Thermal Conductance of a Single-Electron Transistor

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Wiedemann-Franz Law

$$\frac{\kappa}{\sigma} = L_0 T$$

$$L_0 = \frac{\pi^2 {k_b}^2}{3e^2} = 2.44 \times 10^{-18} \mathrm{W\Omega K^{-2}}$$

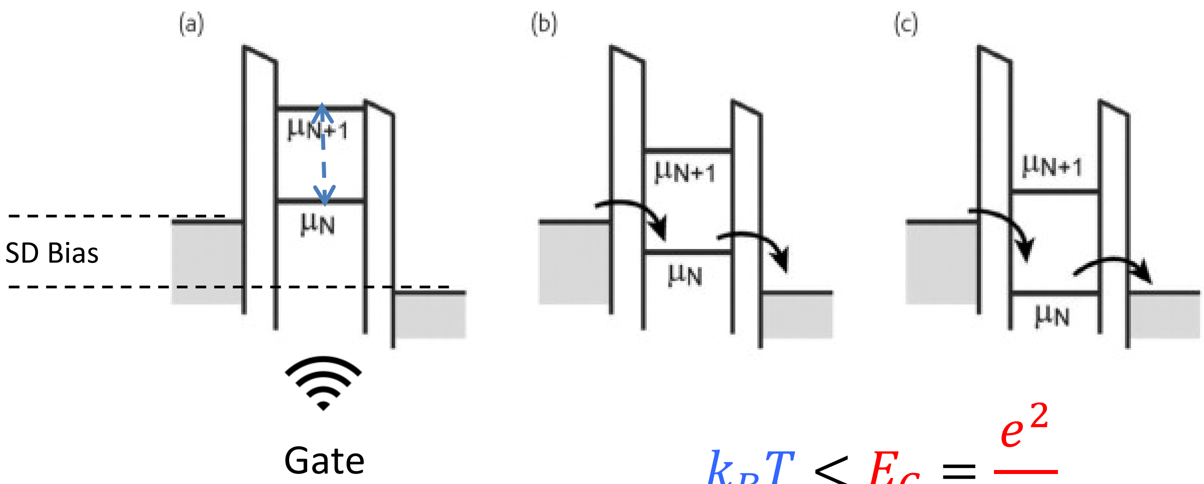
Validity: limiting process

- High temperatures : Phonon scattering

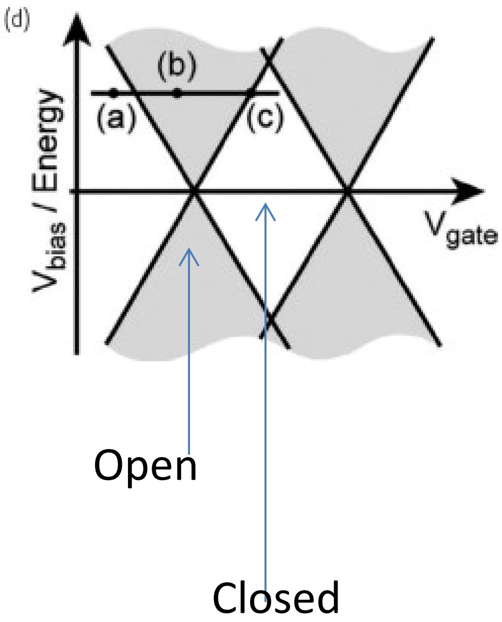
----Deviations----

- Low temperatures : Impurity scattering

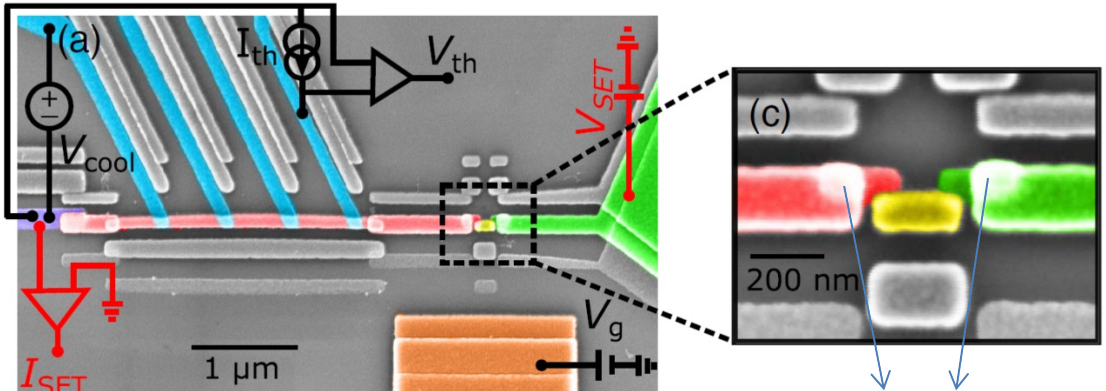
Single Electron Transistor



