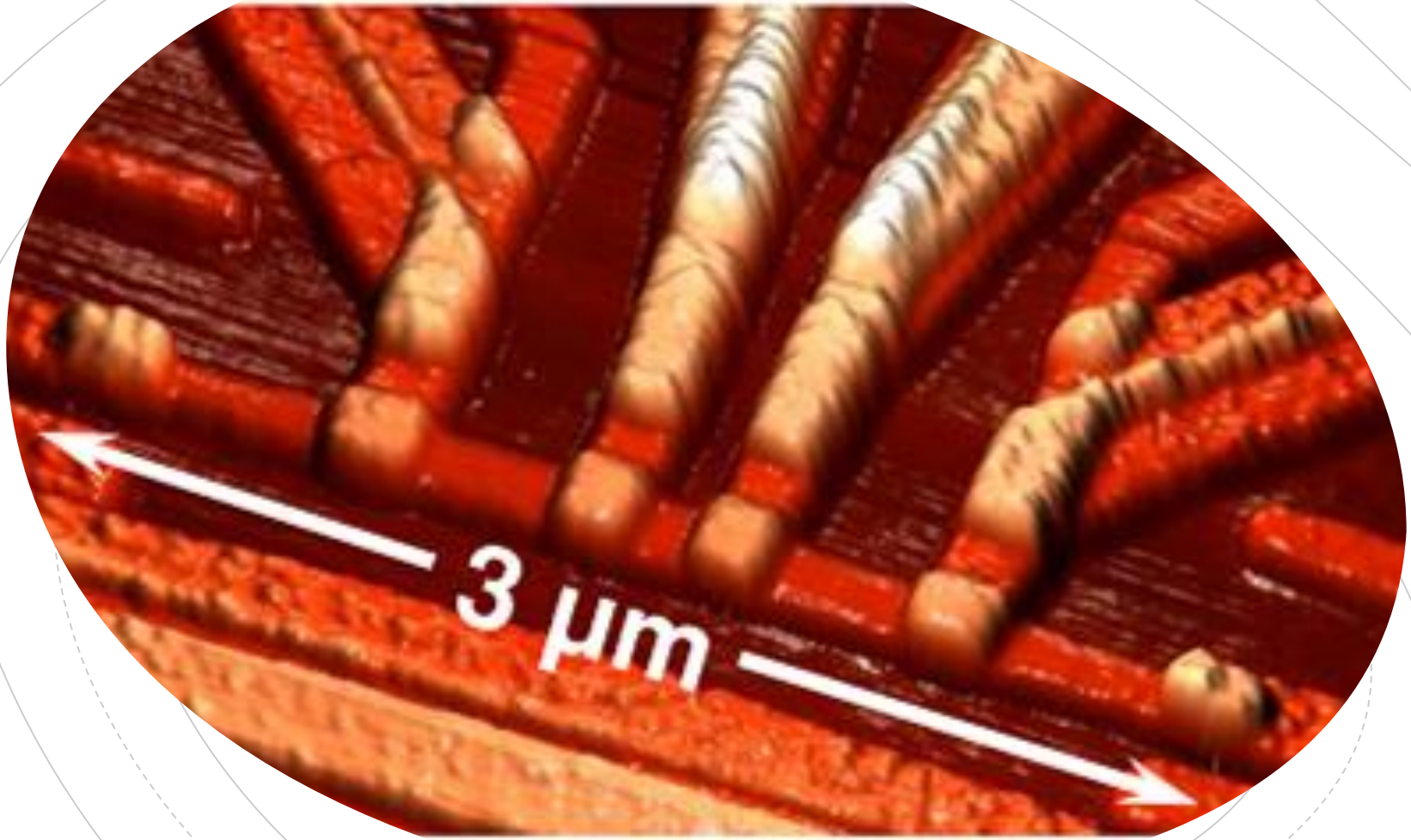
Temperature and thermometry

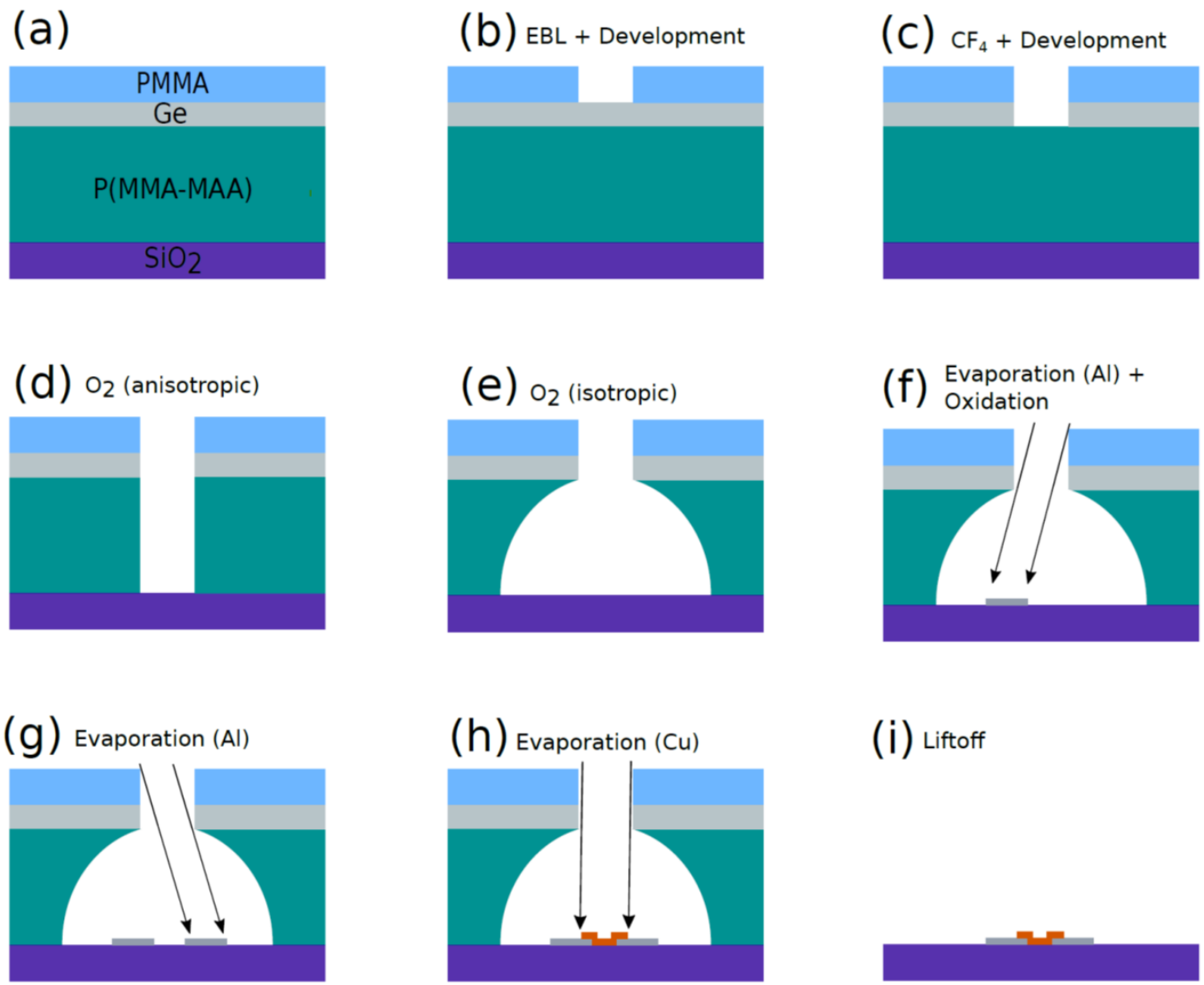


