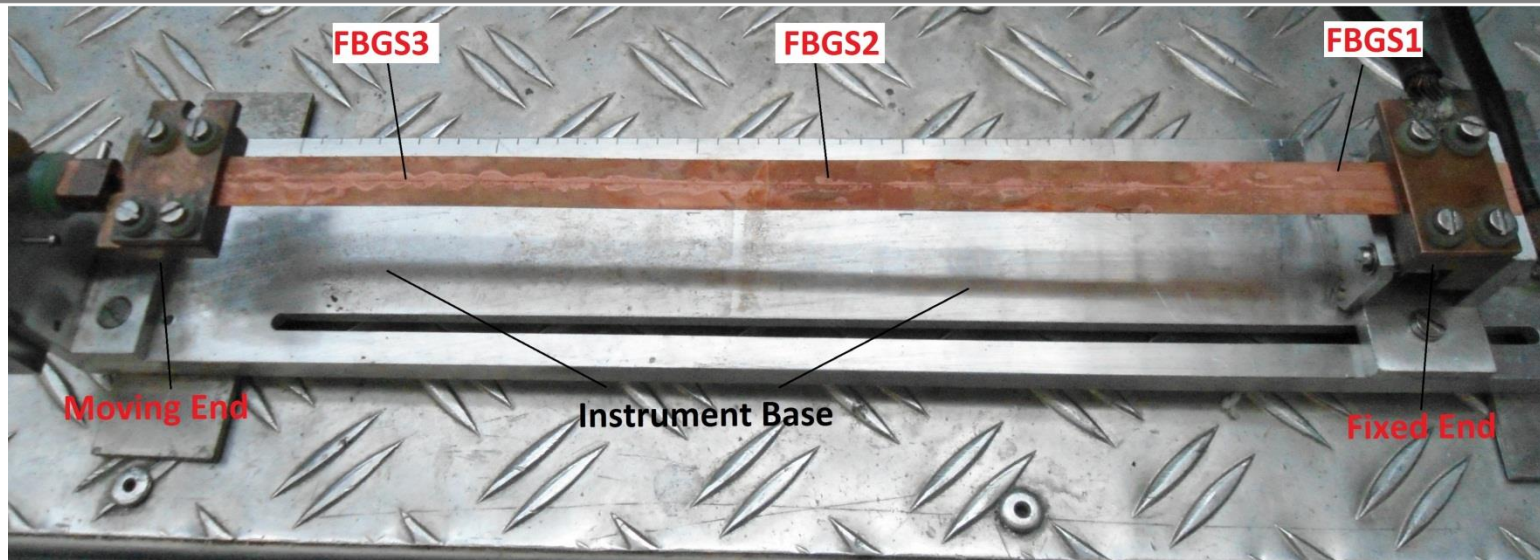


DISTRIBUTED TORSIONAL STRAIN MEASUREMENT USING EMBEDDED FIBER BRAGG GRATINGS ARRAY IN A HTS TAPES.

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IDEAS TO BE SHARED...

- **Motivation**
- **Fiber Bragg Grating (FBG) Sensors**
- **Fabrication of single FBG sensor for strain measurement in HTS tape**
- **Fabrication of Wavelength division multiplexed FBG sensor for strain measurement in HTS tape**
- **Thermal expansion estimation in HTS tapes using FBG**
- **Results of torsional strain measurement.**
- **Further work.**
- **Conclusion**

2G-HTS Roebel conductors in rotating machines

HTS 4 Fusion Conductor Workshop, Karlsruhe, 26 – 27 May 2011
Marijn Oomen, Siemens AG, CT T DE HW4

Unknown

How to make strand and cable insulation

VI-curve at $<1\mu\text{V}/\text{cm}$ → losses, especially at $\approx 30\text{K}$, $\approx 2\text{T}$

Mechanical properties of Roebel-cable winding

Next steps
(planned)

Produce test coils with 25m cables: 0.9 x 1.5m, 5 turns

Test these at 77K, then at 30K, with 2T field applied locally

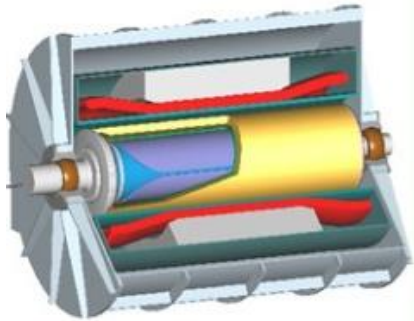
AC loss evaluation → need for strand insulation

Mechanical tests and FEM calculations

Roebel-cable coil in future rotating test rig ??

What are the common possible mechanical issues...???

POSSIBLE COMMON MECHANICAL ISSUES...



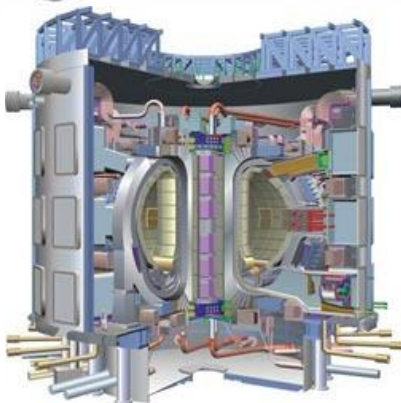
Motors

**Axial Strain
Transverse tension**



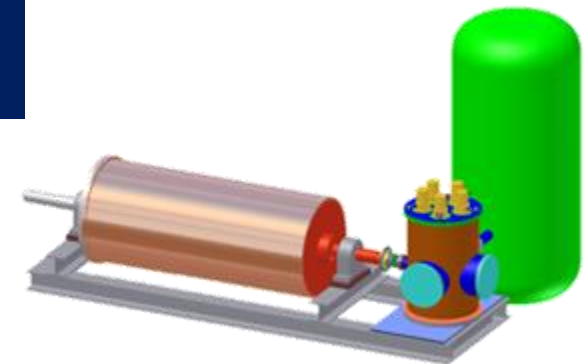
Cables

**Axial Strain
Bending in the hard direction**



**Axial Strain
Transverse compressive stress
Transverse tension stress**

Magnets **Generator**



LIMITING VALUES – TO AVOID DAMAGE



**Degradation of I_C capacity
Crack formation**

ANALYTICAL SOLUTION

Assumptions

Very Difficult for composite structures

Takes away the analysis from practical

Measurement system is necessary to validate the Analysis.

