

Measurements and modeling of the thermal properties of a calorimeter having a sapphire absorber

Y.H. Kim, H. Eguchi, C. Enss, Y.H. Huang,
R.E. Lanou, H.J. Maris, A.N. Mocharnuk-Macchia,
G.M. Seidel, B. Sethumadhavan and W. Yao



Brown University
Department of Physics





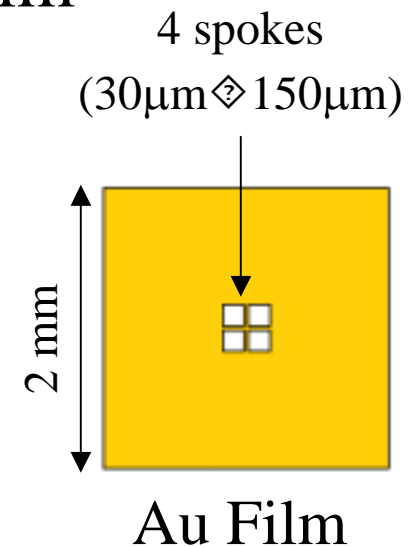
Objective

- Absorber: Sapphire
- Thermal connection: Au film
- Sensor: MMC (Au:Er)
 - Wide operating temperature
 - No additional heat dissipation
 - Fast to detect athermal signals
- Energy transfer
- Thermalizaion mechanism

Different Experimental Conditions

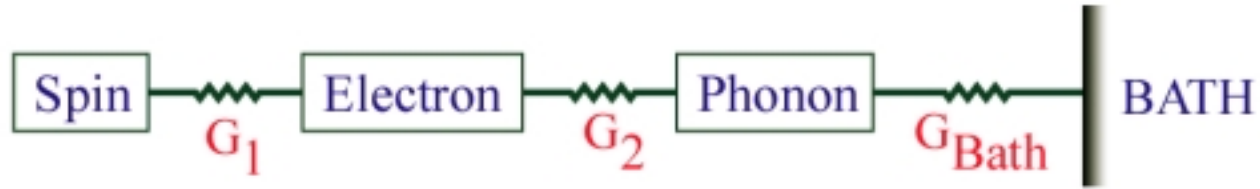
- ^{241}Am Source (60 keV gamma rays)
 - Three different thickness of Au film

Experiment	Main film	Spokes
Case 1	<u>80 nm</u>	<u>80 nm</u>
Case 2	<u>300 nm</u>	<u>300 nm</u>
Case 3	<u>80 nm</u>	<u>300 nm</u>



- Experiment with a heater
 - Steady state heat input
 - Transient measurement

Sub-thermal systems



- Spin: Erbium spins in *Au:Er*
- Electron: Electrons in Au film
- Phonon: Phonons in sapphire
- BATH: Thermal reservoir