Jukka Pekola

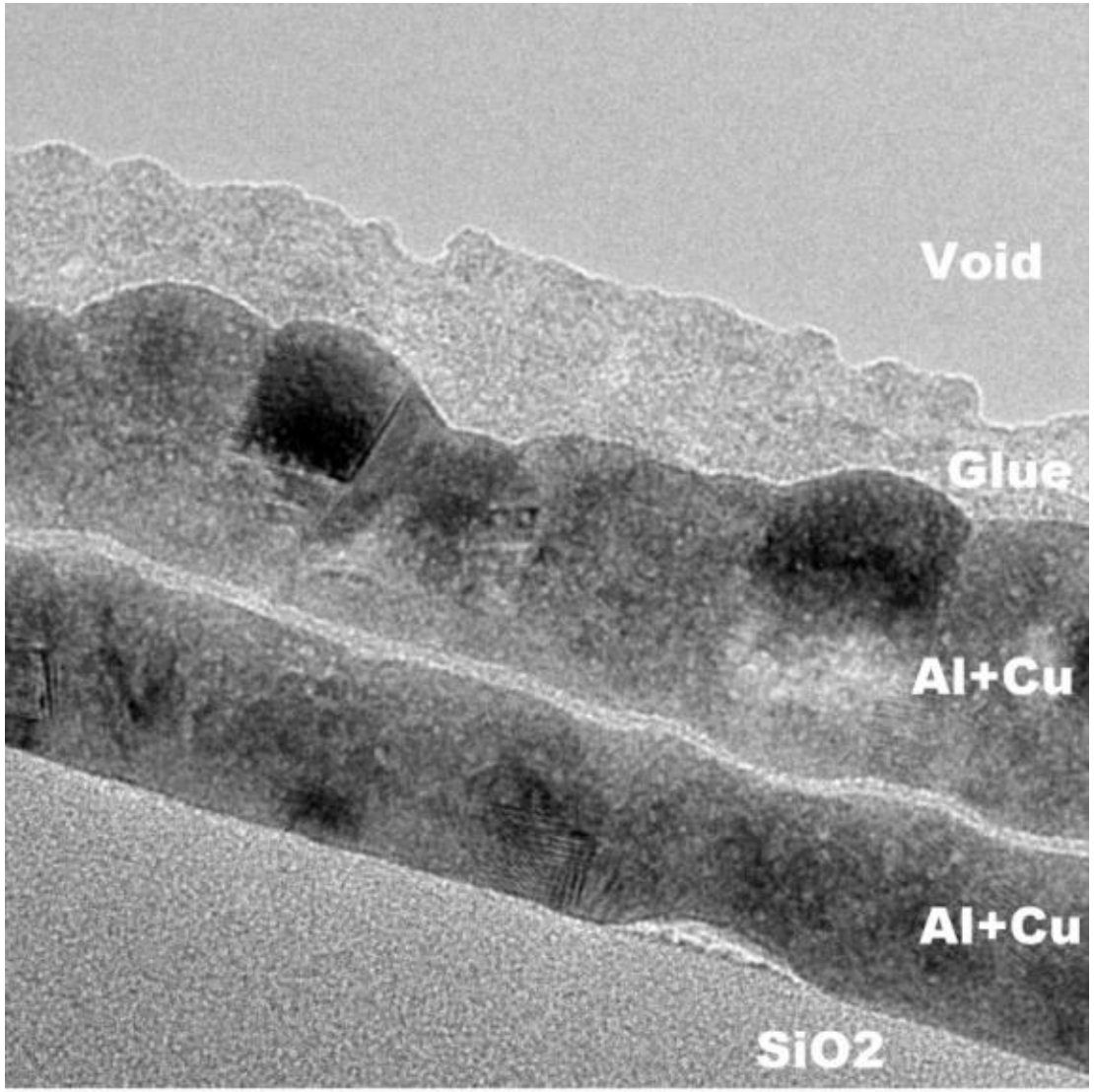
Bayan Karimi

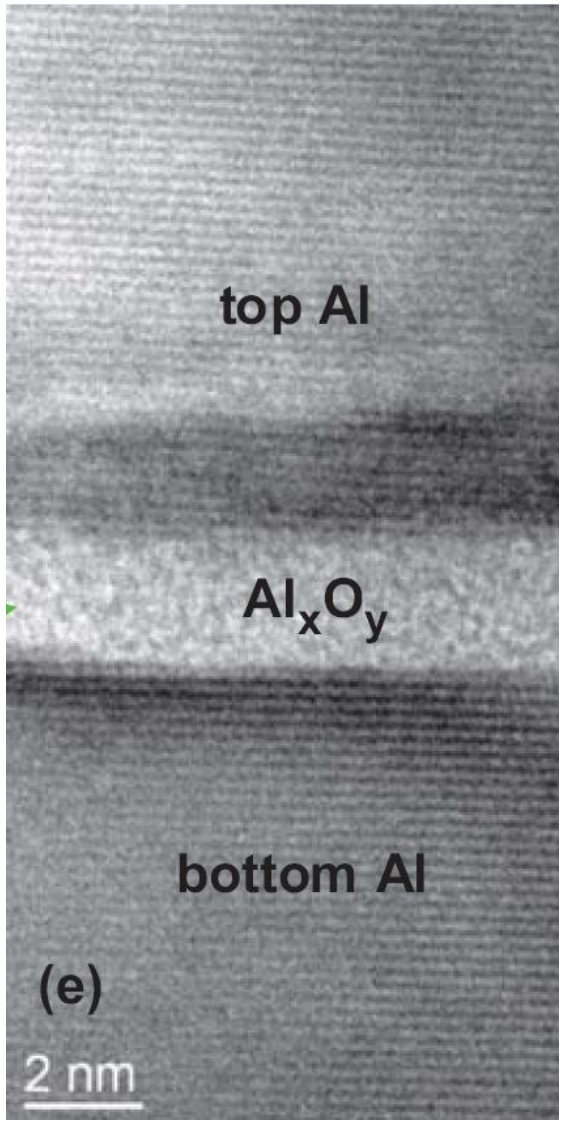
