Electron Energy Relaxation Dynamics

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Université de Sherbrooke
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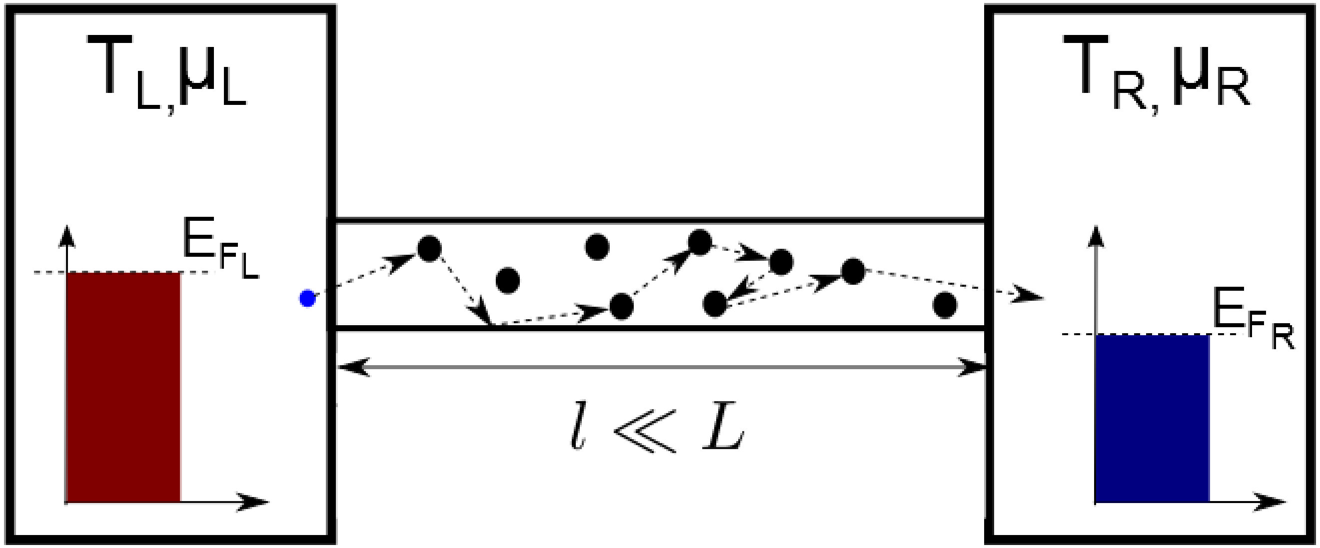
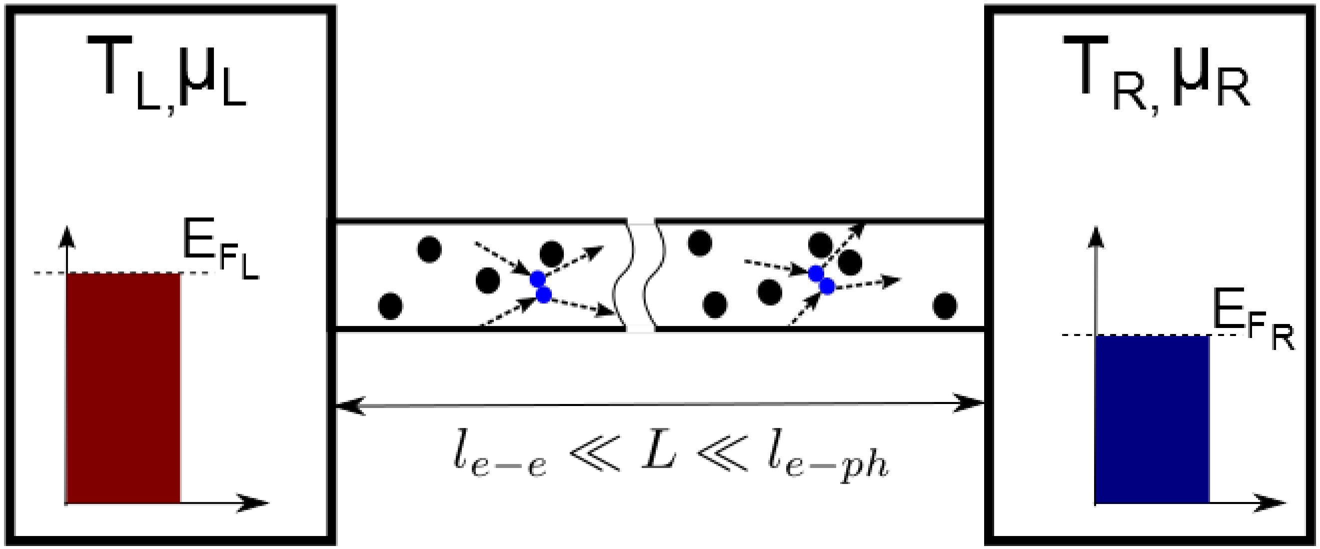
GDR

