Noise Thermal Impedance: a way to access electron dynamics

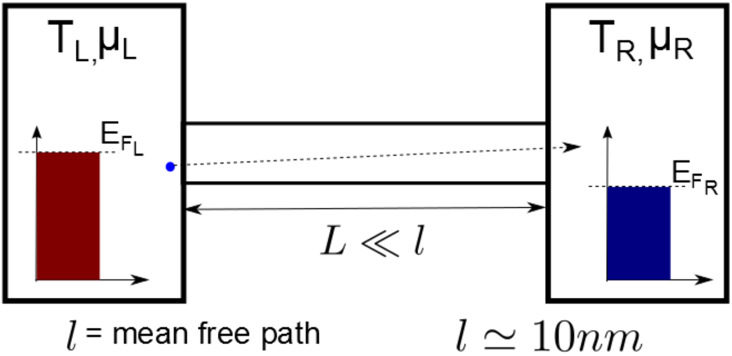
Edouard Pinsolle

University of Sherbrooke

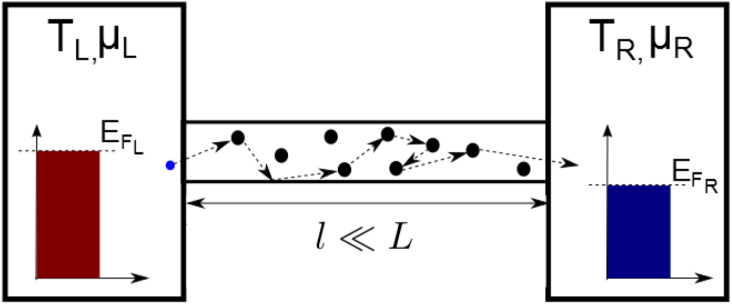
UPON 2015

1. Electronic transport in a metallic wire
   - Ballistic Case
   - Diffusive Case
   - Macroscopic Case
   - Electron dynamic in wires
2. Using noise to probe electron dynamic.
   - Actual Technics
   - Noise Thermal Impedance
3. Experimental Results
   - Experimental setup
   - Noise thermal impedance
   - Relaxation times

Ballistic Case

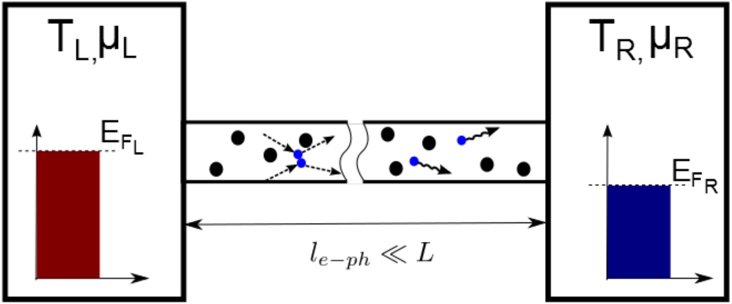


Diffusive Case



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

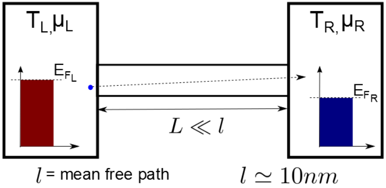
Macroscopic Case

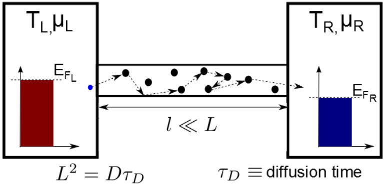


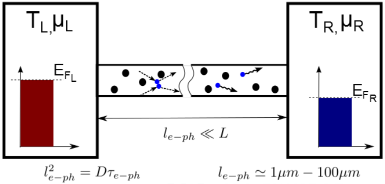
$l_{e-ph}^2 = D\tau_{e-ph}$ $l_{e-ph} \simeq 1\mu m - 100\mu m$

