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# CHARACTERIZING COMMERCIAL FIBER BRAGG GRATING THERMOMETER AT NRC

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**Abstract:** For the last 100 years, the most accurate thermometers below 1000 °C were almost exclusively based on electrical measurements. Such thermometers are sensitive to mechanical shock, thermal stress, chemical contaminants, ionizing radiation damage and electro-magnetic interference. These fundamental limitations have produced considerable interest in the development of temperature sensors based on frequency measurement as an alternative to their electrical counterpart. Photonic thermometers look like potential candidates to provide greater temperature sensitivity and accuracy while being robust against environmental changes. Here we report on the testing of one type of photonic thermometers – commercial silica fiber Bragg grating thermometer.

## 1. INTRODUCTION

For the last 100 years, the most accurate thermometers below 1000 °C were almost exclusively based on electrical measurements [1]. Although in many national metrology institutes, such thermometers can measure temperature with uncertainties approaching a few hundreds of a microkelvin [2], they are sensitive to mechanical shock, thermal stress, humidity and chemical contaminants and hence require frequent replacement/re-calibration [3-6]. In addition, they are prone to ionizing radiation damage and electro-magnetic interference which further limit their wider use. These fundamental limitations have produced considerable interest in the development of temperature sensors based on frequency measurement which exploit the thermo-optic effect to translate thermal changes into frequency shifts as an alternative to their electrical counterparts [7, 8]. Photonic thermometers look like potential candidates to provide greater temperature sensitivity and accuracy while being robust against environmental changes [9-12].

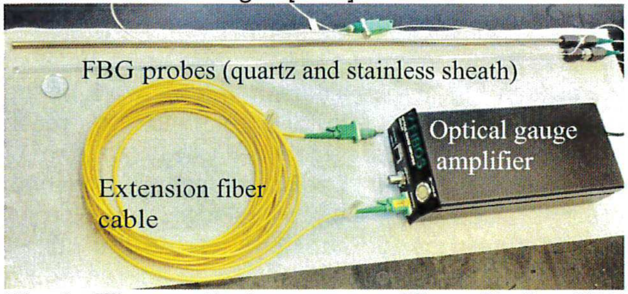

**Fig 1.** *Fibos optical gauge amplifier with the FBG temperature sensor attached. Two low temperature sensors are shown: with ¼" Pyrex and with ¼" metal sheaths. The size of the Bragg grating inscribed at the end of the fiber is approximately equal to the size of the coin.*

In this work we report our initial results of testing photonic thermometers based on silica fiber Bragg grating (FBG) technology supplied by Canadian start-up company Fibos (Fig. 1). We tested temperature sensitivity, repeatability, linearity, stability, resolution and accuracy of Fibos low-temperature (-40 °C to +200 °C) sensors.

## 2. EXPERIMENTAL DETAILS

### 2.1 FBG working principle and Fibos practical realisation

A fiber Bragg grating is manufactured in optical fiber through an inscription process, whether by means of direct writing with a femto-second laser or through a phase mask by a laser with high light intensity, which creates periodic variations of the refractive index. These periodic variations create interference for a specific wavelength of light, known as the Bragg wavelength. When a broadband light source is passed through the optical fiber, the FBG will reflect the Bragg wavelength while allowing all other wavelengths to pass through. From energy and momentum conservation one can derive the first order Bragg condition [13]

$$\lambda_B = 2 \cdot n_{eff} \cdot \Lambda$$

where the Bragg grating wavelength, $\lambda_B$, is the free space center wavelength of the input light that will be back reflected from the Bragg grating, $n_{eff}$ is the effective refractive index of the fiber core at the free space center wavelength and $\Lambda$ is the grating spacing.

The periodic grating defines the Bragg wavelength, but as axial strain is applied to the fiber optic cable or the temperature changes, the pitch of the grating changes, causing the Bragg wavelength to shift as well. This fractional wavelength shift for a temperature change $\Delta T$ may be written as [13]

$$\Delta\lambda_B = \lambda_B \cdot \left(\frac{1}{\Lambda}\cdot\frac{\partial\Lambda}{\partial T} + \frac{1}{n_{eff}}\cdot\frac{\partial n_{eff}}{\partial T}\right)\cdot \Delta T$$

where the first term is the thermal expansion coefficient for the fiber (approximately $0.55\text{x}10^{-6}$ for silica) and the second term represents the thermo-optic coefficient and it is approximately equal to $8.6\text{x}10^{-6}$ for germania-doped, silica-core fiber. From the equation, the expected sensitivity for a ~1550 nm Bragg grating is approximately 13.7 pm/°C.

For interrogating their FBG sensor, Fibos has chosen an active laser interrogation when a tunable narrow band semiconductor laser (inside the amplifier box in Fig. 1) is scanned over the wavelength range containing $\lambda B$-$\Delta\lambda B$ and sensor spectral return is obtained from the photodetector output (amplifier box in Fig 1). The tunable laser wavelength shift (from nominal 1550 nm) corresponding to the peak in the photodetector output is reported to the user.

The manufacturer's expected performance was: a maximum resolution of the probe is 0.002 °C, linearity is ±2 °C, thermal response is 20 ms and thermal drift is 0.1 °C/yr. These numbers were the same for all the probes we tested.

