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Self-field AC loss measurement of a four-tapes HTS stack using Fiber Bragg Grating sensors

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Background

➢AC loss plays an important role for the application of HTS magnet, therefore, it is necessary to measure the AC loss accurately.
➢The method of transport AC loss measurement can be classified as electric method and calorimetric method, and calorimetric method is preferable for the situation when sample is with complex electromagnetic environment.
➢Fiber Bragg grating sensors shows great advantages for calorimetric method due to their inherent property of immune to electromagnetic field interference and small size compare with the traditional electric temperature sensors.

Content

➢ The transport AC loss of a four-tapes stack was measured by three FBG temperature sensors with different coating and installation method.
➢ The calibration between power and wavelength was realized by a resistance heater.
➢ The FBG sensor measured loss values of the stack are compared with the electric measured results as well as the calculated Norris results.
➢ The effect of magnetic strain on loss measurement was evaluated by comparing the results of with and without thermal insulation.

Measurement Principle

➢ An FBG can work as a temperature sensor by measuring the shift of the central wavelength:

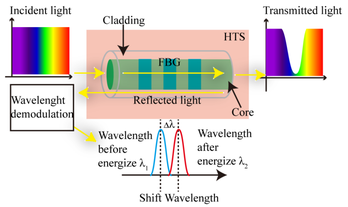
$$\Delta\lambda_B = K_T \cdot \Delta T$$

➢Calorimetric method in this work is based on the measurement of local temperature rise of the sample due to AC loss dissipation using FBG sensors:

$$\Delta T = R_{th} \cdot Q$$

➢ The AC loss can be transferred by the measured FBG wavelength shift:

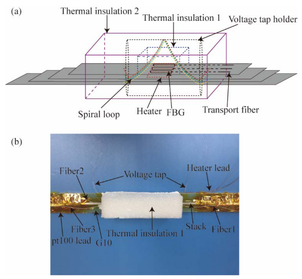
$$Q = K_Q \cdot \Delta\lambda_B$$



Working principle of FBG sensors for AC loss measurement

Experimental Method

➢Four AMSC 8700 wires with 5% Ni-W substrate were used for the stack preparation;
➢Two bare FBG sensors and a silver coated FBG sensor were attached to the top of the stack. One of the bare FBG is single end pasted named FBG2 and the other one is fully bonded named FBG1, the silver coated FBG sensors named FBG3 was also fully bonded;
➢ The relationship between power and wavelength was calibrated by a 120 Ω resistive heater;
➢The sample were insulated by two polystyrene foam thermal insulations to get a measurable small temperature rise.
➢The loss measurement was carried out 67 Hz and 89 Hz, and electric method was to verify the calorimetric methods.



(a) Schematic of the sample arrangement. (b) Photo of the sample with thermal insulation 1.

References

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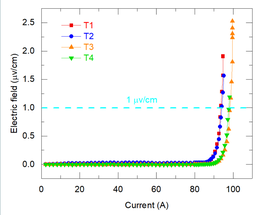
Results

I_c measurement



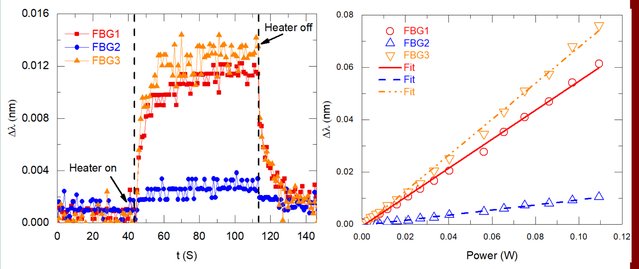
E-I curve of each tape in the stack

	T1	T2	T3	T4	Summation
Self-field I_c (A)	93.7	94.2	98.4	97.8	384

• The I_c of each tape is lower than the self-field I_c of 102 A before sample assembling due to the generated magnetic field of the stack
•The summation of the measured I_c in each tape is 384.01 A can be used for the Norris calculation of the stack.

Results

Calibration between power and wavelength



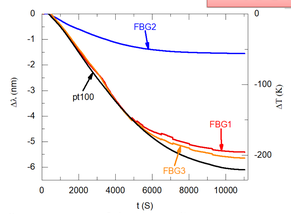
Example of the calibration cycle at the heater input power of 21.2 mW.

