Stretching the Limits for the Decoupling of Strain and Temperature with FBG based sensors

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ABSTRACT

The ability to decouple strain from temperature is being explored using Bragg gratings written in highly birefringent fiber in combination with a high accuracy interrogator. Both the birefringent preform as well as the interrogator have been optimized in order to reach maximum measurement accuracy. The results from calibration measurements will be presented together with the estimated stability.

Keywords: Fiber optics, fiber Bragg gratings, Draw Tower Gratings, fiber sensor, sensor interrogation, birefringence, polarization maintaining fiber

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1. INTRODUCTION

Today, Fiber Bragg Gratings (FBGs) are used in various industries and interest of the technology is still growing. However, the cross-sensitivity between strain (ε) and temperature (T) can be seen as a major challenge for the technology, implying the need for 'temperature compensation' during ε-measurements and 'strain free' mounting during T-sensing. An alternative approach is to use FBGs written in birefringent or Polarization Maintaining (PM) fiber. These PM-FBGs (or Bi-FBGs) have a double Bragg peak that allows the simultaneous measurement of ε and T [1] but this is often at the expense of the measurement accuracy because the decoupled sensitivities are small.

In this article, we will show how the accuracy is being pushed to the limits. FBGS has developed a PM-fiber with an enhanced capability to separate ε and T and FAZ Technology has developed the I4 tunable laser interrogator platform that is capable to measure birefringent FBGs and that has a stability in the femtometer (fm) range, surpassing today's state-of-the-art with at least an order of magnitude. The combination of these two technologies allows separation of ε and T with unprecedented stability.

2. DRAW TOWER GRATINGS IN POLARIZATION MAINTAINING FIBER

Over the years, FBGS has developed a method of writing FBGs during the drawing of an optical fiber [2-4]. Inscription of these so-called Draw Tower Gratings (DTG®s) is done in highly photosensitive fiber in order to achieve grating reflectivities up to 40% using single pulse exposures.

For the inscription of DTG®s in PM fibers, a highly photosensitive and highly birefringent fiber preform was developed together with the Leibniz Institute of Photonic Technology (IPHT Jena). The preform was consisting of different materials and was assembled by the stack and draw technology. Stress birefringence is obtained by including boron doped silica in the preform, which has a considerably different thermal expansion compared to pure silica. To boost the birefringence, the distance between the stress applying parts and the fiber core is minimized while at the same time preventing out coupling of light from the core. The stress birefringence itself is generated during the fiber drawing process due to the different melting temperatures and thermal expansion coefficients of the two preform materials. The fiber core material consists of high Ge doped silica glass.

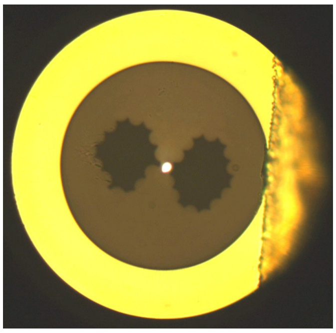

Figure 1: Cross section of generated panda like PM fiber.

An early version of the drawn PM fiber is shown in Figure 1. The initial preform design which is according to a panda fiber is maintained quite well. A typical reflection spectrum of a single pulse draw tower grating within this fiber is shown in Figure 2, revealing a peak separation of around 0.5nm at room temperature. This separation is sufficient to be evaluated with commercial interrogation systems. The achievable reflectivity was between 5% and 20% for the individual polarization peaks. We fabricated single PM-DTG®s as well as PM- DTG® arrays in different configurations.

The response of the individual wavelengths λ_1 and λ_2 to ε and T variations is very similar like the response for regular DTG®s or FBGs but there will be slight differences in sensitivity between the two peaks. Mathematically, we will get a set of two equations that relate λ_1 respectively λ_2 to ε and T with coefficients that are slightly different [1]. Due to this, the set can be inverted and solved for ε and T. In reality, the small differences in sensitivity originate predominantly from the temperature dependence of the stress birefringence and the peak separation can be regarded as a direct measure for it. So more intuitively, changes in peak separation can be directly related to changes in temperature whereas strain changes will mainly cause an equal shift for both wavelengths. Therefore, the sensitivity of the peak separation is a key parameter for the decoupling between ε and T.

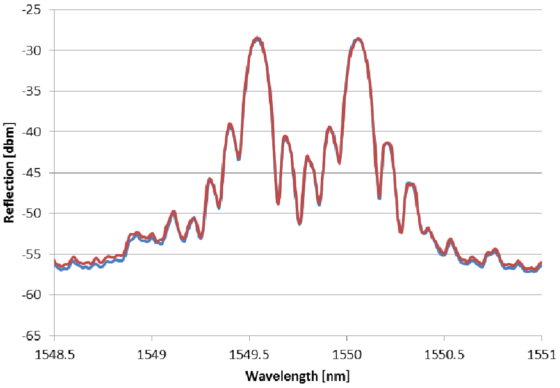

Figure 2: Typical reflection spectrum of PM-DTG® with enhanced capability of ε and T separation.