UNIVERSITÉ DE SHERBROOKE

Various Regimes

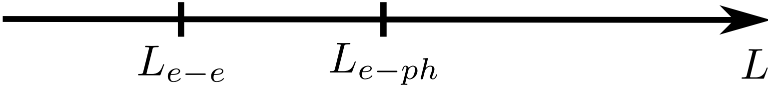




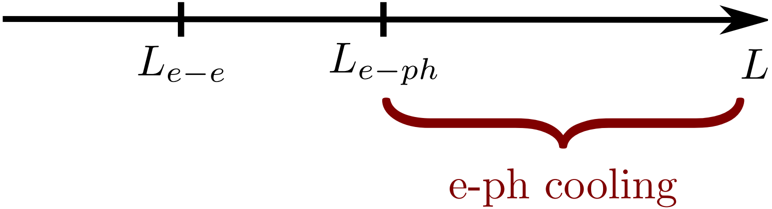


SHERBROOKE

Electron Dynamic

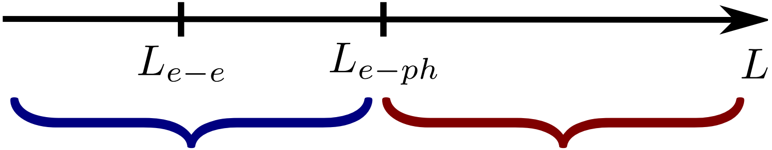


Electron Dynamic



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

Electron Dynamic



Diffusion Cooling — e-ph cooling

$$\frac{1}{\tau_D} = \frac{D}{L^2} \qquad \frac{1}{\tau_{e-ph}} = A \times T^3$$

Actual Technics

Actual Technics

- Diffusion time, low temperature conductivity:

$$\sigma = n \times e^2 D$$

Actual Technics

- Diffusion time, low temperature conductivity:

$$\sigma = n \times e^2 D$$

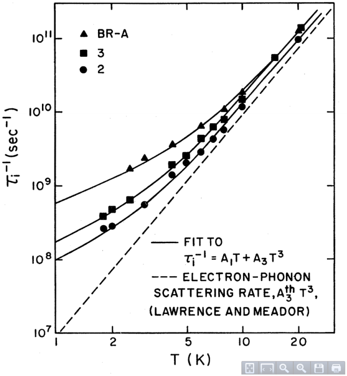
- Interaction times, magneto-conductivity:

Actual Technics

- Diffusion time, low temperature conductivity:

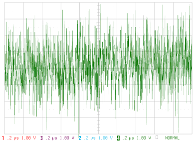
$$\sigma = n \times e^2 D$$

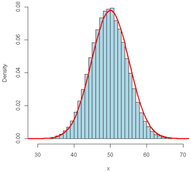
- Interaction times, magneto-conductivity:



UNIVERSITÉ DE SHERBROOKE

Noise in a metallic wire





$$V(t) = V + \delta V(t)$$

We are interested by the second order moment of the distribution P(V):

$$\Delta V^2 = < \delta V(t)^2 >$$

:

In the following experiment we measure the noise in frequency domain:

$$S = TF[\Delta V^2] = 4Rk_B T_e$$

UNIVERSITÉ DE SHERBROOKE

Experimental Principle

Exitation $= \delta P^{\omega}$

UNIVERSITÉ DE SHERBROOKE

Experimental Principle

$$\text{Exitation} = \delta P^{\omega}$$

$$\text{Response} = \delta T_e^{\omega}$$

Experimental Principle

Exitation $= \delta P^{\omega}$

Response $= \delta T_e^{\omega}$

Joule heating:

$$P = \frac{(V_{dc} + \delta V \cos(\omega t))^2}{R}$$

Experimental Principle

$$\text{Exitation} = \delta P^{\omega}$$

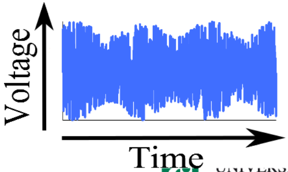
$$\text{Response} = \delta T_e^{\omega}$$

Joule heating:

$$P = \frac{(V_{dc} + \delta V \cos(\omega t))^2}{R}$$

Noise temperature:

$$\delta T_e = \frac{\delta S}{4Rk_B}$$



UNIVERSITÉ DE SHERBROOKE

Experimental Principle

$$\text{Exitation} = \delta P^{\omega}$$

$$\text{Response} = \delta T_e^{\omega}$$

Thermal impedance

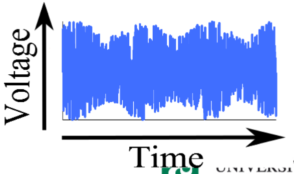
$$R(\omega) = \frac{\delta T_e^{\omega}}{\delta P^{\omega}}$$