$$k_B T < E_C = \frac{e^2}{2C}$$



SET Device with NIS Thermometry

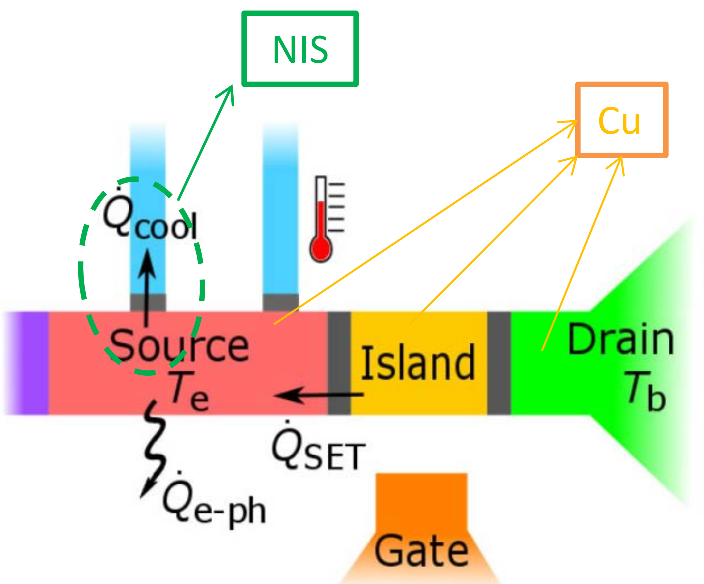


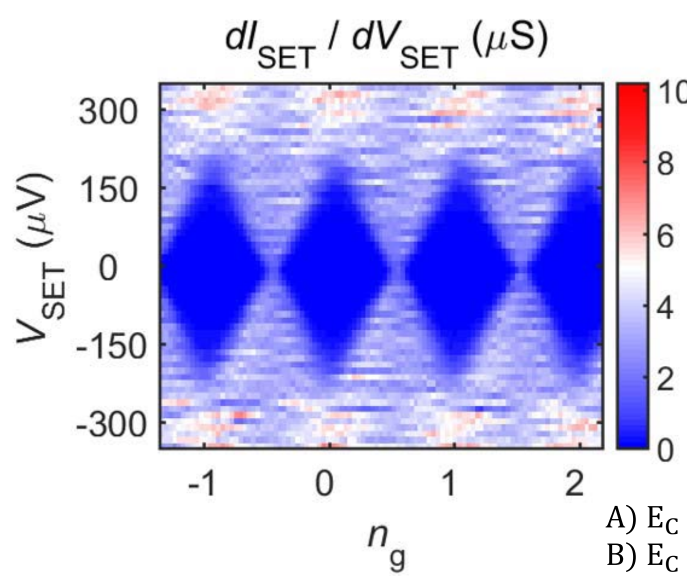
Inverse Proximity Effect*

Red = charge transport
Black = heat transport

Large ground plane : Au(30nm)

1) Cu 30nm for A (164 kΩ)
   45nm for B (52 kΩ)
2) Al 20nm
   in-situ oxidation
3) Cu 30nm





A) $E_C = 155\ \mu eV$
B) $E_C = 100\ \mu eV$

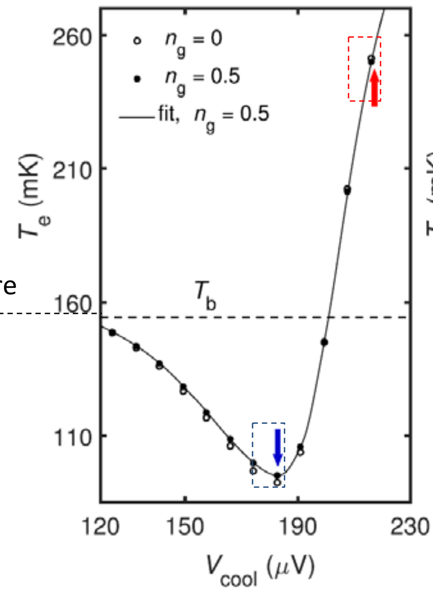
* Koski J.V., et al., Laterally proximized aluminum tunnel junctions, Appl. Phys. Lett. 98, 206501 (2011)