EXPERIMENTAL

Measurement Techniques???
Strain Gauge, Extensometer, X-ray diffraction

Complex
Not for real scenario

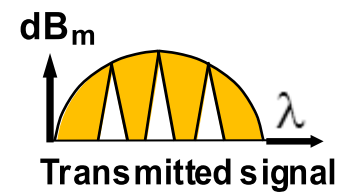
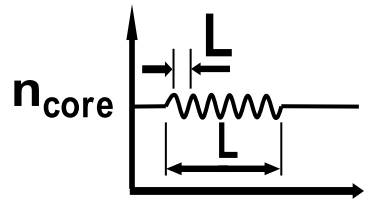
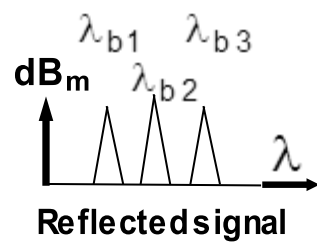
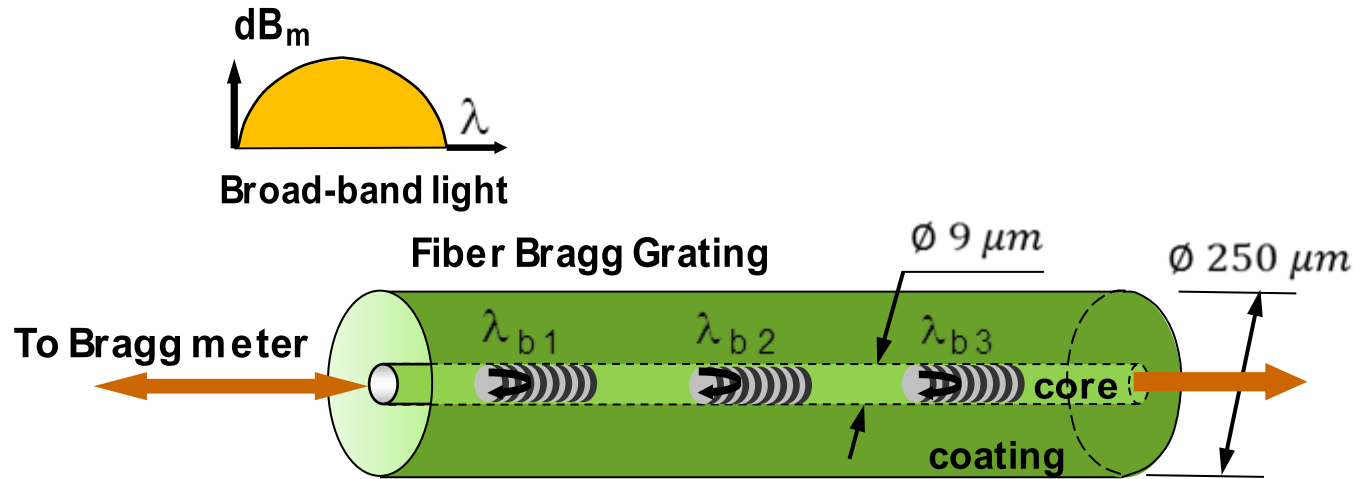
Practical measurement system to understanding the real scenario.

A system to measure local / distributed strain values

- **Define Limiting values :- for given boundary condition**
- **During production & Fabrication :- Tension, bending, Twisting...**
- **In real time operating conditions**
- **Monitoring at regular intervals :- degrading, crack ...**

Fiber Bragg gratings could be a choice

FBG SENSOR PRINCIPLE



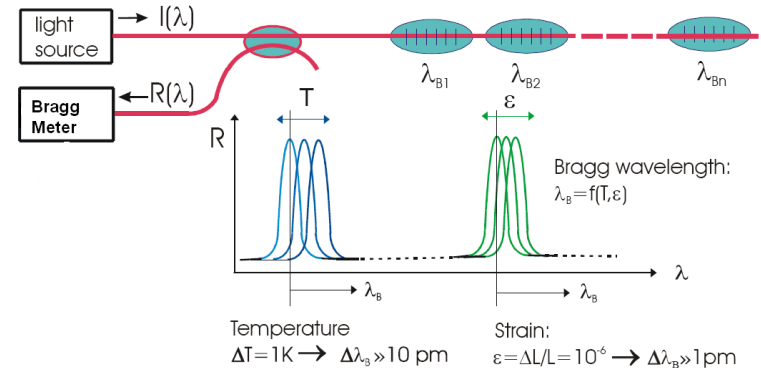
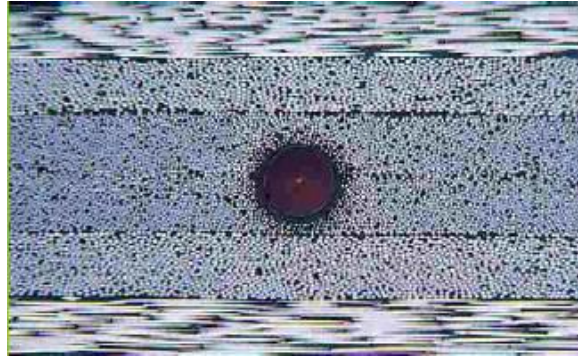
$$\Delta\lambda_b = 2nL(\{1 - (n^2/2)[P_{12} - \nu(P_{11} + P_{12})]\})\varepsilon + [\alpha + (dn/dT)/n]\Delta T$$

Strain

Temperature

ADVANTAGES OF FBG`S

Small in size & less weight



Easy intergration in layered materials

Multiplexing possibilities

Measure Multiparameters

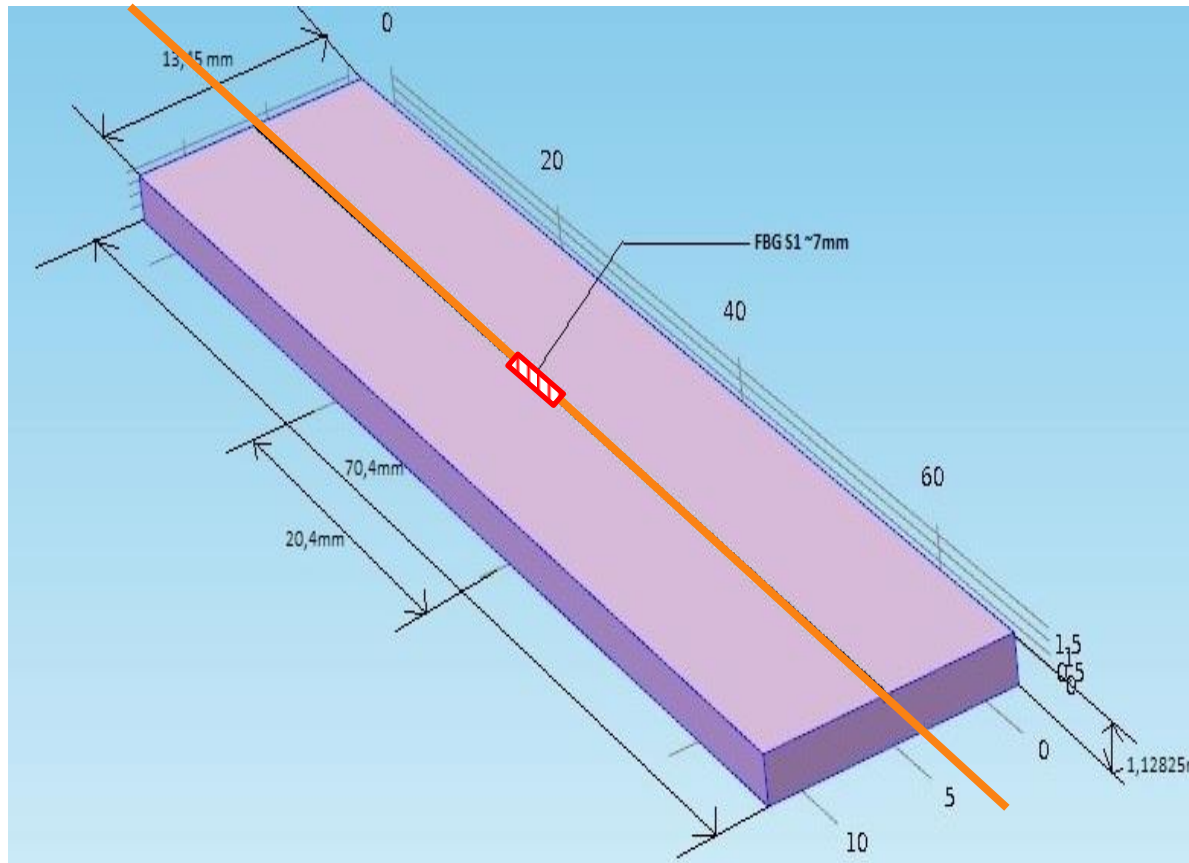
Temperature(quench detection), strain, current distribution in layers??? ...

