

Doped Silicon and NIS junctions for Bolometer Applications

R. Leoni,

B.Buonomo, M.G.Castellano, F.Mattioli, G.Torrioli
Institute of Photonics and Nanotechnology,

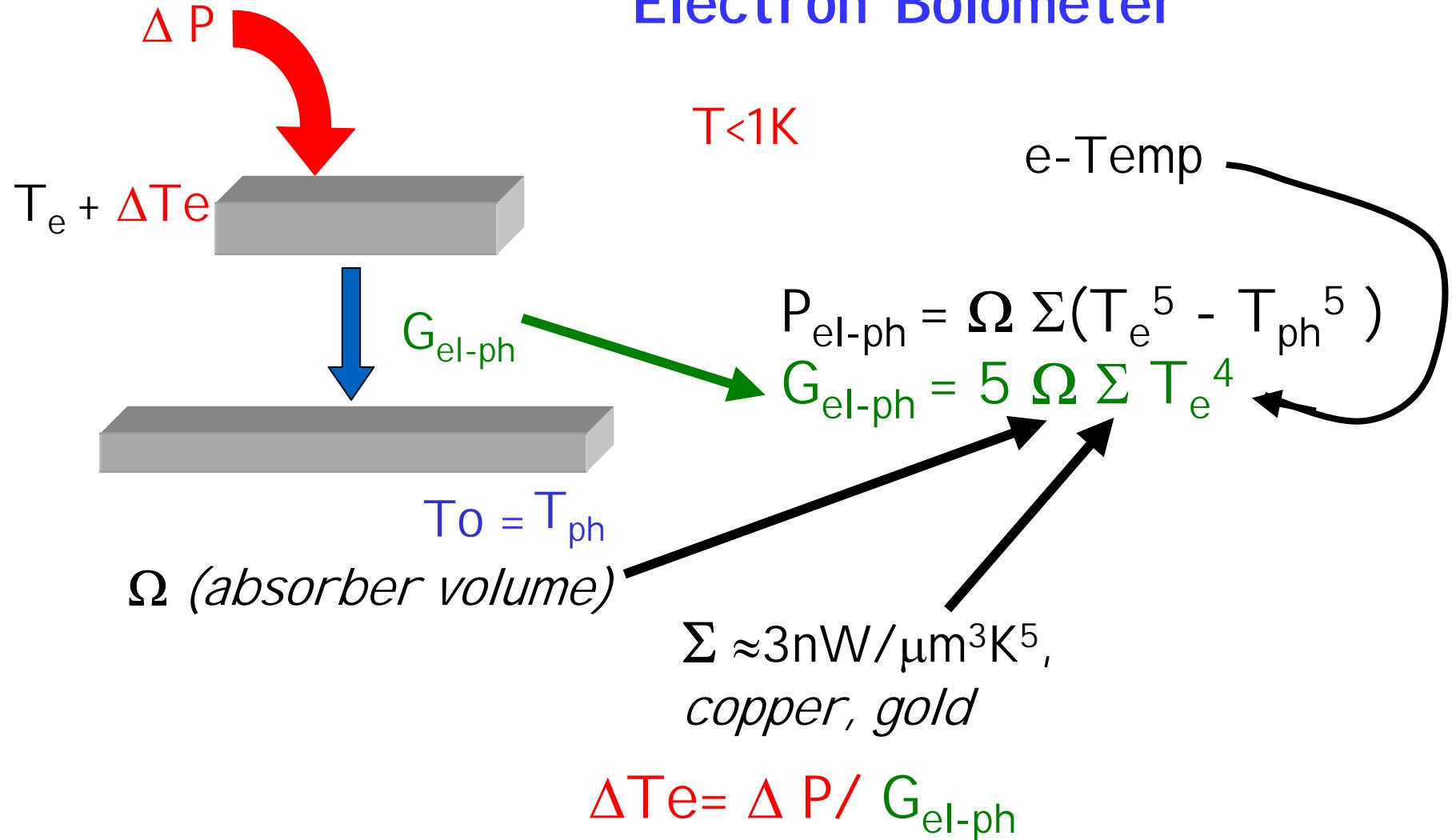
IFN - CNR, Rome, IT

and

L.Di Gaspare, F.Evangelisti

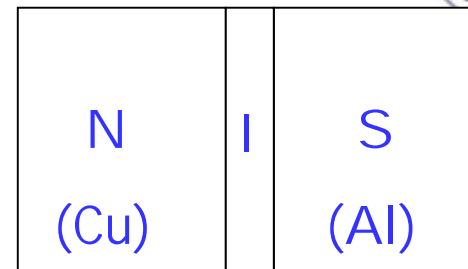
Università di Roma TRE and INFM

(NHEB) Normal-metal Hot Electron Bolometer

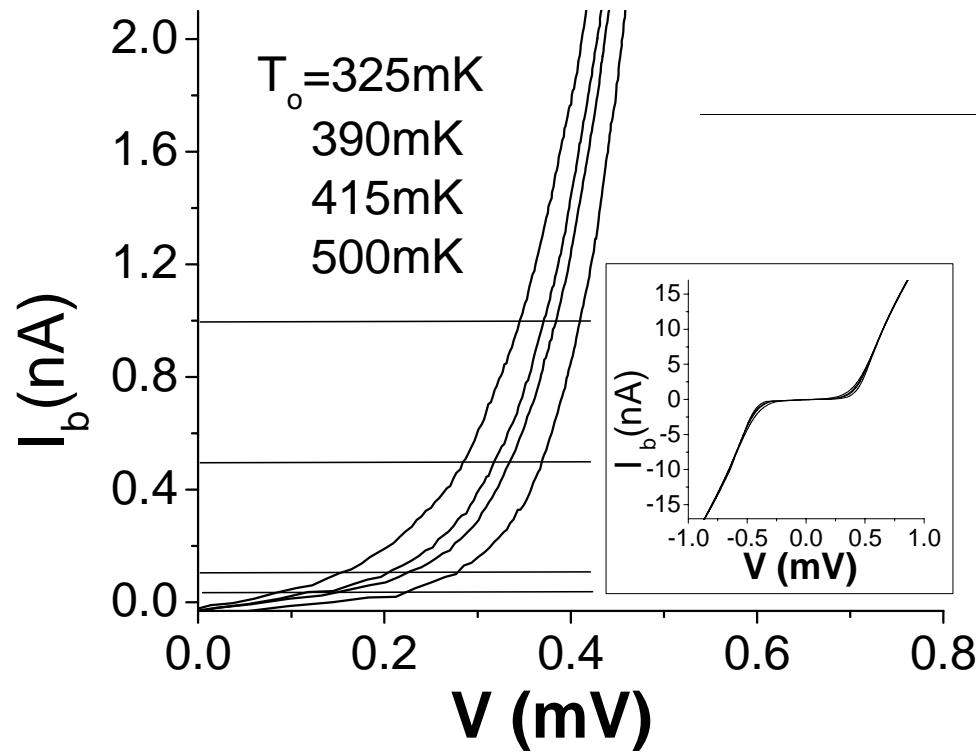


How to Measure the electron temperature?

