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Selecting FBG coatings for optical fiber sensing of Quench in high temperature superconductor coils

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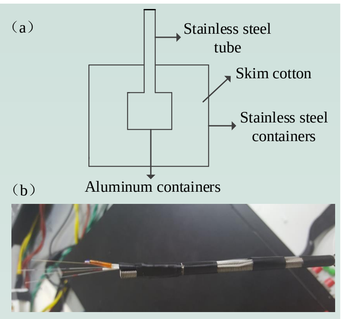
Introduction

- Quench detection in HTS coils is still a big challenge and has not been adequately solved for commercial application, because of the complexity and contingency of the quench.
- Fiber Bragg grating (FBG) temperature sensors may offer potential as a cryogenic temperature sensor for quench detection.
- There are numerous reports on the low-temperature characteristics of FBG temperature sensors [1-7] and monitor system based on FBG [8-11].
- However, most of the research focuses on the improvement of the temperature sensitivity of sensors, the most cost-effective and practical FBG type for HTS coil quench detection has not been proposed yet.
- In order to the obtain the most cost-effective and practical FBG type for HTS coil quench detection, in this work:
  - We measured the thermal cycle (77-293 K) for bare (silica) FBG, acrylic coated, and polyimide coated FBG provided by MOI to compare the effects of different coatings on the sensors.
  - Three thermal cycles of six samples were carried out to study the effects of different fabrication processes on the sensor.
  - We have theoretically predicted the sensor response from 4K to 293K by the coefficients in the literature [1, 2, 12] and compared with the measured temperature response.
  - The measurement of quench induced temperature change in an epoxy potted HTS coil was simulated through fabrication of bare FBG sensor embedded in a 10 mm×2 mm×4 mm epoxy block.

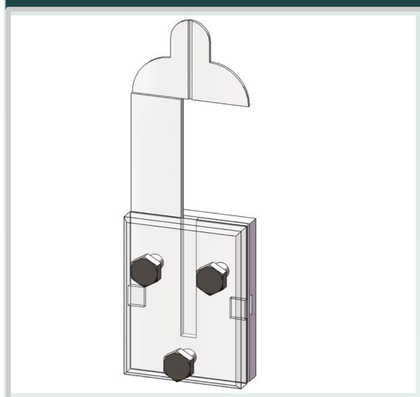
Experimental Method

- Our sensing device consists of a big stainless steel cylinder container and a small aluminum cylindrical container, the small aluminum cylindrical was placed inside the big one and they are separated by skim cotton.
- The whole system is placed in the foam container, and cooling down and warming up of the sample would be done naturally.
- The average temperature rate of cooling down and warming up is 0.012 K/s and 0.01 K/s, respectively. It costs 11 hours for the whole thermal cycle.

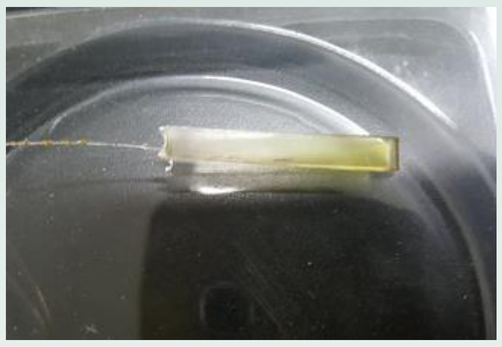


The device for temperature sensing

Sensor Sample Impregnation



Mold for impregnation



Sensor after impregnated

- Bisphenol A epoxy resin was used in our experiment, and the sensor was cured in a high temperature oven for 4 hours by means of the impregnation mold as shown in figure.
- The impregnation process was completely and successful, and the sensor was not damaged