Pico group, Aalto University

Sample fabrication



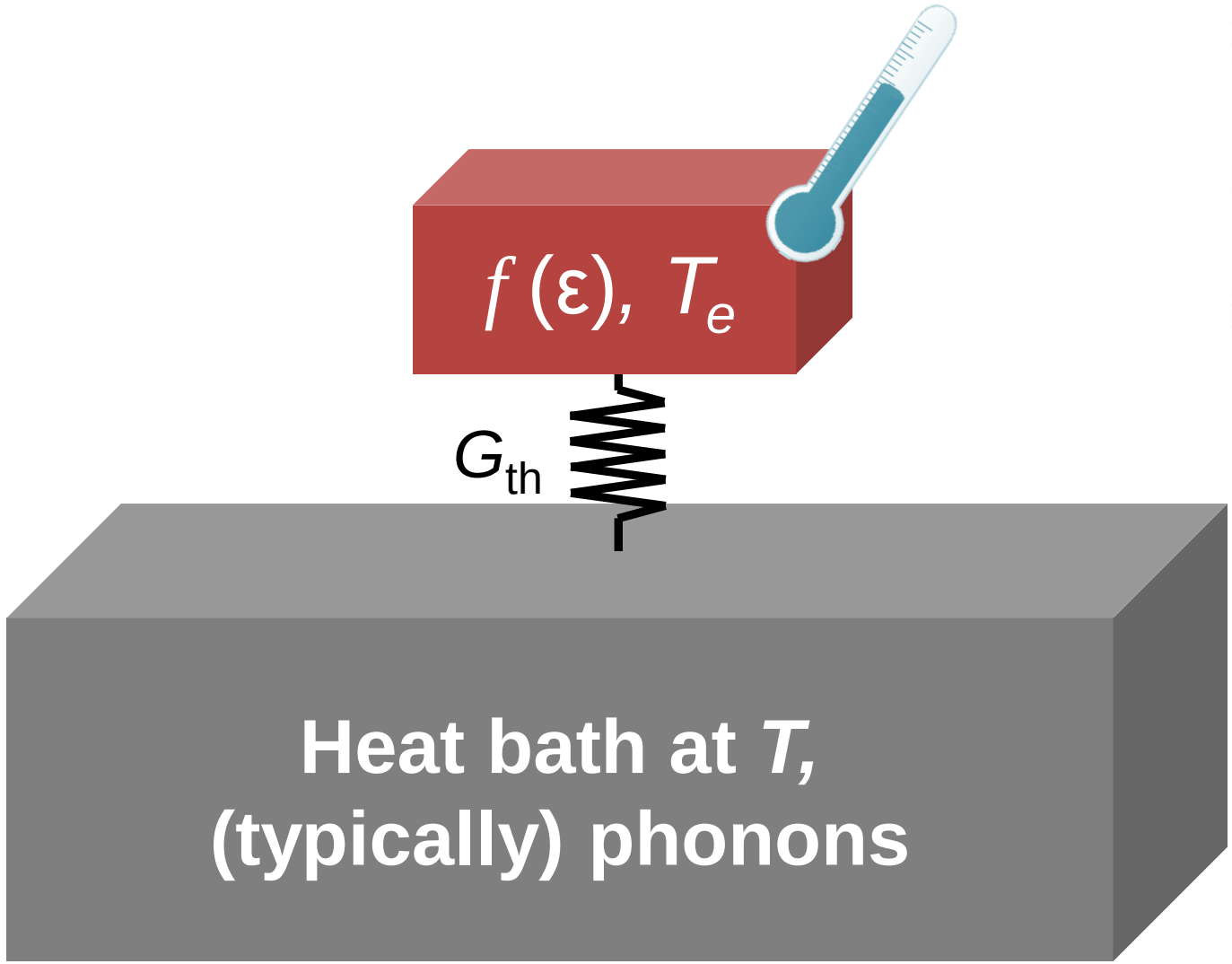
Tunnel barrier