Calibration curve of power and wavelength shift for three FBG sensors

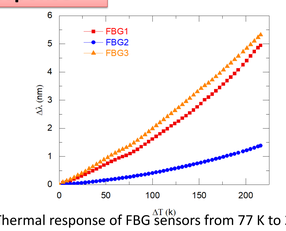
•The determined time constant for the warming up and cooling down of is approximately 5 S and 8 S separately.
•The relationship between heater power and wavelength shift is linear as we expected for all the FBG sensors.
•The slope of FBG1 and FBG3 are similar, and FBG2 shows the lowest slope, the difference of the slope is corresponding to the difference of the temperature sensitivity.

Results

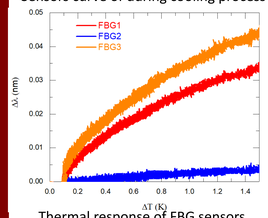
FBG response



Sensors curve of during cooling process



Thermal response of FBG sensors from 77 K to 293 K

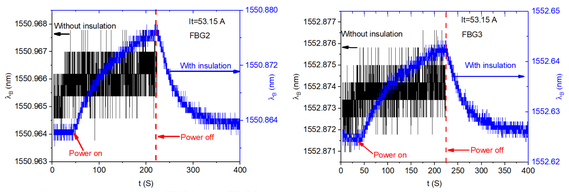


Thermal response of FBG sensors from 77 K to 78.5 K

•The curve trend of FBG sensor agree well with pt100 sensor for cooling process demonstrates that all the FBGs survived during sample preparation
• In the whole temperature range both FBG1 and FBG3 show much higher temperature sensitivity than FBG2.
•In temperature change range of 1.5 K, the wavelength shift are 0.044 nm, 0.034 nm and 0.004 nm respectively for FBG3, FBG1 and FBG2

Results

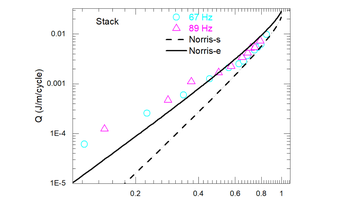
Effect of magnetic strain on loss measurement



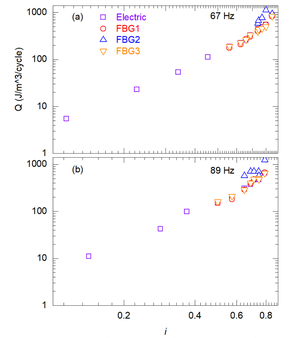
Wavelength shift of FBG1 and FBG3 for the situation with and without thermal insulation at 53.15 A for 89 Hz.

• The effect of magnetic strain on AC loss measurement was studied by comparing the measurement between sample with and without the thermal insulation;
• There is no wavelength shift was observed for both FBG1 and FBG3 in the situation without thermal insulation.
• The magnetic strain has no effect on the loss measurement.

AC loss results



Electric measured AC losses in the stack



Comparison between electric and calorimetric measured transport AC loss: (a) 67 Hz (b) 89 Hz

•The AC loss results at two different frequencies agree well with each other.
• The results of both FBG1 and FBG3 agree well with the electric method results, and the loss sensitivity is approximately 188 W/m^3.
•No response was observed at the lower current for FBG2, and the transferred AC loss of FBG2 at higher current is bigger than FBG1 and FBG3

Conclusion

➢ We measured the self-field AC loss of a four-tapes HTS stack using three FBG sensors with different coating and bonding method.
➢ The fully bonded bare FBG and silver coated FBG shows much higher wavelength shift even in a small temperature rise of 1.5 K compare with bare FBG sensor.
➢The calibration between wavelength shift and power also show that FBG1 and FBG3 have much higher loss sensitivity than FBG2, this is corresponding to the temperature sensitivity difference.
➢ The results of AC loss measured by FBG1 and FBG3 show good agreement with the electric measured results as well the Norris calculated results, the results of FBG2 shows a big deviation from FBG1 and FBG3 due to the low temperature sensitivity and the loose contact between tape and FBG.
➢Magnetic strain of the four-tapes HTS stack has no effect on the AC loss measurement of FBG sensors.