J. Schwartz, Florida State University, USA

No electro-magnetic intereference

Long life-time ~ 20 years

SINGLE FBG INTEGRATION

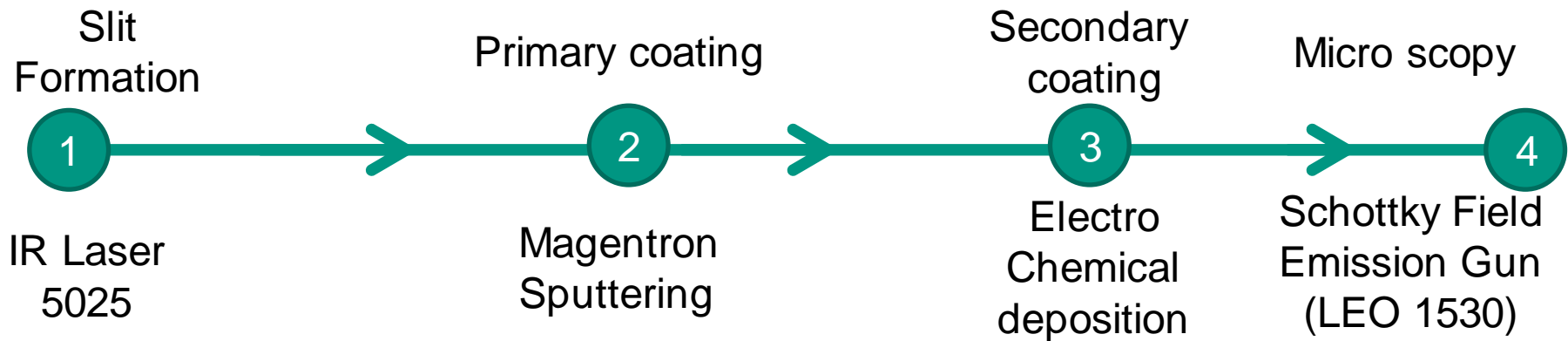
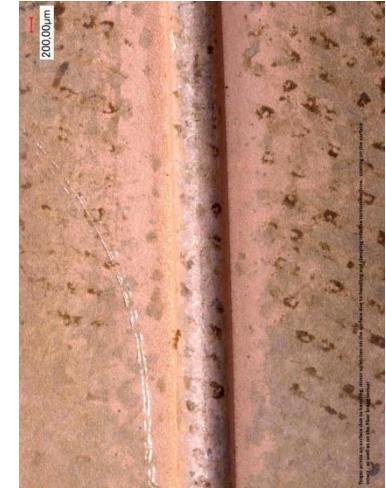
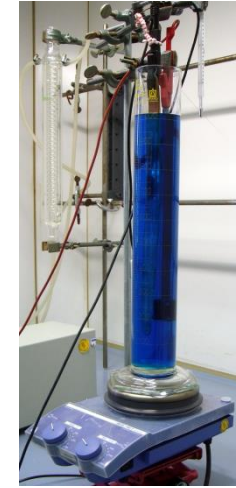
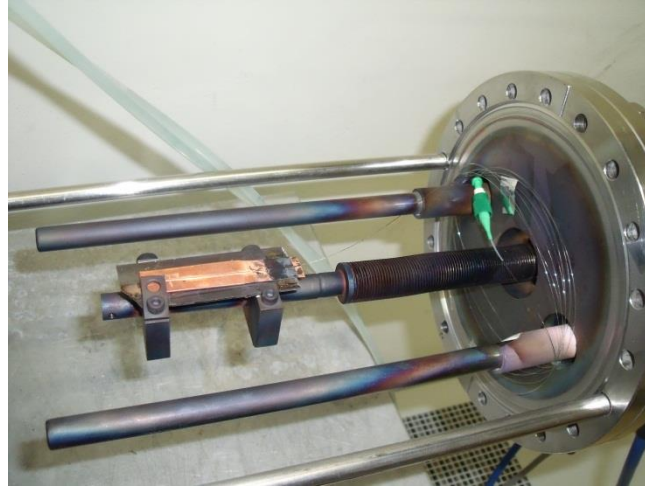
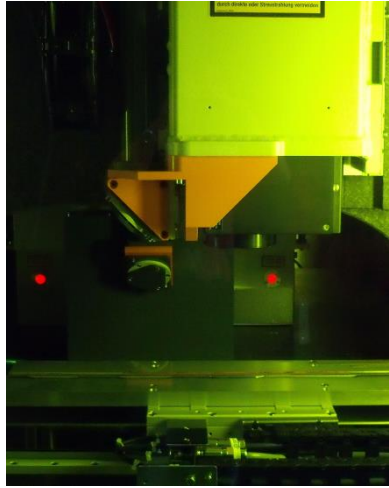