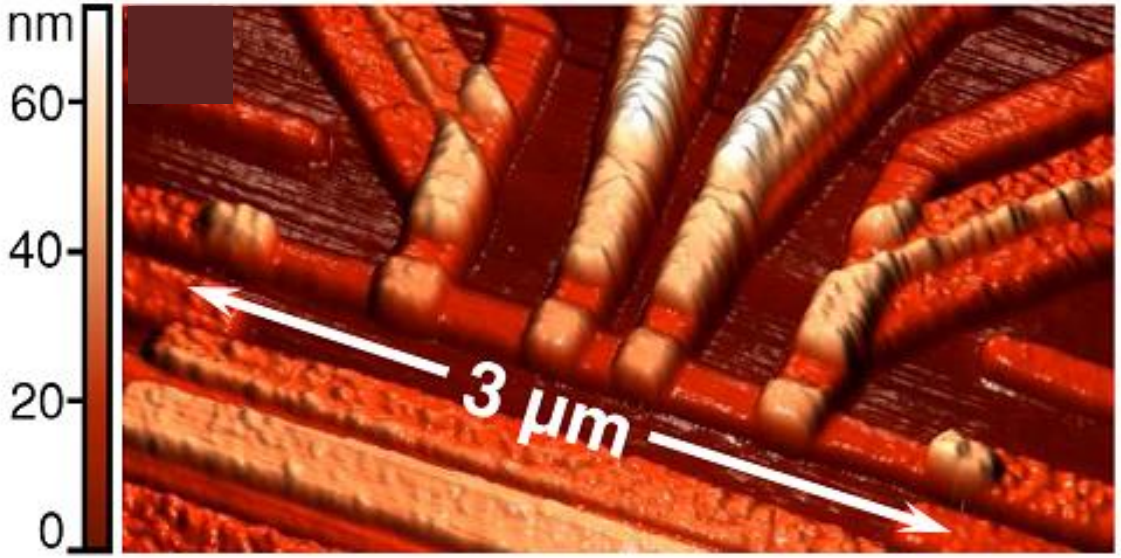




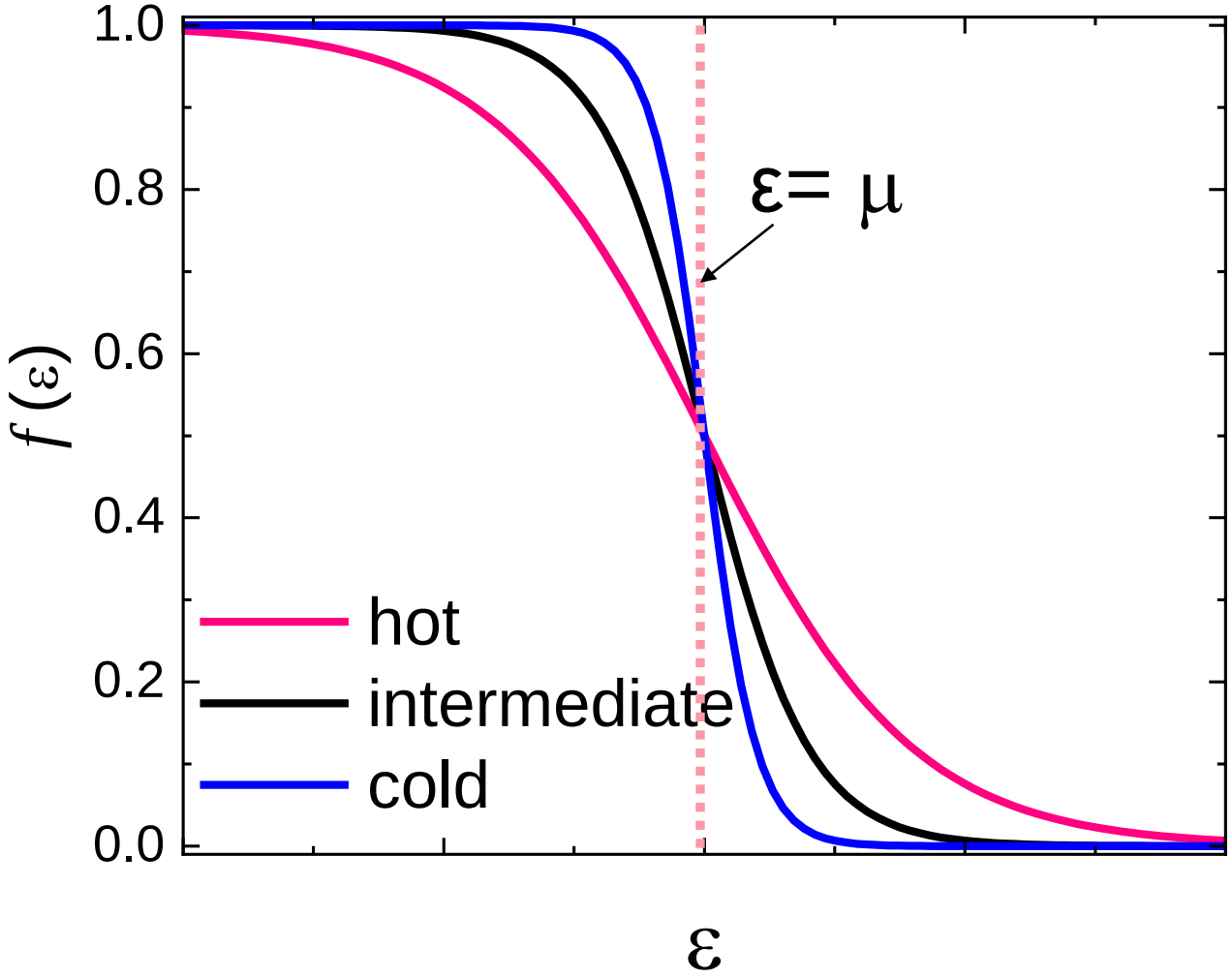
Examples of aluminium-oxide tunnel barriers