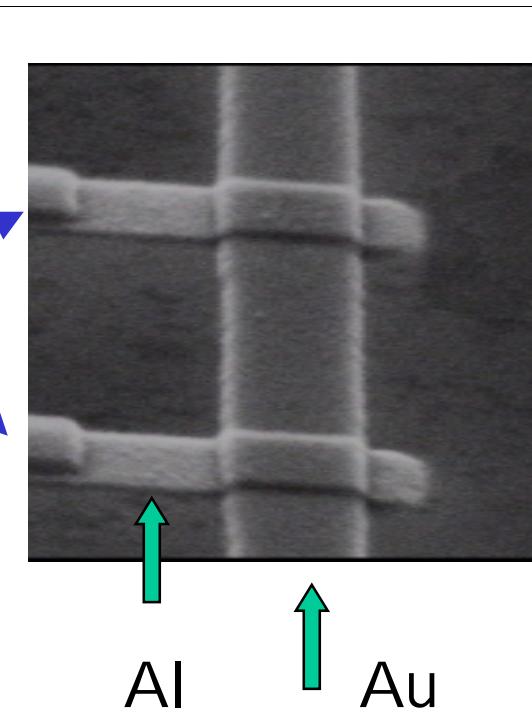
Normal-Insulator-Superconductor
NIS thermometer



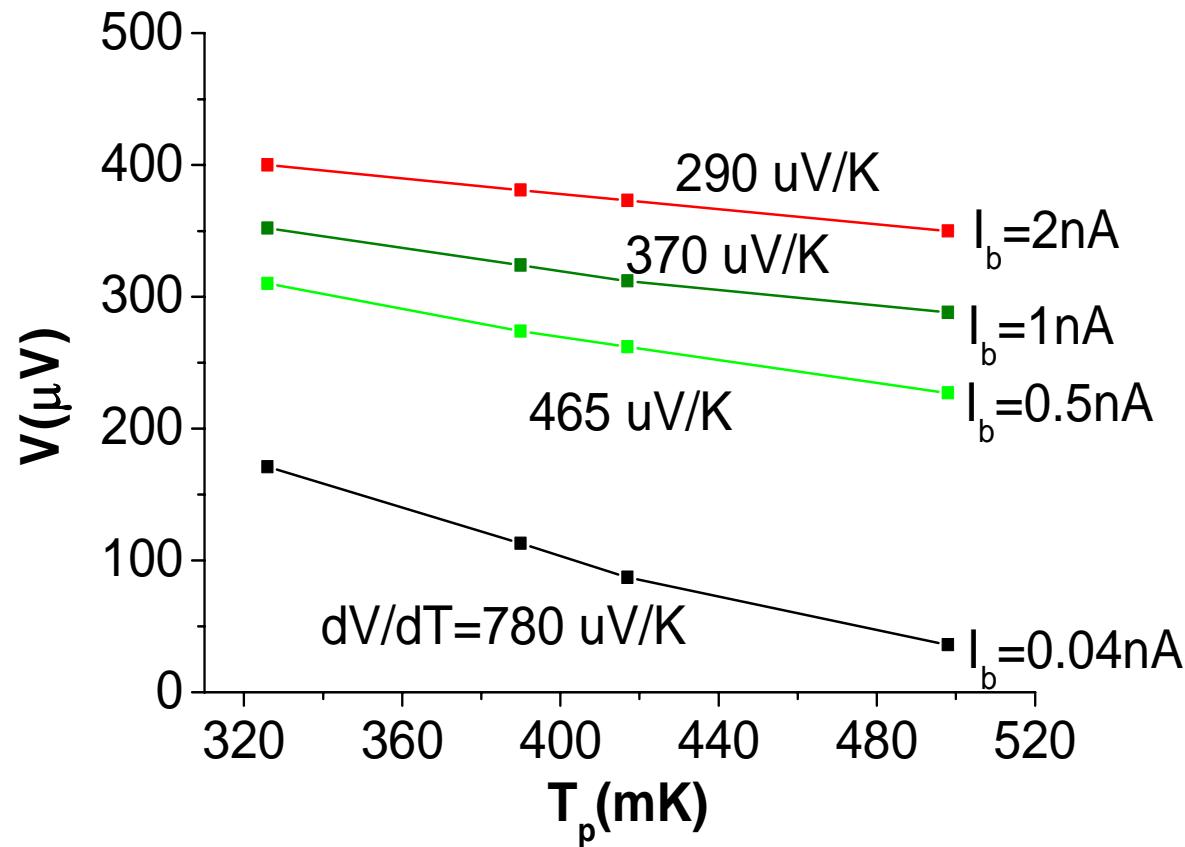
AlOx(5nm)
0.3μm



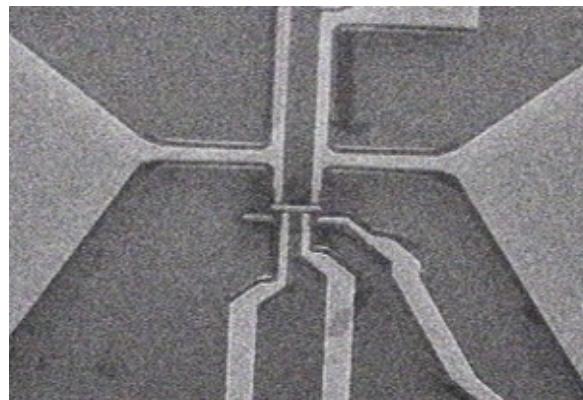
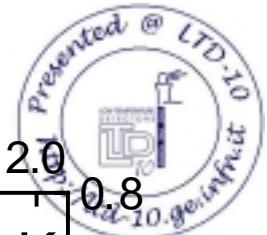
SINIS



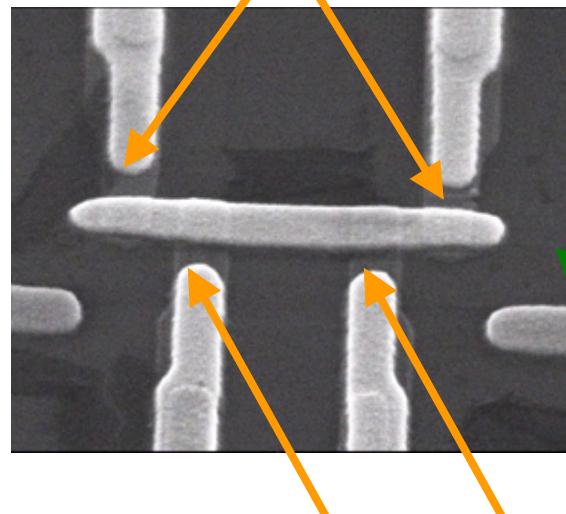
Temperature response of a SINIS thermometer