FBG Sensor Specification

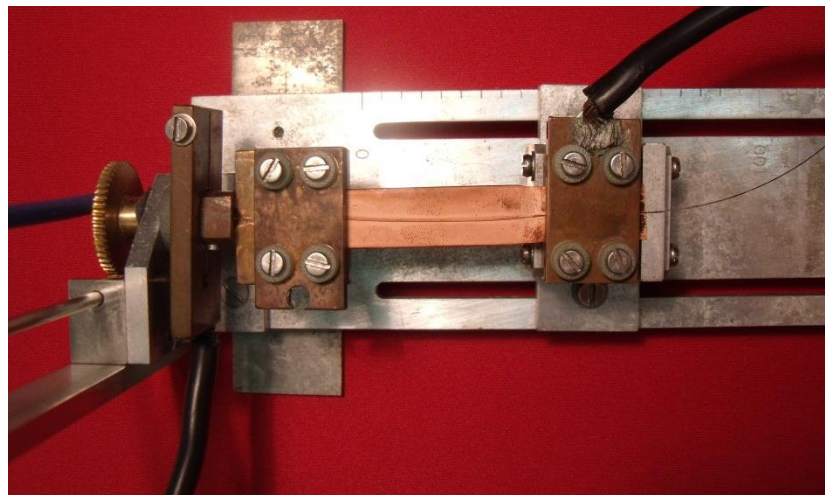
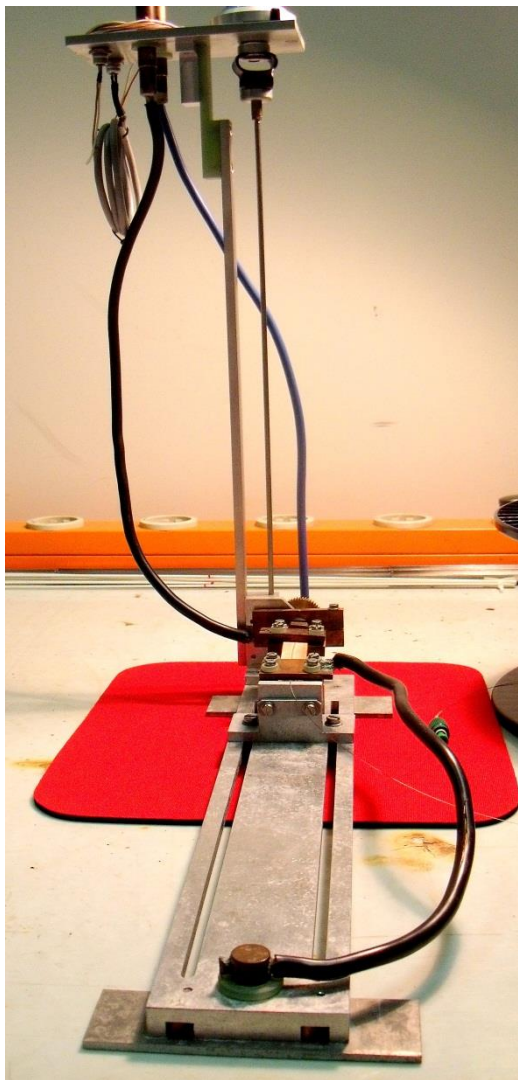


Single mode Fiber : SMF 28
Recoating : Ormocer
Bragg wavelength : 1550 nm
Grating length : 10 mm

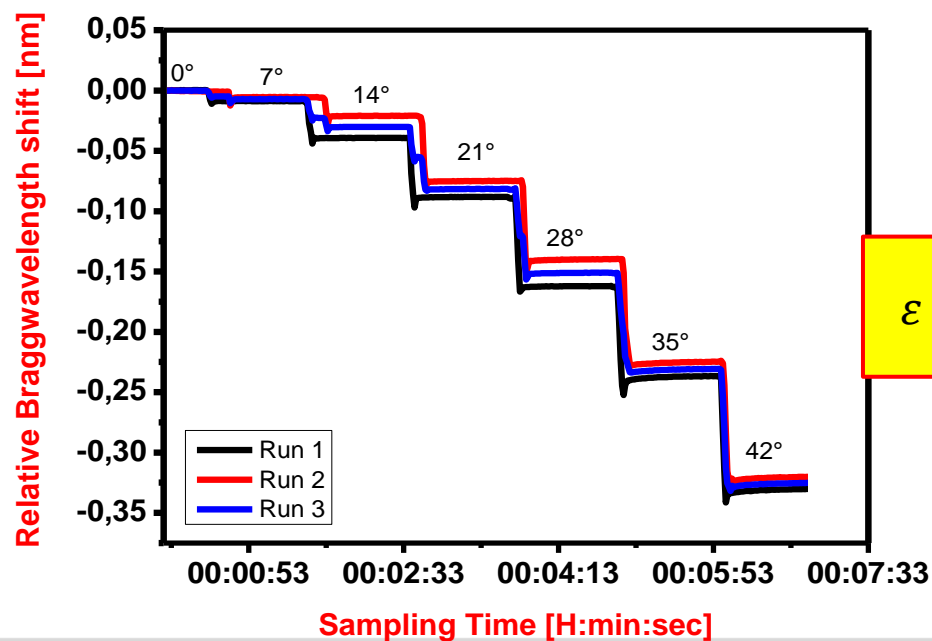
FABRICATION PROCESS :- Single FBG



EXPERIMENT

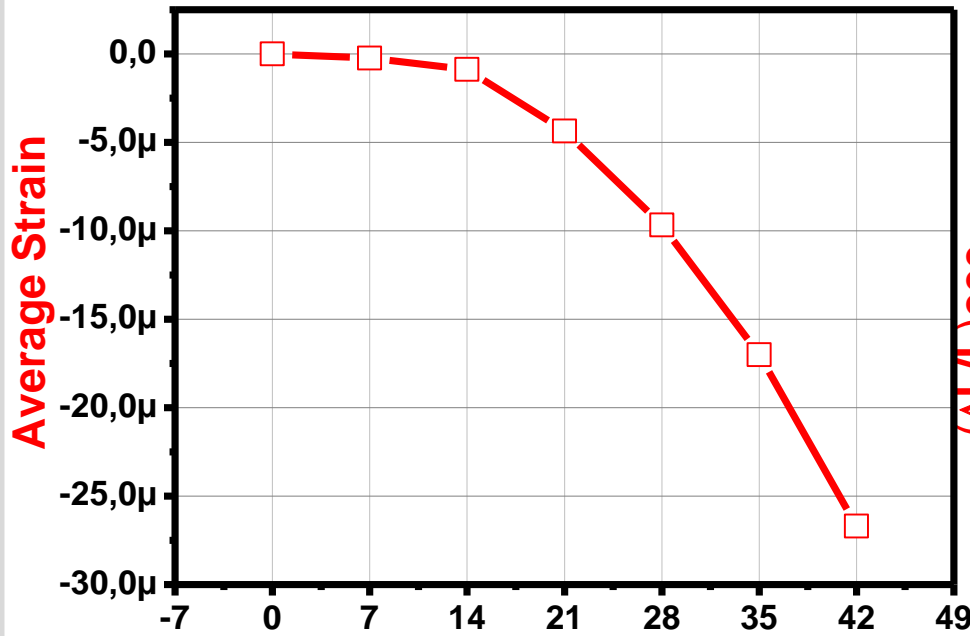


Bragg wavelength
Shift to strain
conversion



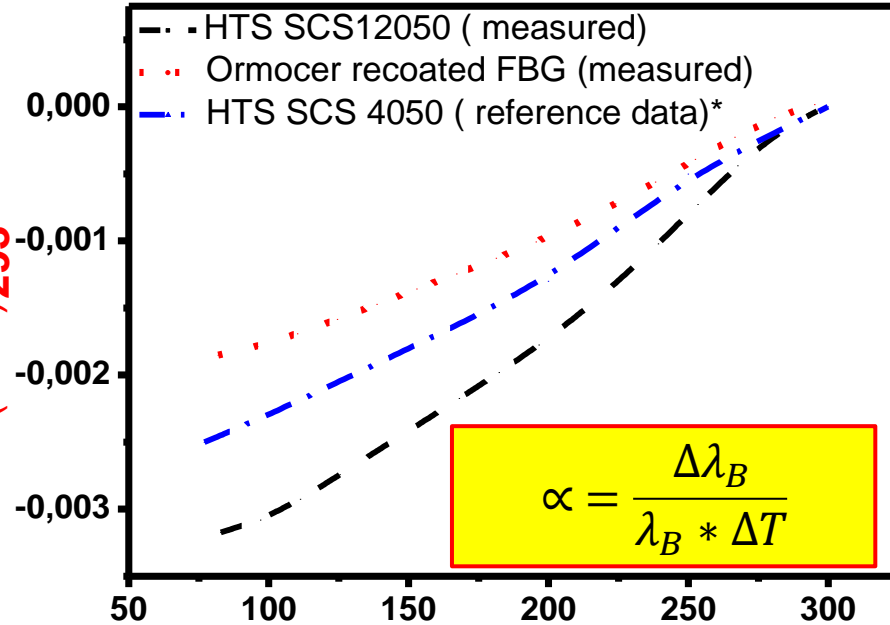
$$\varepsilon = \frac{\Delta\lambda_B}{\lambda_B * (1 - p_e)}$$

