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)
     - 405 nm (3.98 eV) photons from a Blu-ray disc outside the crystal
     - Photon pulse width: 0.7 us, repetition rate: 70 kHz
     - 10,000 triggered records at each T

   ![Diagram of MPT operation](https://ntrs.nasa.gov/search.jsp?R=20150018422)

   - A persistent current is trapped in the bias circuit above the Tc of aluminum wirebonds, each sensor's superconducting transition.
   - The inductance of the meander changes as the MoAu film expels 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.

Measuring C and G

- Free energy difference between superconducting and normal states of MPT
- Continuous noise spectrum of MPT
- A persistent current is trapped in the bias circuit above the Tc of aluminum wirebonds, each sensor's superconducting transition.
- The inductance of the meander changes as the MoAu film expels or allows entry of flux, and we measure a current proportional to the sensor's magnetic response.
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- Photon pulse width: 0.7 us, repetition rate: 70 kHz
- 10,000 triggered records at each T

- Photon noise $\Delta I/\sqrt{I}$ subtracted

- 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/dT and $\tau$ values

Theory

1. Free-energy difference between superconducting and normal states of MPT
   - $f$ = fraction of meander length for which MoAu enters a partly-normal intermediate state
   - $g$ = fractional width of normal stripes in intermediate state region
   - $C_s$ = superconducting energy gap reduction in Ginzburg-Landau equation
   - $S$ = number of superconducting energy gap reductions
   - $M$ = Magnetic field
   - $N$ = Normal region
   - $T_0$ = Critical temperature
   - $\phi$ = Magnetic flux
   - $\lambda$ = Ginzburg-Landau parameter
   - $\alpha$ = Electronic parameter
   - $\beta$ = Magnetic parameter

2. Heat capacity from second derivative of free energy
   - $C(T)$ = heat capacity
   - $\Delta T$ = Temperature
   - $\Delta G(T)$ = Free energy difference
   - $\Delta M(T)$ = Magnetic field difference

3. Thermal conductance: 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 $\delta$ from the electronic and mechanical parameters for Mo and Au. A priori values fit dI/dT data within one order of magnitude.

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 and G show peaks in approximate agreement with a Ginzburg-Landau model of the superconducting intermediate state of an MPT.

References