Noise Thermal Impedance: a way to access electron dynamics.

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I. INTRODUCTION

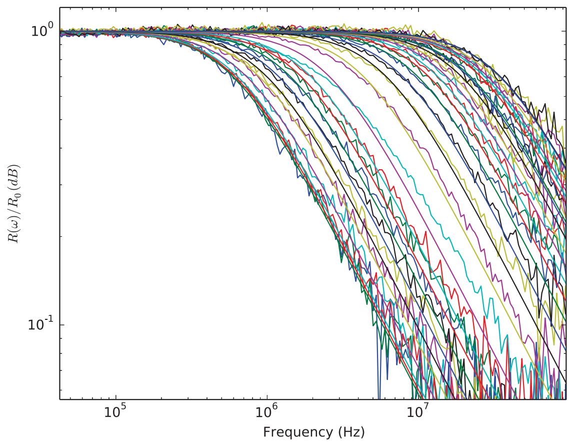
In good conductors the frequency dependence of the conductance and the noise is given only by charge screening. To have access to inelastic processes or diffusion times in such samples one need to measure small quantum corrections to the conductance[1] or tunneling properties on materials with which tunnel junction can be made[2]. Those are inderect measurements of interactionis and diffusion time and are sometimes hard to access. Recently B. Reulet and D.E. Prober have proposed a new technique based on Johnson noise measurement to directly access the dynamic of electrons in normal metals[3]. They named it Noise Thermal Impedance (NTI).

II. EXPERIMENTAL PRINCIPAL AND RESULTS

In the case of Johnson noise the current noise density S_2 is determined directly by the electron gaz temperature T by: $S_2 = 4kBTG$. It's interesting to generalize this link by defining the noise temperature $T_N = S_2/(4k_BG)$. The NTI measure the fluctuations of the noise temperature δT_N^ω of an electron gaz heated by an oscillating power δP_J^ω at frequency ω. This complex response function is define as $R(\omega) = \delta T_N^\omega/\delta P_J^\omega$.
B. Reulet and D.E Prober calculated[3] the expected form of this response function for a metallic diffusive wire for several limiting cases. In those kind of samples one can distinguish between three regimes depending on the sample length and the temperature. For long sample $L \gg L_{e-ph}$ the energie relaxation of the electron gaz is dominated by electron-phonon interactions, this is called the macroscopic regime. In this case the energie relaxation occurs in a time τ_{e-ph} given by the mean electron-phonon interaction time and the NTI have the form:

$$R(\omega) = \frac{\delta T_e^\omega}{\delta P_J^\omega} = \frac{G_{e-ph}^{-1}}{(1 + i\omega\tau_{e-ph})} \tag{1}$$

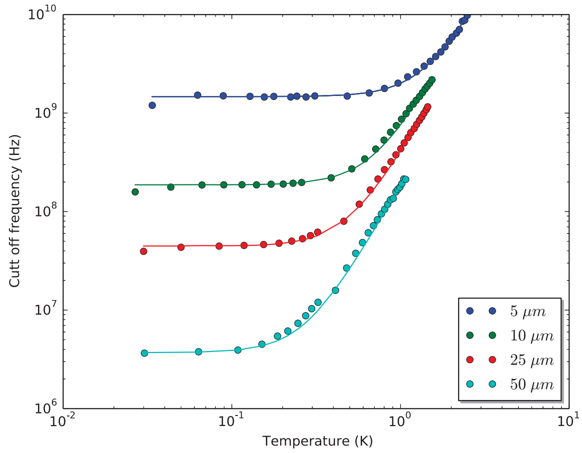
For smaller samples $L \ll L_{e-ph}$ electron-phonon processes are ineficient and the energie relaxation is dominated by diffusion of hot electrons into the leads. The time scale associated is given by the diffusion time τ_D. In this length scale one can discriminate between a case $L_{e-e} \ll L$ where electrons exchange energie, called hot electron regime, and a case where electrons don't interacte with each others, called independent electron regime. In those two regimes the time scale of energie relaxation is given by the diffusion time τ_D. We have applied this technique to different metallic wires to measure directly the electron-phonon interaction times and the diffusion time in function of temperature and length to go throught hot electron regime to macroscopic regime.
"In Fig. (1)" we present the noise thermal impedance for a 50 μm long aluminum wire at different temperatures. Those curves are in good agreement with the equation 1 superposed to the experimental data. We have repeted this experiment for different wire lenghtes from $5\mu m$ to $50\mu m$ and extract the cutoff frequencies.



"FIG. 1. Amplitude of the normalised noise thermal impedance in function of frequency for a 50 μm long aluminum wire. The different curves correspond to different electron noise temperatures from around 30 mK to 1.5 K. Those curves are fitted with the equation 1 which permit to extract a cutoff frequency "

"In Fig. (2)" we present those cutoff frequencies in function of temperature for the different wires. At high temperature we observe a power law caracteristic of an electron-phonon interaction time ($\tau_{e-ph}^{-1} = A * T^3$)[4]. When we decrease the temperature we acess a regime where the energy relaxation is dominated by diffusion. As we expected, this diffusion time is independant of temperature which gives rise to a plateau at law temperature. The different curves as been fited by assuming that, in presence of different relaxation processes, the frequencies add up $\tau_{relaxation}^{-1} = \tau_D^{-1} + \tau_{e-ph}^{-1}$. We checked that the diffusion time is proportionnal to the sample length in

agreement with a diffusion law $L^2 = D\tau_D$. This permit us to extract the diffusion coefficient.
This experiment demonstrate that a NTI measurement is of great interest to access dynamics of electron gazes. This could be applied to probe diffusion times in new materials such as h-graphene or to investigate electron-phonon interaction in High T_c superconductors. One could also imagine to study diffusion law in more fancy sample with a fractal dimention[5].



"FIG. 2. Energy relaxation frequencies in function of electron noise temperature for aluminum wires of different lengthes."

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