Different Regimes: Diffusive/Elastic



$L^2 = D\tau_D$ $\tau_D \equiv$ diffusion time

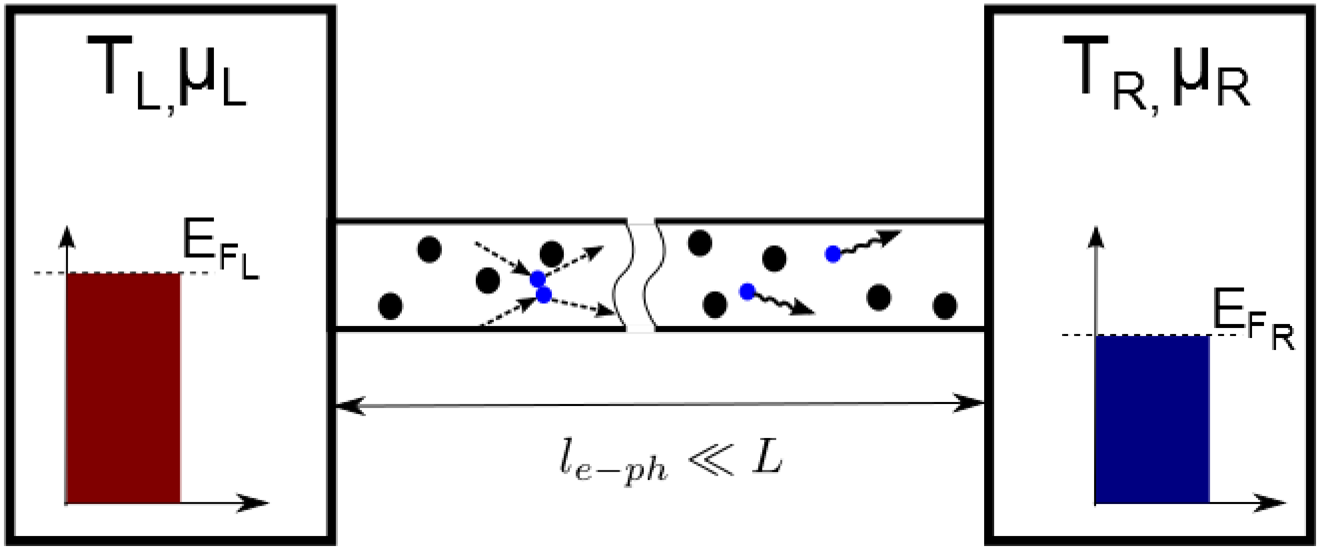
Different Regimes: Hot Electrons



$l_{e-e}^2 = D\tau_{e-e}$

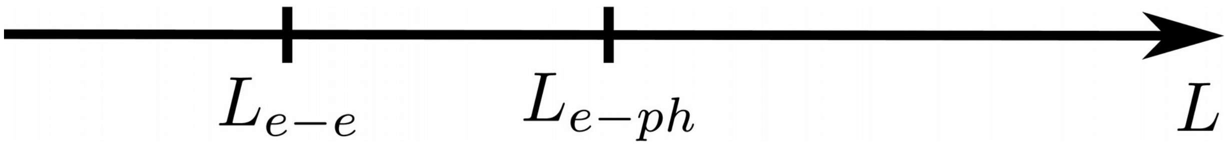
$l_{e-e} \simeq 1\mu m$

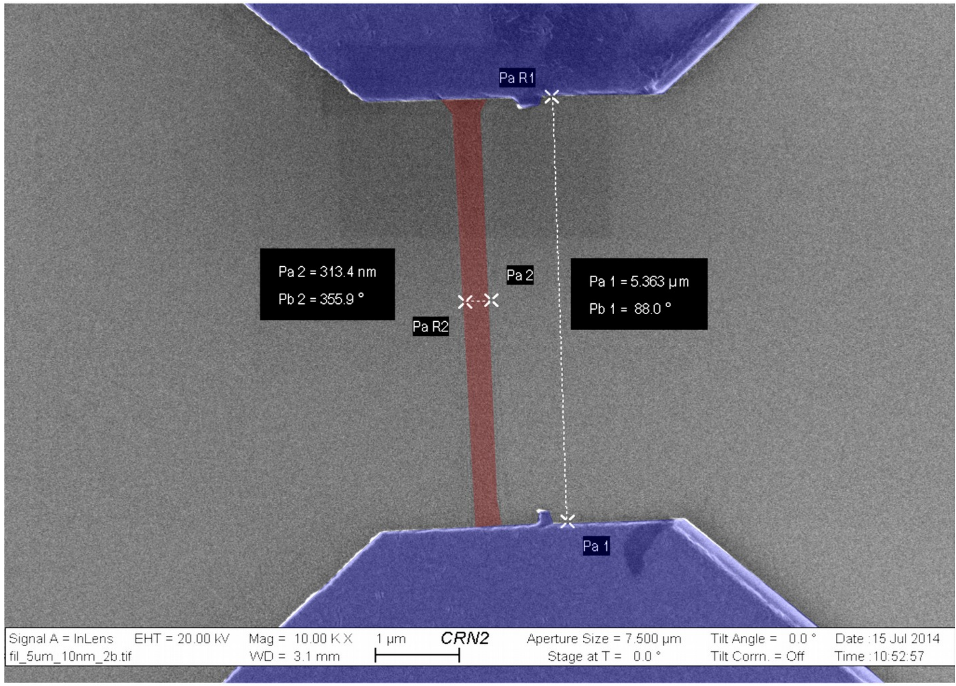
Different Regimes: Macroscopic



$l_{e-ph}^2 = D\tau_{e-ph}$ $\quad$ $l_{e-ph} \simeq 1\mu m - 100\mu m$

Cooling Processes in Metals





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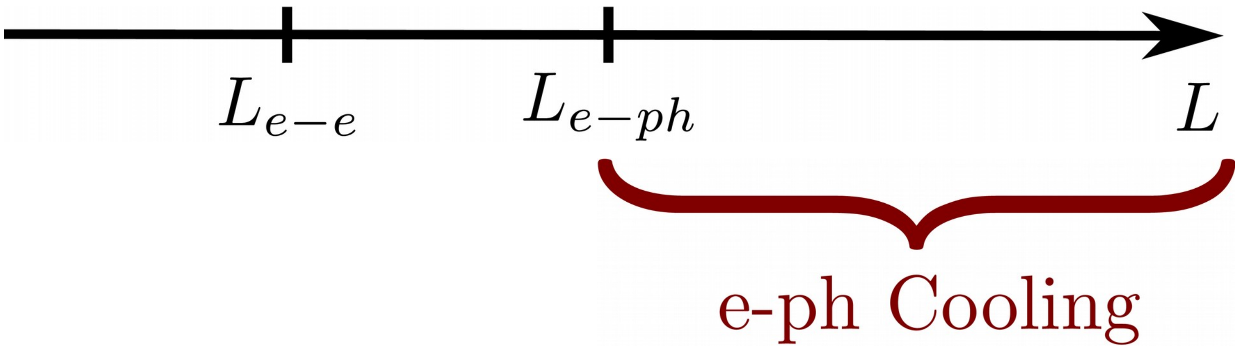
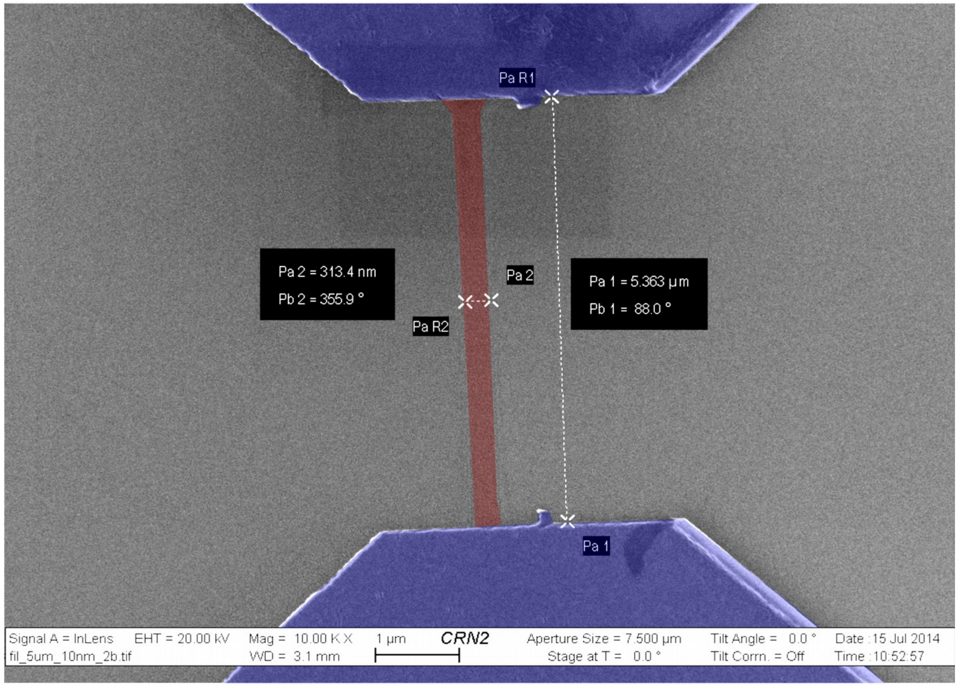


$$\frac{1}{\tau_{e-ph}} = A \times T^3$$



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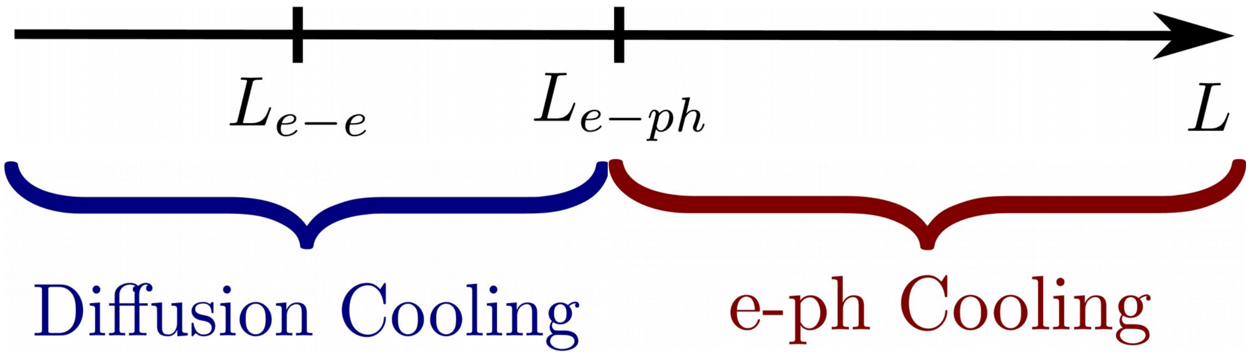
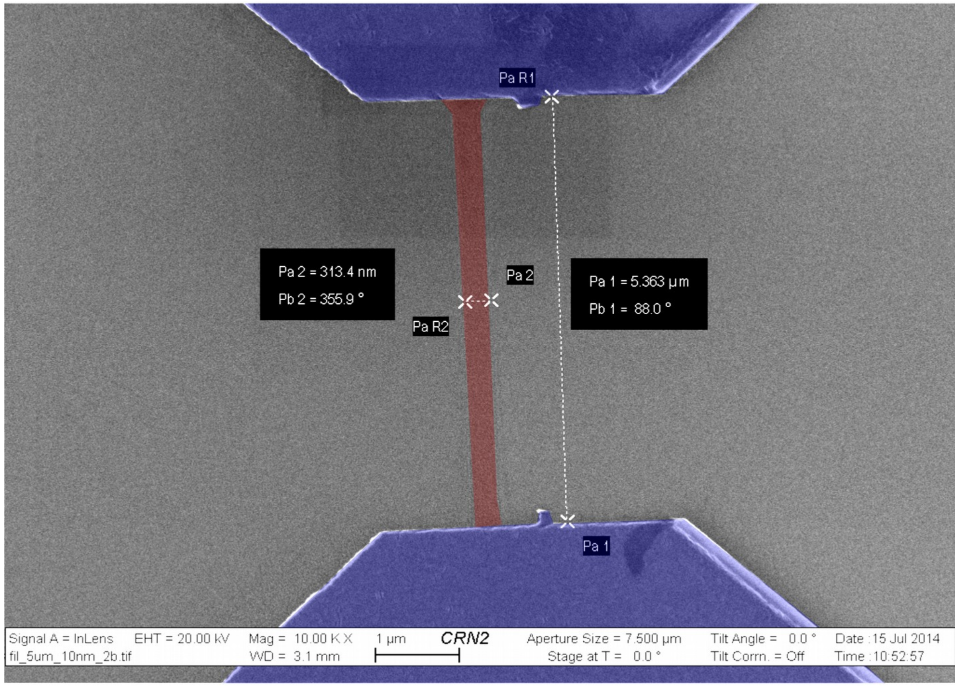
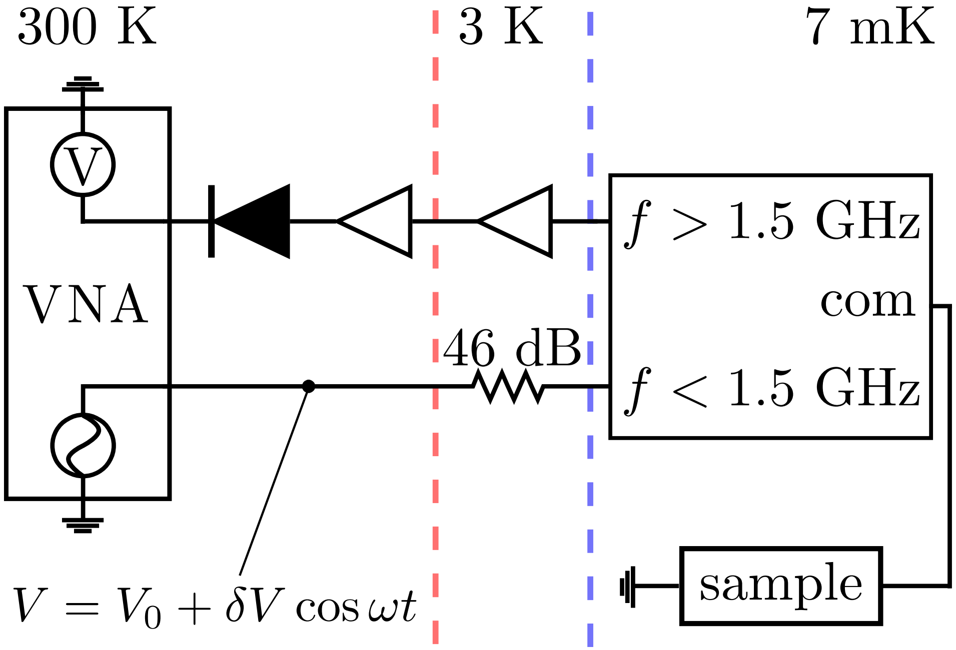


$$\frac{1}{\tau_{e-ph}} = A \times T^3$$

$$\frac{1}{\tau_D} = \frac{D}{L^2}$$



The Experimental Concept



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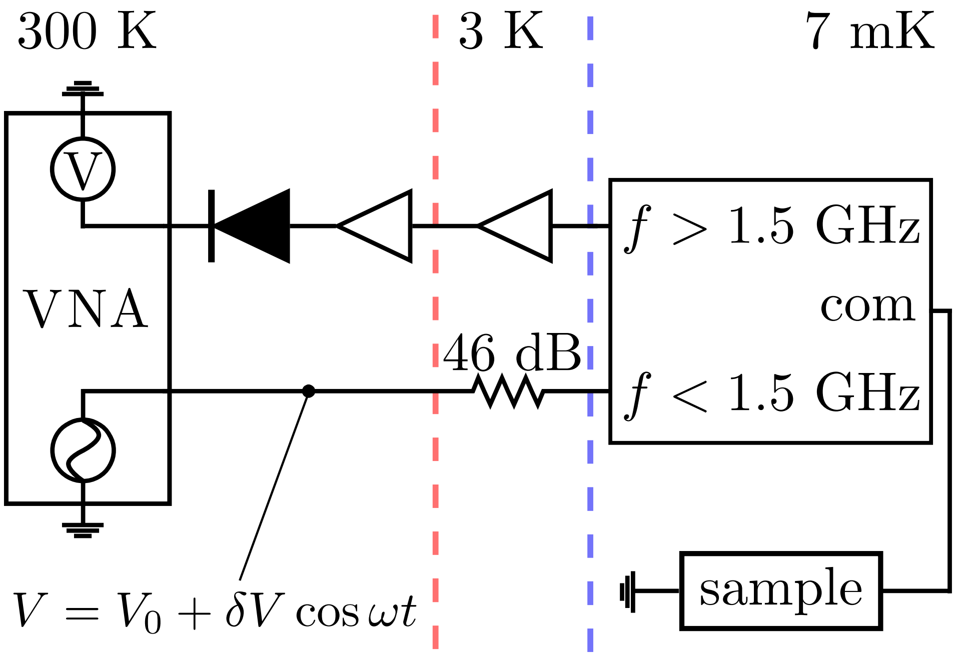
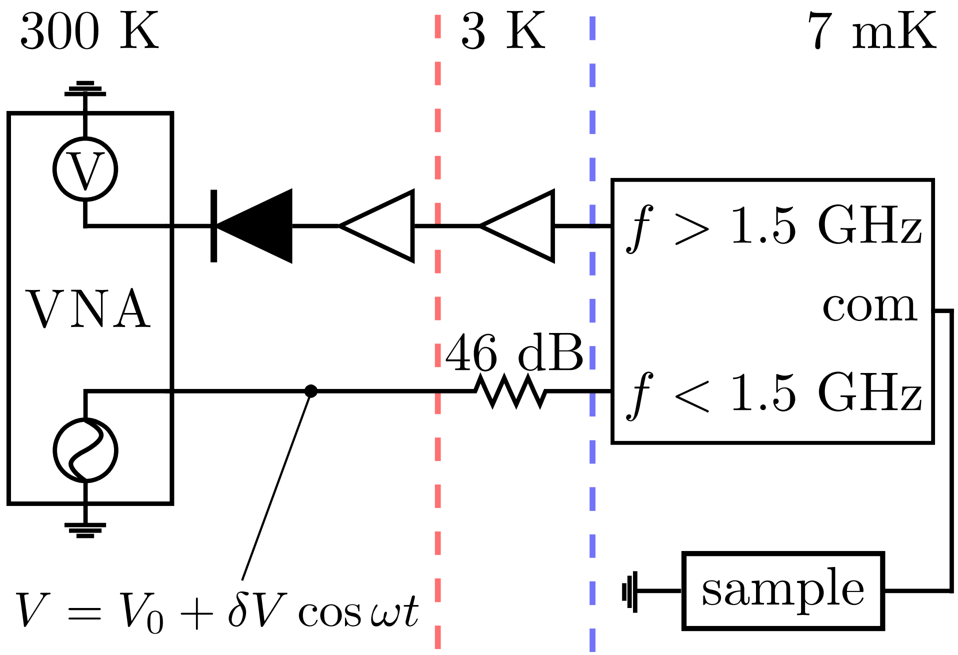