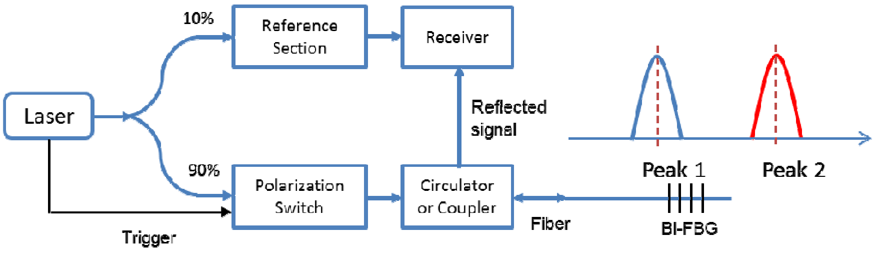

Figure 3: Basic schematic diagram for a single channel FAZT interrogator.

3. THE I4 TUNABLE LASER PLATFORM

The FAZT I4 optical interrogator is based on a semiconductor tunable laser diode that has no moving parts delivering high level of reliability and accuracy in addition to a power and wavelength reference section. It includes several fine and coarse periodic wavelength references to correct for any drifts in the laser. The laser scans the C-band (40nm) at a rate of 1kHz and the output power is split over four separate channels (typically +3dBm/channel) with the minimum detectable power at the receive end ~-45dBm. The received reflected signal is sampled with 1pm resolution. The I4 interrogator can also capture the full C-band spectrum (40nm@1pm sample size) at 20Hz rate. Figure 3 shows a basic schematic diagram illustrating a single channel interrogator connection.

The FAZ interrogator also includes the option to mitigate polarization effects using a two state polarization switch. Without a suitable polarization mitigation scheme, it would be practically impossible to interrogate the peaks from PM-FBGs with a highly polarized laser source. The solution that the I4 uses is to synchronize the polarization switch rate with the sampling rate and to average over at least two subsequent samples. In this way, the polarization dependence of the double refection peak is almost completely removed.

4. TEMPERATURE AND STRAIN CALIBRATION

To evaluate the response of the PM-DTG®s to temperature, calibrations were performed on PM-DTG® samples placed in a dry well calibrator that has a T-stability of ± 0.005°C. The temperature was varied from 0°C to 100°C and back in steps of 10°C with 30 minutes waiting time per step. Data was collected with the I4 sampling at 20 Hz with the polarization switch enabled and averaging over 20 samples. The evolution of the peak separation is shown in Figure 4. The stability of the signal is better than 50 fm (peak to peak) and the standard deviation (1σ) equals 10 fm.

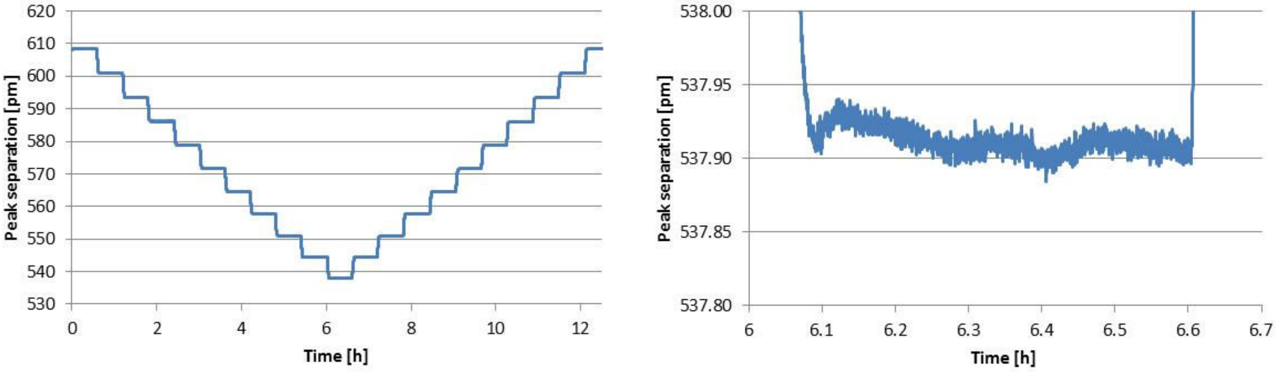

Figure 4: Left: evolution of the peak separation during the temperature calibration; right: zoom for the step at T=100°C.

