Solutions for humidity and temperature monitoring in the Silicon Tracking System of the CBM experiment: Sensors, Testing and DCS integration

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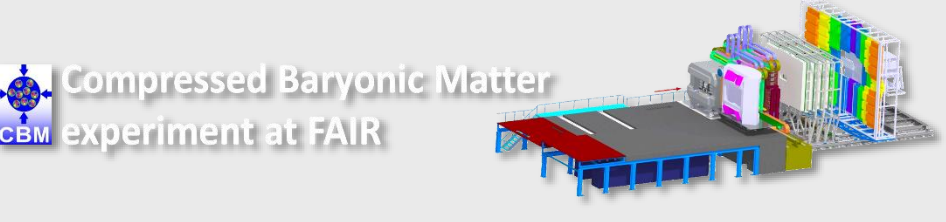


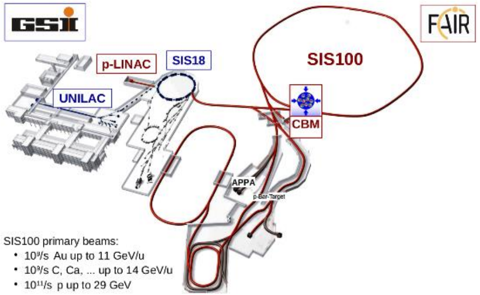
Abstract

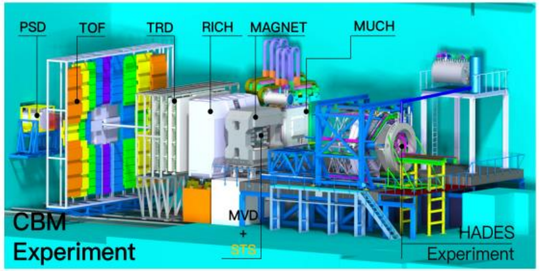
The Compressed Baryonic Matter (CBM) is one of the core experiments at the future Facility for Anti-proton and Ion Research (FAIR), Darmstadt, Germany. The Silicon Tracking System (STS) is a central detector system of CBM, placed inside a 1Tm magnet and the operation temperature is set to -10°C to mitigate low radiation-induced bulk current in the silicon sensors.

Due to the conditions inside the STS an efficient temperature and humidity monitoring and control are required to avoid icing or water condensation on the electronics or silicon sensors. The most important properties of a suitable sensor candidate are resilience to the magnetic field, ionizing radiation tolerance and a fairly small size.

In this contribution, we introduce two different approaches to implement relative humidity (RH) and temperature Fiber Bragg Grating Fiber Optic Sensors (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.

The Compressed Baryonic Matter experiment is one of the scientific pillars of the Facility for Antiproton and Ion Research (FAIR), Darmstadt, Germany. It aims to explore the QCD diagram in the region of high baryon densities using high-energy nucleus-nucleus collisions.



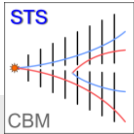


CBM subsystems' requirements:

- Fast & radiation hard detectors
- Free-streaming DAQ
- 4D tracking (space, time)
- Online event reconstruction and selection
- Tracking acceptance: $2.5^\circ < \theta_{Lab} < 25^\circ$

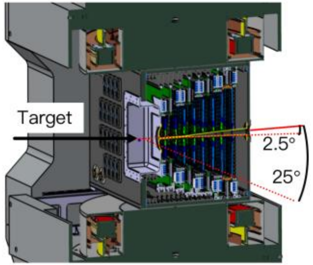
The GSI division of the CBM experiment is responsible for:

- Design, development and construction of the Silicon Tracking System (STS) which is the key detector of the CBM experiment

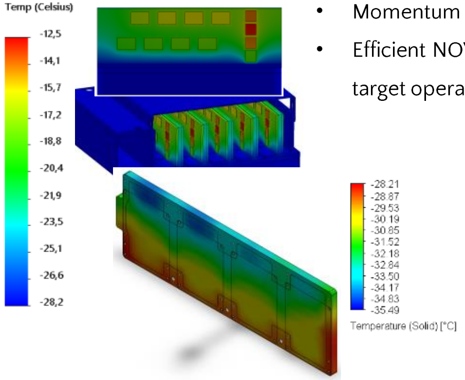


The Silicon Tracking System – design and sensor choice considerations

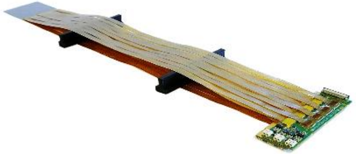
The Silicon Tracking System design and requirements



- 8 tracking stations populated with 876 modules comprising of Front End Electronics, microcables and double-sided microstrip silicon sensors
- The subsystem is placed inside a 1Tm magnet
- Radiation tolerance of the system – it needs to withstand up to 10^{14} 1 MeV n_{eq} cm^{2}
- High tracking efficiency ~97% for p > 1 GeV/c
- Momentum resolution <2%
- Efficient NOVEC-based cooling system to ensure the target operation temperature of -10°C



FEE temperatures [1]

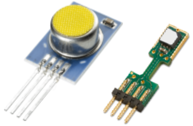


An example of the module

Ambient conditions and sensor requirements

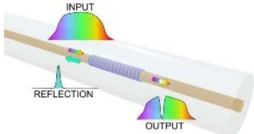
In order to reduce the leakage current associated with the radiation damaged, the target operation temperature of the STS should be around -10°C. The relative humidity values need to be measured to ensure safety of the detector, especially scenarios in which frost point/dew point get close to the ambient temperature. An ideal sensor needs to meet a number of requirements, most importantly it needs to be radiation tolerant and insensitive to magnetic field.

