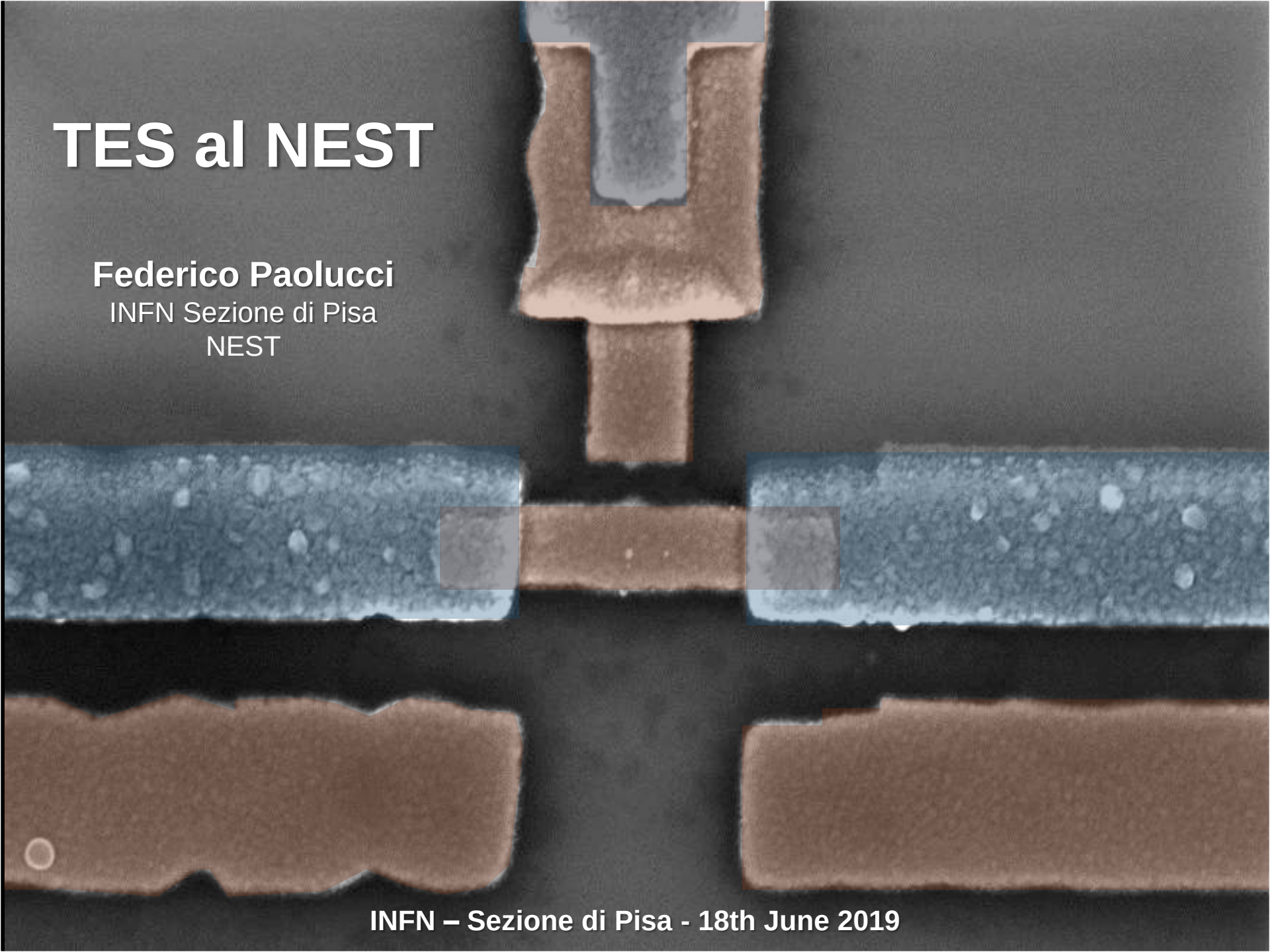
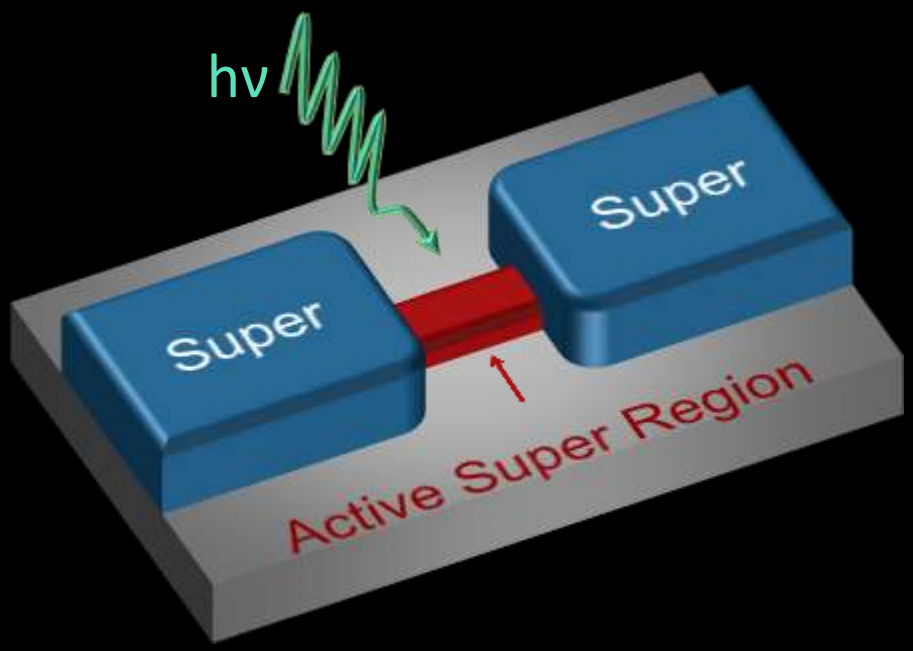
TES al NEST