Heat capacities are known

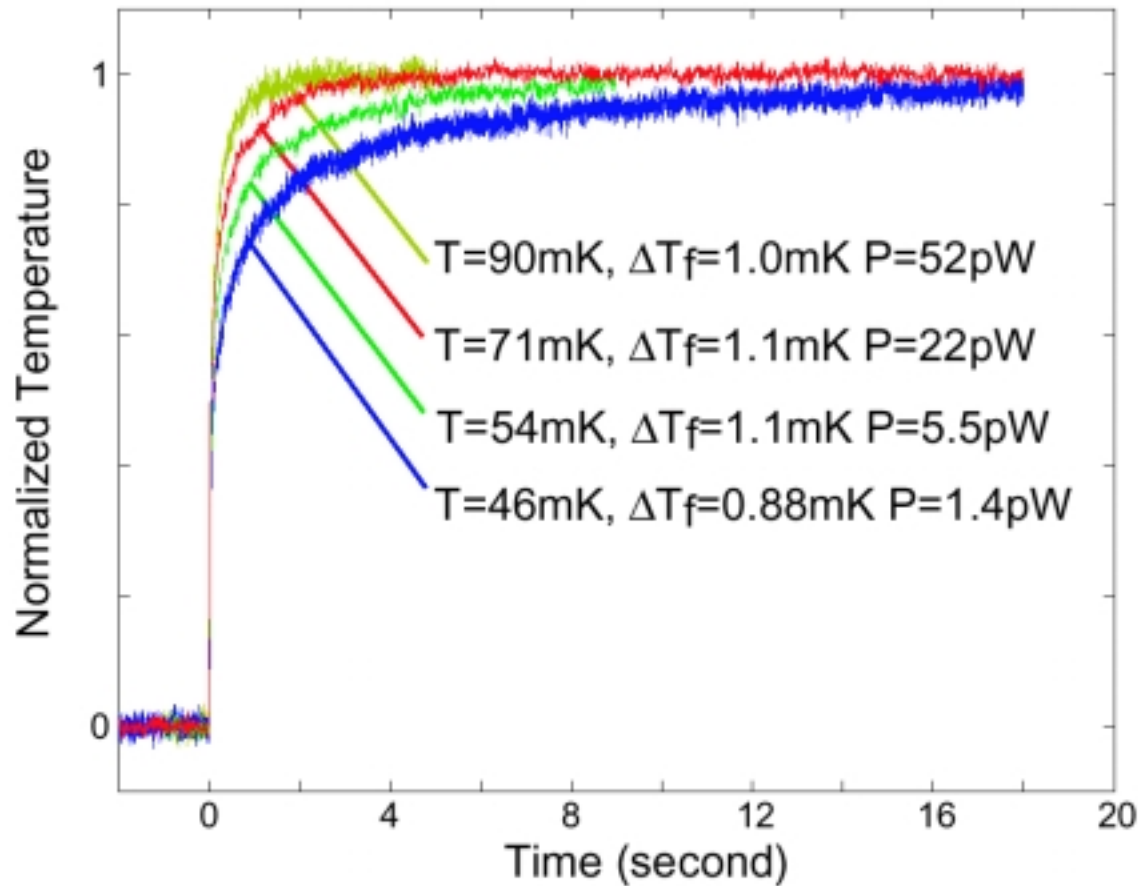
$G_1, G_2, G_{\text{Bath}}$?



Experiment with a heater

- Heater: Au film (300nm \times 30 μ m \times 5.3cm)
- Steady state heat input:
 G_{Bath} is measured
- Transient measurement:
Existence of Tunneling Systems
weakly coupled to Lattice

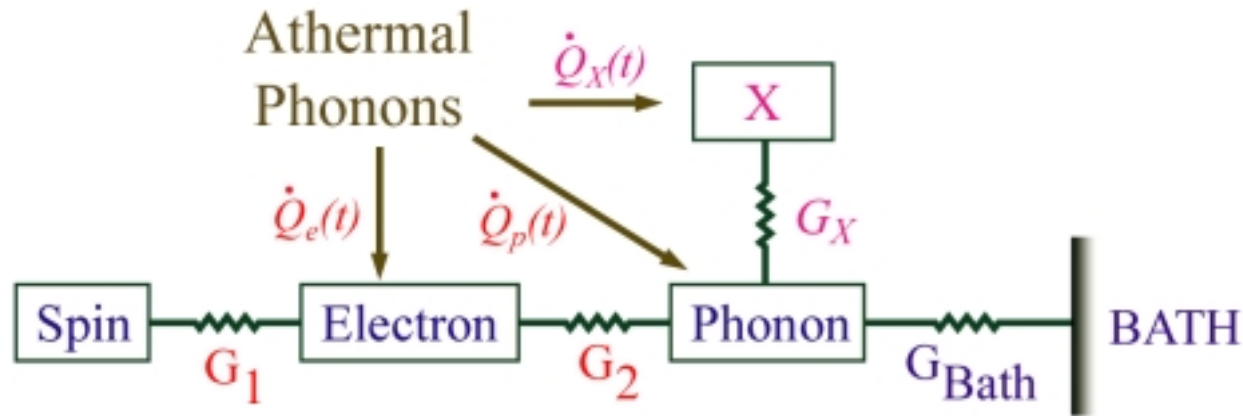
Transient measurement



Tunneling Systems

- Weakly coupled to lattice
- $C_{\text{lattice}} \gg C_x$
- Not single conductance