Most common RH sensors



HYT221[2] SHT85[3]

Industrial capacitive sensors



Fiber Optic Sensors[4]

Chilled Mirror Hygrometers/Sniffing systems

With use of all three technologies we will monitor relative humidity/frost point and temperature during STS operation. Nevertheless, each of the mentioned technologies has its drawbacks and it's suitable for use in a certain conditions.

Fiber Bragg Grating Fiber Optic Sensors (FBG FOS) design and state of art

FBG FOS main features:

- Immunity to electromagnetic interference
- Radiation hardness depends on the chosen materials
- Absence of electronic circuitry
- Multiplexing capabilities (depending on the wavelength readouts capabilities)
- Reliable readouts over long distances >100m

What is a Fiber Bragg Grating?

A selective filter which reflects the light signal at certain wavelength named as Bragg wavelength

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

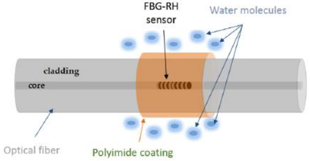
Λ – grating pitch, n_{eff} – effective refractive index

State of Art

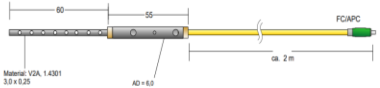
FBG sensors are sensitive to strain and temperature changes. By applying a thin layer of hygroscopic polymer on the grating it's possible to develop a relative humidity sensor. Furthermore, it was shown in the literature that Bragg wavelength shift is a superposition of temperature and humidity effects.

$$\frac{\Delta\lambda_B}{\lambda_B} = \Delta RHS_T + \Delta TS_{RH}$$

Bragg wavelength shift



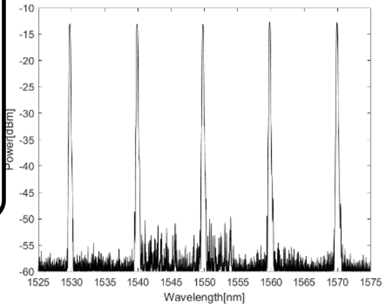
FBG-RH sensor [5]



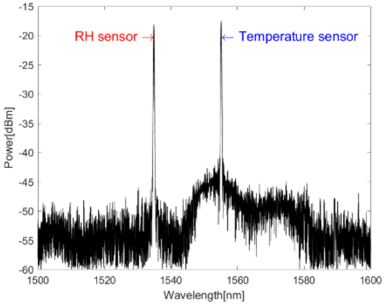
RH FOS packaging design – AOS Dresden
Single RH sensor

Two different designs of FBG FOS were tested – 5 sensors in an array (multiplexed version) and a single RH sensor combined with a temperature sensor for compensation. The polyimide coating was 20μm in both cases.

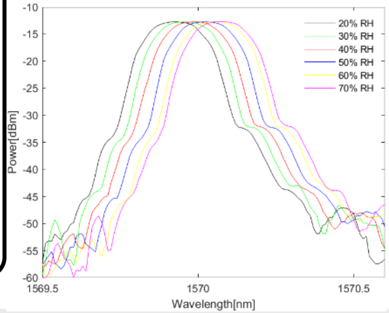
Humidity array (5 sensors)

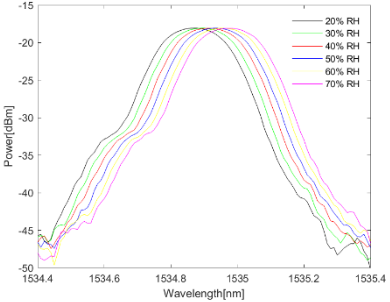


Single RH sensors



Response to humidity change at constant temperatures





Fiber Bragg Grating Fiber Optic Sensors (FBG FOS) testing and results

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RH sensors array (RH1-5)

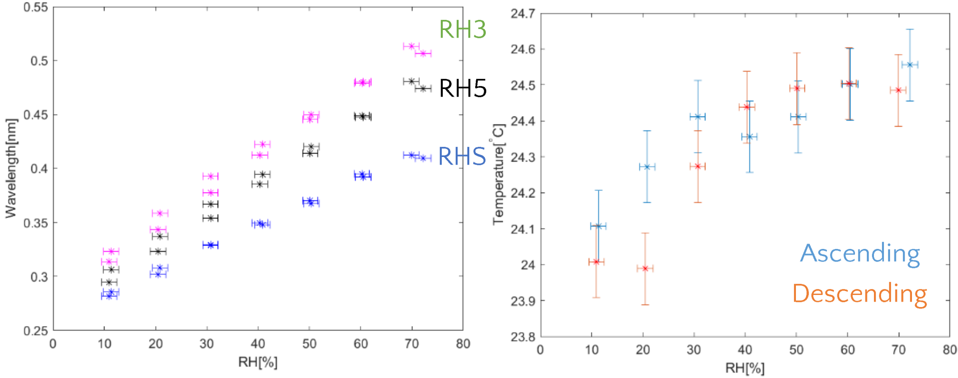
Combined temperature and RH sensors (RHS)