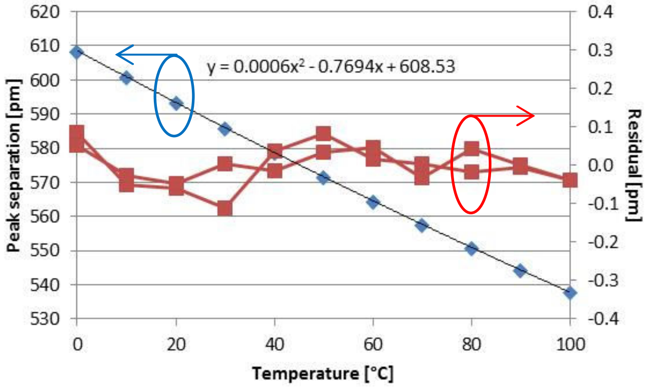

Figure 5: Peak separation as a function of the applied temperature together with the calculated residual peak shifts.

The linear sensitivity of the peak separation to T is shown in Figure 5 and amounts 0.769 pm/°C. The difference between the fitted curve and the measured data (the ‘residuals’) are a measure of the accuracy of the calibration and are also shown in the figure. Their variation is found to be < 0.1 pm (or 100 fm). The long term stability (> 10 h) of the peak separation was also monitored and was found to be < 150 fm (peak to peak). The standard deviation (1σ) was 29 fm. Given these values, we can estimate the decoupled temperature stability to be better than 0.15 / 0.769 = 0.2 °C.

In similarity, strain calibrations have been performed on another sample that was mounted on 2 translation stages. A known amount of strain could be applied by moving one of the stages with fixed steps up and down. The fiber itself ran through a climatic chamber being kept at 30°C in order to avoid temperature fluctuations. The wait time for each step was two minutes. Data recording was done only during stable strain conditions. The sensitivity of the two individual peaks to strain were found to be 1.176 pm/με and 1.191 pm/με and so are almost identical.

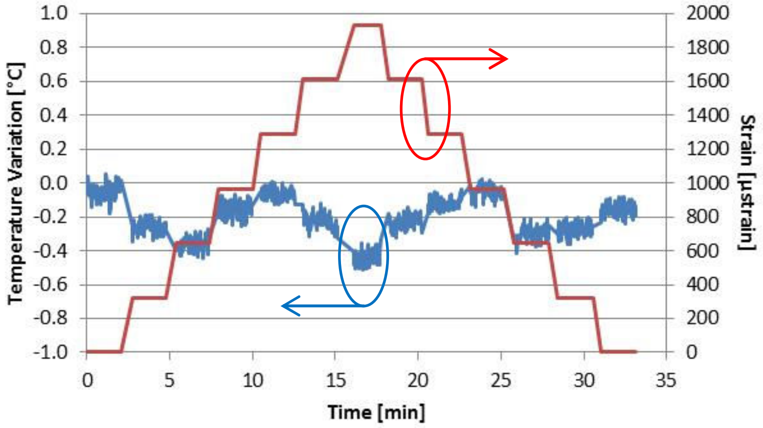

Figure 6: Calculated temperature variation during the strain calibration together with the applied strain profile.

In order to validate the ability of the PM-DTG®s to separate strain from temperature, we have calculated the temperature variation during the different strain steps in the above described calibration test. For the calculation, we have used the individual peak sensitivities for λ_1 and λ_2 as derived from the above calibrations and these values are used to solve the set of linear equations to ε and T. The result for the temperature variation is shown in Figure 6. As can be seen, the variation is in the range of ±0.2°C and thus corresponds to the earlier estimated temperature stability. This result was obtained while the strain was changing over almost 2000 µstrain and therefore illustrates the capabilities of the combined setup.

5. CONCLUSION AND OUTLOOK

We have shown that the PM-DTG®s from FBGS together with the FAZT I4 interrogator allow for separation of strain and temperature effects with high accuracy. This was illustrated by calculating the temperature variation during a strain calibration measurement and the stability was found to be approximately ±0.2°C. Further evaluations will be done in order to estimate the measurement performance during combined temperature and strain transients and further optimizations will be required for the sensor (peak width, peak separation, …) and for the measurement system in order to measure more dynamically.

REFERENCES

[1] Ferreira L. A.; Santos J. L.; Farahi F.; Araujo F. M., "Simultaneous measurement of strain and temperature using interferometrically interrogated fiber Bragg grating sensors", Opt. Eng. 39(8), 2226-2234 (2000)

[2] See http://www.fbgs.com/technology/dtg-technology/

[3] Chojetzki C., Rothhardt M., Ommer J., Unger S., Schuster K. and Mueller H.R., "High-reflectivity draw-tower fiber Bragg gratings-arrays and single gratings of type II", Opt. Eng. 44, 060503 (2005)

[4] Lindner E., Chojetzki C., Brueckner S., Becker M., Rothhardt M., and Bartelt H., "Thermal regeneration of fiber Bragg gratings in photosensitive fibers", Opt. Express 17, 12523-12531 (2009)