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Solutions for humidity and temperature monitoring in the Silicon Tracking System of the Compressed Baryonic Matter experiment: sensors, and testing

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The Compressed Baryonic Matter (CBM) is one of the leading scientific programs of the future Facility for Anti-proton and Ion Research (FAIR), Darmstadt, Germany. The Silicon Tracking System (STS) will be the core detector system of CBM for charged-particle reconstruction and momentum measurement. It will be placed inside a 1T·m magnet and kept at an ambient temperature of about $-10\,^{\circ}$C to mitigate radiation-induced bulk current in the silicon sensors. Due to the conditions inside the STS reliable monitoring and control of humidity and temperature is required to avoid icing or water condensation on the electronics or silicon sensors. Fiber Optic Sensors (FOS) based on Fiber Bragg Grating (FBG) have proven to be suitable environmental monitoring sensors due to their resilience to the magnetic field, ionizing radiation, and miniature size. In this contribution, we introduce two different approaches to implement relative humidity (RH) and temperature FBG FOS. The first approach is based on inscribing both RH and temperature FBG into one fiber and the second one features two separate FBGs arrays. In both cases, the RH-sensitive FBGs are coated with polyimide.

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1. The Silicon Tracking System - temperature and humidity monitoring

The design of the Silicon Tracking System (STS) [1] defines the requirements for ambient sensors. Apart from resilience to the radiation and magnetic field, the dew point and ambient temperature define the sensor's working range. The minimum temperature inside the STS is defined by the coolant (3M NOVEC 649) temperature of −40 °C used for cooling the Front-End Electronics (FEE), whereas the targeted ambient temperature is −10 °C. To avoid icing or condensation and any potential damage to the detector, the ambient parameters like Relative Humidity (RH) or temperature need to be monitored. In order to mitigate the risk, the dew point will be kept at levels below −45 °C.

Three different sensor technologies will be measuring the ambient parameters: Fiber Bragg Grating (FBG) sensors, commercially available capacitive sensors (SHT series), and a sniffing system based on trace humidity sensors. Several sniffing points inside the detector enclosure will measure trace humidity and serve as a reference for the two other measurement technologies. Moreover, the sniffing system is going to be the base for the interlock system, which will take action in case of hazardous humidity levels. In this contribution, we summarize efforts to choose, design, and characterize RH FBG sensors.

2. Fiber Bragg Grating sensors

Fiber Bragg Grating is a selective filter that reflects the light signal at a certain wavelength named Bragg wavelength (see Figure 1). A bare FBG, inscribed into the fiber core, is sensitive to temperature, and strain.

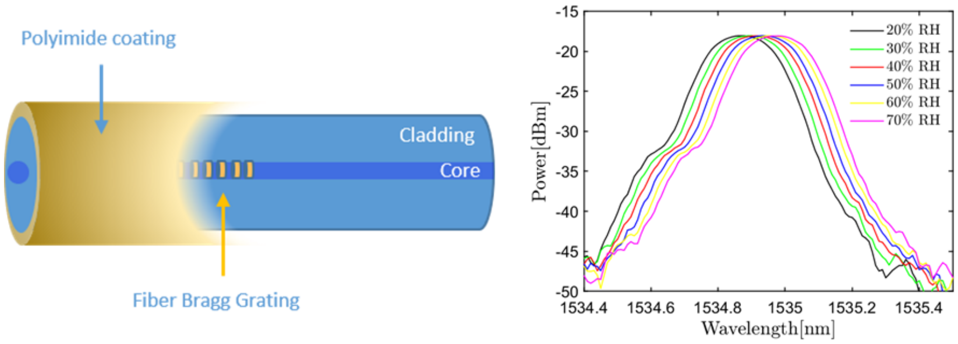

Figure 1: FBG-based RH sensor (left side) and wavelength shift induced by relative humidity change (20% to 70%)

By applying a hygroscopic material (for example polyimide) over the cladding, we can measure RH instead of strain. In this case, the Bragg wavelength shift becomes a superposition of temperature and humidity effects (see equation 1) [2].

$$\frac{\Delta\lambda_B}{\lambda_B} = \Delta T S_T + \Delta RH S_{RH} \tag{1}$$

where λ_B is the Bragg wavelength, S_T is the temperature sensitivity and S_{RH} is the relative humidity sensitivity.