Thermal model of particle detections



1. Athermal phonons with measurable life time

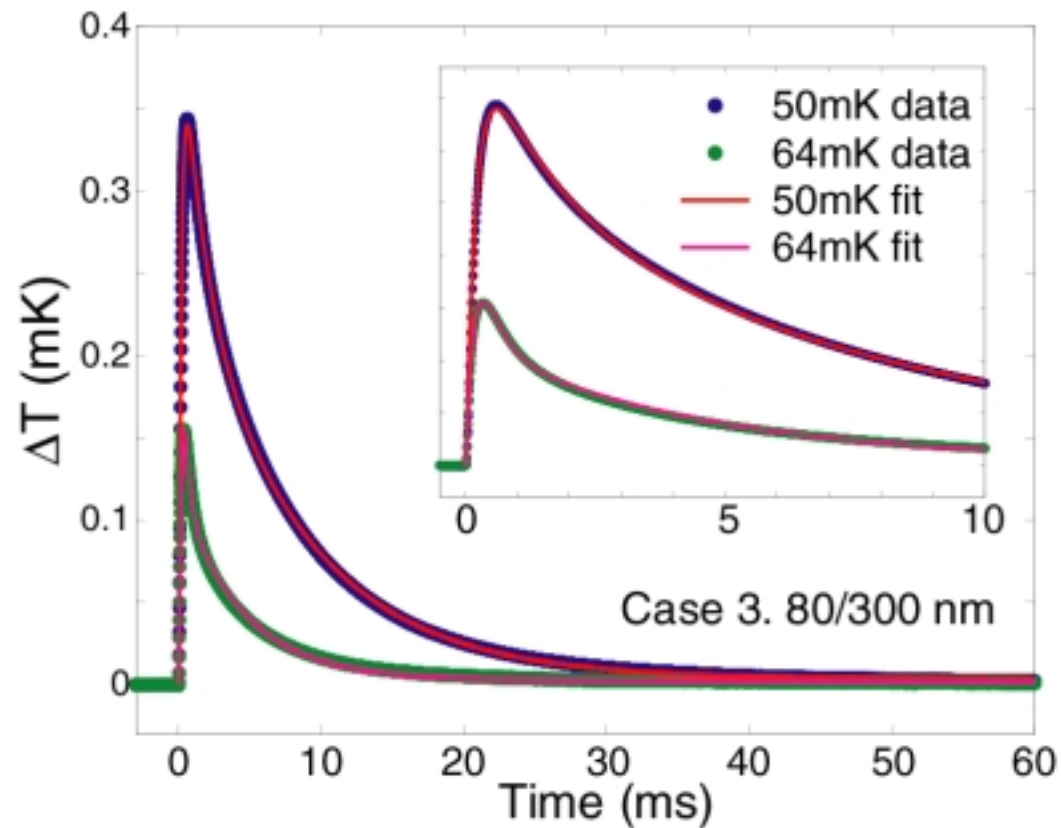
$$\dot{Q}_i(t) = \frac{E}{\tau_i} e^{-t/\tau}, \quad i = e, p, x \quad \tau = \left(\frac{1}{\tau_e} + \frac{1}{\tau_p} + \frac{1}{\tau_x} \right)^{-1}$$