MECHANICAL CHARACTERISTICS



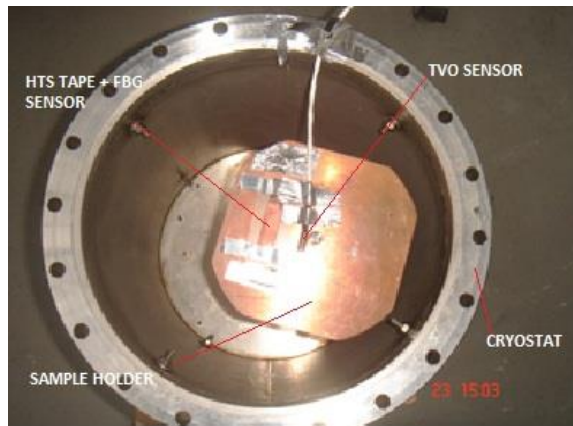
Torsion Angle [°]

Torsional strain



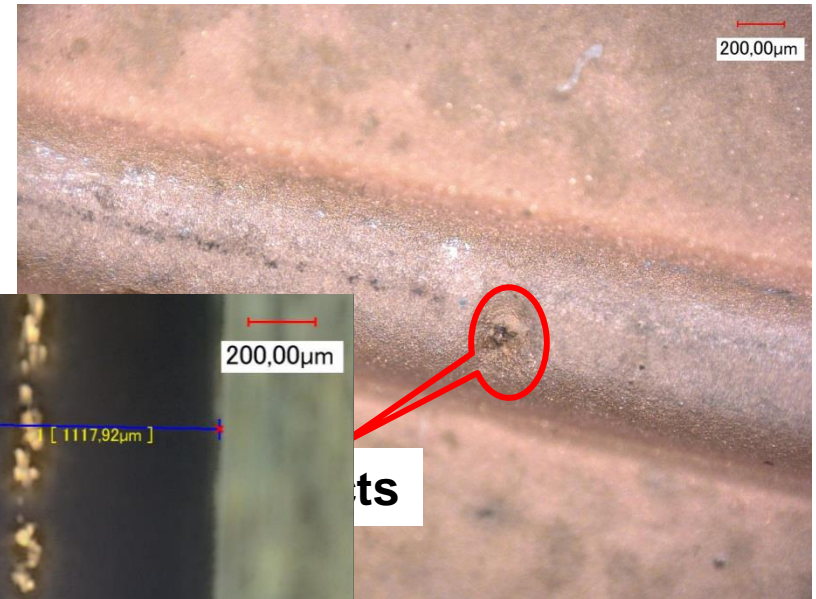
Temperature [K]

Thermal Expansion

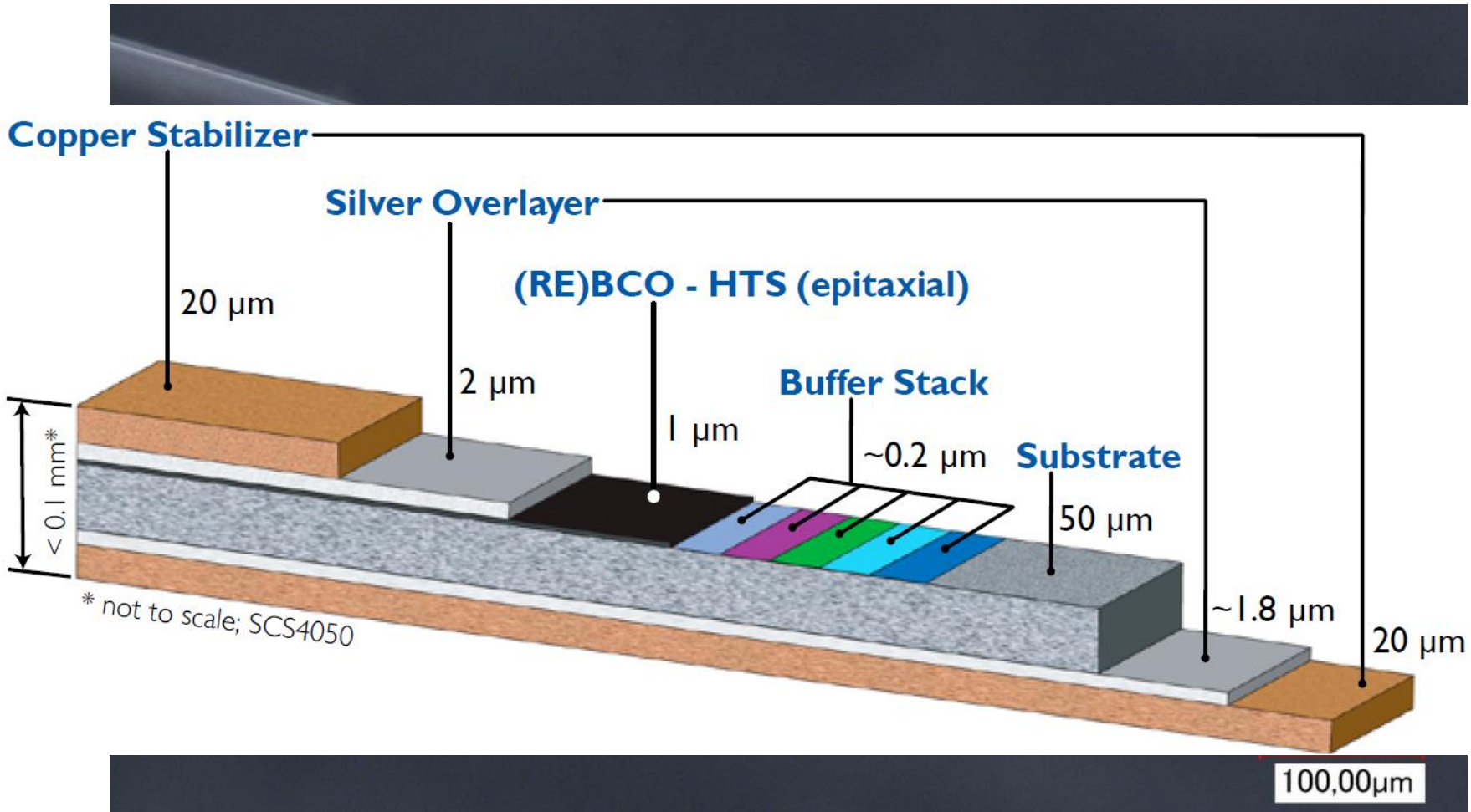


(*) *IEEE Transactions on Applied Superconductivity* **19**, No. 3, Part 2, 2218 - 2222 (2009)

