Heat Capacity and Thermal Conductance Measurements of a Superconducting/Normal Mixed State by Detection of Single 3 eV Photons in a Magnetic Penetration Thermometer

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C and G Measurements

1. Using 3-eV photons from a Blu-ray disc

An example data set at 1001 uA and 100 mK ( photon number resolved )

\[ C = \frac{E_{\text{f}}}{\Delta T/\Delta N} = \frac{E_{\text{f}}}{(1/\Delta T) + (1/\Delta T)} \]

\[ G = C/\tau \]

- 405 nm (3.06 eV) photons from a Blu-ray disc outside the crystal
- Photon pulse width: 0.7 ns, repetition rate: 70 ns
- 10,000 triggered records at each T

An example data set at 1001 uA and 109 mK ( photon number not resolved )

- 405 nm (3.06 eV) photons from a Blu-ray disc outside the crystal
- Photon pulse width: 0.7 ns, repetition rate: 70 ns
- 10,000 triggered records at each T

2. Noise spectra measurement

- Measured C and G using 3-eV photon data only (left) and together with noise spectrum data (right)
- The two methods share the same dI/dV and τ values

MPT operation

- Cartoon of self-inductance MPT
- MPT circuit diagram

• A persistent current is trapped in the bias circuit above the Tc of aluminum wirebonds that each sensor to its associated SQUID.
• As we cool or warm through the MoAu superconducting transition, the inductance of the meander changes as the MoAu film expands or allows entry of flux, and we measure a current proportional to the sensor’s magnetic response.
• MPTs give us a unique avenue to probe superconducting effects in MoAu films.

M vs T

• Four different bias currents (806 uA, 903 uA, 952 uA, 1001 uA)

More jumps and more hysteresis at higher currents

Theory

1. Free-energy difference between superconducting and normal states of MPT

- \[ J = \text{fraction of meander length for which MoAu enters a partly-normal intermediate state} \]
- \[ g = \text{fractional width of normal stripes in intermediate state region} \]
- \[ C = \text{superconducting energy gap reduction in Ginzburg-Landau equation} \]

Solve to find state with minimum free energy of MPT relative to fully normal state. Free energy contains inductive and condensate terms:

\[ G = G_{\text{f}} + \frac{1}{2} \frac{1}{2} \sum_i \left( \frac{d}{dN} \right) \left( \frac{d^2}{dN^2} \right) \left( \frac{d^2}{dN^2} \right) \]

2. Heat capacity from second derivative of free energy

- \[ C = \sum_i \left( \frac{d}{dN} \right) \left( \frac{d^2}{dN^2} \right) \left( \frac{d^2}{dN^2} \right) \]

3. Thermal conduction: quasiparticle recombination & electron-phonon cooling

- In superconducting regions, recombination of quasiparticles into Cooper pairs should be dominant cooling mechanism.
- In normal regions, quasiparticles cool by only phonon emission.
- We estimated Kaplan’s \( \tau_c \) and Wellstood’s \( \tau_c^* \) from the electronic and mechanical parameters for Mo and Au. A priori values fit dI/dV data within one order of magnitude.
- Fit results: \( \tau_c = 56 \mu s, 2.1 \times 10^{10} \mu \text{s/mK} \)

Conclusions

- We measured the variation in heat capacity and thermal conductance of a molybdenum-gold Magnetic Penetration Thermometer (MPT) near its field dependent Meissner transition temperature.
- We did this by two methods: detection of pulses in response to absorption of one or more 3 eV photons, and equilibrium noise measurements.
- Observed C & G show peaks in approximate agreement with a Ginzburg-Landau model of the superconducting intermediate state of an MPT.

References