2. Thermal processes
3. Measure temperature of Spin.

Parameters

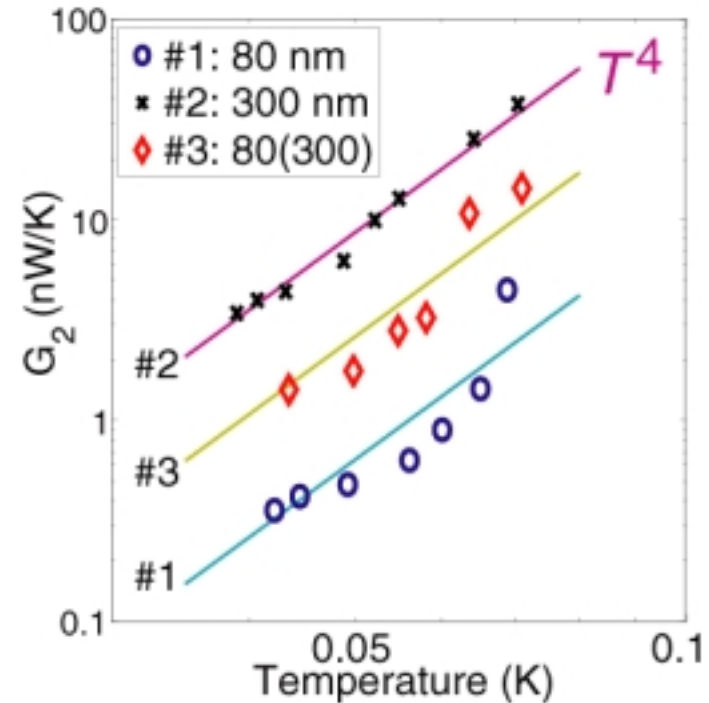
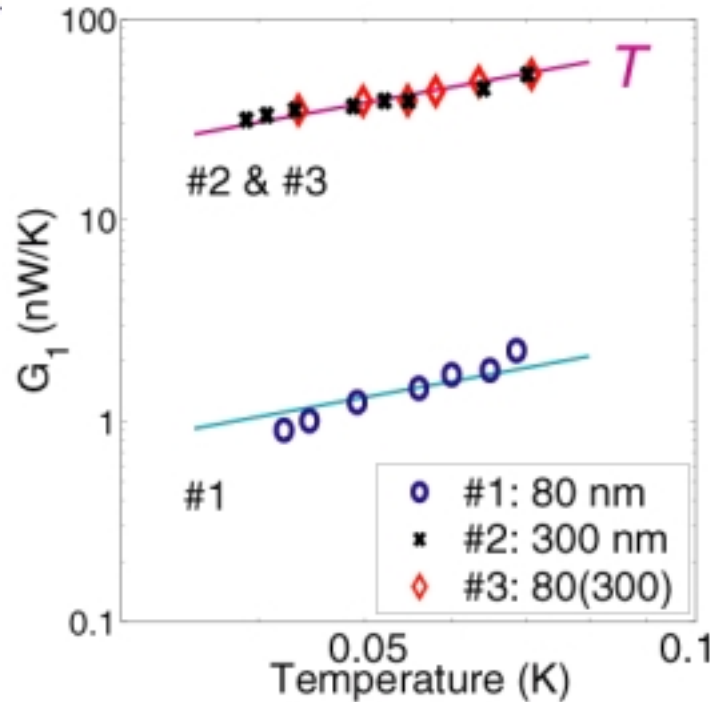
Major parameters: G_1 , G_2 , τ_e , and τ_p