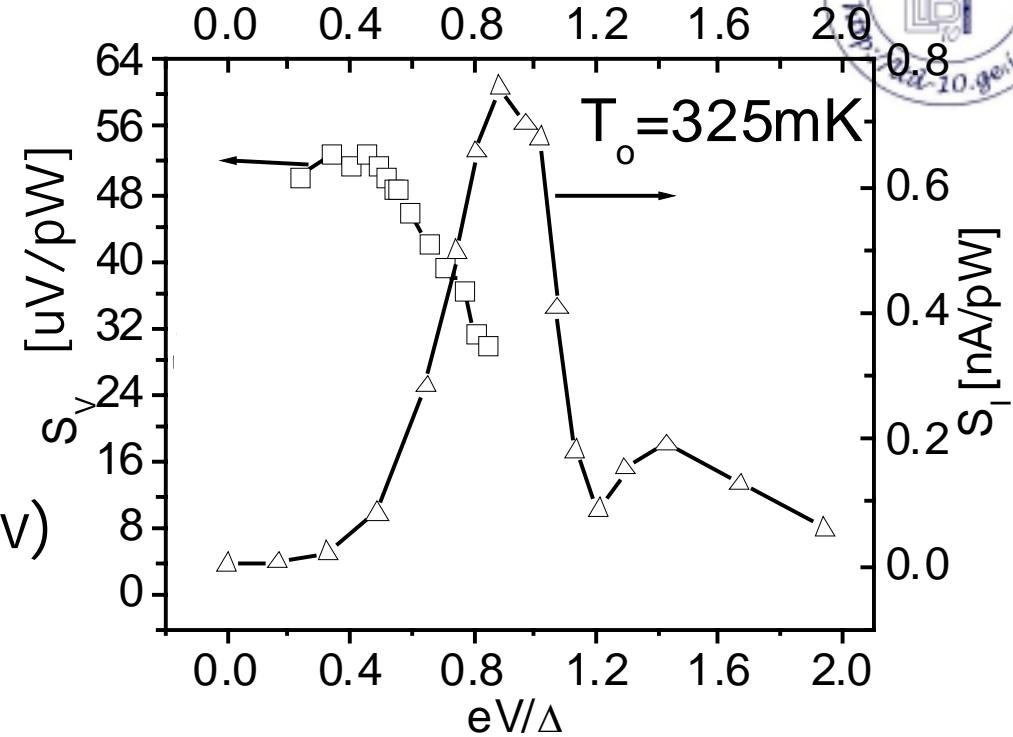
Power Response @ T=0.32K



Contacts SN (Andreev)



SINIS Thermometer



$$Gel-ph = (dI / dT) / S_I = 6.7 \text{ pW/K}$$

$$5 \text{nA/K}$$

Au Absorber

$$\Omega = 2.5 \times 0.25 \times 0.06 \mu\text{m}^3 = 0.04 \mu\text{m}^3$$

Summary: NIS junctions made by metals



- Quasi-ideal IV characteristics
- intrinsic phonon NEP = $\sqrt{4K_B T^2 G_{el-ph}} \approx 6 \cdot 10^{-18} \text{ W} \sqrt{\text{Hz}}$
@0.3K

but

- exp NEP $\approx 10^{-16} \text{ W} \sqrt{\text{Hz}}$ is limited by amplifier noise
($6\text{nV}/\sqrt{\text{Hz}}$) @10Hz

(because the power response $Sv \approx 60\text{uV/pW}$)

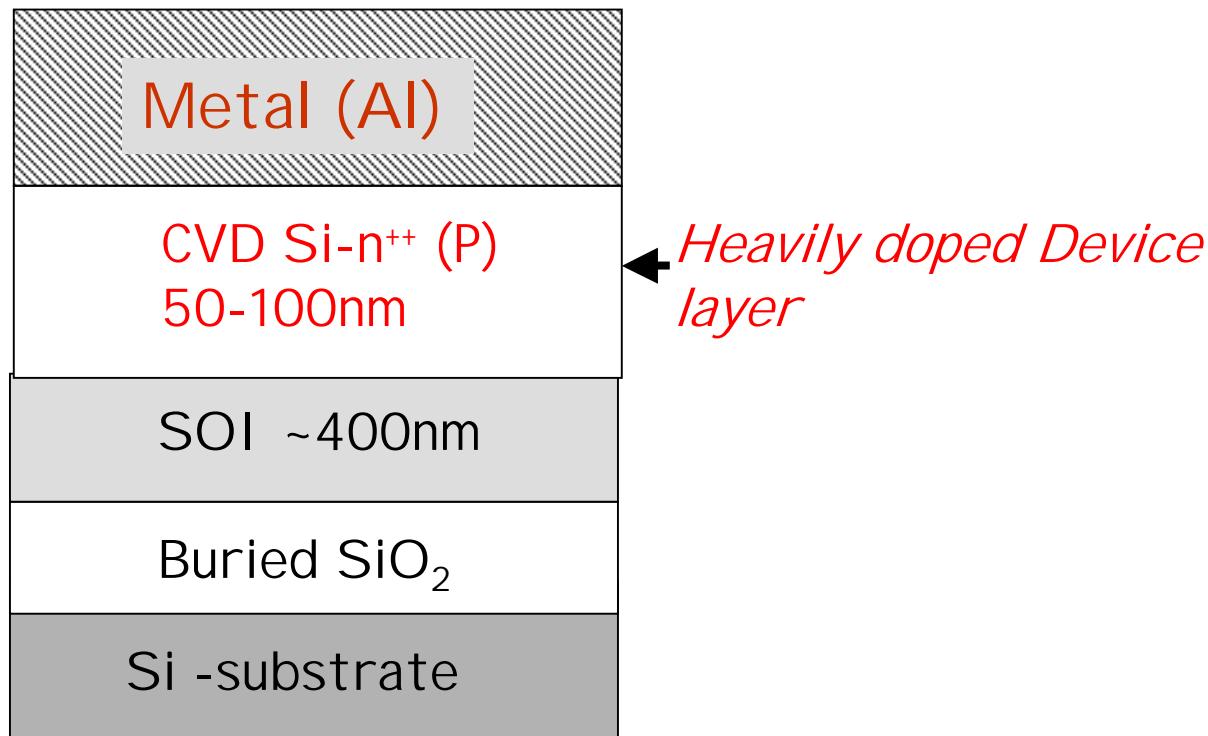
we need it larger

- NIS junctions are quite fragile (suffer thermal cycles)