Federico Paolucci
INFN Sezione di Pisa
NEST

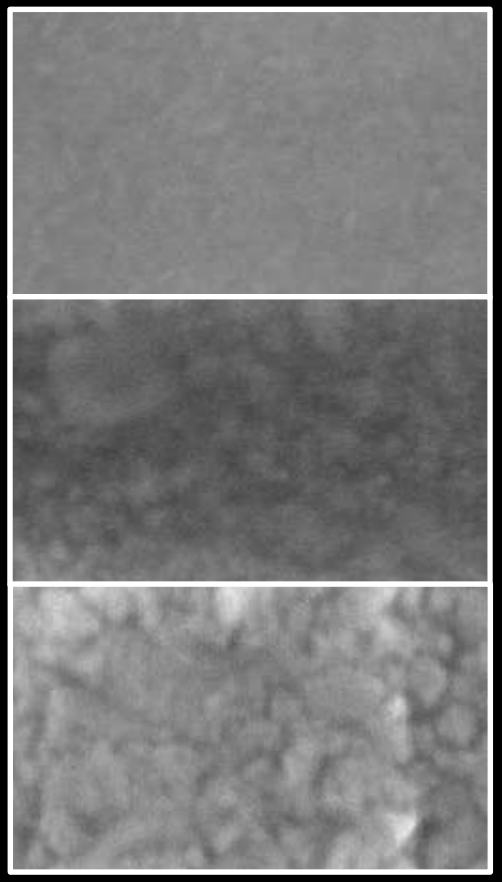


INFN – Sezione di Pisa - 18th June 2019

People involved



Nadia Ligato (CNR-Nano)
Giorgio De Simoni (CNR-Nano)
Francesco Giazotto (CNR-Nano)
Paolo Spagnolo (INFN Pisa)