Joule heating:

$$P = \frac{(V_{dc} + \delta V \cos(\omega t))^2}{R}$$

Noise temperature:

$$\delta T_e = \frac{\delta S}{4 R k_B}$$



UNIVERSITÉ DE SHERBROOKE

Experimental Principle

$$\text{Exitation} = \delta P^{\omega}$$

$$\text{Response} = \delta T_e^{\omega}$$

Thermal impedance

$$R(\omega) = \frac{\delta T_e^{\omega}}{\delta P^{\omega}}$$

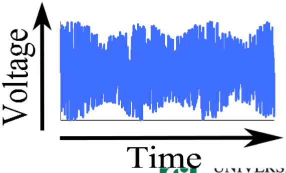
$$\|R(\omega)\| = \frac{G_{e-ph}^{-1}}{\sqrt{1 + (\omega \tau_{e-ph})^2}}$$

Joule heating:

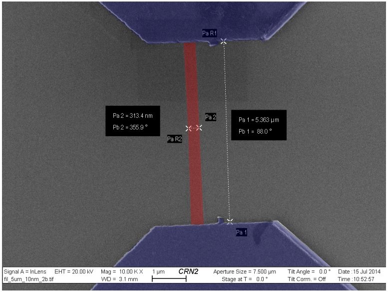
$$P = \frac{(V_{dc} + \delta V \cos(\omega t))^2}{R}$$

Noise temperature:

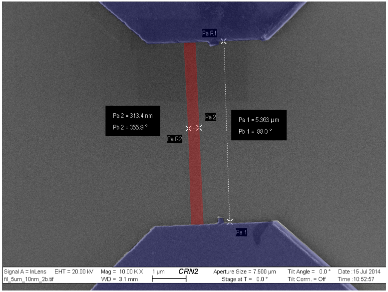
$$\delta T_e = \frac{\delta S}{4 R k_B}$$