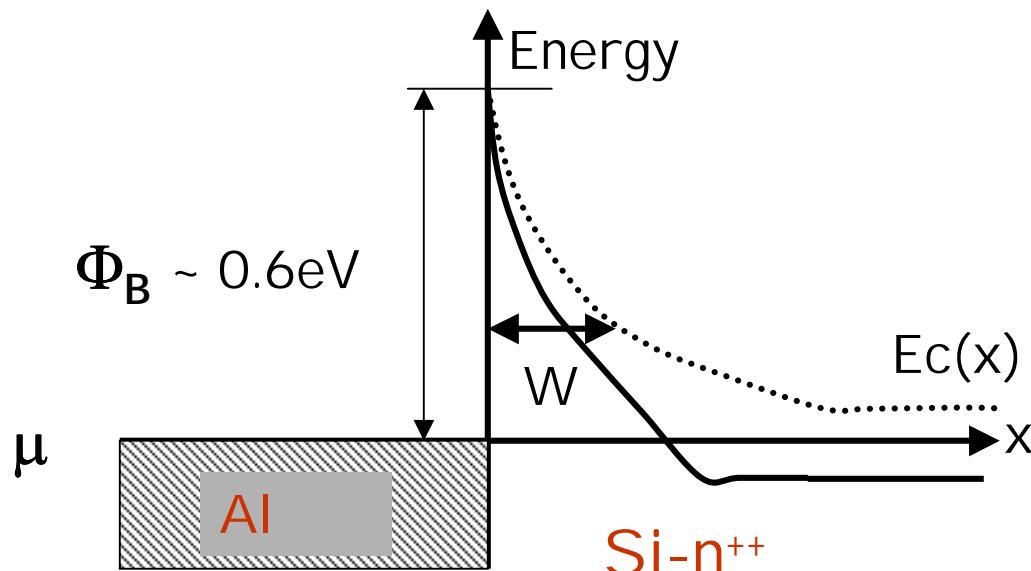
Si-n⁺⁺-Schottky barrier-Superconductor junctions



- SMALLER electron-phonon thermal coupling
 $\Sigma \approx 0.1 \text{nW}/\mu\text{m}^3\text{K}^5$, Si-n⁺⁺ (Savin et al. APL 2001)
- MORE robust



Energy diagram at $T > T_c \sim 1.2K$



Schottky Tunnel
barrier

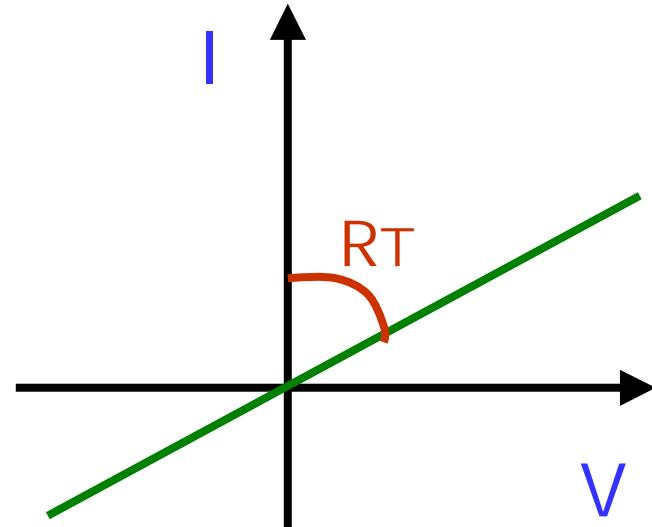
$$W = \text{cost} / \sqrt{N_D} < 10\text{nm}$$

if $N_D \sim 10^{19} \text{ cm}^{-3}$

At low temperature

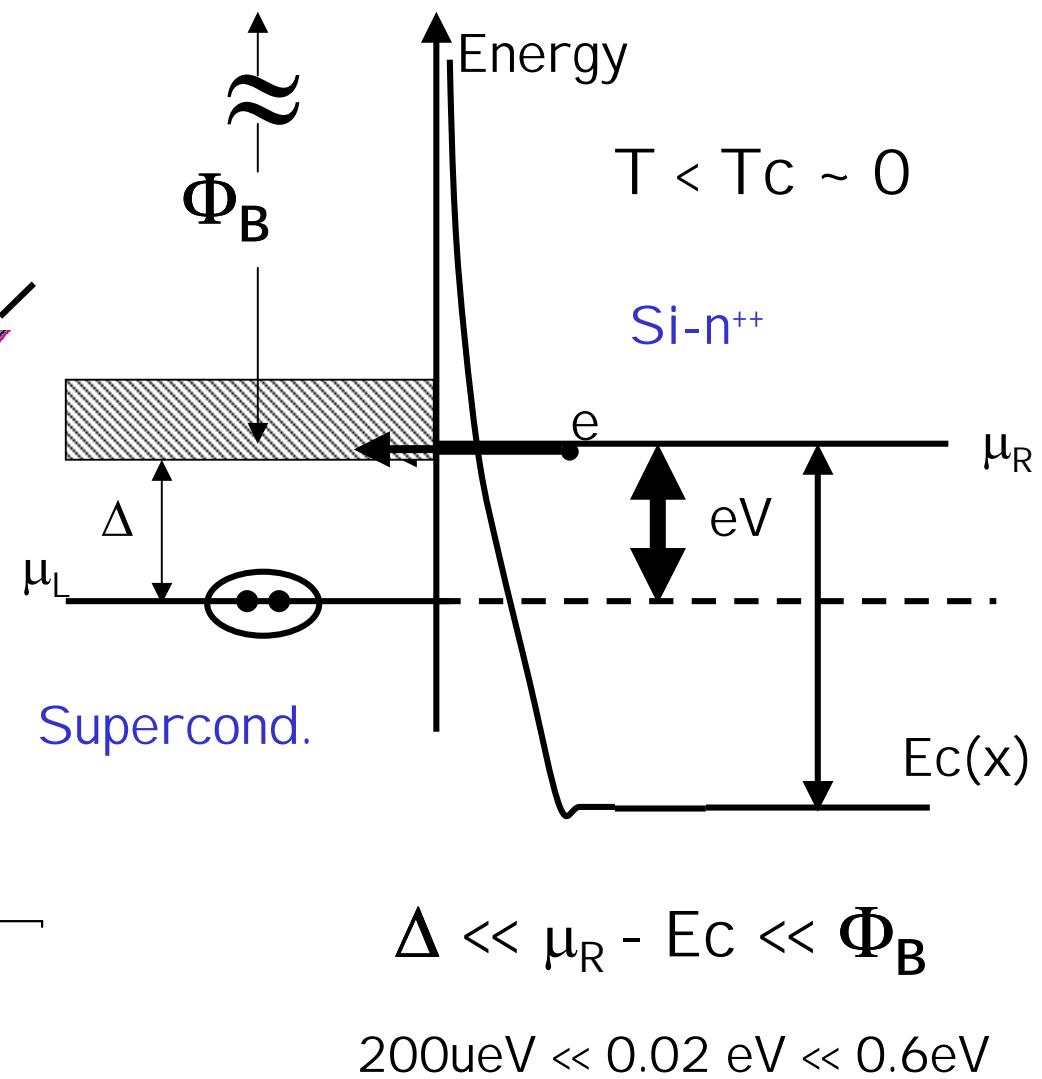
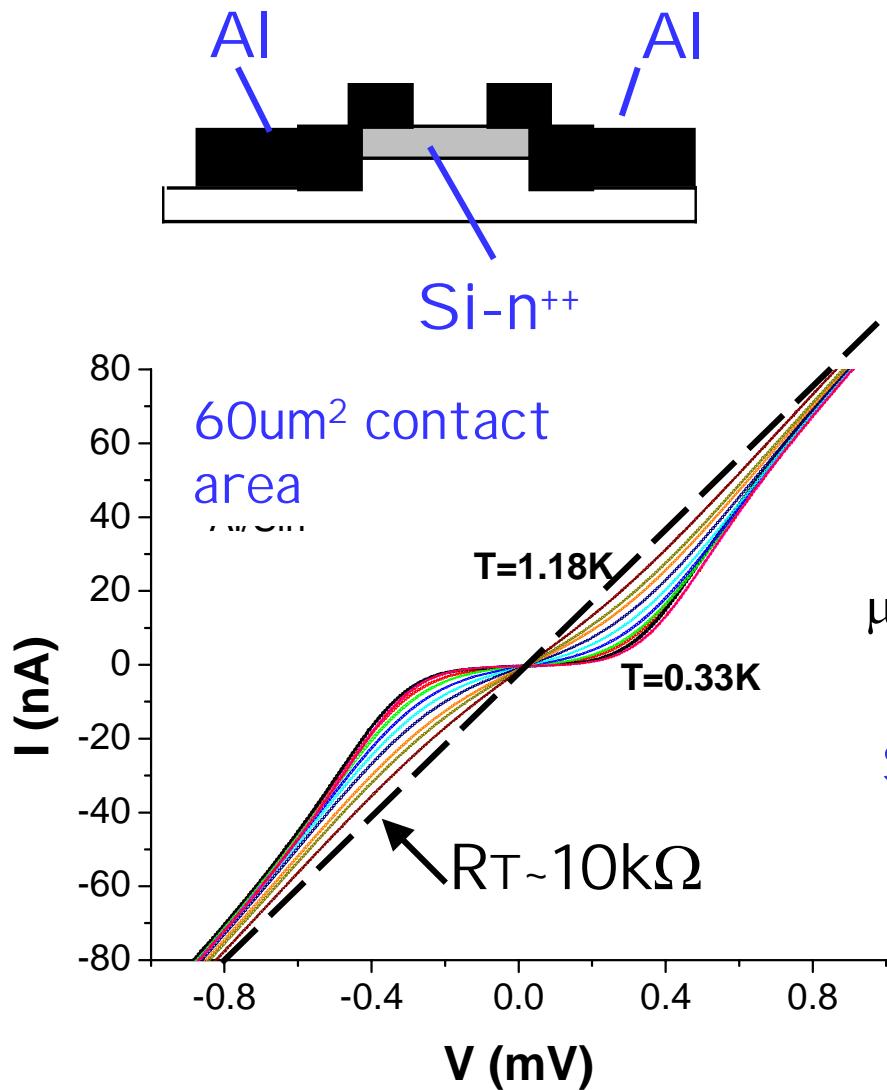
$$I = I(\text{thermoionic}) + I(\text{tunnel})$$

