>
<td>0.915</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FS-FBG 80 b</td>
<td>1544.128</td>
<td>327.51</td>
<td>20.24</td>
<td>1.025</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 3 (a) shows the spread of SLSR values across the different FBG samples while Figure 3 (b) shows the spread of FBG shape asymmetry (As) between the different samples. For optimum FBG peak tracking, sharp and symmetric FBG responses are desirable. Sharper FBGs with narrow widths (FWHM) can improve the repeatability of the measurements.

Figure 3. Spread of SLSR measurements (Top - A) and Asymmetry ratio factor (bottom - B) for the FBG samples.

The PDFS of the different FBG samples was measured by placing a manual polarization controller between the sensor and the interrogator which was adjusted over a short period of time while the interrogator orthogonal polarization switch (Pol. SW) as shown in figure 1 was active (switching between 2 orthogonal polarization states between consecutive sweeps) and the laser was sweeping at 1kHz scan rate [5]. The resulting maximum variation of the FBG peak wavelength is directly correlated to the amount of PDFS in the sensor as shown in figure 4.
The polarization state in standard single mode fiber (SMF) in real world installations would change depending on the temperature and any movement of the connection fiber between the source/detector system and the sensing point. This could influence the accuracy of the FBG peak measurements and will have an impact on the overall system measurement using a polarized tunable laser based optical interrogator (e.g. for a FBG based temperature sensor that has a 10 pm/°C sensitivity, a 10 pm PDFS will cause a 1°C error in the absolute temperature measurement). In order to reduce this error the FBGs and fiber used need to be designed to have low birefringence. PDFS is also not commonly characterized by FBG suppliers and is not provided with typical FBG datasheets. It is possible to mitigate the PDFS induced error of FBG peak wavelength by using polarization scrambling and polarization control/switching techniques (e.g. using an orthogonal polarization switch [5]). Figure 5 shows the spread of PDFS peak to peak values in pm across the different FBG samples from the different suppliers and the residual PDFS (RPDFS) remained after using a polarization mitigation technique using an orthogonal polarization switch that changes the laser output polarization state between two consecutive sweeps and averages out the measurement over the two orthogonal sweeps.

Figure 5. Spread of PDFS and RPDFS measurements for the FBG samples.

Figure 6 shows the PSD plots for the 80 µm FBGs from the different suppliers (FBG, DTG®, FS-FBG) measured over 1 day with a 60 second window. The same PSD calculations were done for all the different FBGs (80 µm and 125 µm fiber) and from the PSD plots the PSDN was calculated and summarized in figure 7. Clearly, the FBGs manufactured with the strip & recoat technique demonstrate a significantly higher (3-10 dB) noise floor and significantly higher variation between samples, in comparison to the DTG® and FS-FBG samples. This variability in the noise floor could be...
due to several reasons including: the variability in the shape (sharpness), distortion/ripple that could be superimposed on the FBG response due to the writing technique, bad termination or connector reflections, and the variability in signal to noise ratio (SNR) of reflected response detected at the receiver side due to the different FBG reflectivity and optical loss (splice/connector loss).

For the long term measurements, the FAZ I4 interrogator was setup to track all the FBGs from each supplier for 7 days in different runs. All FBGs were placed in an isolated lab environment with a typical temperature variation of a couple of degrees from day and night and a more stable temperature variation during the weekend.

Figure 8 shows the time plots the 80 µm FBGs from the different suppliers (FBG, DTG®, FS-FBG) measured over 7 days, low pass filtered (LPF) (frequency cutoff of 0.2 Hz) and then down sampled (DS) to 1Hz. The maximum peak-to-peak wavelength shift for the individual tracked FBGs measured over the 7 days @ 1 kHz of the different type of FBGs and are shown in figure 9.