MICROSCOPIC INVESTIGATION

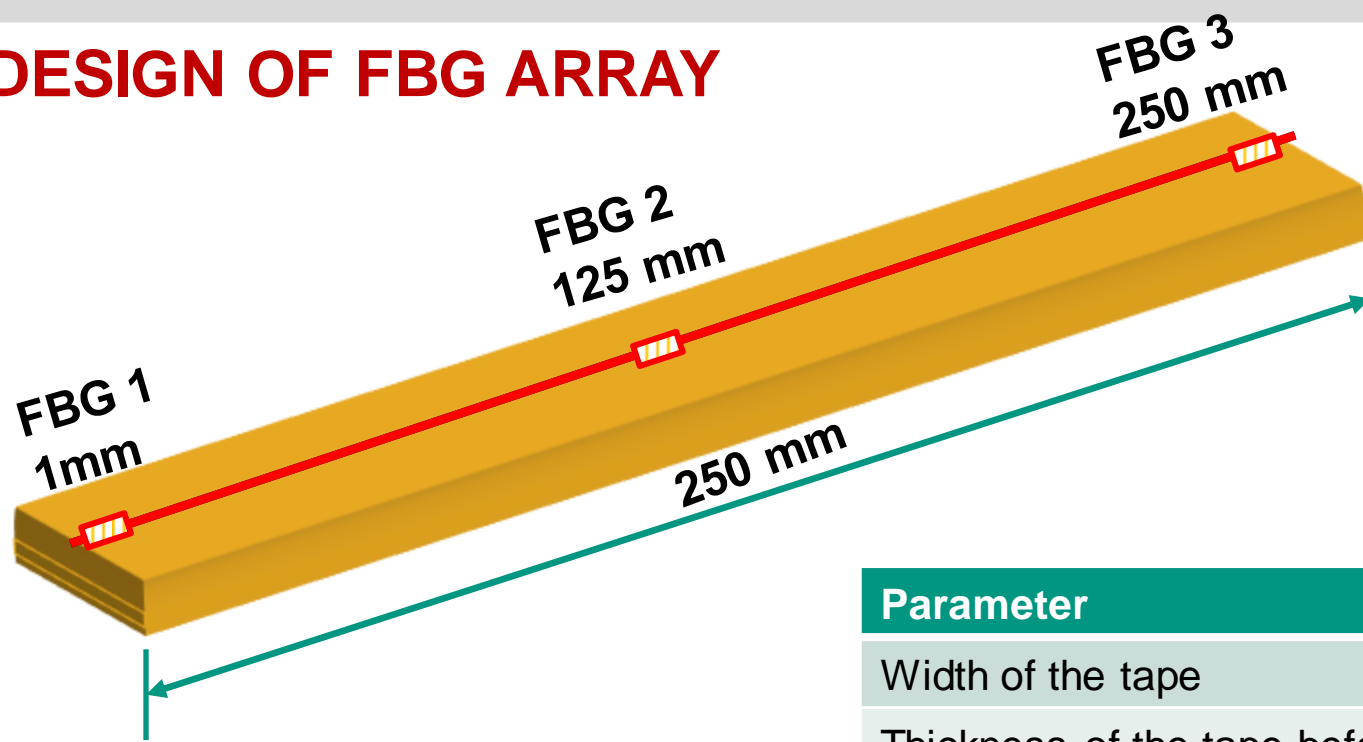


INTEGRATION OF 3 FBG ARRAY

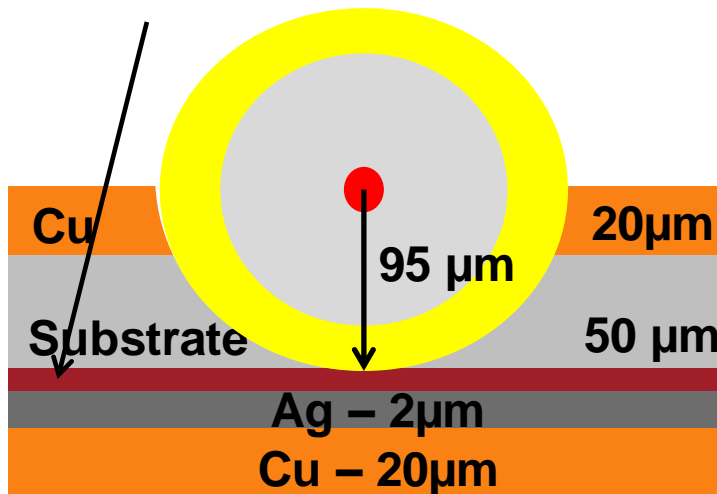


100 μm for SF12100

DESIGN OF FBG ARRAY

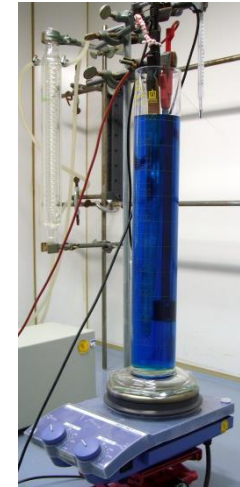
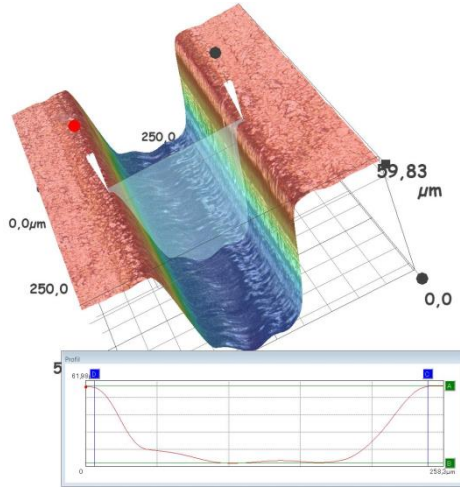
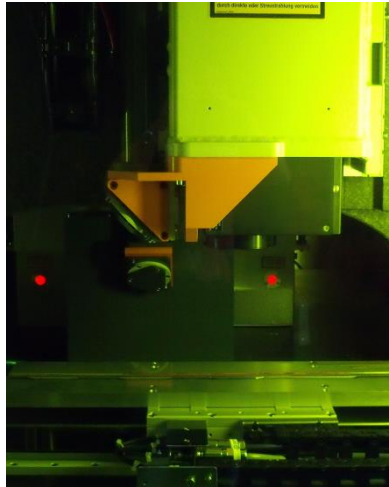


(RE)BCO -1 μm



Parameter	Specification
Width of the tape	12 mm
Thickness of the tape before coating	100 μm
Thickness of the tape after coating	300 μm
Length of the grating element	10 mm
Sensor wavelength (nm)	1539,1549,1559
Locations of the sensor (mm)	30, 130, 230
Depth of the laser slit	59.83 μm
Width of the laser slit	250 μm