$$R_T = (dI/dV)^{-1}_{V=0} \sim \exp(C\Phi_B / \sqrt{N_D})$$

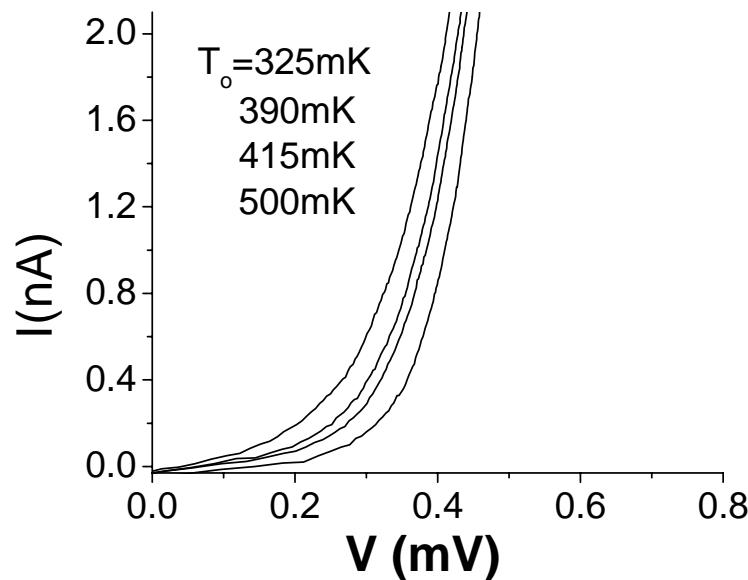


$T < T_c$

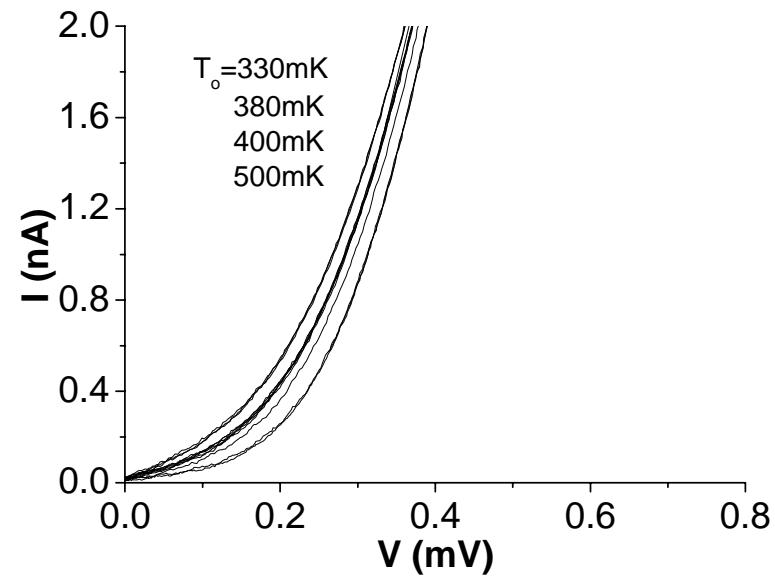
Si-n⁺⁺-Schottky barrier-Superconductor thermometer



Thermometer comparison



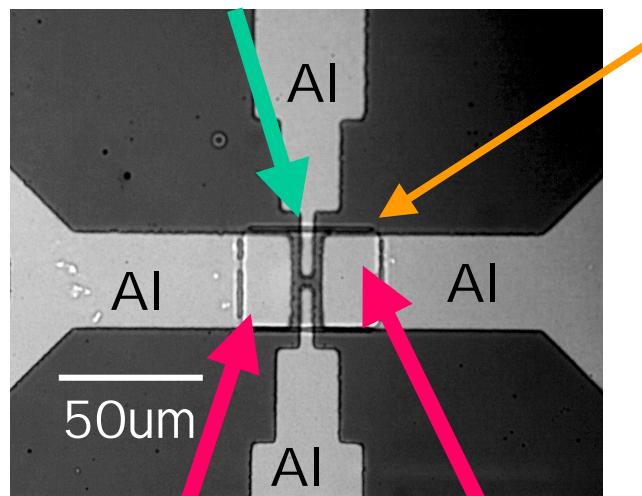
SINIS thermometer $75\text{k}\Omega$
Al-Au-Al and AlOx barrier