Evaluating sensor performance

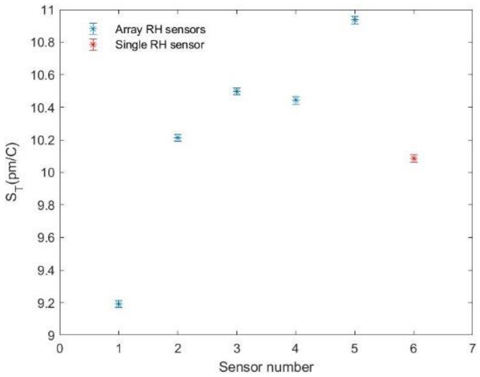
To evaluate FBG FOS's performance we measured the wavelength change at different RH (10-80%) and temperature values(30°C to -20°C). *Time* response, hysteresis and repeatability also play important role in comparing sensors' performance.

- Humidity sensitivity for the array sensors averages around 3pm/%RH in comparison with ~2.1pm/%RH for the single sensor
- Temperature sensitivity for the sensors varies from 9.2pm/°C to 11 pm/°C
- **According to those values it's extremely important to precisely measure temperature (1°C error may lead to 3-5% uncertainty in RH)**
- Hysteresis uncertainty reaches ~2% for the sensors in array and less than 0,5% for the single sensor
- Time response is twice longer for the sensors in the array (10min vs. 5min)

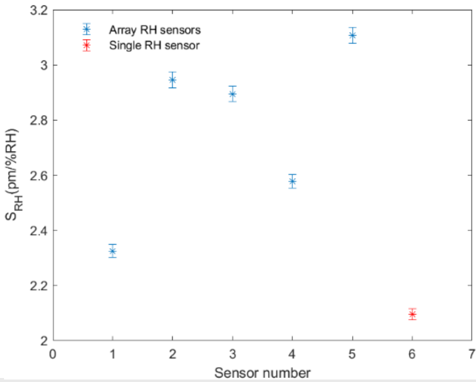
Hysteresis at 25°C



Temperature sensitivity coefficient



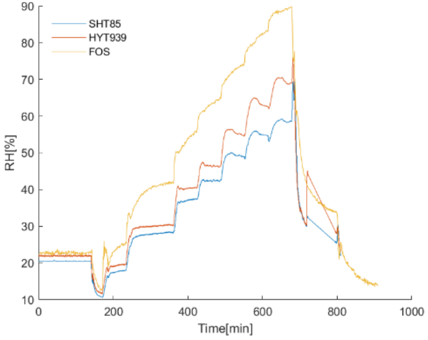
Humidity sensitivity coefficient



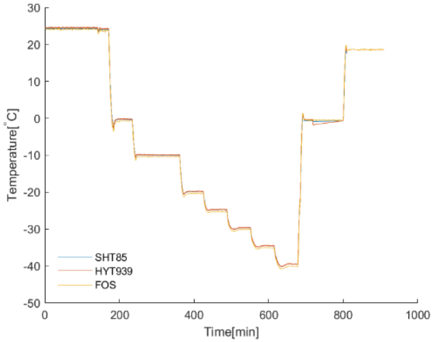
Summary and outlook

Summary

The comparison of FOS, SHT85 and HYT221 measurements down to -40°C can be seen below. FBG sensors show linear response to humidity in the range from 30°C to temperatures slightly below 0°C. At around -20°C humidity sensitivity coefficient rises. Nevertheless, the sensors show significant sensitivity in the tested regime.



Performance check – RH



Performance check – temperature

Both capacitive and fiber optic sensors provide accurate measurements at positive temperatures. In case of temperatures below 0°C and especially lower than -20°C it's extremely difficult to asses the uncertainty and accuracy of the measurements .

Outlook

- In case of capacitive sensors and so-called sniffing system the integration with the hardware interlock is well-established and based on commonly used protocols and modules. On the contrary, a FOS readout needs some additional efforts to employ it in a PLC based safety system
- In order to ensure detector safety and precise dew point measurements we are going to use sniffing system based on quartz or ceramic sensors
- All the mentioned technologies will be tested at low temperatures and humidity values in the thermal demonstrator, which aims to evaluate cooling concept for the final STS

References

1. K. Agarwal et al, Conceptual Design Report of the STS Cooling System, 2018
2. HYT 221 Digital Humidity and Temperature Module Datasheet, IST
3. Sensiron SHT85 datasheet
4. Diego Pugliese et al, Bioresorbable optical fiber Bragg gratings, Optics Letters 2018
5. Gaia Maria Berruti, Radiation tolerant fiber optic humidity sensors for High Energy Physics Applications, CERN-THESIS-2015-321 15/12/2015