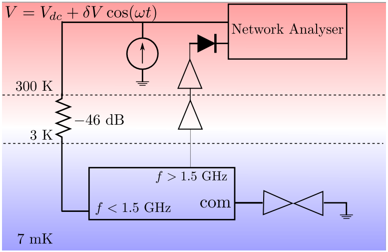


Experimental setup

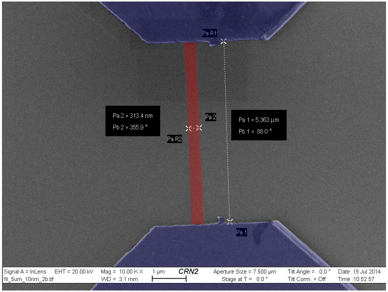


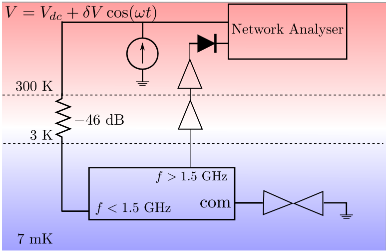
Experimental setup





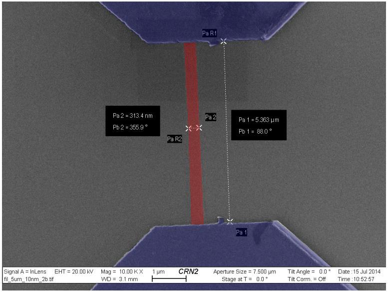
Experimental setup

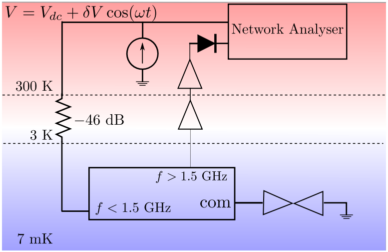




- $\delta V \ll V_0$

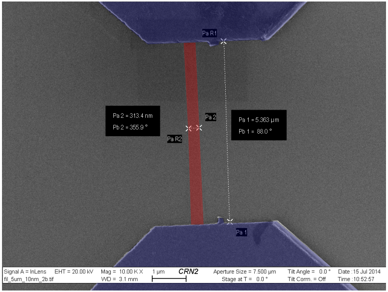
Experimental setup

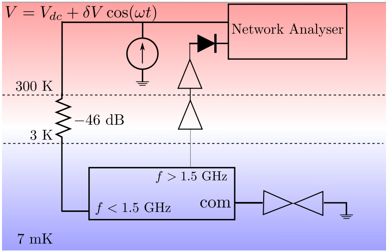




- $\delta V \ll V_0$
- $\omega \ll \tau_{diode}^{-1}$

Experimental setup



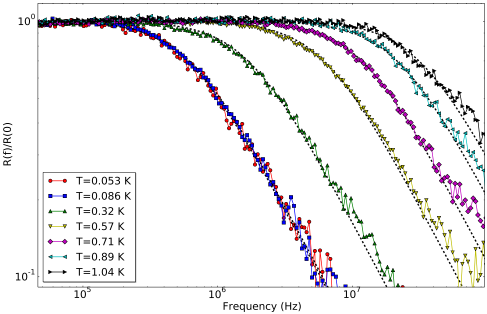


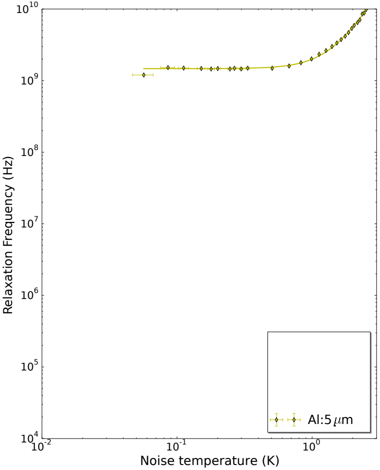
- $\delta V \ll V_0$
- $\omega \ll \tau_{diode}^{-1}$
- $\tau_{diode}^{-1} \ll f_{mesure}$

UNIVERSITÉ DE SHERBROOKE

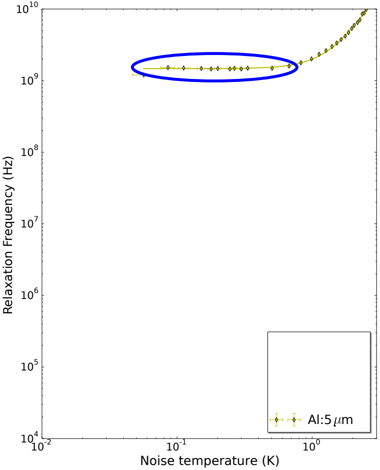
Noise Thermal Impedance

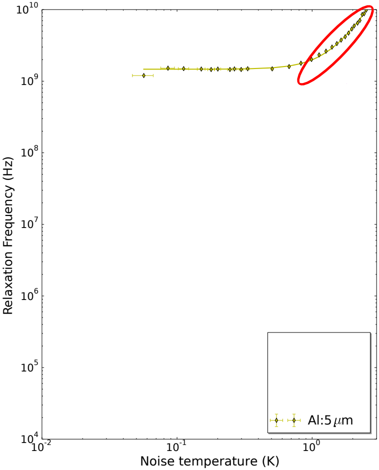
$$\|R(\omega)\| = \frac{G_{e-ph}^{-1}}{\sqrt{1 + (\omega\tau_{e-ph})^2}}$$

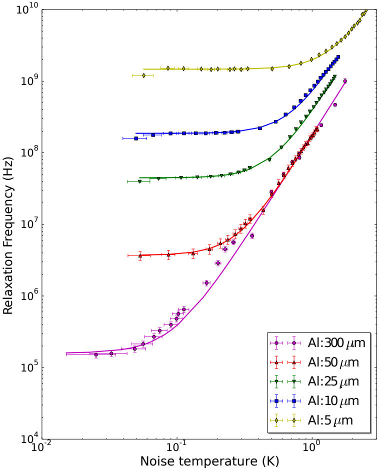




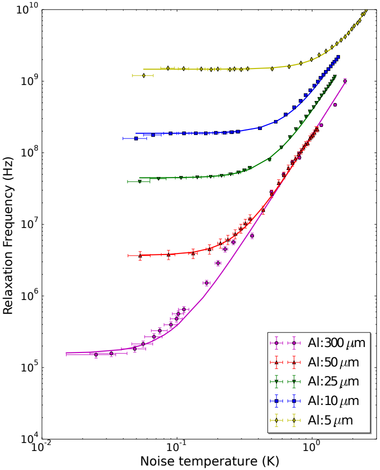
Relaxation Frequency (Hz)
Noise temperature (K)
Al:5 μm


Relaxation Frequency (Hz)
Noise temperature (K)
Al:5 μm
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{-2}
10^{-1}
10^{0}