### 2.2 NRC testing apparatus and procedures

At NRC we tested the sensors' temperature stability and repeatability using water calibration bath (long-term stability) and a triple point of water cell (short-term stability, repeatability) combined with the thermal cycling over the sensors' working temperature range in the annealing furnace. The Sensors' response while in the annealing furnace was monitored with uncalibrated standard platinum resistance thermometer since we were only interested in the relative changes.

## 3. RESULTS

During the initial testing of the low-temperature optical gauge sensors we discovered that they drift at the triple point of water an equivalent of +0.014 °C/min and at temperatures above 175 °C, an equivalent of -0.003 °C/min even after prolonged exposure to the given temperature (over 1 h). In addition, wavelength shift at the triple point of water was observed to change by up to an equivalent of 0.2 °C upon power cycling the optical gauge amplifier.

Based on our initial feedback, Fibos refined their temperature sensors and optical gauge amplifiers eliminating or minimizing most of the issues. The modifications made by manufacturer included:

- Changing the fiber Bragg grating coating – previously, the sensors drifted at the triple point of water possibly due to tension generated between the coating and the fiber;
- Improved sheath sealing - improvements in the sealing of the fibers in the sheaths to reduce exposure to humidity;
- Better wavelength calibration (±0.3 pm at 1550 nm or, equivalently, ±0.03 °C at the triple point of water);
- Improvements to the wavelength tuning algorithm in optical gauge amplifiers.

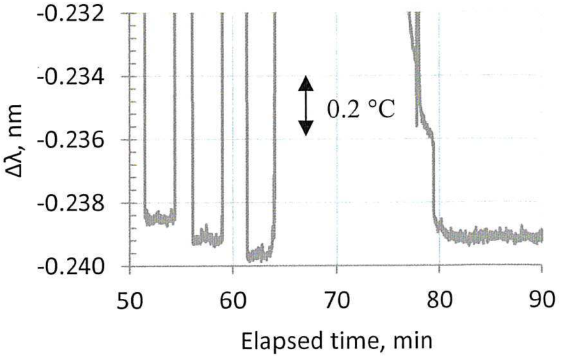

**Fig. 2.** *Triple point of water stability of probe Q5 (¼" OD, Pyrex) after 13 h at 175 °C in the annealing furnace (201 h total time in the furnace). The breaks indicate power cycling of the optical gauge amplifier FIB18010033 (first 3 cycles before 65 min mark) and withdrawing the probe (past 70 min mark);*

With these improvements in place we were able to achieve better reproducibility at the triple point of water (see Fig. 2 - 4), although, further work on the optical gauge amplifier is required to reach manufacturer's accuracy goal of 1 pm (equivalent of 0.1 °C) or better. In particular, laser wavelength (optical gauge amplifier) reproducibility upon power cycling should be further improved and the drift at temperatures above 150 °C should be addressed.

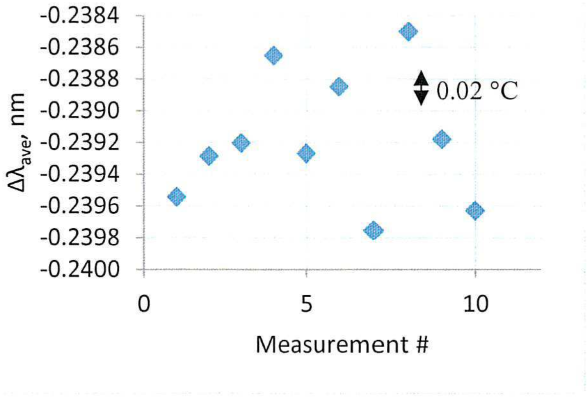

**Fig. 3.** *1 min averages of all the power cycling data in Fig.1 including the ones not shown (note that $\sigma_{1min} \leq 0.01$ °C).*

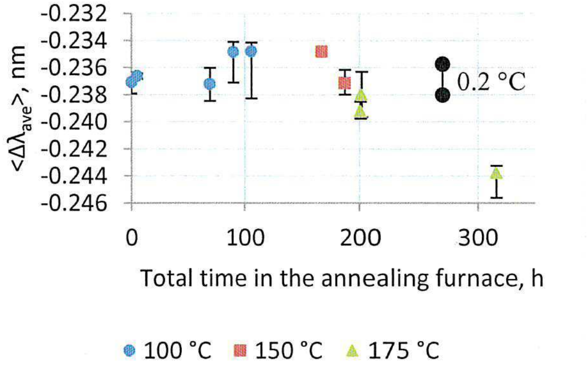

**Fig. 4.** *Average of all the power cycling values for probe Q5 annealed consecutively in the annealing furnace at 100 °C, 150 °C and 175 °C as a function of total time in the furnace, error bars correspond to minimum and maximum values in Fig. 3. Notice the drift in the average wavelength shift at the triple point of water after a prolonged exposure to 175 °C.*

## 4. CONCLUSIONS

We have tested temperature stability and repeatability of Fibos low-temperature fiber Bragg grating thermometers and found that manufacturer's goal of 0.1 °C accuracy is not achieved yet. Based on our findings, significant improvements to the low-temperature sensors were made by the manufacturer eliminating the drift at the triple point of water and improving the signal reproducibility. The knowledge learned during this test was used to build a photonic thermometer characterization setup at NRC – a capability nonexistent at NRC before.

## ACKNOWLEDGEMENTS

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