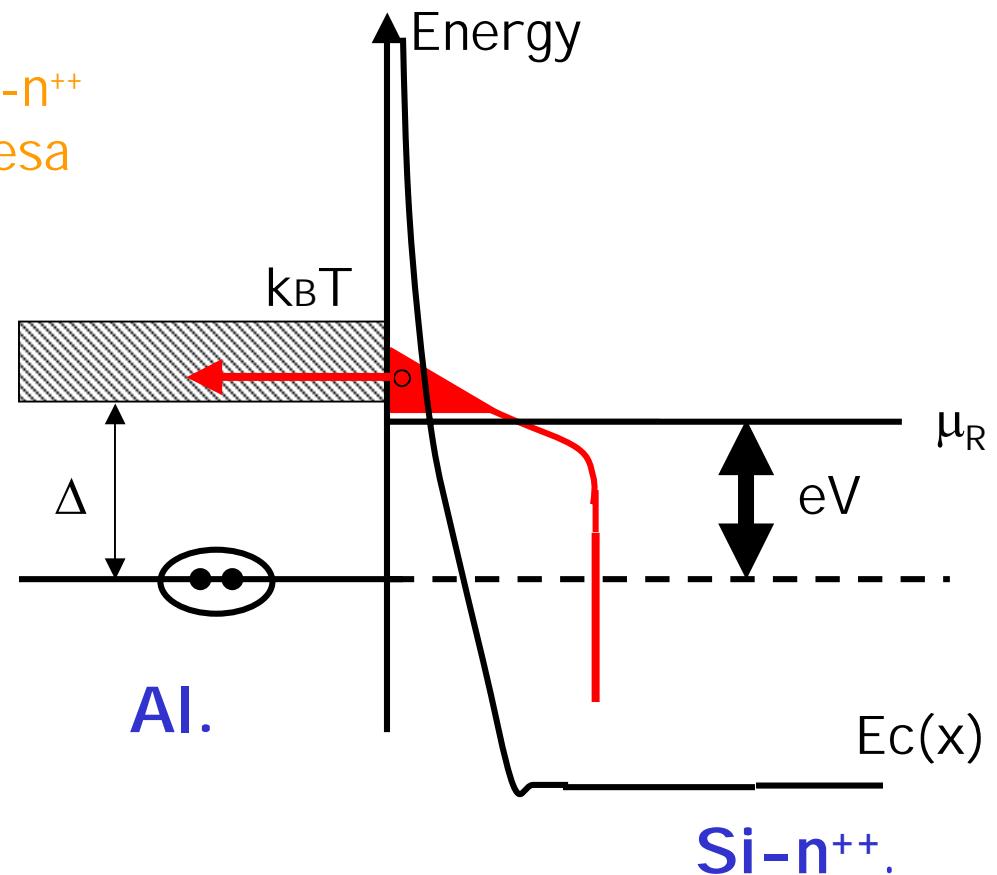
S-Sm-S thermometer $72\text{k}\Omega$
Al-Si n⁺⁺-Al Schottky barrier

Test of the electron-phonon thermal decoupling: the electron cooling

2 small area contacts Al /Si-n⁺⁺/Al
 (thermometer)

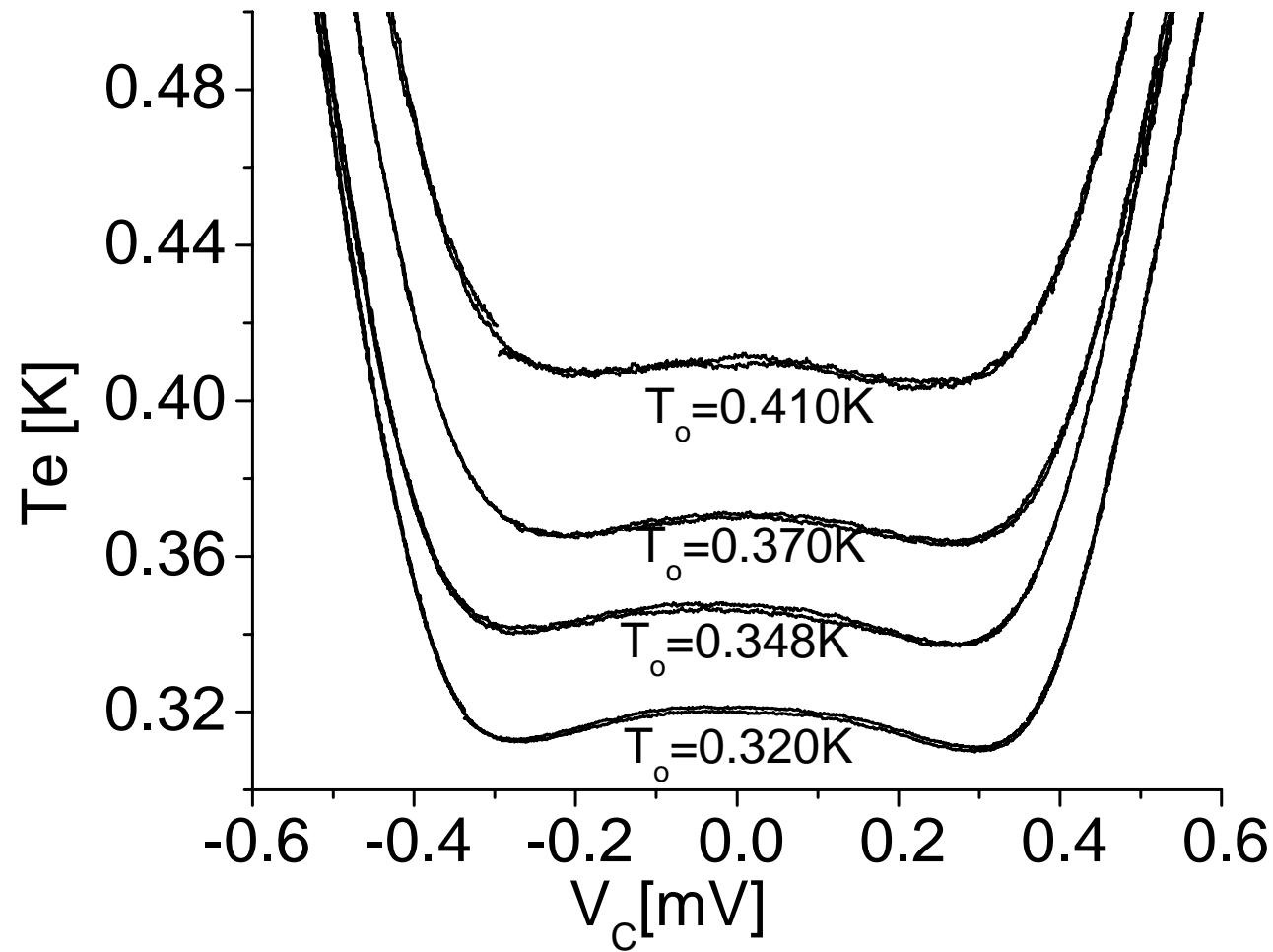


2 large area contacts
 Al /Si-n⁺⁺/Al
 (refrigerator)