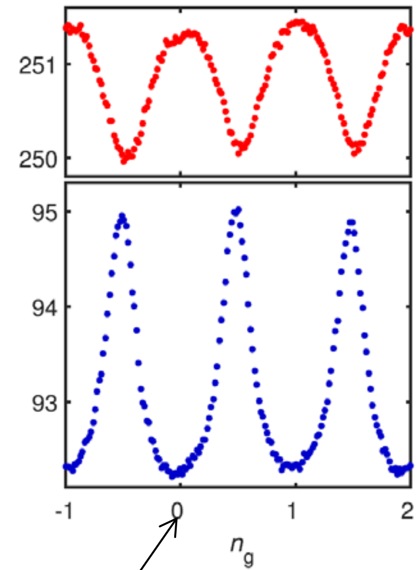
T_e vs T_b : Overheating and Cooling

$T_e > T_b$

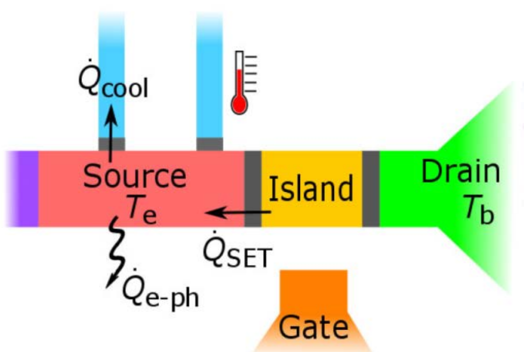
Bath temperature

$T_e < T_b$





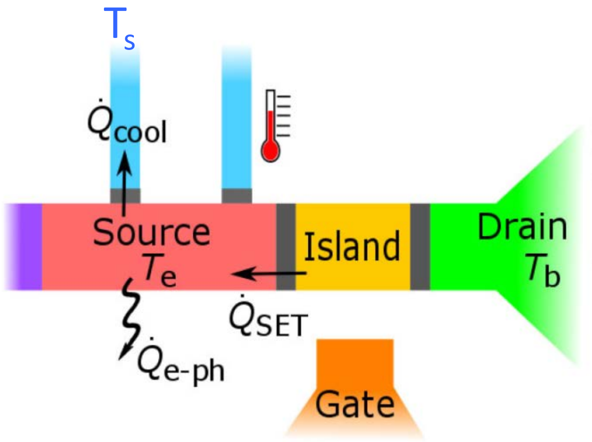
Gate closed



Maximum cooling ≈ $\Delta_{Al} = 208\ \mu eV$

*Nahum M. et al., Electronic microrefrigerator based on a NIS tunnel junction, APL, 65, 3123 (1994)

Analysis



Thermal Balance in the source

$$\dot{Q}_{cool} = \left(\frac{1}{e^2 R_{cool}}\right) \int_{-\infty}^{+\infty} (E - eV_{cool})\ n_s(E)\ [f_{source}(E - eV_{cool}) - f_s(E)]dE - \dot{Q}_0$$