Voltage fluctuations and Temperature:

$$S = 2Rk_BT_e$$

The Experimental Concept



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$$P = V^2/R$$

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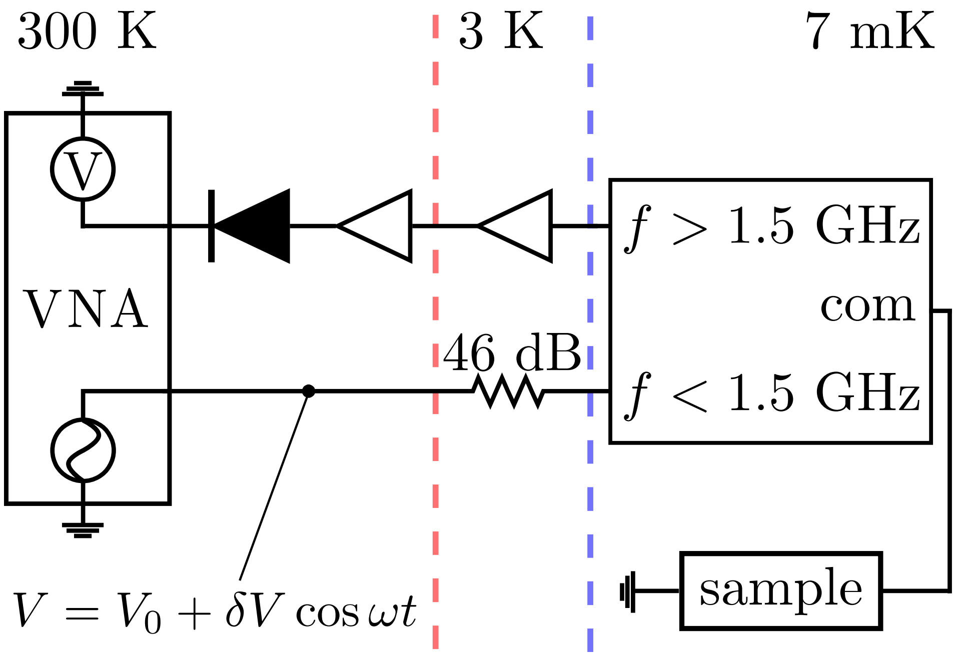

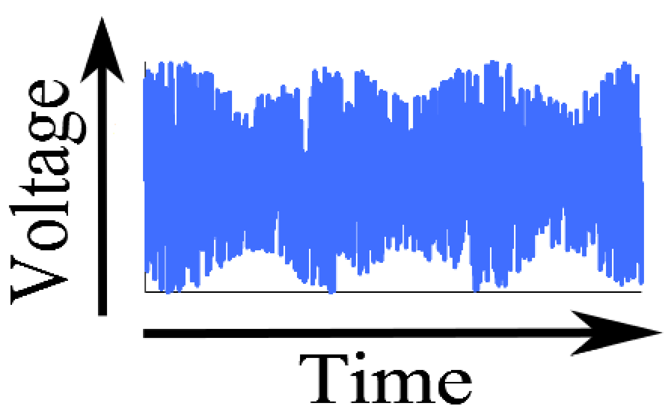

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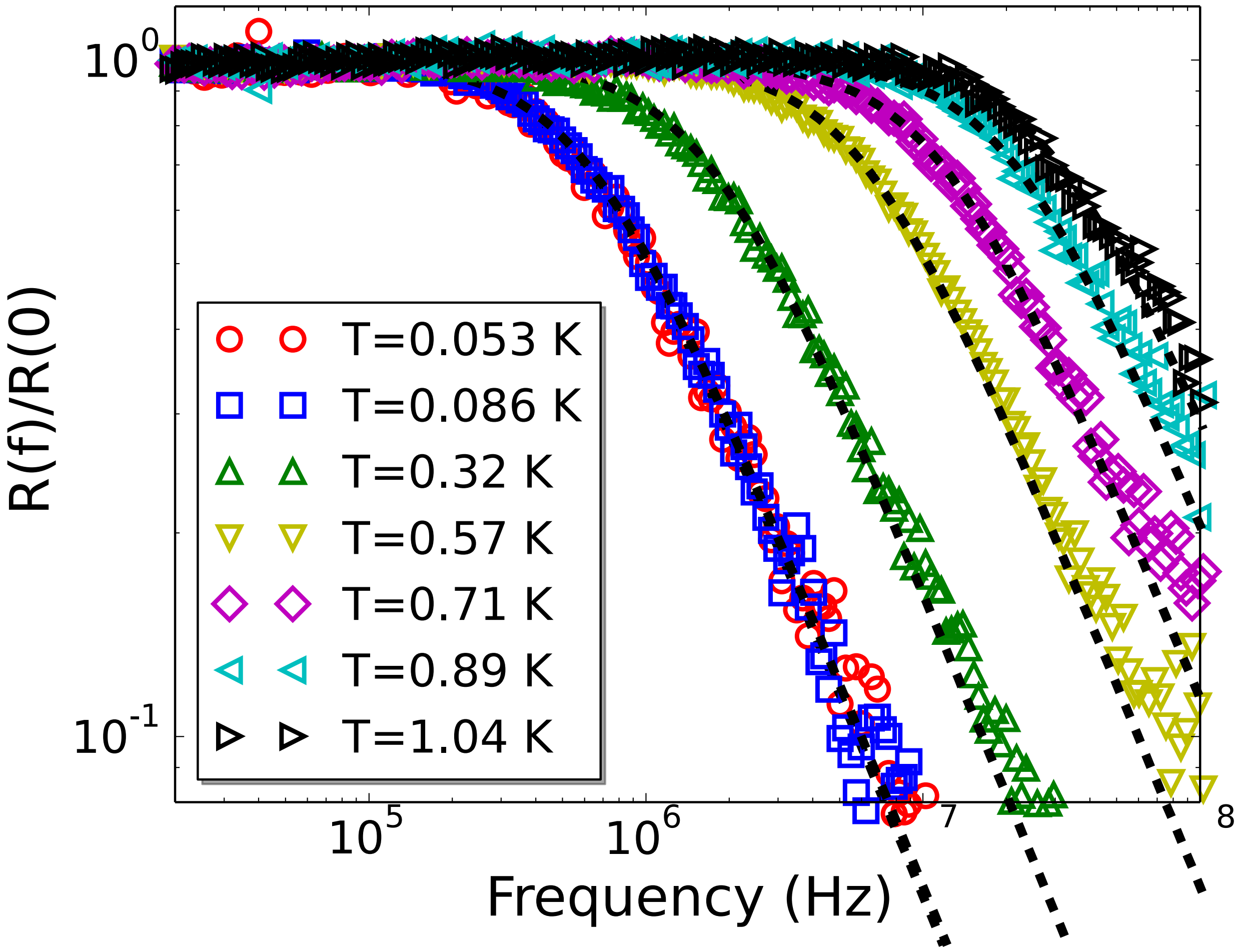
Thermal Impedance:

$$R(\omega) = \delta T_e(\omega)/\delta P(\omega)$$

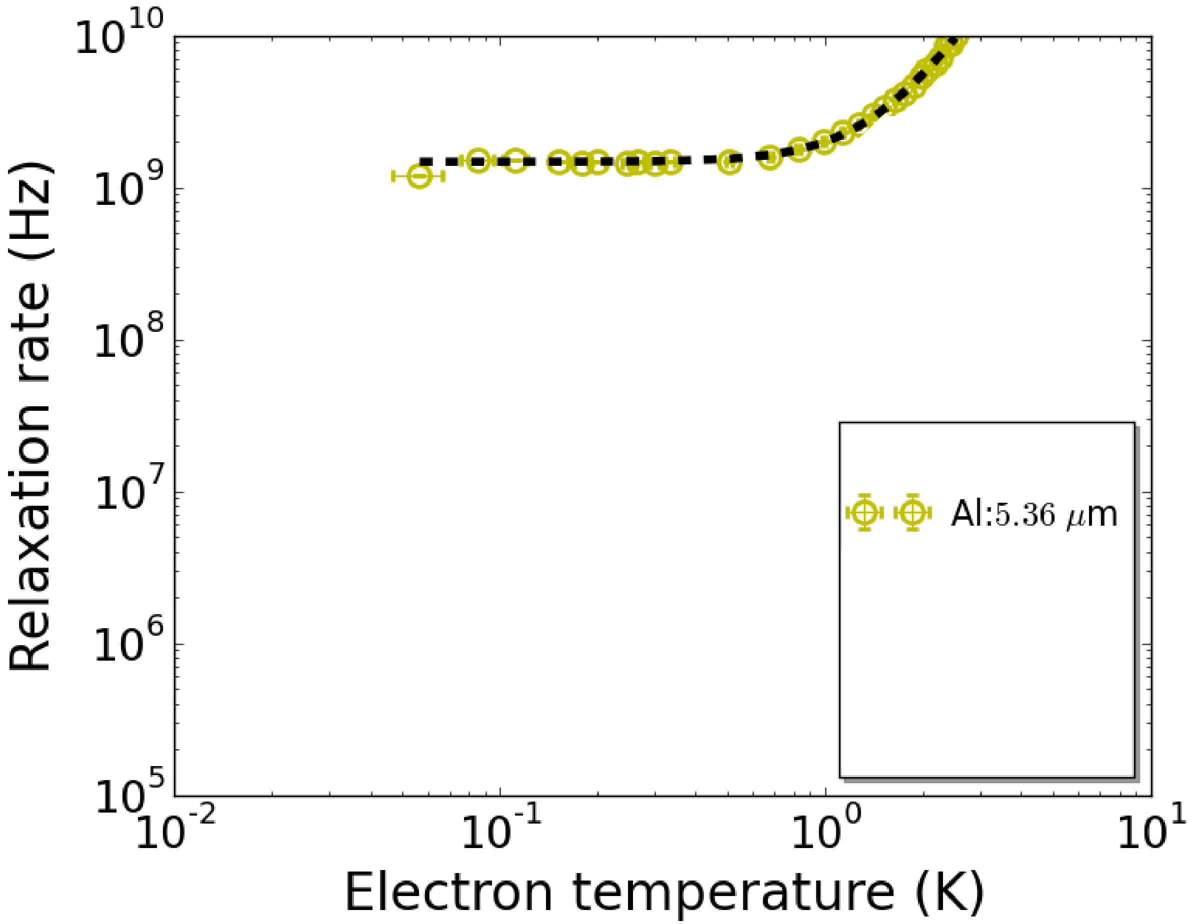
NTI for a 50 micrometers Long Wire



Lorentzian fit:

$$\left|\frac{R(f)}{R(0)}\right|^2 = \frac{1}{1+(2\pi f\tau)^2}$$

Measured Relaxation Rates



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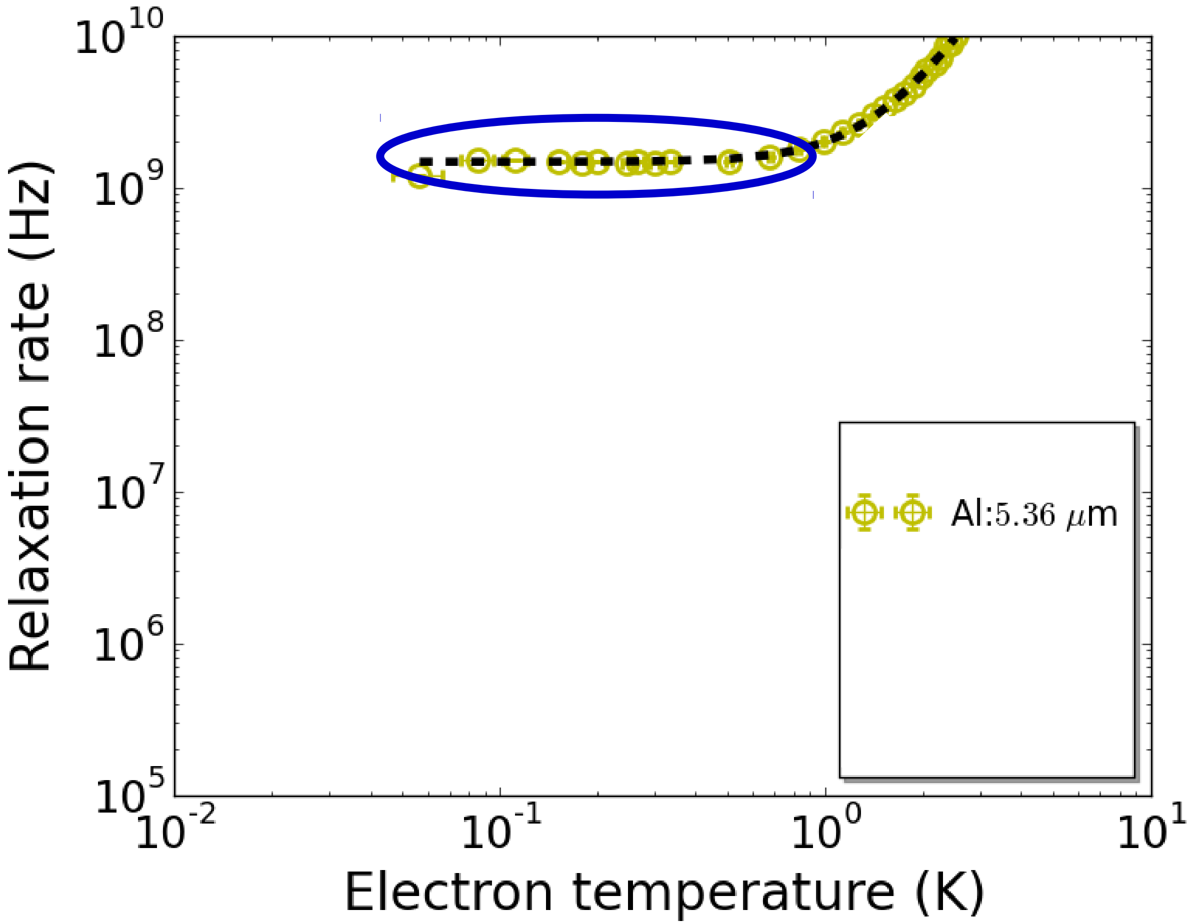

Plateau at low temperature:

$$f_D = cste$$

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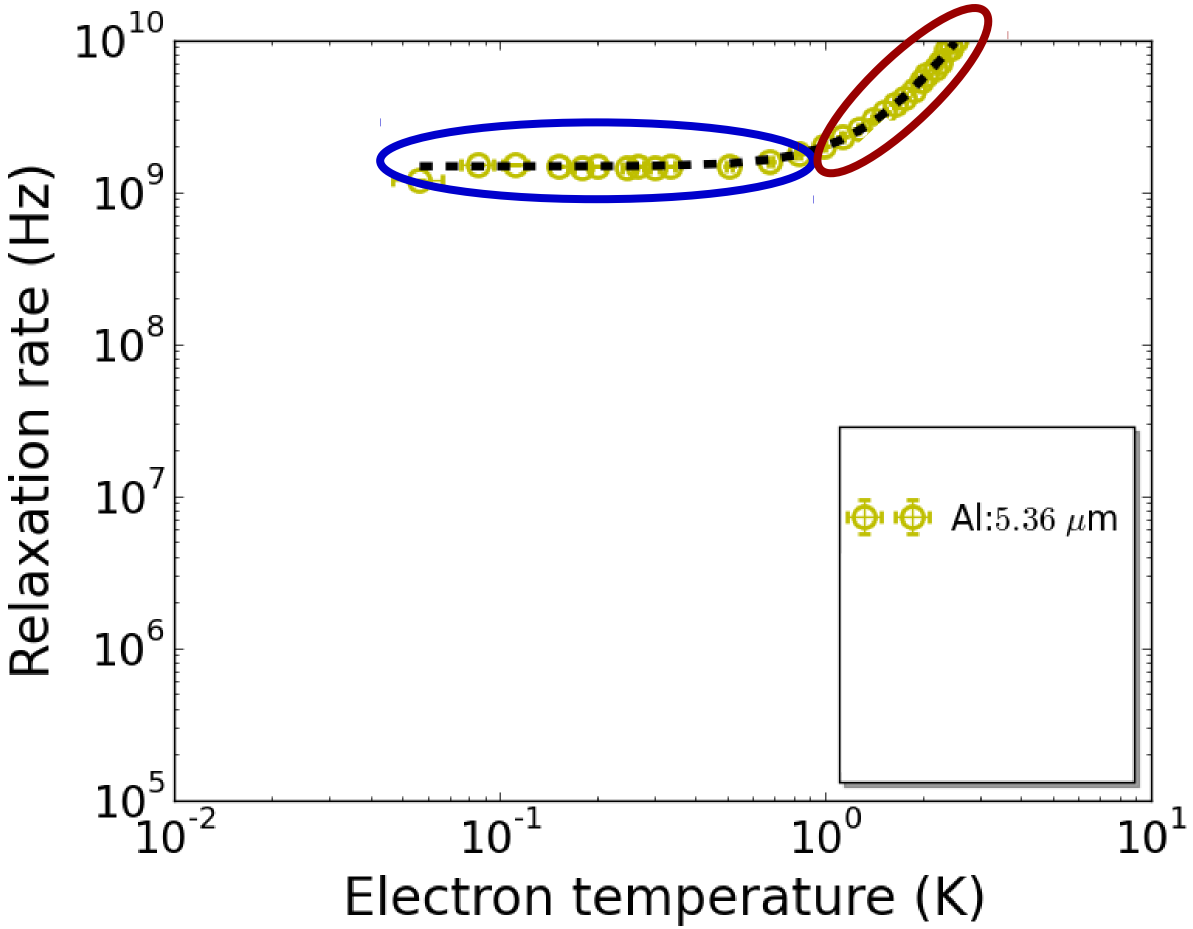

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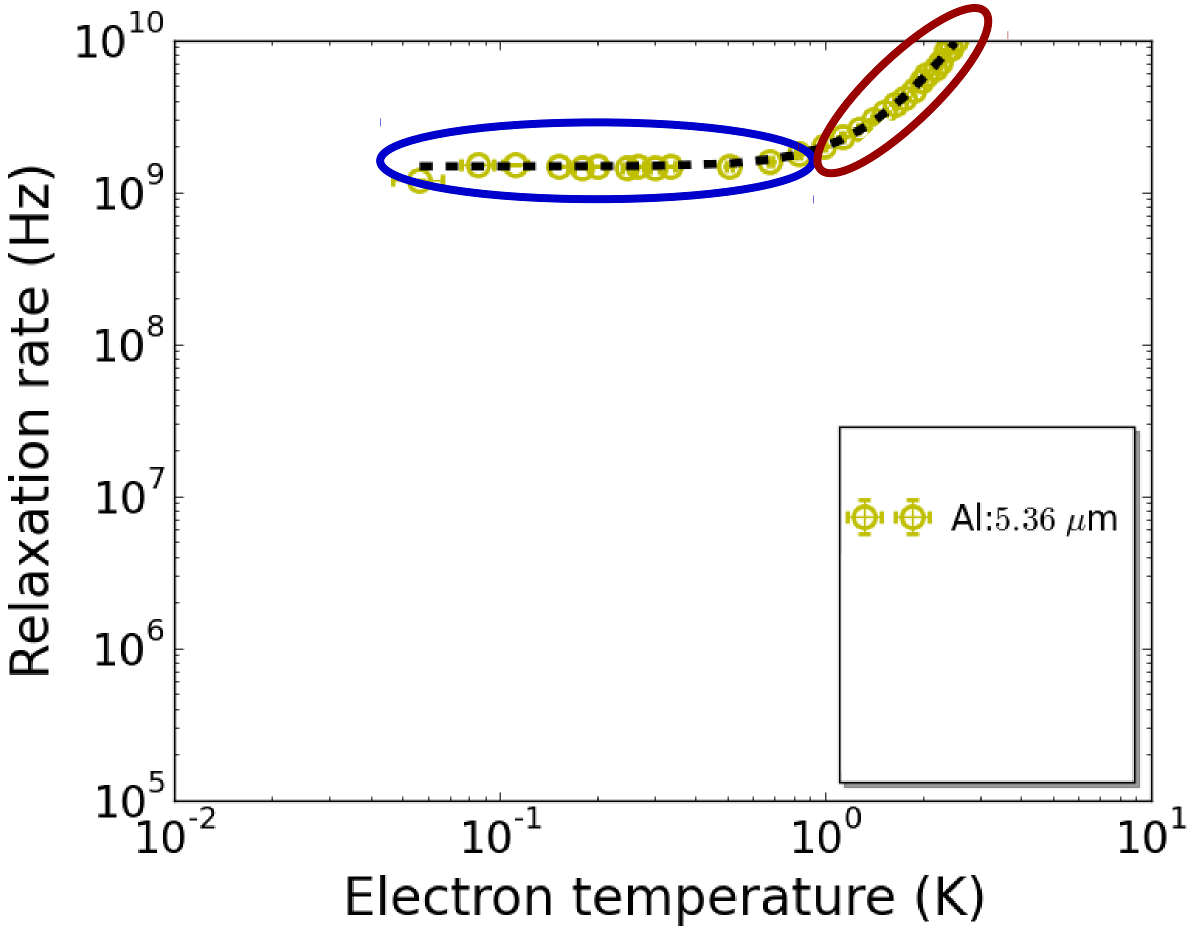