References

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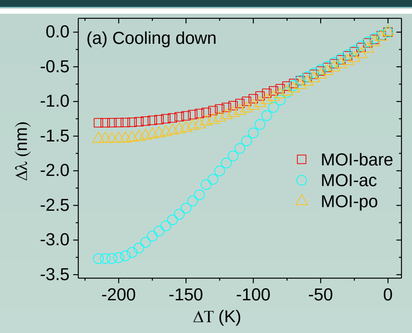
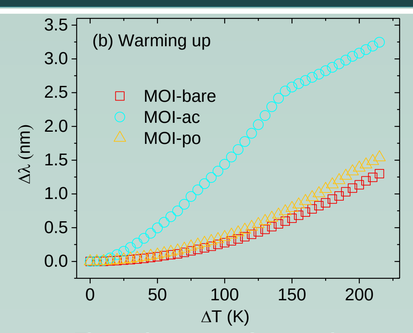
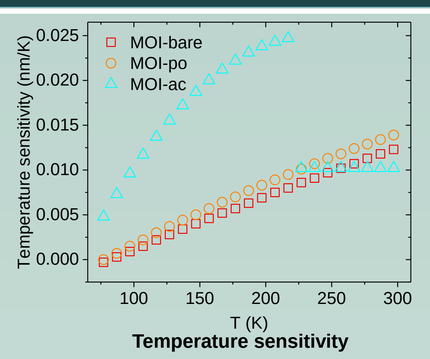
Results-Thermal characteristic of FBG sensors



Thermal response for cooling down

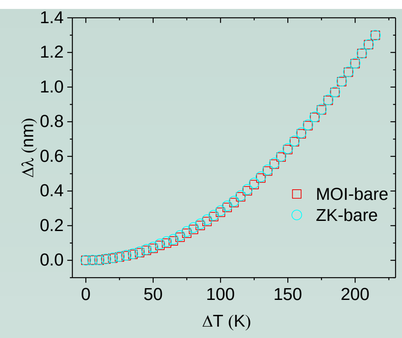


Thermal response for warming up

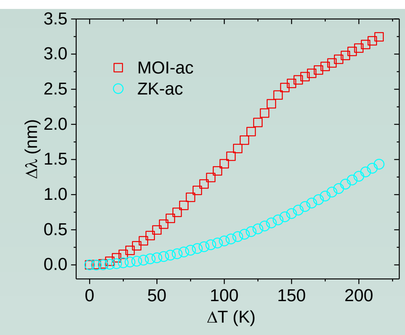


Temperature sensitivity

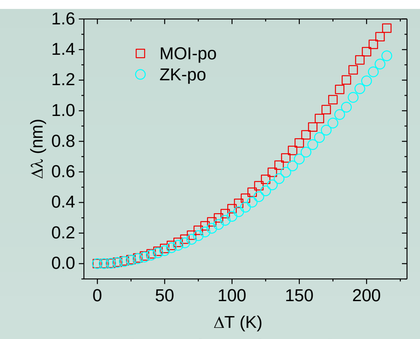
- In the temperature range of 223 K-293 K, the temperature sensitivity of the three sensors is basically the same, and the wavelength almost decreases linearly with temperature decreasing.
- In the temperature range of 77 K-223 K, the temperature sensitivity decreases nonlinearly with temperature decreasing, MOI-ac shows a big difference from other two.



Comparison of bare FBG



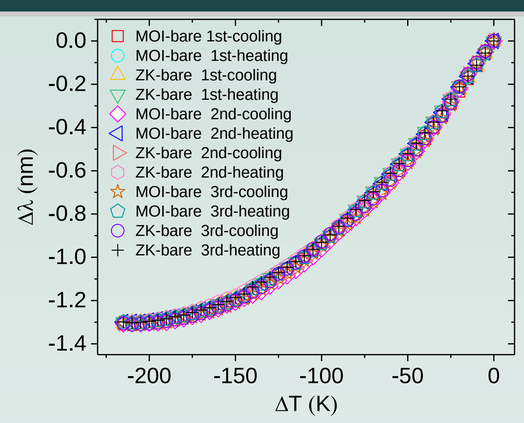
Comparison of ac FBG



Comparison of po FBG

- For bare FBG, the production process does not affect the thermal response of bare FBG.
- For acrylic coated and polyimide coated FBG, the production process has a big influence on the thermal response.