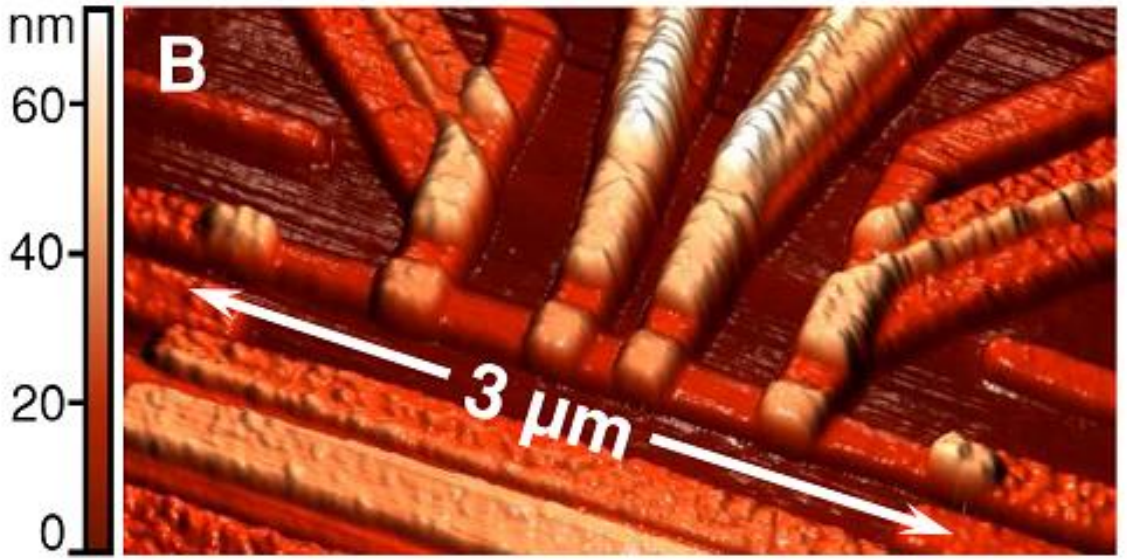
Generic thermal model for an electronic conductor





