Interface Characterization for 2-omega Method for Thermal Conductivity Measurement in a Pulsed Magnetic Field

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Introduction

The magnetic field dependence of thermal properties is crucial for understanding materials like high-T\textsubscript{c} super conductors. The 2-\textomega technique enables measurements of thermal conductivity with the 60-T long pulses at NHMFL-LANL and it has been under developments for some time [1]. 2\omega method is a combination of 3\omega method [2] and ac calorimetry, and it is suitable for the high-noise environment of pulsed magnets [1]. For the simplest case, as in other thermal measurements, good thermal conductance through the material interface is assumed. The Kapitza resistance as well as the thermal resistance associated with defects at the interfaces is expected to be present. In this study, thermal resistance is carefully tested by experiment and also its effects and behavior are derived by calculation.

Experiment

Ac voltage between 10 to 1000 Hz was applied to the heater. The 2\omega signals of the three thermometers were recorded by a home-made fixed-phase digital lock-in amplifier and multi-harmonic data acquisition with a LabView program. These allow measurements with low noise, high resolution and short time constant. The Oxford \textsuperscript{4}He flow cryostat was used to control temperature between 4 K and 150 K.

Calculation

In the schematic of 2\omega method [1], in presence of thermal resistance, the ac component of the thermometer temperature is calculated as

$$T_w(t) = \frac{Q_0e^{i2\omega t}}{\sqrt{2\omega e_{\text{sample}}^2} e^{i\delta} \cdot 2d \cdot \rho_{\text{substrate}} C_{p_{\text{substrate}}} \left(1 - \frac{e_{\text{sample}}}{e_{\text{substrate}}} \right)^2}$$

where $e_{\text{sample}}$ is the effective thermal effusivity of the sample. It is reduced by the boundary effect by $e_{\text{sample}} = e_{\text{sample}}(1 - \delta)$ where $\delta = \alpha / (\alpha + e_{\text{sample}})$ and $\alpha = 1 / R_B \sqrt{2\omega} e^{-\alpha^2/4}$. $R_B$ is the boundary resistance between the sample and the substrate, and according to the calculation, the phase of $T_w(t)$ depends on the frequency.

Acknowledgements

We thank Christophe Marcenat and Yoshimitsu Kohama for their useful suggestions and discussions. This work was supported by the NSF, the State of Florida and the DOE through the NHMFL.

References