THREE SENSOR FABRICATION STEPS



Slit
Formation

Micro
scopy

Primary
coating

Secondary
coating

Micro
scopy

1

2

3

4

5

IR Laser
5025

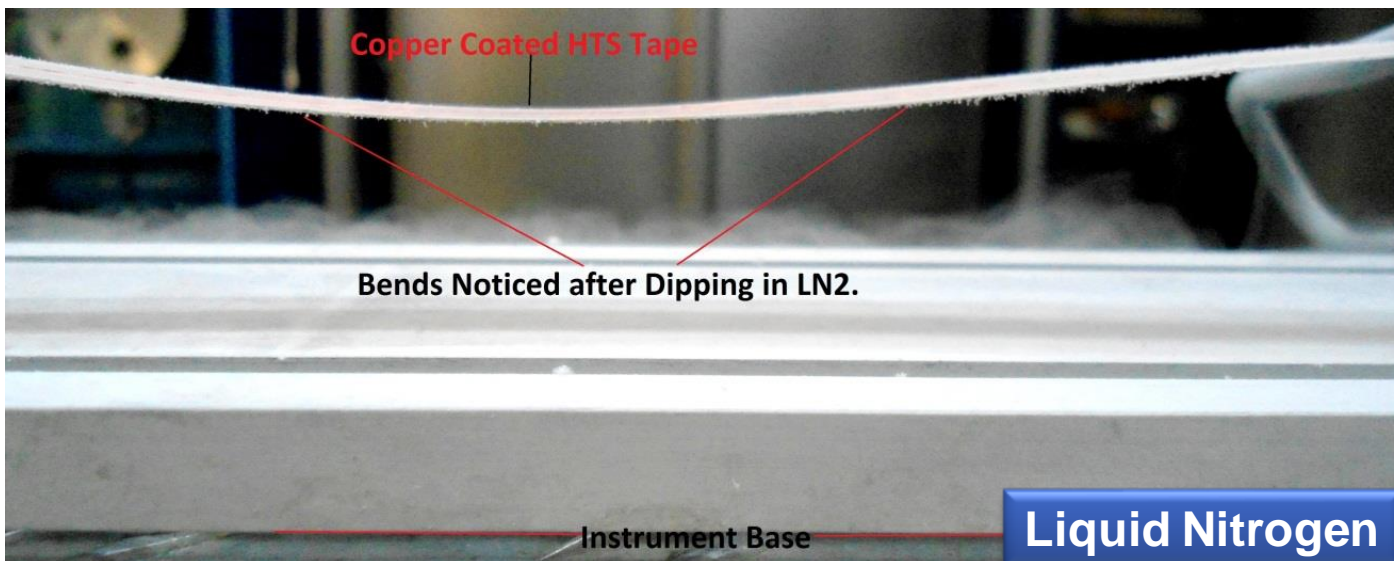
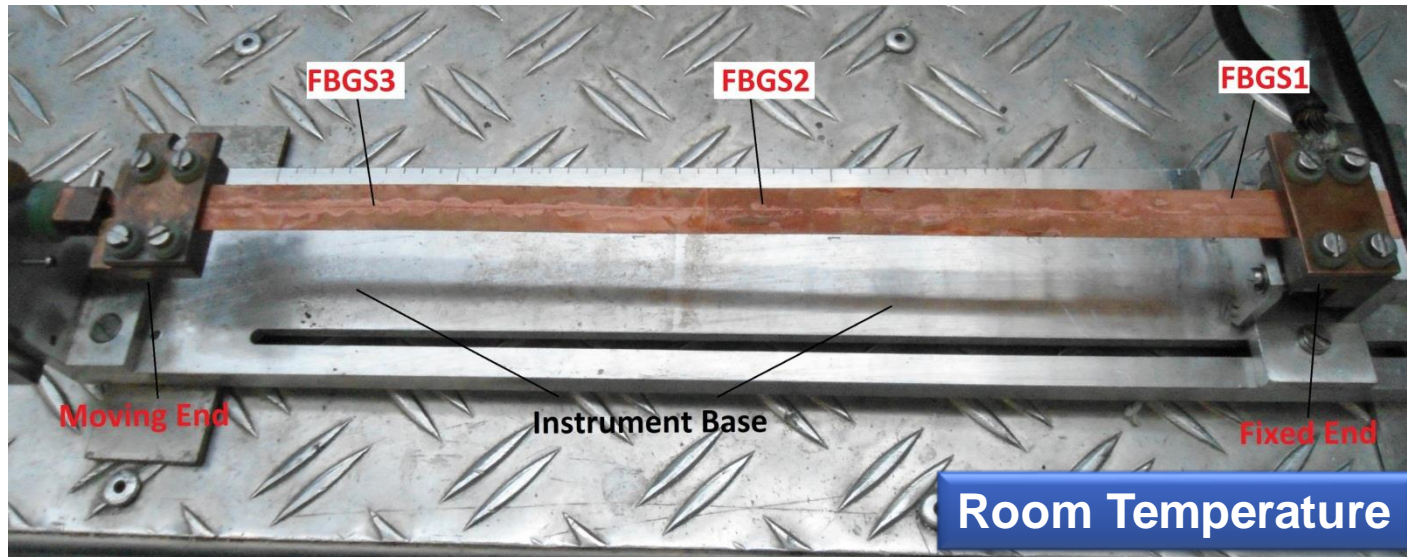
Schottky Field
Emission Gun
(LEO 1530)