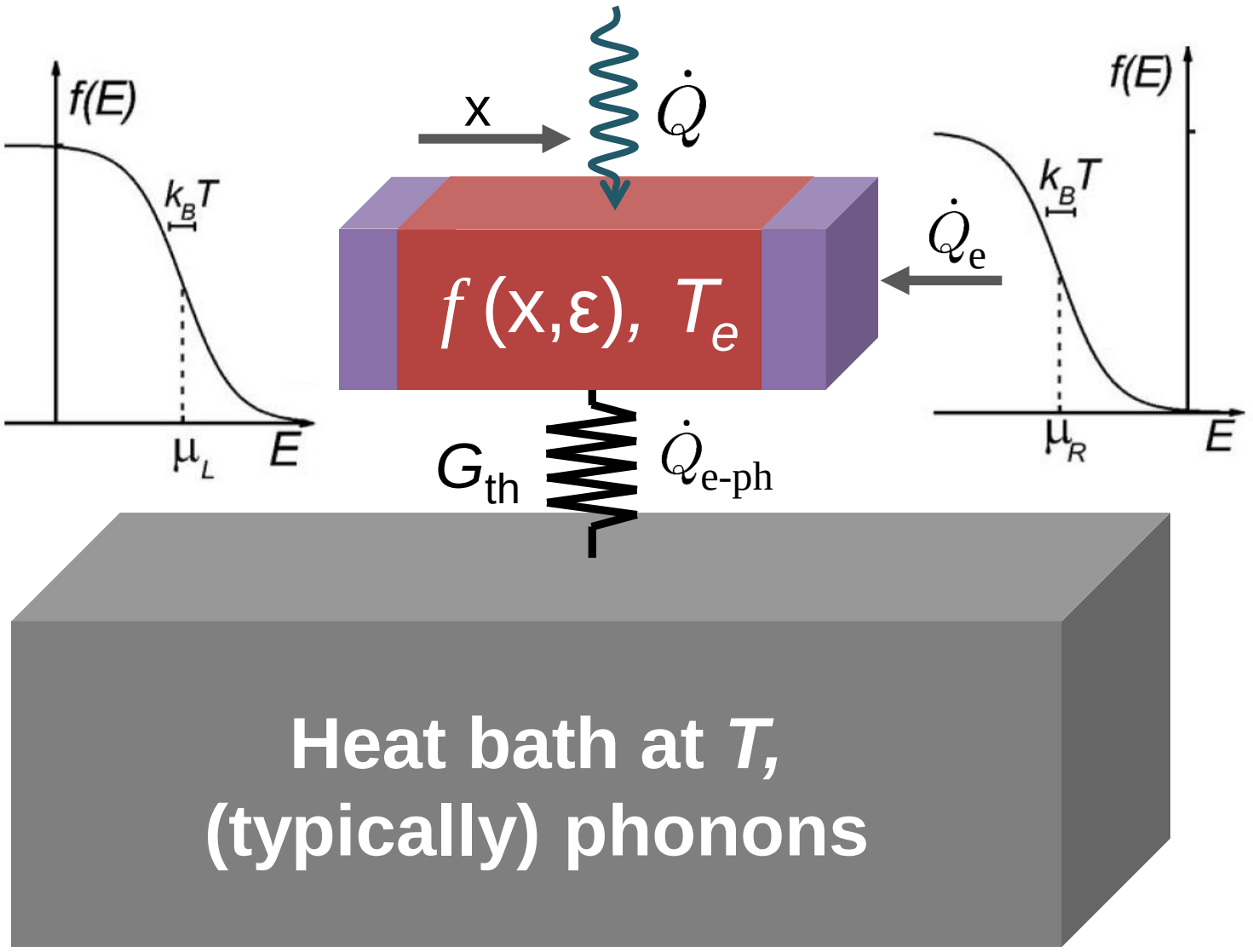
Temperature in an electronic device

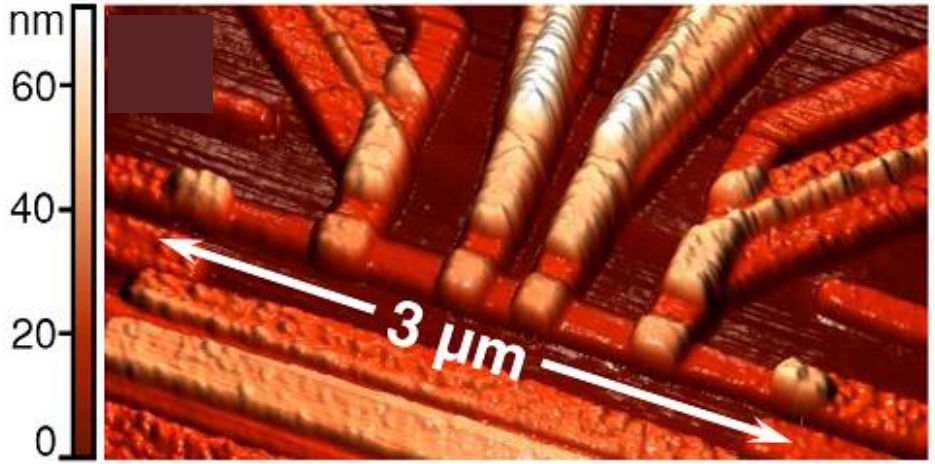




$$f(\epsilon) = \frac{1}{1 + e^{\beta(\epsilon - \mu)}}$$

Generic thermal model for an electronic conductor

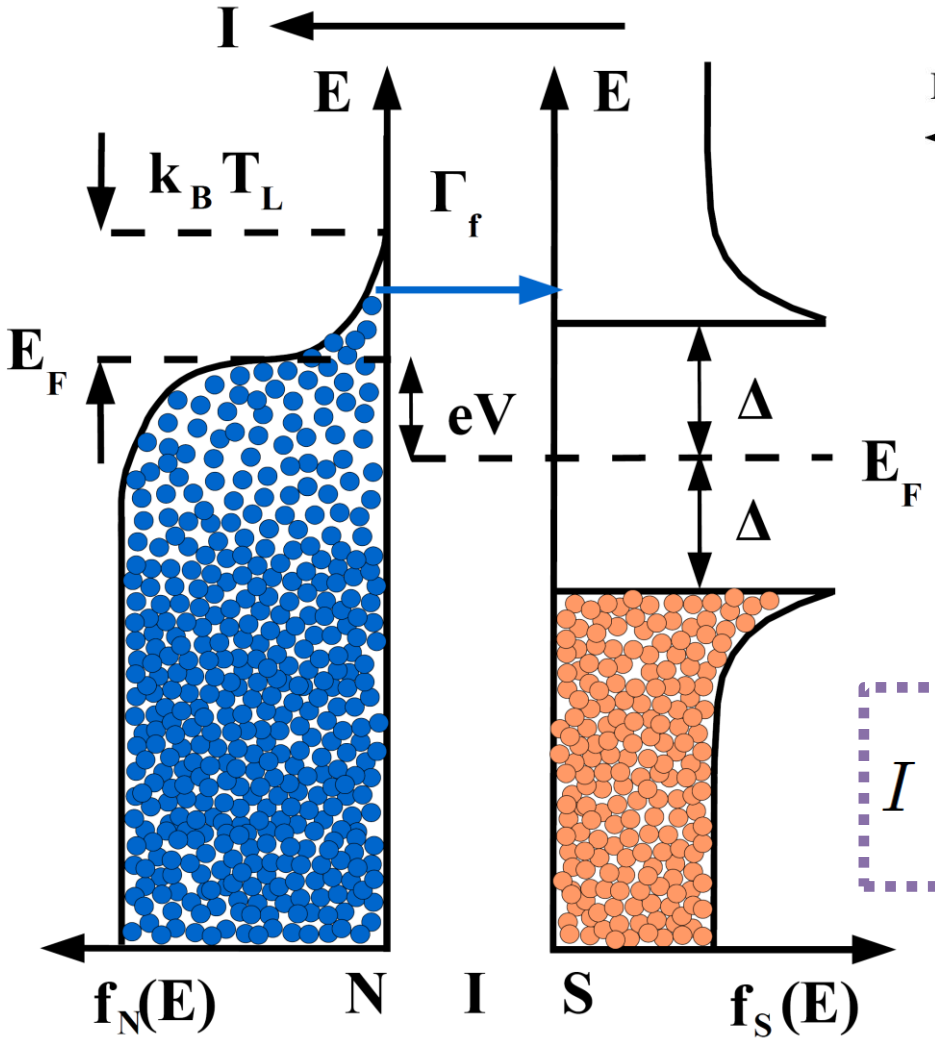


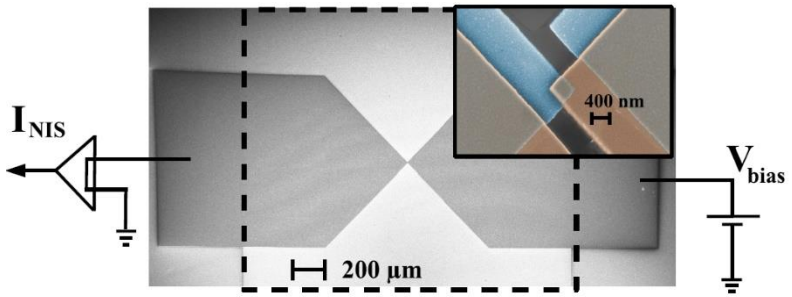