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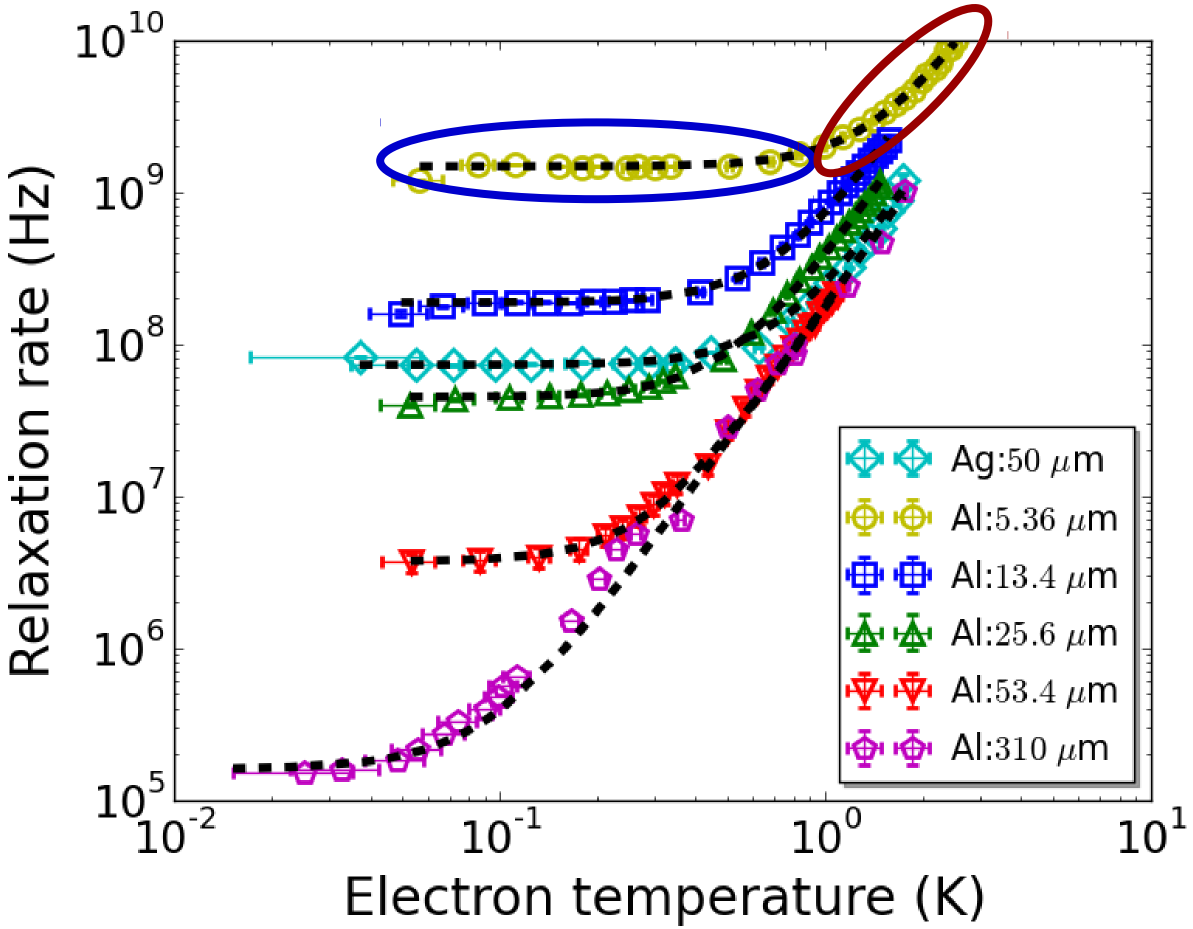

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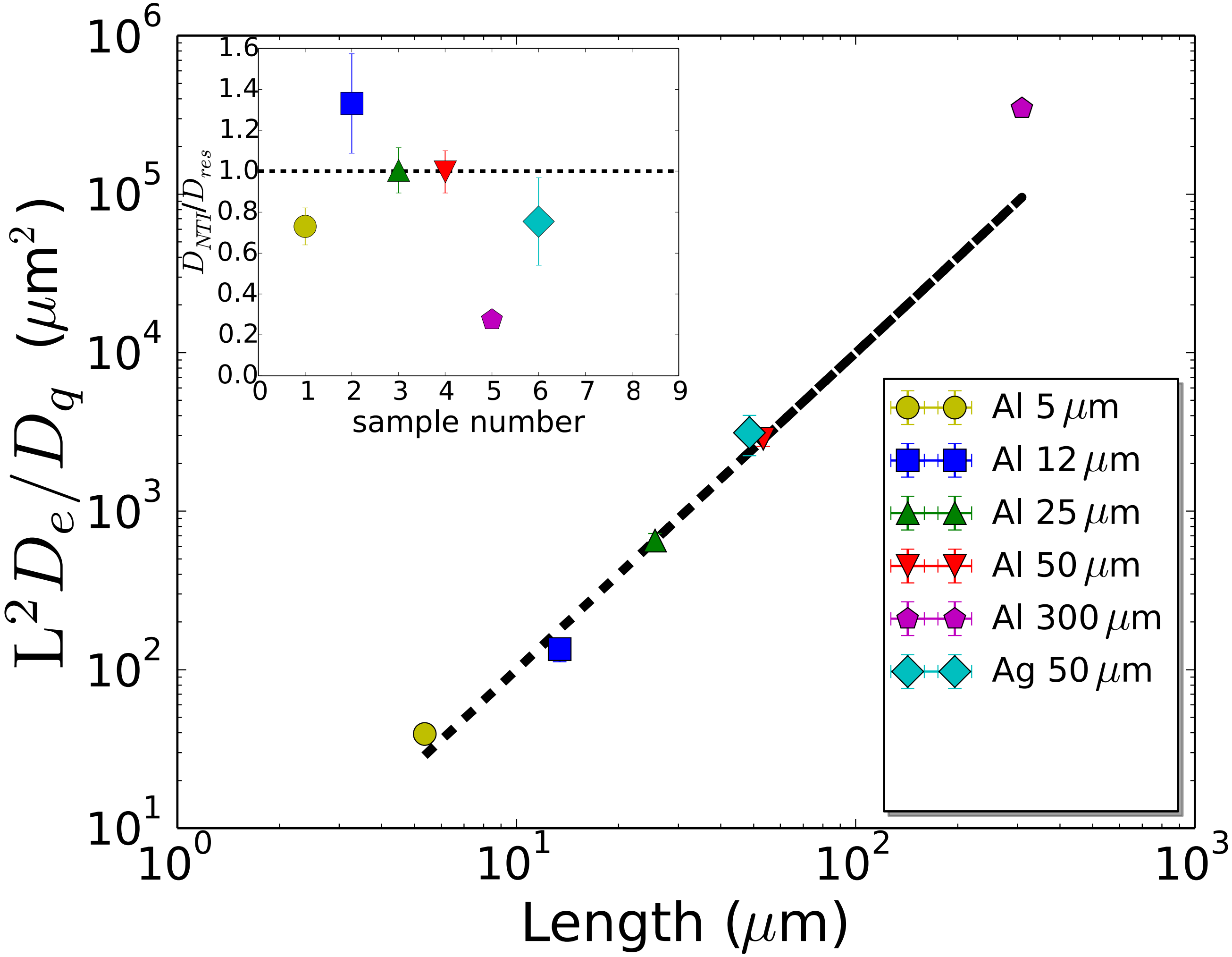
Wiedemann-Franz and Diffusion law



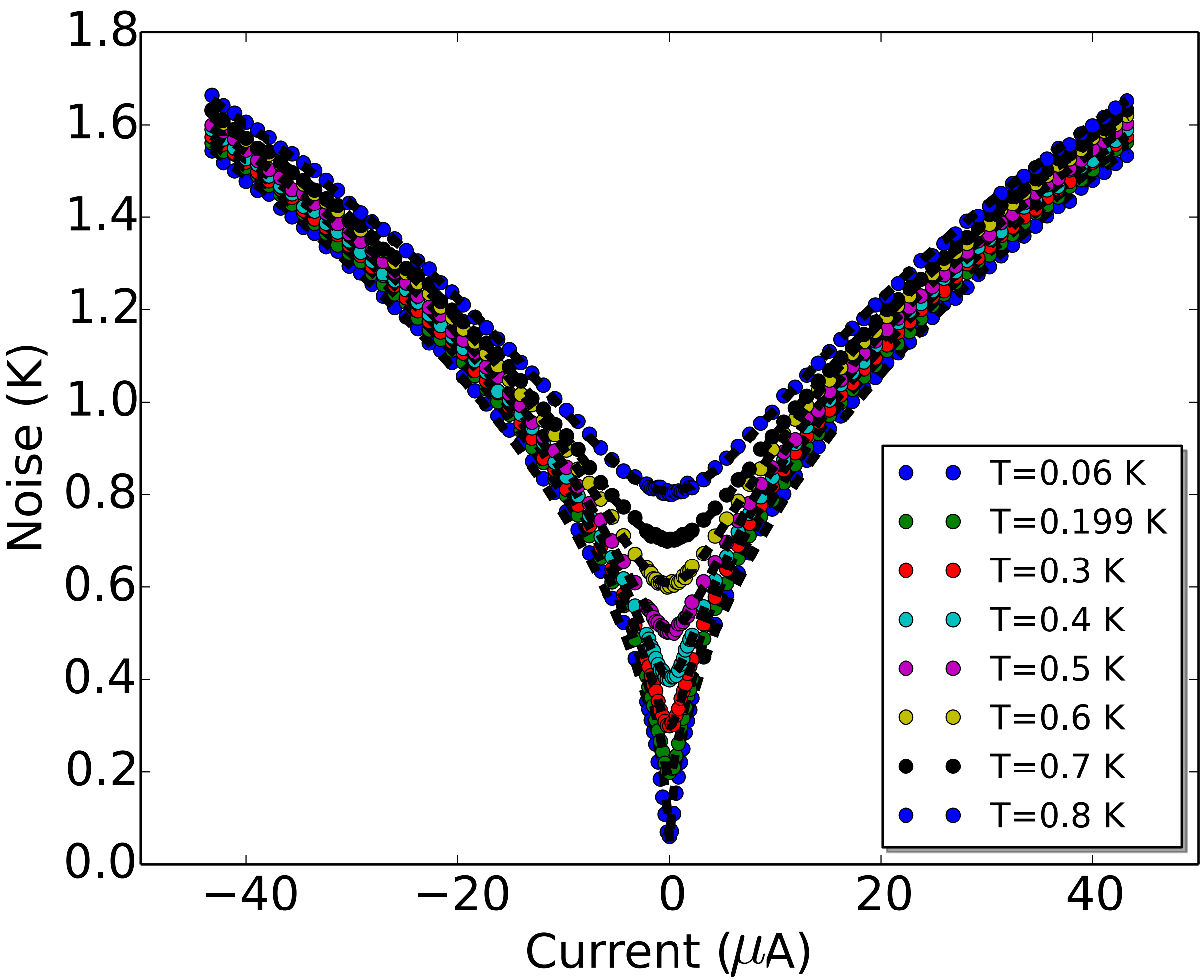
Diffusion Law:

$$L^2 = \tau_D D_q$$

Einstein Relation:

$$\sigma = ne^2 D_e$$

Noise at Zero Frequency



Thermal Noise in presence of joule heating:

$$S = 2Rk_BT_e$$

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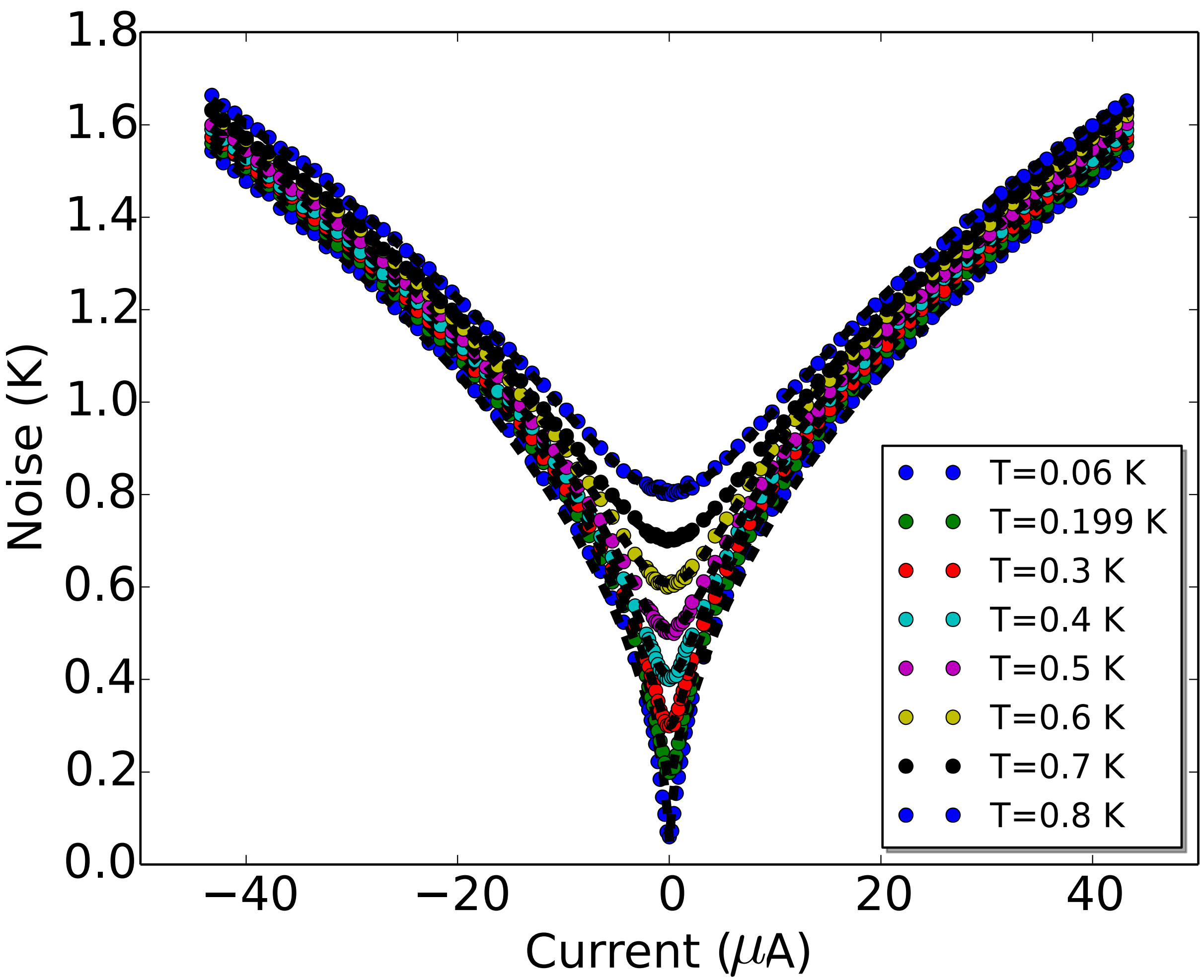

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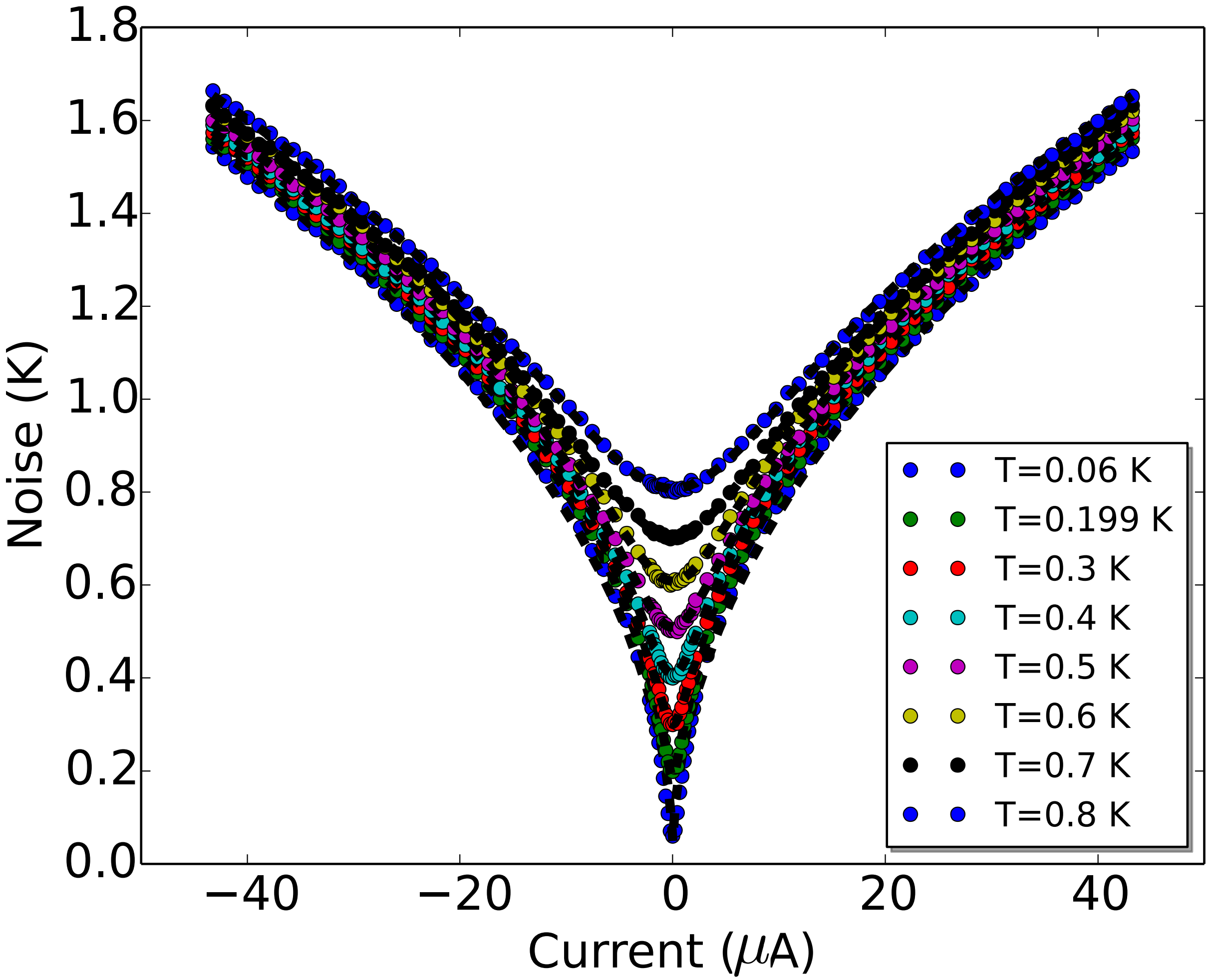

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Thermal conductance:

$$G_{e-ph} = 5\Sigma V T_e^4$$

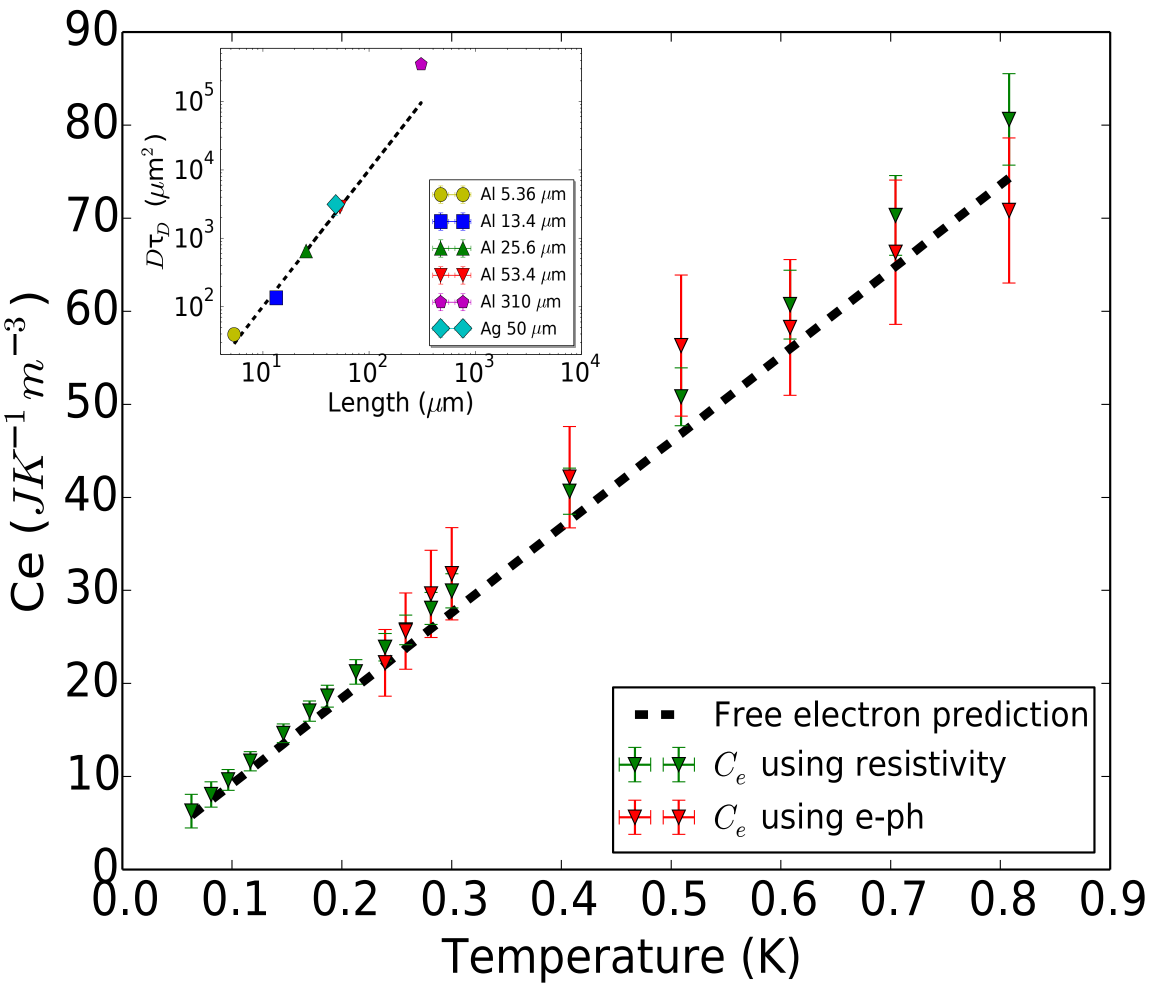
Specific Heat

We can compute the specific heat.