Magnetron
Sputtering

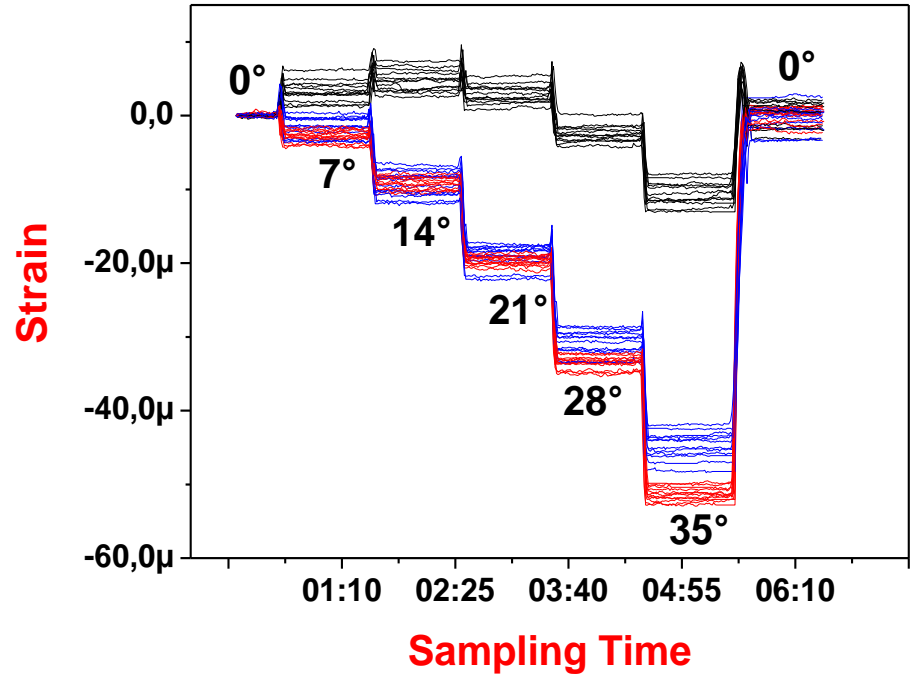
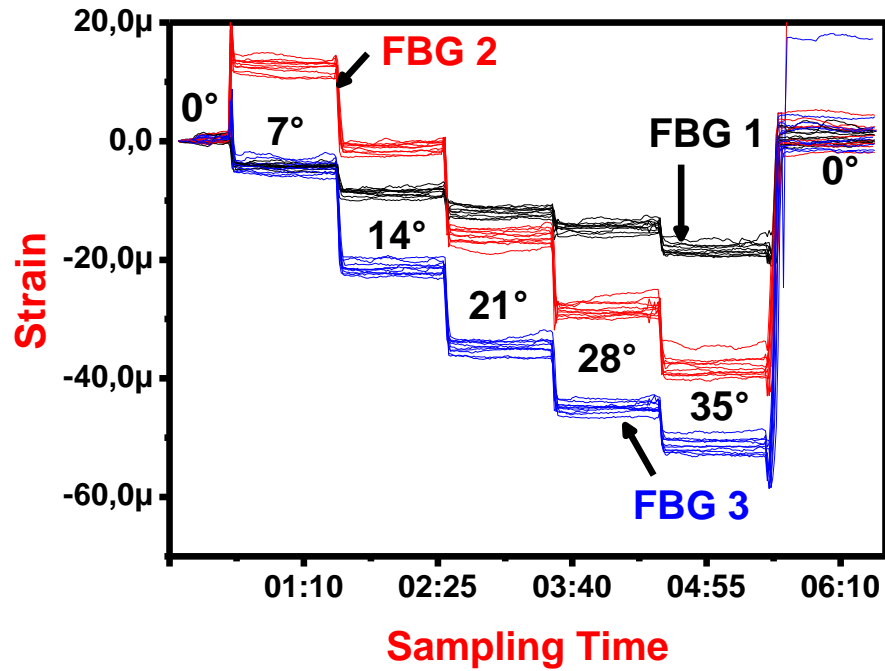
Electro
Chemical
deposition

Sliver paste

EXPERIMENTS



THREE FBG ARRAY RESPONSE



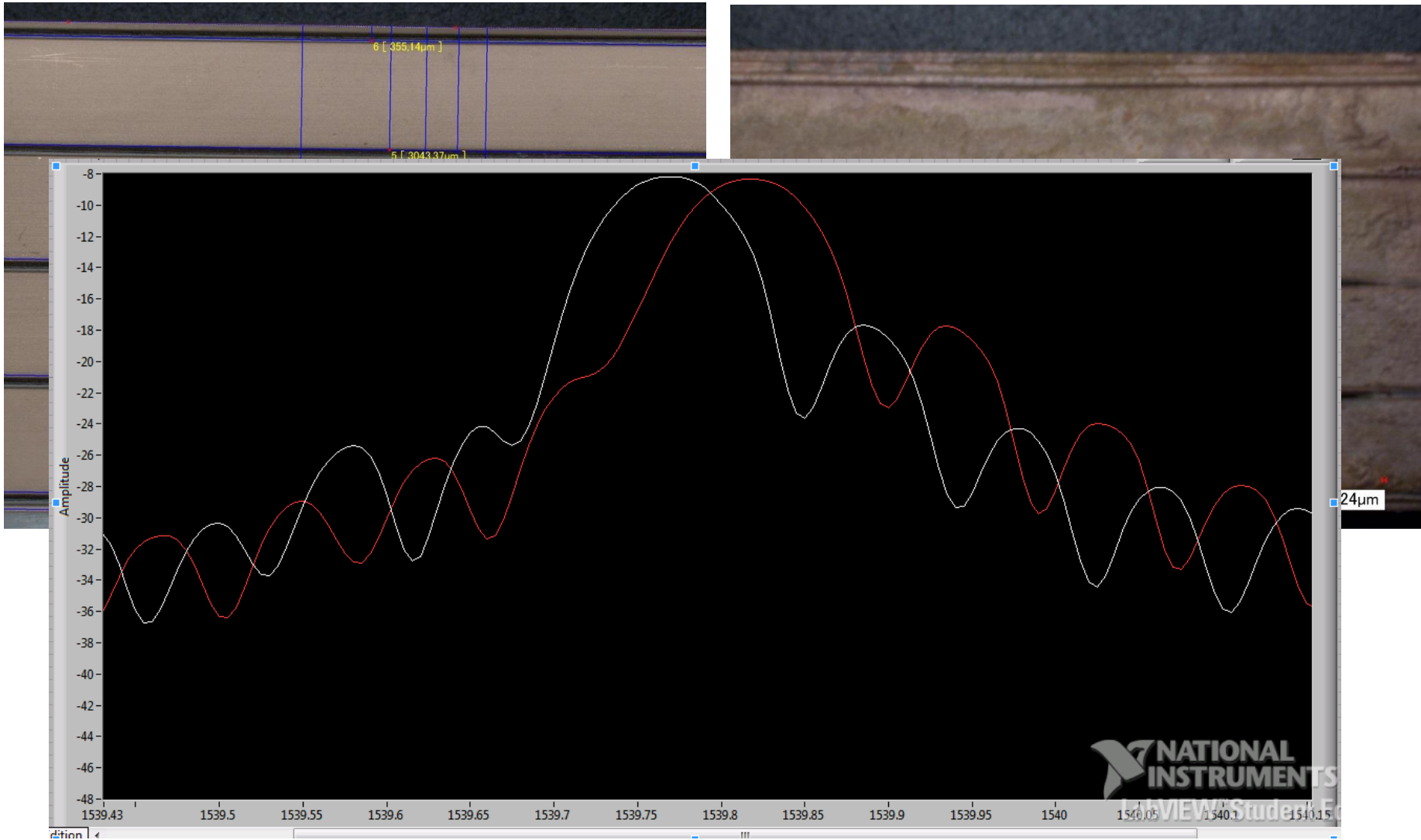
Room Temperature

77 K

Sensor was not damaged

Highly repetable measurements

FURTHER WORK ...



CONCLUSION

SUMMARY

- **Single FBG sensor was integrated in HTS tape and the performance was Satisfactory.**
- **Three FBG array was integrated and tested. The performance has to be investigated in detail.**

Further work

- **Reduction of FBG dimension for better integration**
- **Better primary coating approach**
- **Study mechanical characteristics in various FBG configuration**

Final Goal

- **Develop a FBG based integrated sensing system to measure multiple parameters.**
- **System that can be used as a Structural Health Monitoring in HTS based magnets**

THANK YOU FOR YOUR ATTENTION

I_c MEASUREMENT