Peltier effect

$$P_{\text{cool}} (\text{eV} \sim \Delta) \approx k_B T (I/e) \approx (k_B T / \Delta)^{3/2} (\Delta/e)^2 / R T$$

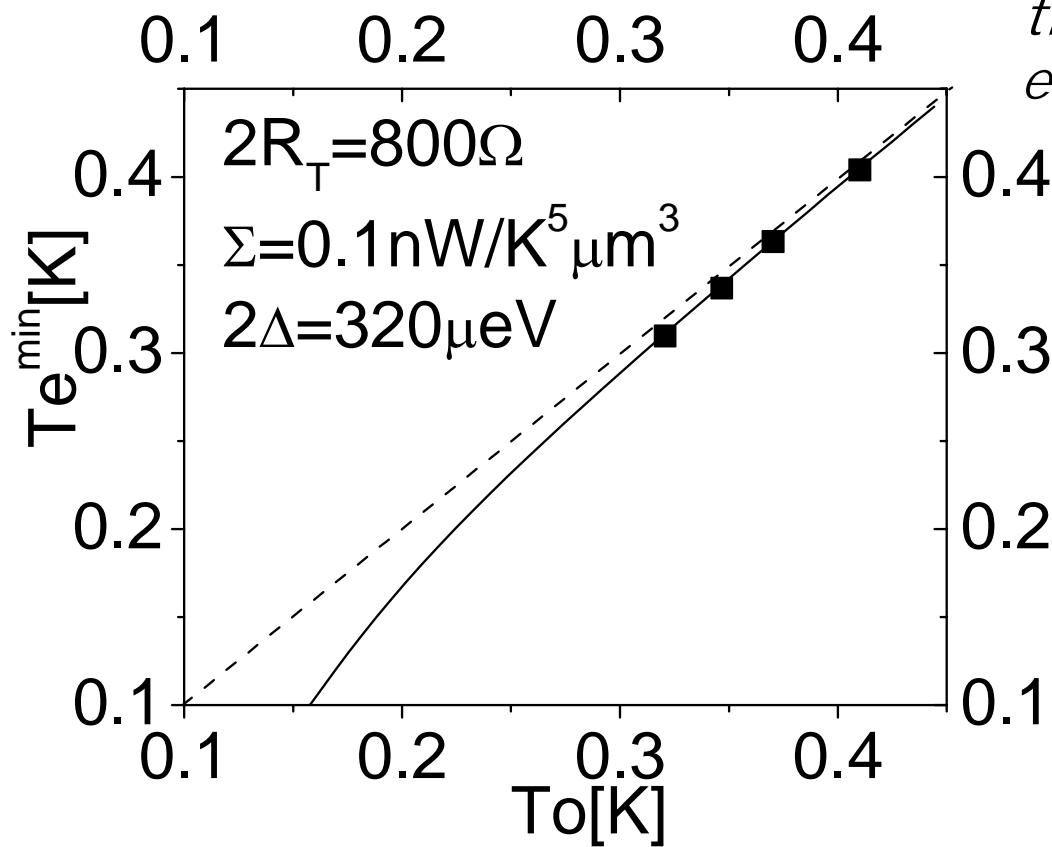


Comparison with theory

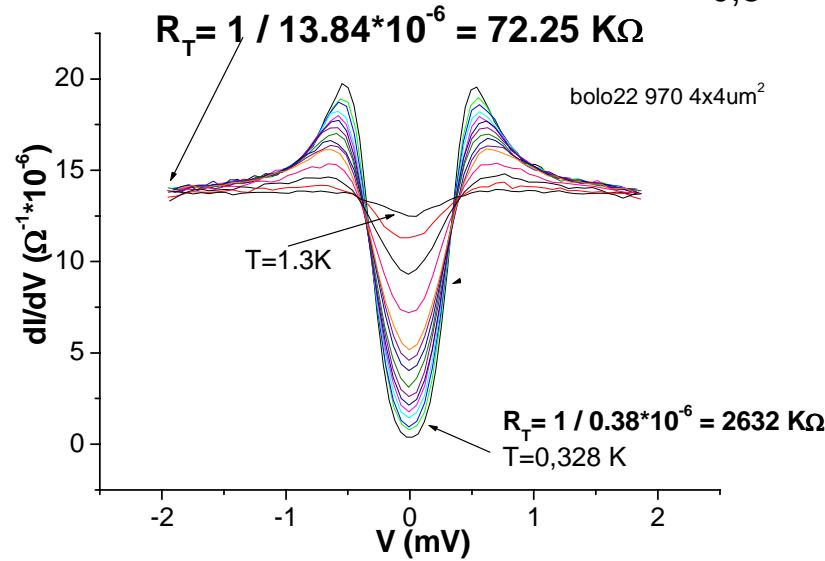
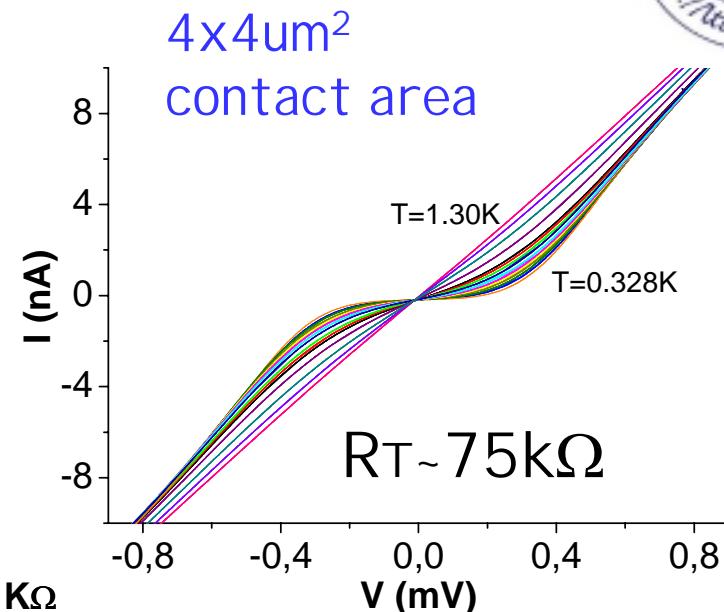
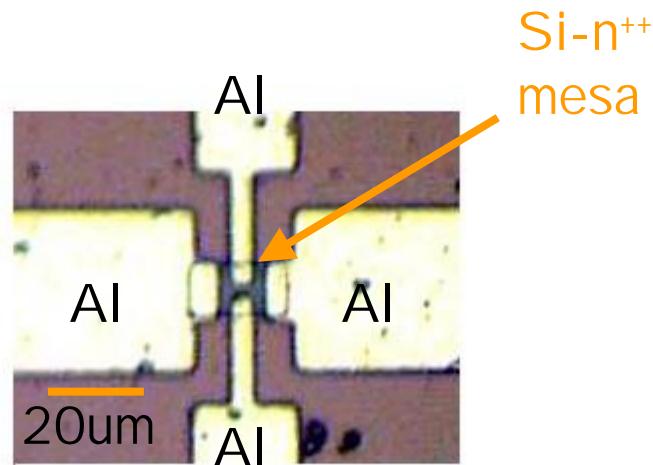