C_x , G_x fit after 10 ms, $1/\tau_x$ small





Thermal conductance, G_1 & G_2

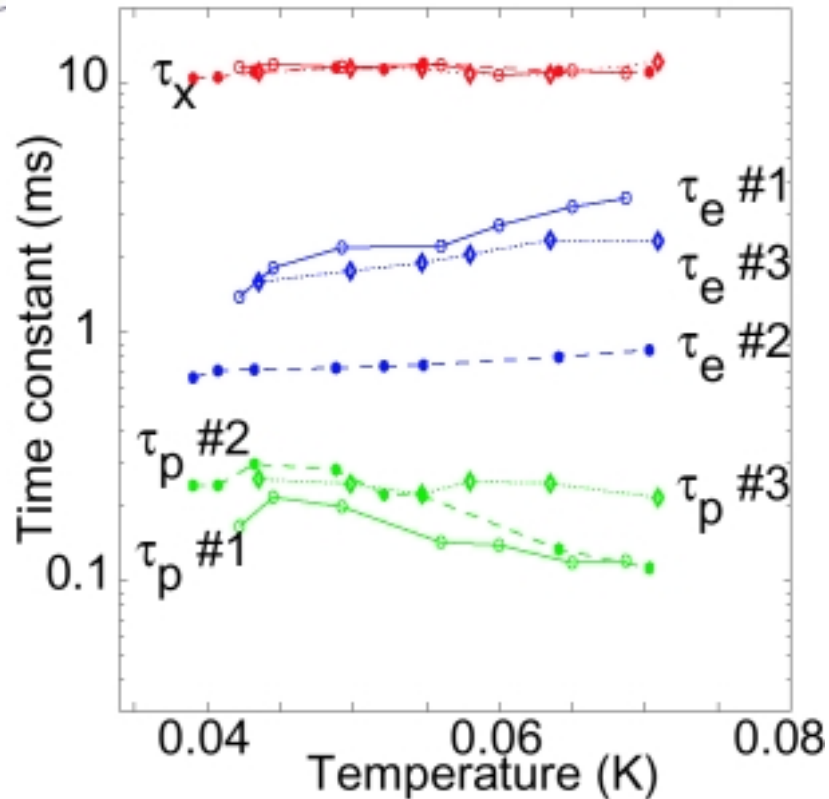


- $G_1 \sim T$
- Agreement within 15% of electronic thermal conductance of spokes

- $G_2 \sim T^4$, $G_2 \sim V_{\text{film}}$
- $\Sigma = G_2/5VT^4$, e-p in Au
 $= 2.4 \times 10^8 \text{ W/m}^3\text{K}^5$



Time constants



τ_x (all cases) ~ 10 ms

τ_e (case 1 & 3) ~ 2 ms
(case 2) ~ 0.7 ms

τ_p (all cases) ~ 0.2 ms

$$1/\tau_x \propto 1/\tau_1$$

τ_e has film thickness dependence



Time constant τ_e

$$\tau_e = \tau_{\text{geo}} / \eta$$

- Geometrical time constant:

$$\tau_{\text{geo}} \approx \frac{2V_{\text{crystal}}}{A_{\text{film}} \langle v_{\perp} \rangle} \approx 0.17 \text{ ms}$$

- Probability (η) of athermal phonons to scatter electrons in Au. $\lambda_{20\text{K}}$ in Au $\sim 2 \mu\text{m}$

Experiment	Thickness	τ_e	τ_{geo}/τ_e
Case #2.	<u>300 nm</u>	0.7 ms	0.24
Case #1.& #3.	<u>80 nm</u>	2 ms	0.085



Time constant τ_p

Thermalization mechanism

- Inelastic impurity scattering
- Inelastic surface scattering

$$\tau_p \propto \frac{V_{\text{crystal}}}{A_{\text{crystal}}}$$

Measurement	Sapphire dimension	$\tau_l/(V/A)$
Present work	2×1×0.5 cm	1.5 ms/cm
CRESST	4×2×1 cm	1.3
CRESST	4×4×4.1 cm	1.9, 2.7

1000 scatters



Summary

- Electron-phonon interactions in Au film.

$$\Sigma = 2.4 \times 10^8 \text{ W/m}^3\text{K}^5$$

- Energy transfer from athermal phonons

τ_e : *Geometrical time constant and
Phonon attenuation in Au film.*

τ_p : *Inelastic surface scattering*

- Existence of TS

Fast signals are not affected.