Relaxation Frequency (Hz)
Noise temperature (K)
Al:5 μm
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^-2
10^-1
10^0



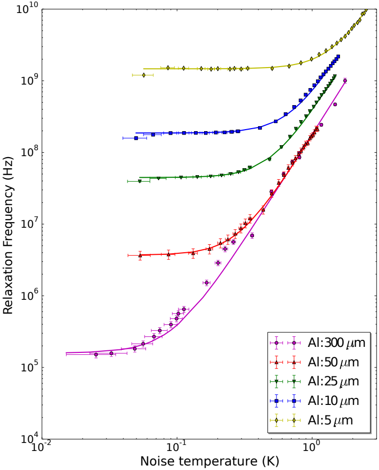
UNIVERSITÉ DE SHERBROOKE



- At low temperature cooling through diffusion:

$$f_D = cste$$

UNIVERSITÉ DE SHERBROOKE

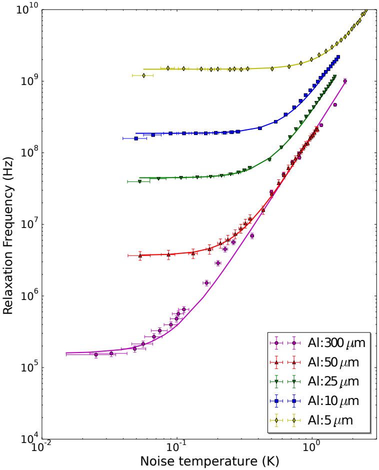


- At low temperature cooling through diffusion:

$$f_D = cste$$

- At high temperature cooling through e-ph interaction:

$$f_{e-ph} = AT^3$$



- At low temperature cooling through diffusion:

$$f_D = cste$$

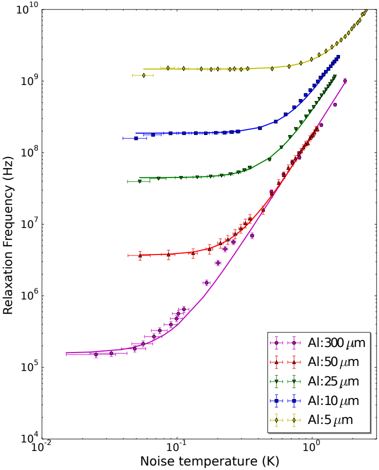
- At high temperature cooling through e-ph interaction:

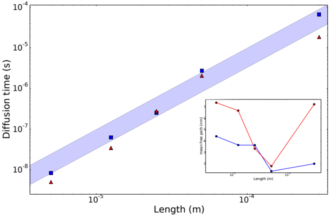
$$f_{e-ph} = AT^3$$

- The fit suppose that relaxation frequencies add up:

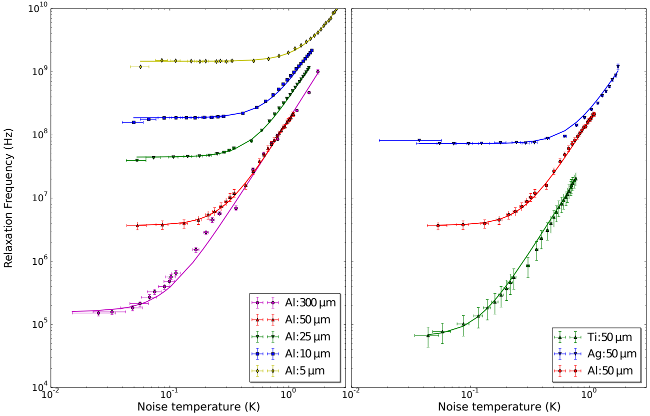
$$f_{tot} = f_{e-ph} + f_D$$

UNIVERSITÉ DE SHERBROOKE


Relaxation Frequency (Hz)
Noise temperature (K)
Al:300 µm
Al:50 µm
Al:25 µm
Al:10 µm
Al:5 µm


Diffusion time (s)
Length (m)

$$L^2 = D\tau_D$$



Relaxation Frequency (Hz)
Noise temperature (K)
Noise temperature (K)
Al:300 µm
Al:50 µm
Al:25 µm
Al:10 µm
Al:5 µm
Ti:50 µm
Ag:50 µm
Al:50 µm

Thank you for your attention