In order to measure RH, it is crucial to have precise temperature readouts in the vicinity of the coated FBG. Otherwise, the actual RH readout may be dominated by uncertainty or just the inaccurate temperature measurement.

3. Results

Two different designs of FOS were tested – 5 sensors in an array (a multiplexed version was produced by Technica Optical Components) and a single RH sensor combined with a temperature sensor (hygrometer was produced by AOS Electronics). The polyimide coating was 15 μm thick for the hygrometer and 4x5 μm for the array. Both kinds of sensors were characterized in terms of sensitivity to temperature ($-20\,^{\circ}$C to $30\,^{\circ}$C, see Figure 2) and humidity (10% to 80%, see Figure 3), time response, hysteresis, and repeatability.

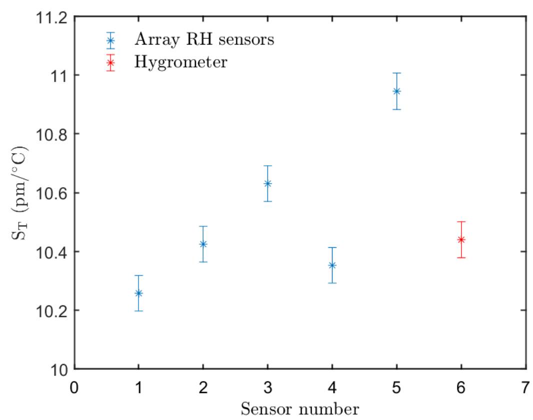

Figure 2: Sensors temperature sensitivity S_T

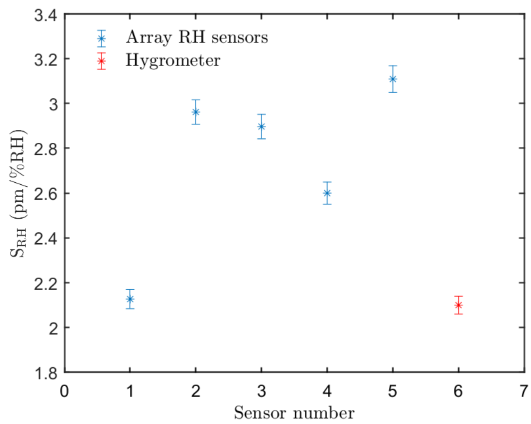

Figure 3: Sensors humidity sensitivity S_{RH}

The average temperature sensitivity S_T value for the array is $10.25 \pm 0.02\,\frac{\text{pm}}{^{\circ}\text{C}}$ and for the hygrometer $10.87 \pm 0.02\,\frac{\text{pm}}{^{\circ}\text{C}}$ (see Figure 2). On the other hand, the thicker layer of polyimide coating results in higher RH sensitivity S_{RH} for sensors 1–5, enabling more precise RH measurements with the array. The average S_{RH} value for the array is $2.77 \pm 0.03\,\frac{\text{pm}}{\%\text{RH}}$ and for the hygrometer $2.09 \pm 0.02\,\frac{\text{pm}}{\%\text{RH}}$ (see Figure 3).

To evaluate the time response all sensors were subjected to the humidity change from 10% to 80%. The array sensors have a longer response time (described as a time to reach 63% of the final RH $\tau_{63} = 10$ min) than the hygrometer ($\tau_{63} = 6$ min), which is also related to the coating thickness. A thicker coating of more than 20 μm leads to increasing time response and humidity sensitivity [3]. The hygrometer's uncertainty is around 1%, whereas for the array on average around 2.5%.

4. Conclusions

The hygrometer shows generally a better performance (time response, hysteresis, repeatability) than the sensors in the array. Dew points down to $-70\,^{\circ}\mathrm{C}$ will be further tested with the thermal demonstrator, which simulates final STS ambient conditions. Due to the sensor's characteristic, it will not measure accurately below 1% RH. Nevertheless, the main features that make the sensor a viable solution are radiation hardness and repeatability. It is going to provide a valuable insight into the detector's environment conditions throughout its lifetime. In addition, sensors' readouts will ensure safe operation of the detector.

References

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