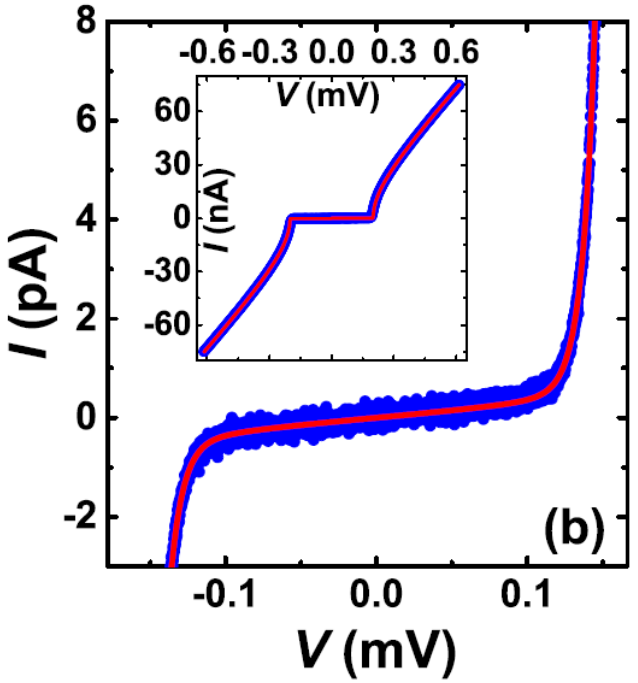
Separation of time scales:
$\tau_{e\text{-}e} < 10^{-9}$ s, $\tau_{e\text{-}ph} > 10^{-6}$ s

Metal – Insulator – Superconductor

NIS tunnel junction







$$I = \frac{1}{eR_T}\int d\epsilon\; n_S(\epsilon)[f_S(\epsilon) - f_N(\epsilon + eV)]$$