From electron-phonon regime:

$$C_e = G_{e-ph}\tau_{e-ph}$$

Specific Heat



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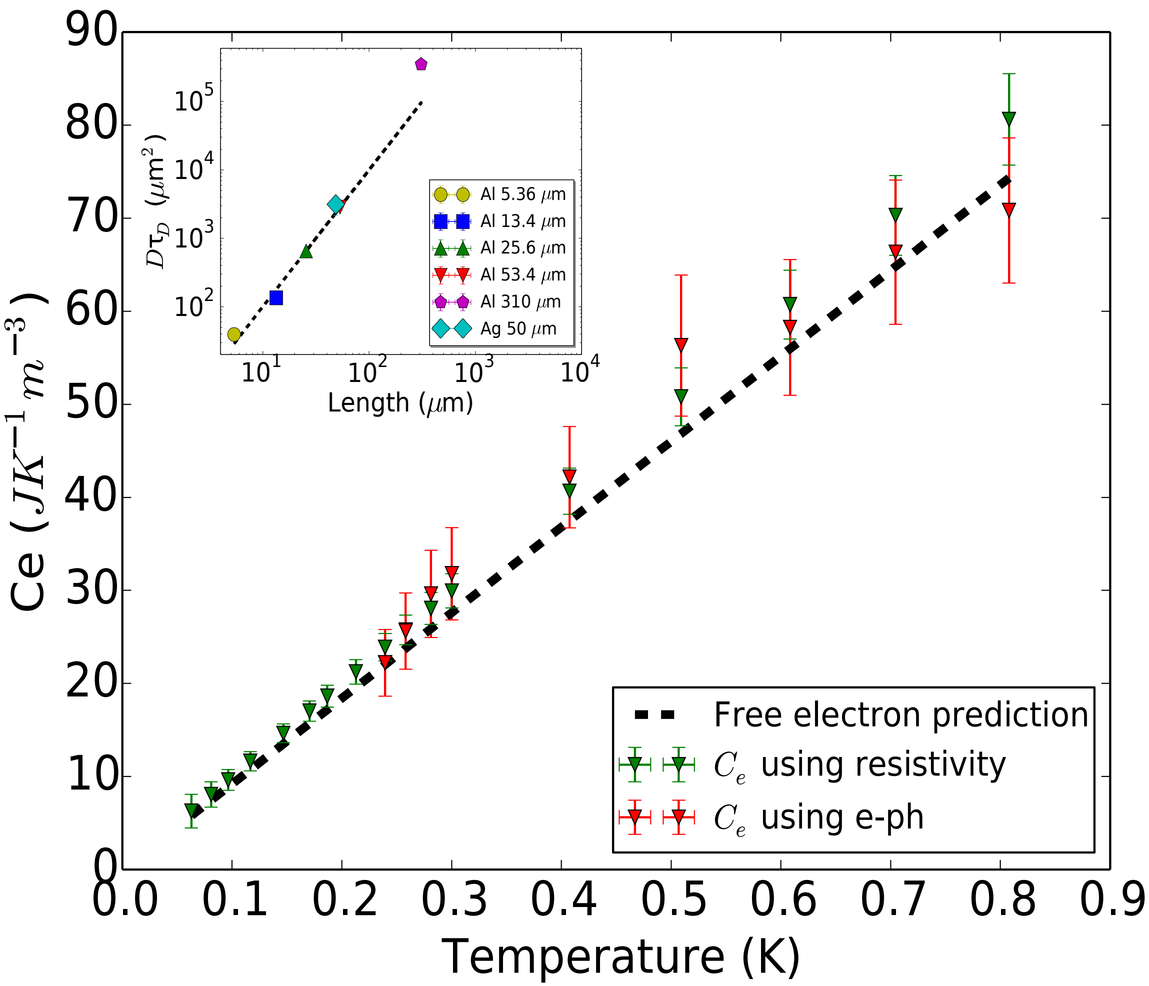

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$$C_e = \gamma T$$

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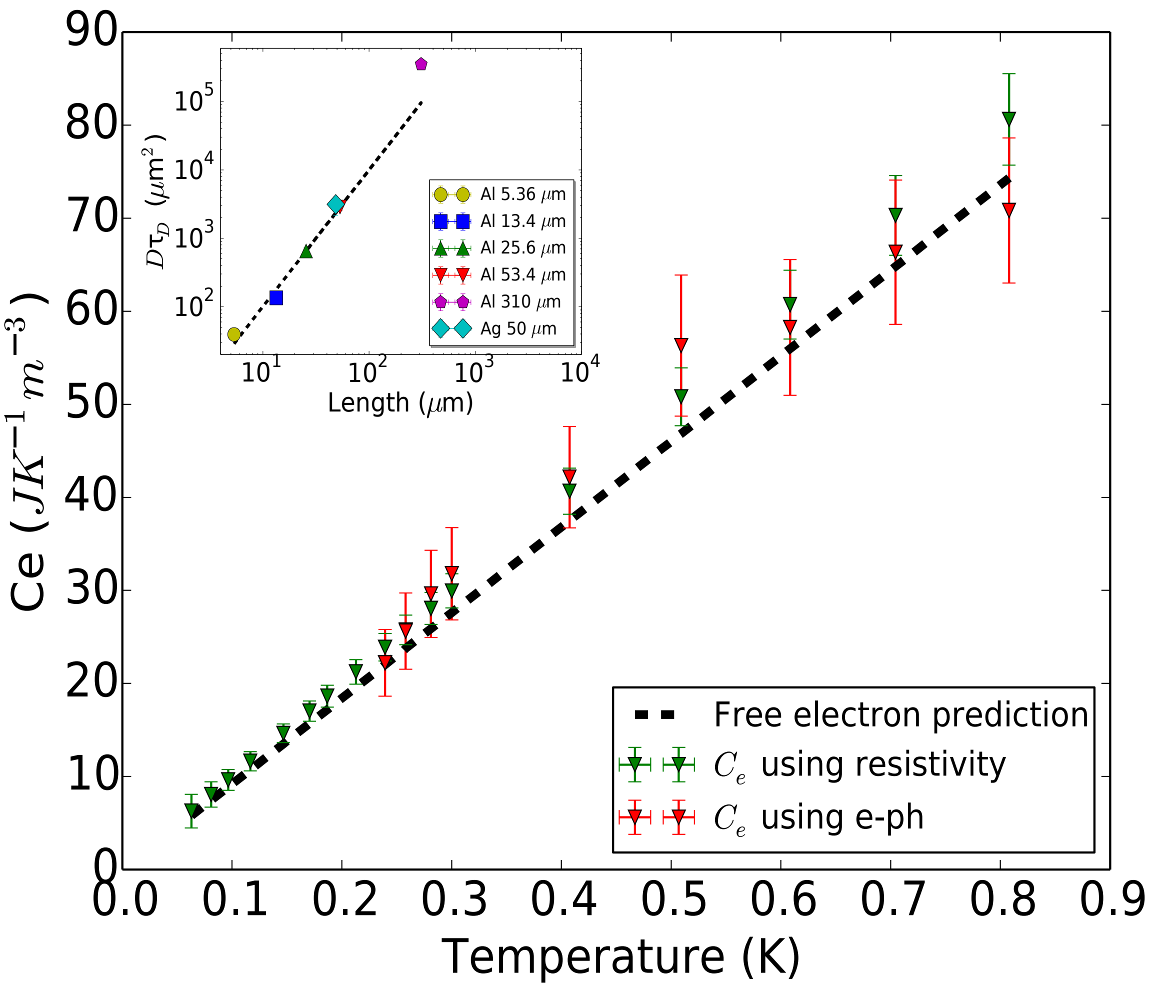

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$$\gamma = 115 J.K^{-2}m^{-3}$$

Effective Mass

Specific heat in a free electron gas:

$$\gamma = \frac{1}{3}\pi^2 k_B^2 n(E_F) = \frac{k_B^2}{3\hbar^2} V k_F m$$

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Effective mass and density of states:

$$\frac{m*}{m} = \frac{n(E_F)*}{n(E_F)} = (1 + \lambda_{ph} + \lambda_c)\frac{m_b}{m}$$

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Metal	Theory				Experiment
	λ_{ph}	λ_c	m_b/m	m^*/m	m^*/m
Al	0.49(0.38) 0.53	−0.01 −0.01	1.04[a]	1.54[c] 1.58[d]	1.48[b]

A. Tari, *The specific Heat of Matter at low Temperatures*, Imperial College Press

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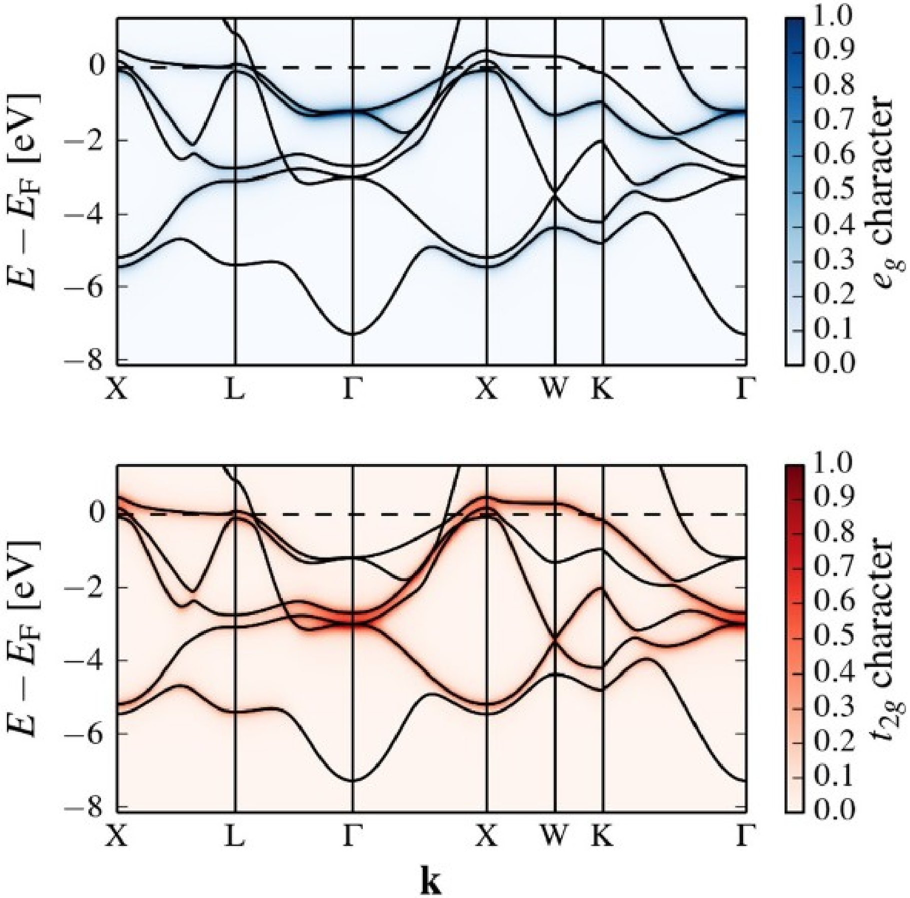
Band structure of Palladium



A. Ostlin et al. PRB 93, 155152

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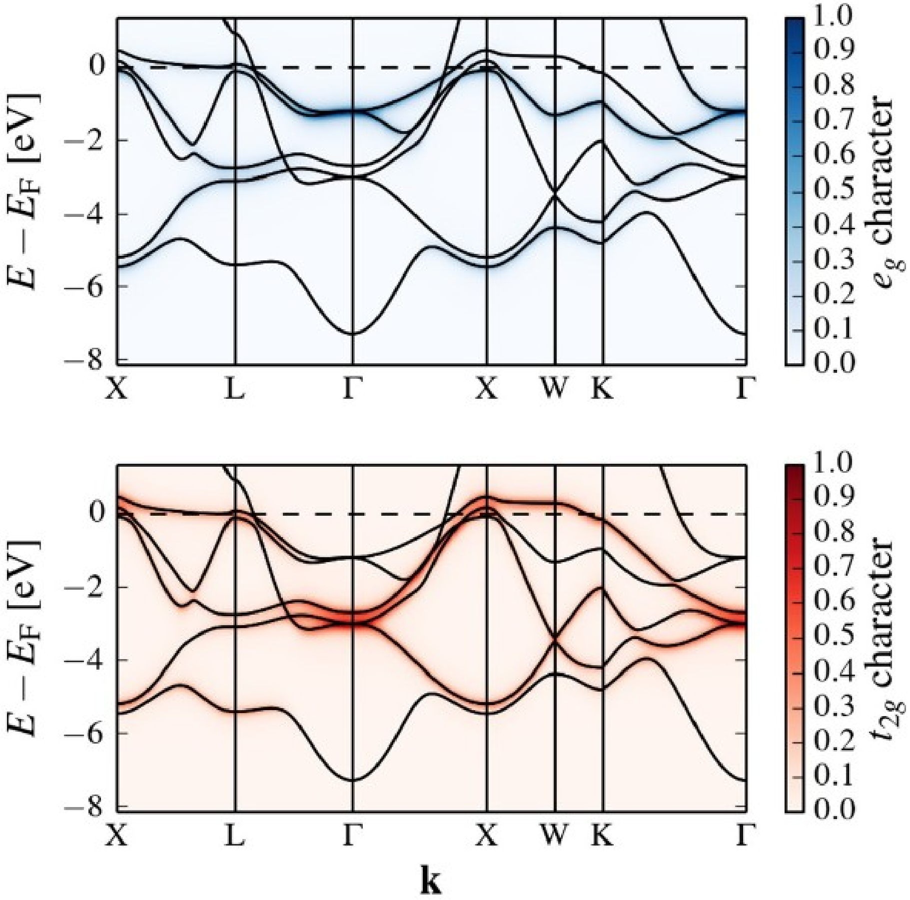