Tunnel Junction Resistance

BCS DOS

Thermal Energy Distribution

Parasitic Power

0.1 fW

Relaxation channel

$$\dot{Q}_{e-ph} = \Sigma\nu(T_e^5 - T_{ph}^5)$$

$$T_b = T_{ph}$$

$$\dot{Q}_{SET} = \dot{Q}_{cool} + \dot{Q}_{e-ph}$$

dI/dV

Extracted + T_e by NIS + V_{cool} = $T_s(V_{cool})$

Gate open position

$$\frac{\kappa}{\sigma} = L_0 T$$

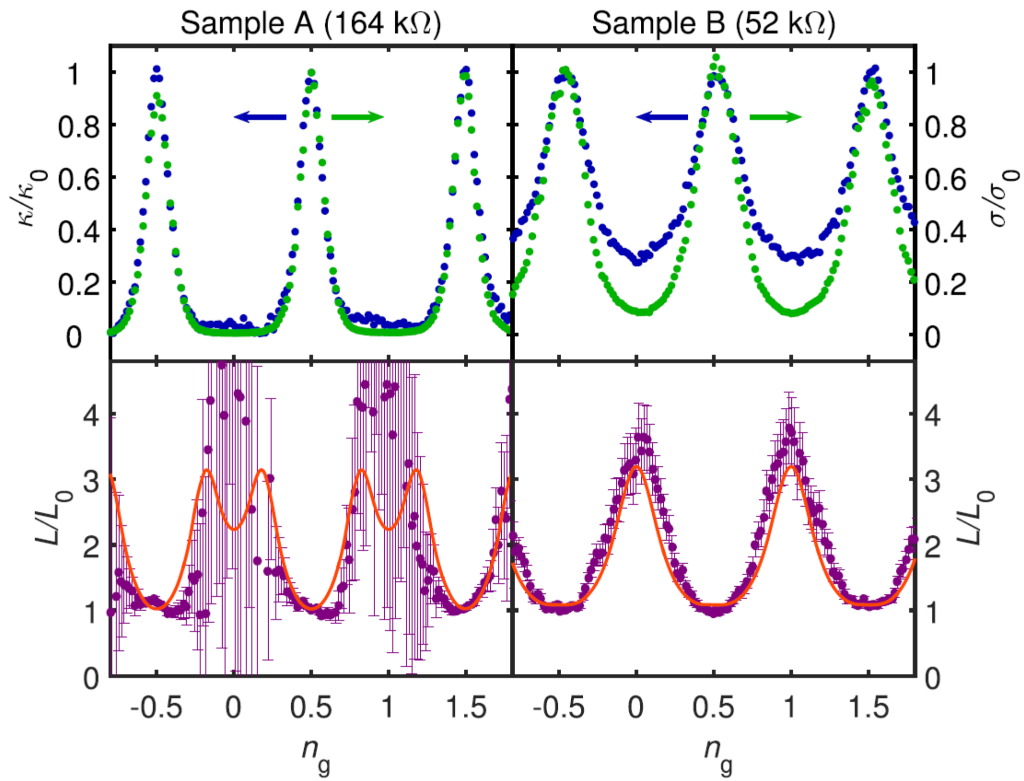
Mesaured $T_e(n_g)$

$$P = \sigma_0 L T_m (T_b - T_e)$$

$$T_m = (T_e + T_b)/2$$

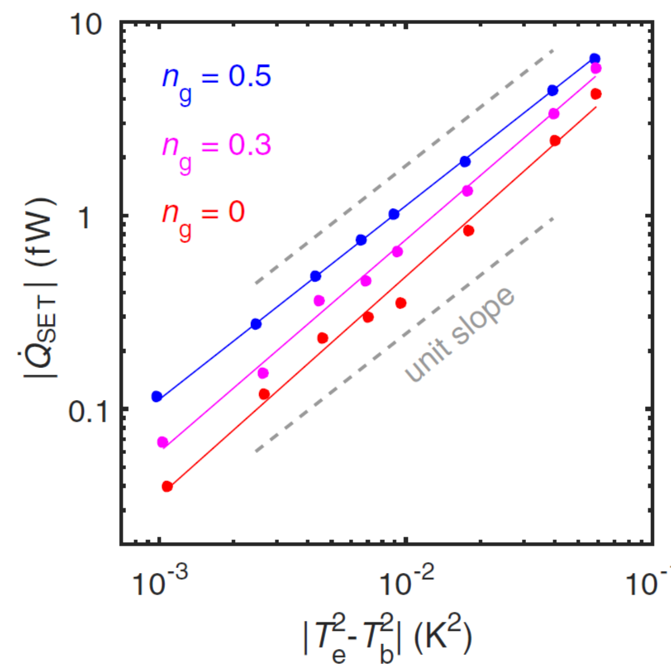
$$\kappa = \frac{\dot{Q}_{SET}}{(T_b - T_e)}$$

Violation of Wiedemann-Franz Law



$T_b = 132\ mK$
$V_{SET} = 22.4\ \mu V$

$T_b = 152\ mK$
$V_{SET} = 19.2\ \mu V$



Large temperature differences

$\kappa \sim T$

$\kappa_0 = \sigma_0 L_0 T_m (n_g = 0.5)$ $\qquad L = \kappa/(\sigma T_m)$

$T_m = (T_e + T_b)/2$

$$\frac{L}{L_0} \neq 1$$

Conclusion

Thermal conductance of SET is investigated

Validity of Wiedemann-Franz Law is tested

NIS Thermometry is used

Thermal conductance depends on the SET state

Vioaltions of Wiedemann-Franz Law

Thank you