$$I(-V) = -I(V)$$

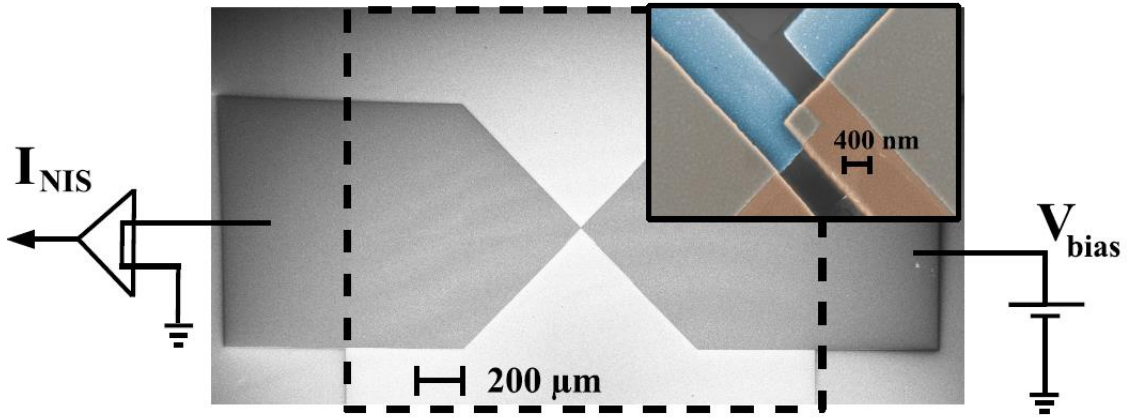
$$I = \frac{1}{2eR_T}\int d\epsilon\; n_S(\epsilon)[f_N(\epsilon - eV) - f_N(\epsilon + eV)]$$

Probes electron temperature of N electrode (and not of S!)

NIS-thermometry

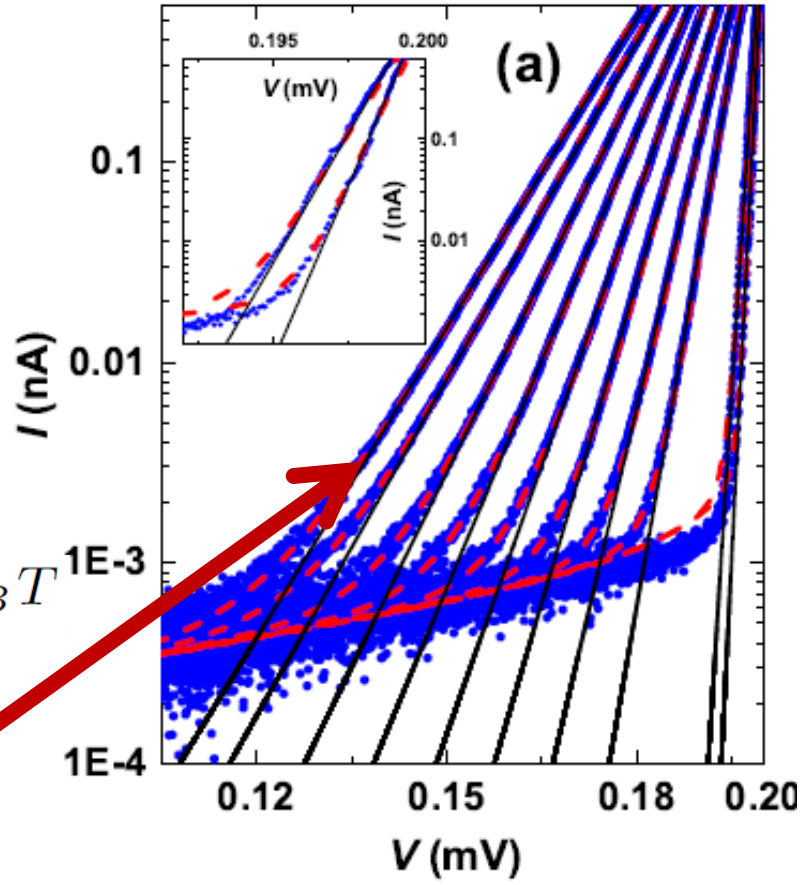
$$I = \frac{1}{2eR_T}\int n_S(E)[f_N(E-eV) - f_N(E+eV)]dE$$

Probes electron temperature of N electrode (and not of S!)



$$I \approx I_0 e^{-(\Delta - eV)/k_B T}$$

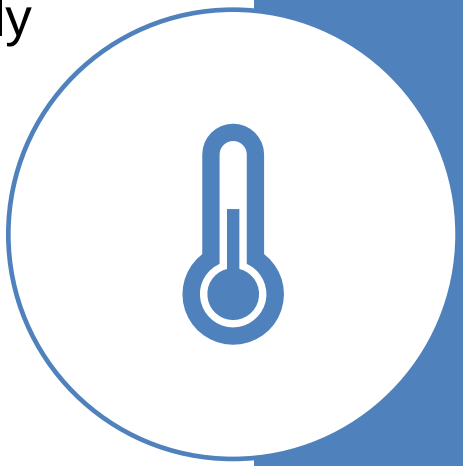
$$\frac{\mathrm{d}\ln(I/I_0)}{\mathrm{d}V} \approx \frac{e}{k_B T}$$



A. V. Feshchenko et.al., Phys. Rev. Appl. 4, 034001 (2015).

Low-temperature thermometry

- The thermometer should have a wide operating temperature range and should be insensitive to environmental changes, such as magnetic fields.
- The property x to be measured must be easily, quickly, and exactly accessible to an experiment.
- The temperature dependence of the measured property, x(T) should be expressible by a reasonably simple law
- The sensitivity $(\Delta x/x)/(\Delta T/T)$ should be high
- The thermometer should reach equilibrium in a “short” time, both within itself and with its surroundings whose temperature it is supposed to measure. Therefore it should have a small heat capacity , good thermal conductivity and good thermal contact to its surroundings. In particular, the thermal contact problem is ever present for thermometry at $T \leq 1$ K.
- The relevant measurement should introduce a minimum of heat to avoid heating of the surroundings of the thermometer and of course, above all, heating of itself; this becomes more important the lower the temperature.



Frank Pobell, Matter and methods at low temperatures, Third Edition, Springer, 2007.