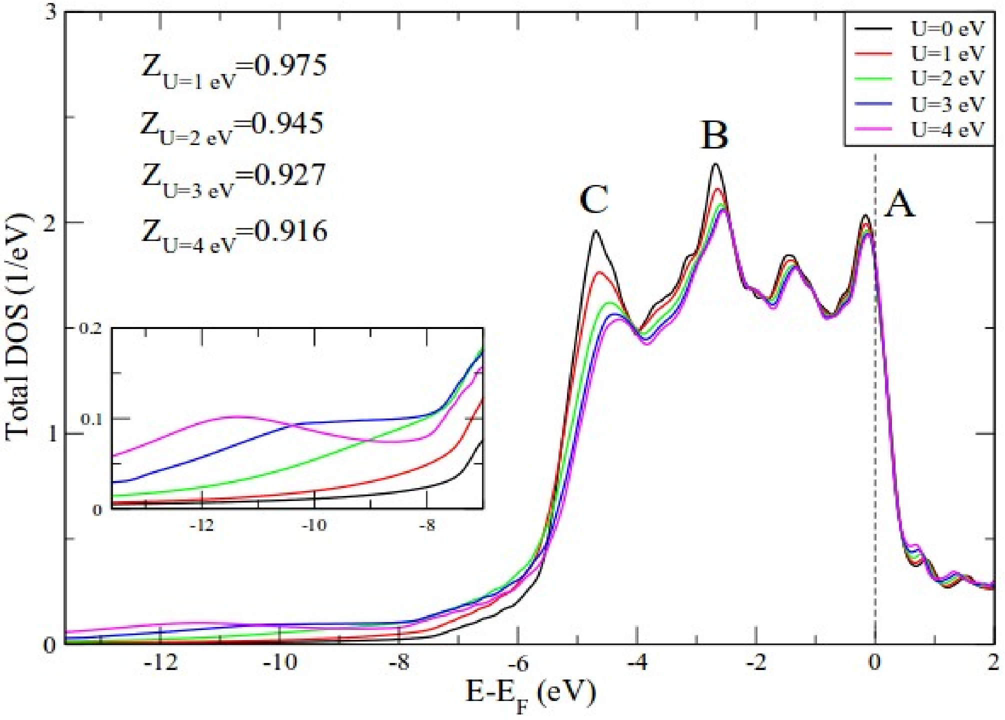

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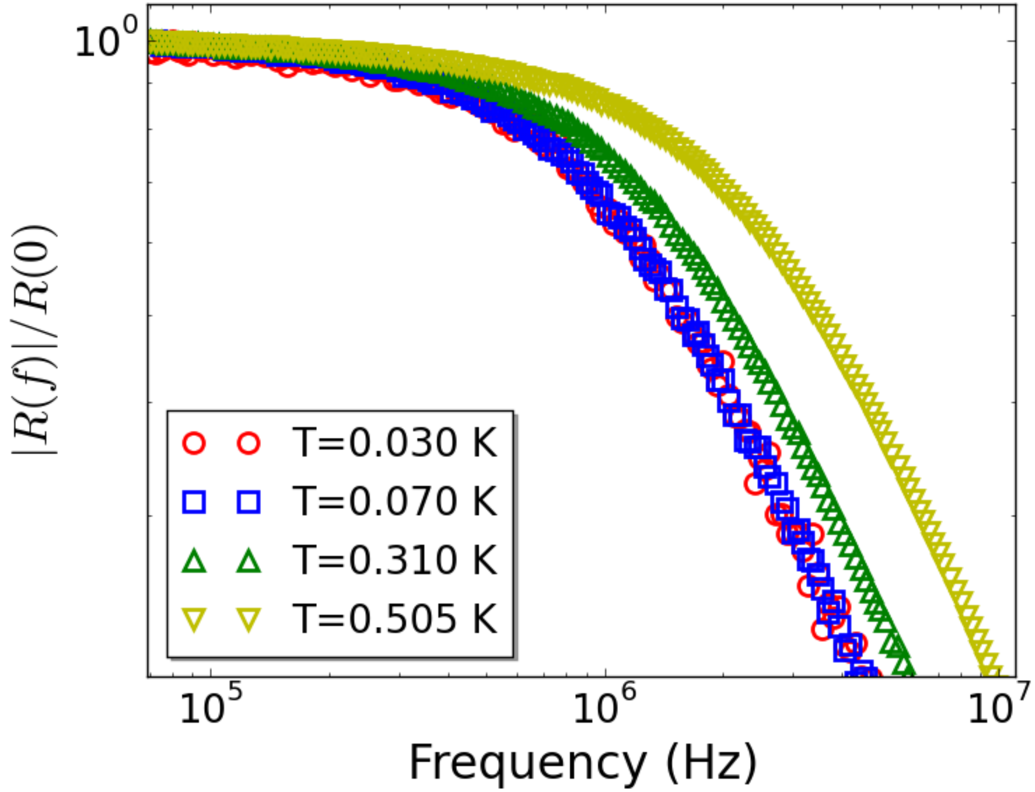
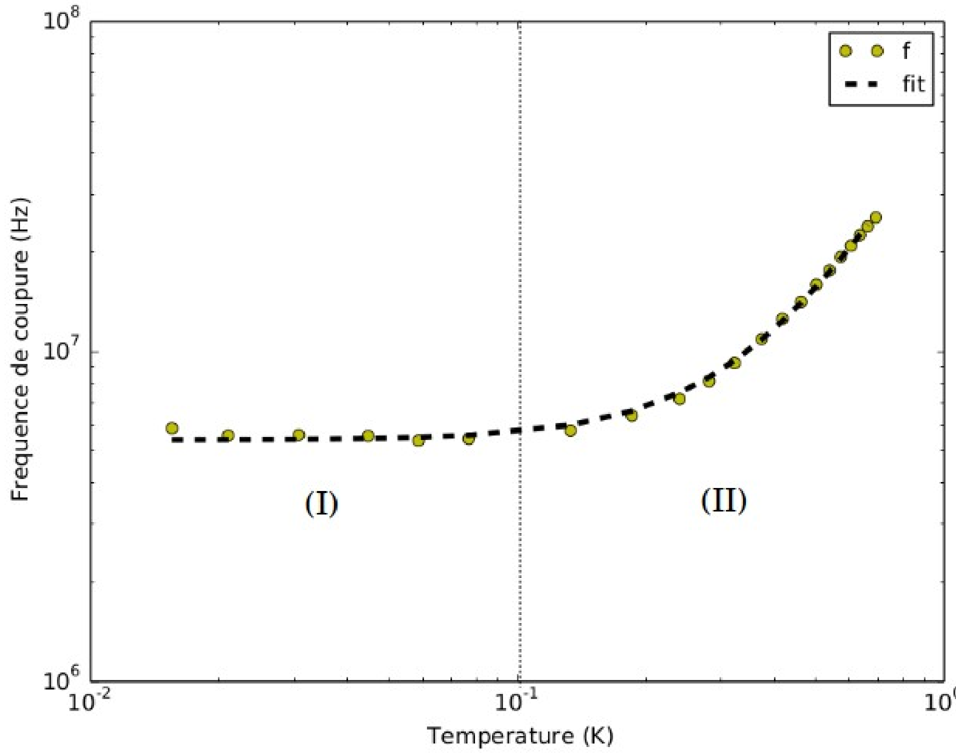
NTI on Palladium





Effective Mass

Specific heat mesured in our Palladium sample:

$$\gamma = 830 J.K^{-2}.m^{-3}$$

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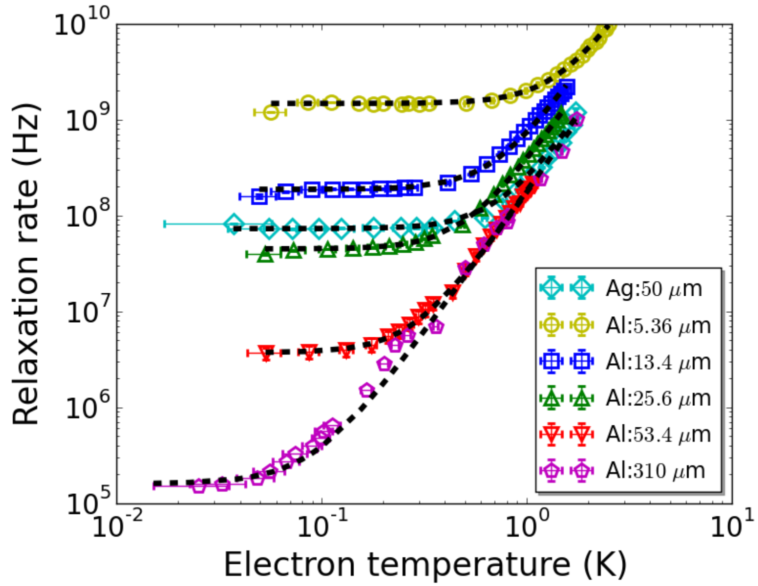
	Theory				Experiment
Metal	λ_{ph}	λ_c	m_b / m	m^* / m	m^* / m
Pd	0.20[e]	0.37[f]	1.66[g]	1.71[h]	

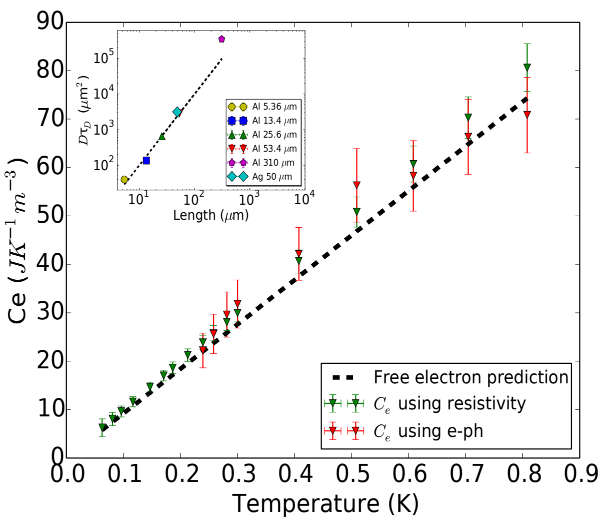
Conclusion



We have developed a technique to mesure directly relaxation times such as:

-Electron-phonon time.

-Diffusion time.



-By combining with resistivity, we were able to check the validity of the Wiedemann-Franz law

-By combining with noise measurements, we were able to extract the specific heat of our samples.