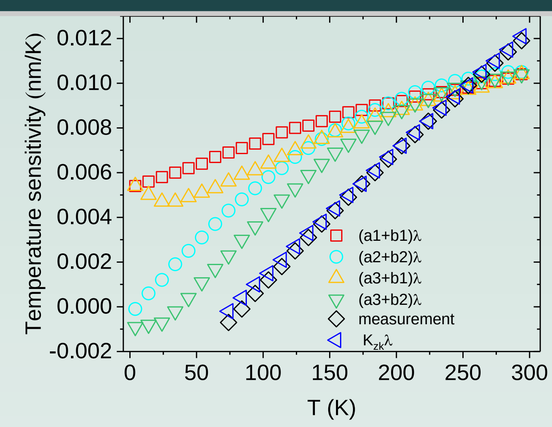
Results-Thermal cycles



Thermal response for cycles

- The characteristics of bare FBG from different companies are basically the same.
- We don't need to calibrate repeatedly in the process of quench detection.
- Bare FBG has a good performance in terms of repeatability and hysteresis.

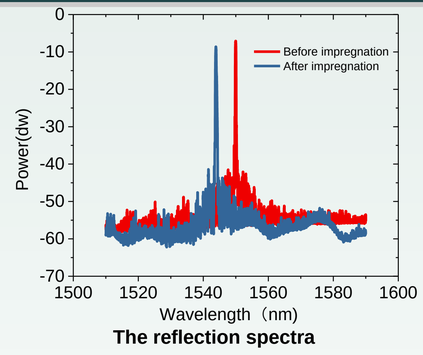
Results-Calculation



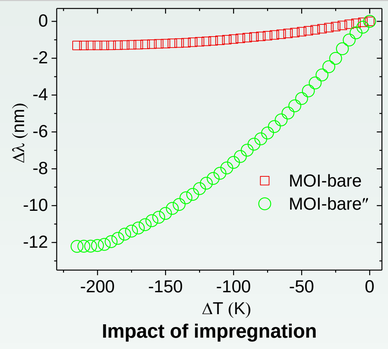
Calculation and measurement

- The TOC dominates the temperature response of FBG.
- The calculated results of all the coefficients in the literature are significantly different from the measured results.
- The temperature response of all the bare FBG sensors could be obtained from TEC+TOC of any one of the selected bare FBG sensor.

Results-Impact of impregnation on FBG sensor



The reflection spectra



Impact of impregnation

- The shape of the spectrum did not change significantly before and after the impregnation, however, the center wavelength of the FBG is drifted due to the stress of the epoxy resin during the curing process.
- The temperature sensitivity of the sensor after impregnation with the epoxy resin is almost one order bigger than that of the FBG before the impregnation

Conclusion

- The temperature response of the samples is nonlinearity at the low temperature and the acrylate coated FBG exhibits a very severe nonlinearity than the others.
- Although the temperature sensitivity of acrylate-coated FBG and polyimide-coated FBG was much higher than bare FBG, the production process has a great impact on the acrylate coated FBG and polyimide coated FBG, which indicates that both of these samples should be calibrated repeatedly in the real case.
- The impact of the production process on the bare FBG is very small, and the bare FBG is superior in terms of repeatability and hysteresis, which means that the use of bare FBG at low temperatures does not require repeated calibration.
- The comparison between the predicted value and the experimental value of bare FBG also shows that as long as we know the experimental data of any one of bare FBG, we can get the temperature response of other bare FBG.
- The bare FBG was embedded in the coil with epoxy resin, not only can be integrated with the coil, but can improve its temperature sensitivity.