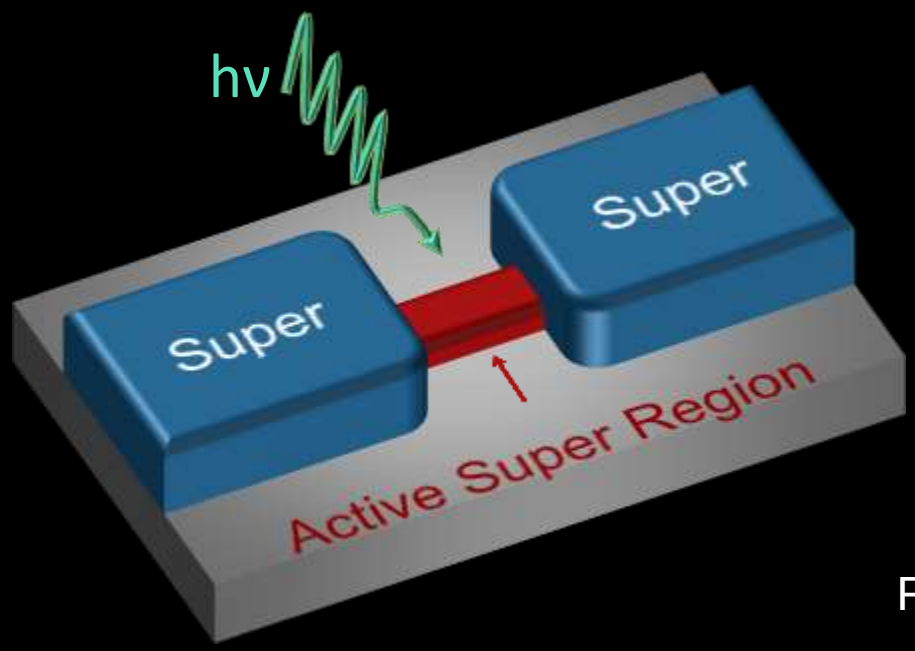
INFN Istituto Nazionale di Fisica Nucleare

CNRNANO PISA NEST

Outline

- Transition Edge Sensors (TES)
- Tuning T_C via Inverse Proximity Effect
- Device Structure
- TES Critical Temperature
- Tuning T_C by Current Injection
- Bolometer
- Calorimeter
- Resume of Results
- Future work

Transition Edge Sensors



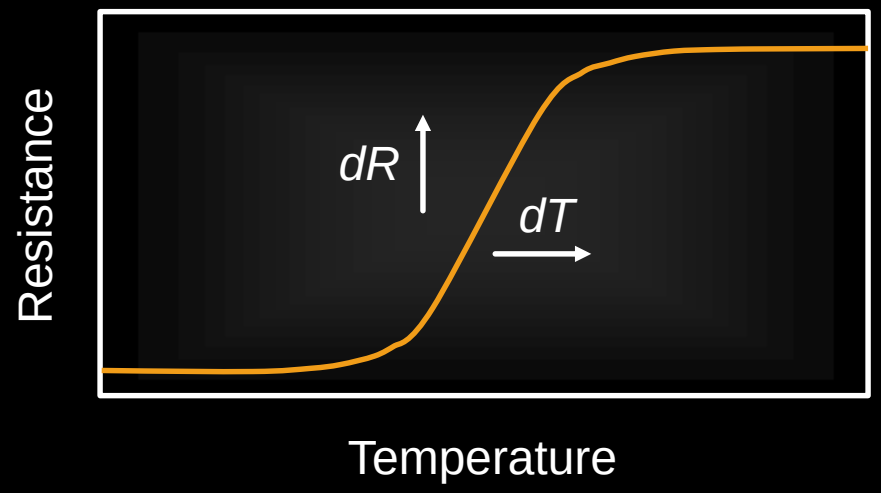
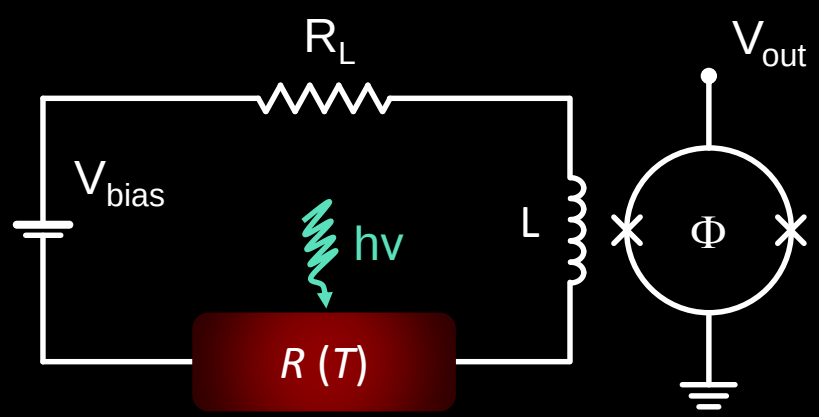