$P_{\text{cool}} + P_{\text{el-ph}} = 0$

thermal equilibrium master equation



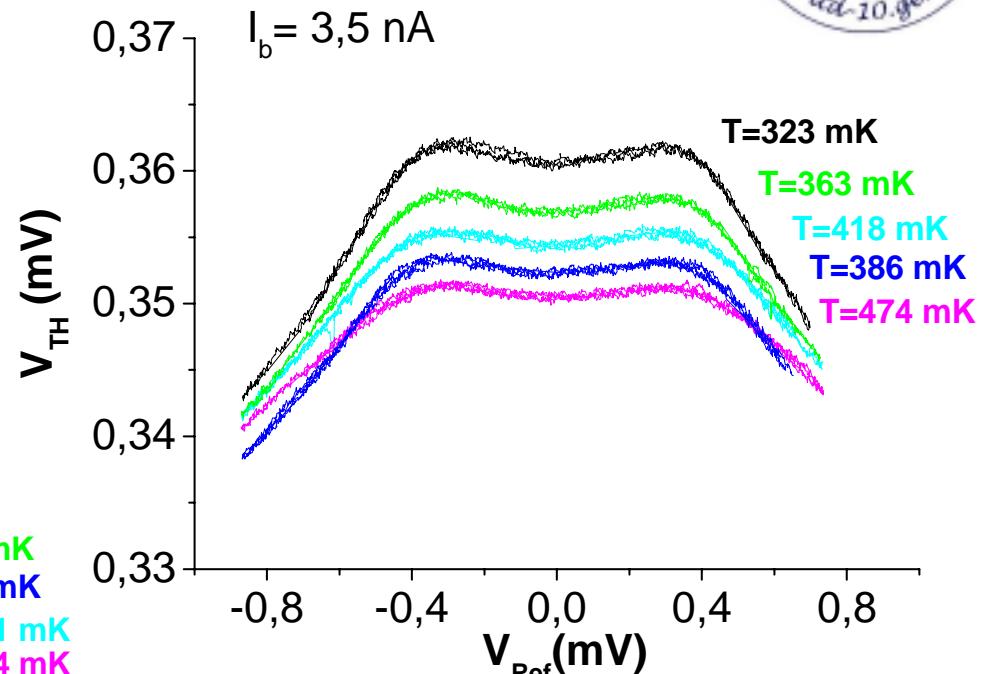
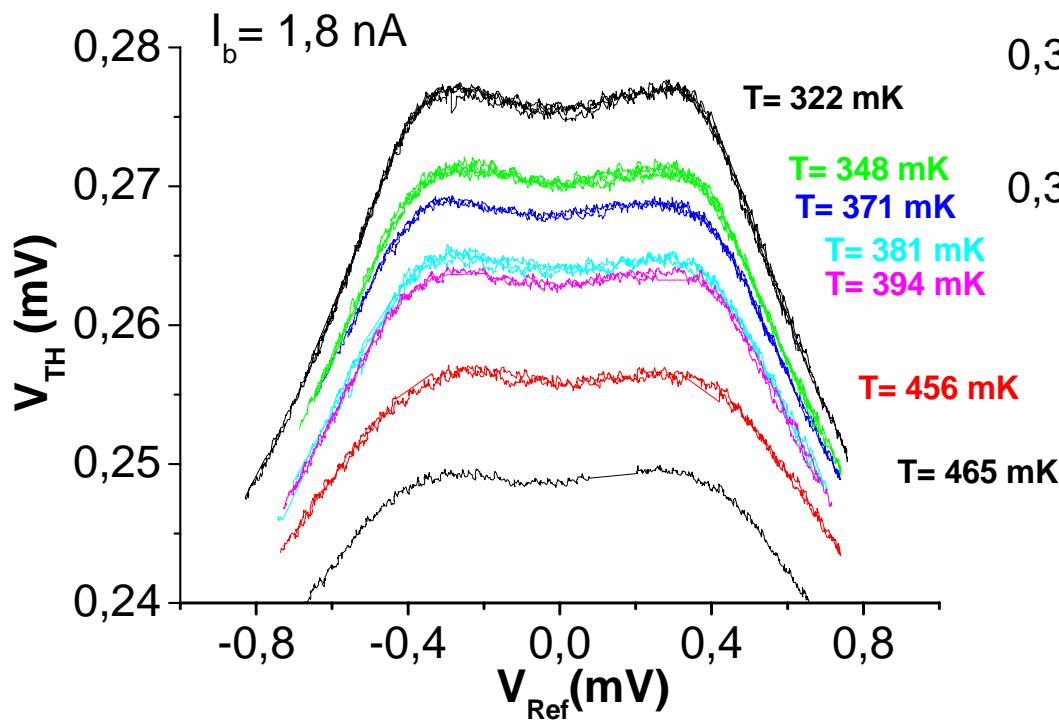
A Smaller Mesa (and smaller junctions)



Thermometer
 $|V$ and dI/dV

Electron Cooling in smaller mesas

thermometer response
at different bias points

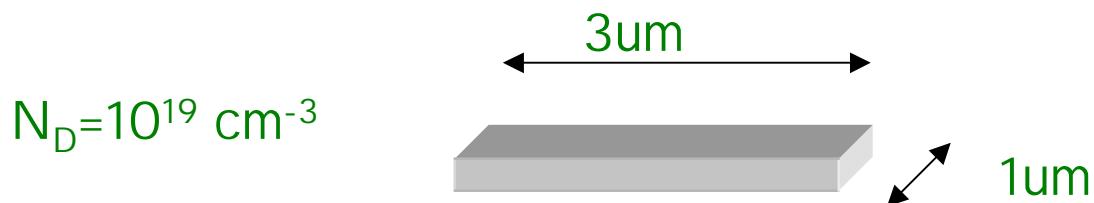


Conclusions

We observed:

- S-Sm-S structures with metallic silicon work well as electronic thermometers.
- Small Σ (small electron-phonon thermal coupling)

We expect:



T (K)	t (um)	Sv(uV/pW)	NEPamp (W $\sqrt{\text{Hz}}$)	NEPphon (W $\sqrt{\text{Hz}}$)
0.3	0.050	400 (60)	$6 \cdot 10^{-18}$ (10 $^{-16}$)	$1.7 \cdot 10^{-18}$