The maximum peak-to-peak wavelength shift observed for the FBGs shown in Figure 8 and 9 could be mainly induced by thermal effects, and humidity sensitivity. Even though the different FBGs from the different suppliers were tested in different runs, if all the FBGs had the same temperature and humidity sensitivity their Bragg wavelengths should have varied by the same amount while being exposed to identical conditions. However a variation in the maximum wavelength deviation of 10.7pm, 11.4pm, and 26.9pm was observed for the FBG, DTG®, and FS-FBG batch test runs respectively. When designing temperature independent sensors (e.g. strain, pressure, etc.) the thermal effect is compensated for by adding a second FBG that experiences the same thermal effects.
For an ideal temperature compensation both FBGs will see the same temperature fluctuations and will react in the same way. However in reality two different FBGs cannot be 100% identical and could drift in different ways due to the manufacturing tolerances in specifications, coating uniformity, birefringence, etc. In order to evaluate the different effects two FBGs from the same supplier (FBG, DTG®, FS-FBG) and same specifications (coating, diameter) were measured together to calculate a relative wavelength shift (differential measurements) for the two FBGs. The tests were carried out over 7 days were both FBGs were kept isolated in the same lab environment.

Figure 9. Spread of the maximum FBG peak-to-peak wavelength drift over 7 days for the different type of FBGs

Figure 10 shows an example of the relative wavelength shift between two 80µm FBGs for the different suppliers (FBG, DTG®, FS-FBG) measured over 7 days with the polarization mitigation enabled and the data down sampled to 1Hz on the graph. It is clear from the graph that the standard (strip & recoat manufactured) 80 µm FBG pair did not report the same wavelength shift and the difference was up to 8.6 pm. The variation between identically produced Gratings is considerably lower in before-coating and through-coating formed gratings, as seen Figure 10 (center and right, respectively). Figure 11 shows the maximum peak-to-peak wavelength shift and standard deviation for all of the relative (differential) tracked FBG pairs measured over 7 days @ 1 kHz for the different type of FBGs, which further reinforces this observation. The result is deemed to be most likely due to differences in the recoating diameters, often observable under the microscope.

Figure 10. Time series plots for the different type of 80µm differential FBG pairs measured over 7 days (DS to 1Hz)
4. CONCLUSION

We have shown that different types of FBGs (FBG, DTG®, FS-FBG) supplied from different vendors and manufactured with different techniques exhibit considerably different characteristics in their Bragg wavelengths, their stability, reproducibility as well as the polarization influences. The observed levels of Polarization Dependent Frequency Shift (PDFS) (1pm up to 25.7pm) and residual PDFS (0.2pm up to 4.4pm) highlights the need to improve the birefringence effect on the FBG and/or use polarization mitigation techniques. We have also reported different long term differential wavelength drifts for a similar type FBG pair in the order of 0.85-8.6pm (p-p) and 0.17-2.8pm (standard deviation 1σ) varying depending on the type of FBG pair used in the measurement. This has a strong influence when selecting FBGs to design long term stable sensors (e.g. strain and pressure). In addition to the long term performance there was a >10dB variation observed on the noise floor calculated be measuring the PSD of the FBG wavelength peaks tracked over 24 hours and calculated using a 60 second window. This parameter is very important when designing FBG sensors for dynamic applications, for example accelerometers or acoustic detectors that are used in different structure health monitoring and seismic applications or when performing measurements of vibration signals with fiber optic sensors embedded in composite parts such as fuselage of an aircraft or the blades of a wind turbine.

In order to improve the quality and reproducibility of FBG based optical sensors, the variability of different FBG specifications needs to be improved on and better understood by the FBG suppliers and FBG users, not just for the optical properties as focused in this study but also regarding the mechanical characteristics of the fibers. As mentioned above, different manufacturing techniques can result in different fiber strengths and lifetime characteristics. Furthermore, technique of the grating manufacturing can result in differences in resistance to harsh conditions, such as operating with stable reflectivity up to extreme temperatures of 300-400°C or higher, or resistivity to chemical effects such as hydrogen darkening. Finally, the different coating chemistries can enable enhanced operation under specific conditions. While certain coatings degrade in lower temperatures others such as polyimide maintain their properties to higher levels. Additionally the rigidity and mechanical stability of the coating becomes a highly important parameter when considering applications where the FBG needs to be exposed to relatively high levels of tension.

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