Figure of merit: $\alpha = \frac{T}{R}\frac{dR}{dT}$



R - resistance of active region
T - temperature of active region

Energy resolution: $\Delta E \cong 2.35\sqrt{2k_B T^2 \frac{C}{\alpha}}$
k_B - Boltzmann constant
Heat capacity: $C = \gamma V_{Active} T$
γ - Sommerfeld coefficient
V_{Active} - active region volume

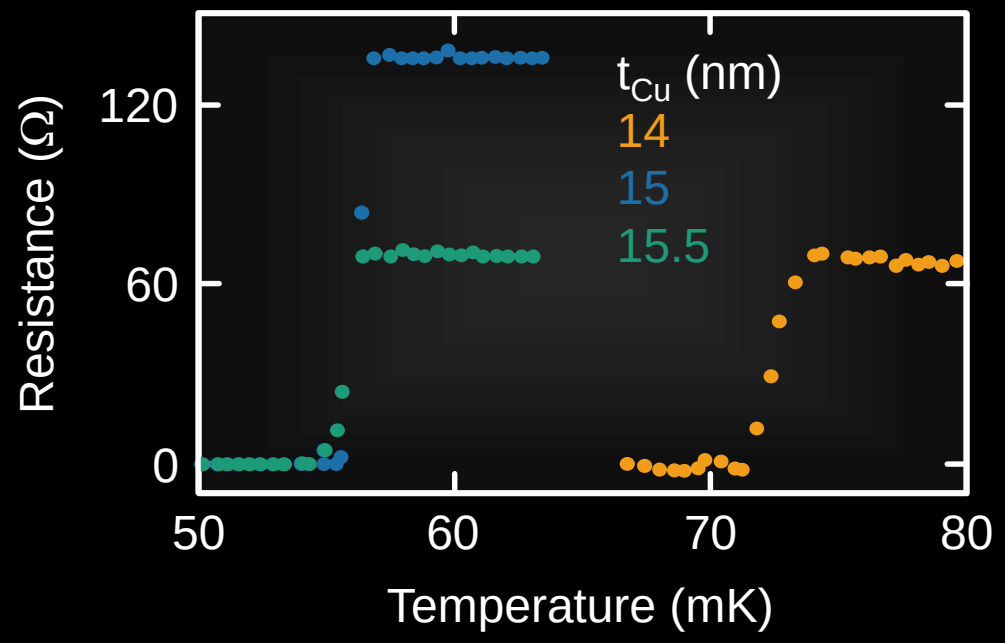
Tuning T_C via Inverse Proximity Effect

Al/Cu bilayers with constant Al thickness and variable Cu thickness

width = 120nm
t_{Al} = 10nm

t_{Cu} (nm)	T_C (mK)
14	72
15	56
15.5	55

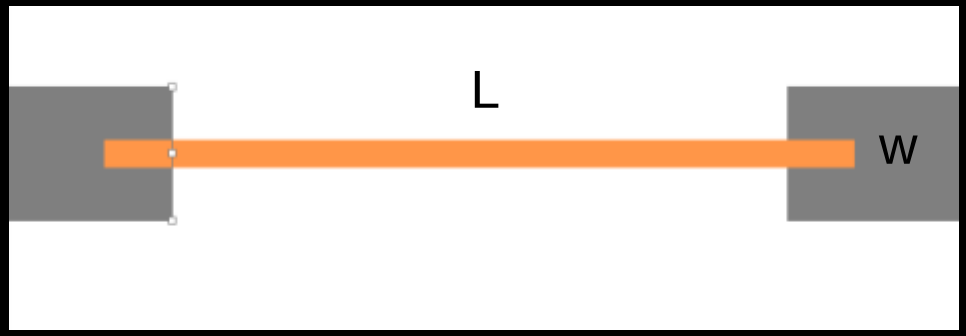
Courtesy of N. Ligato



The *Tc* decreases with increasing Cu thickness

Low control on grain size for thin-film deposited at room temperature

Device Structure

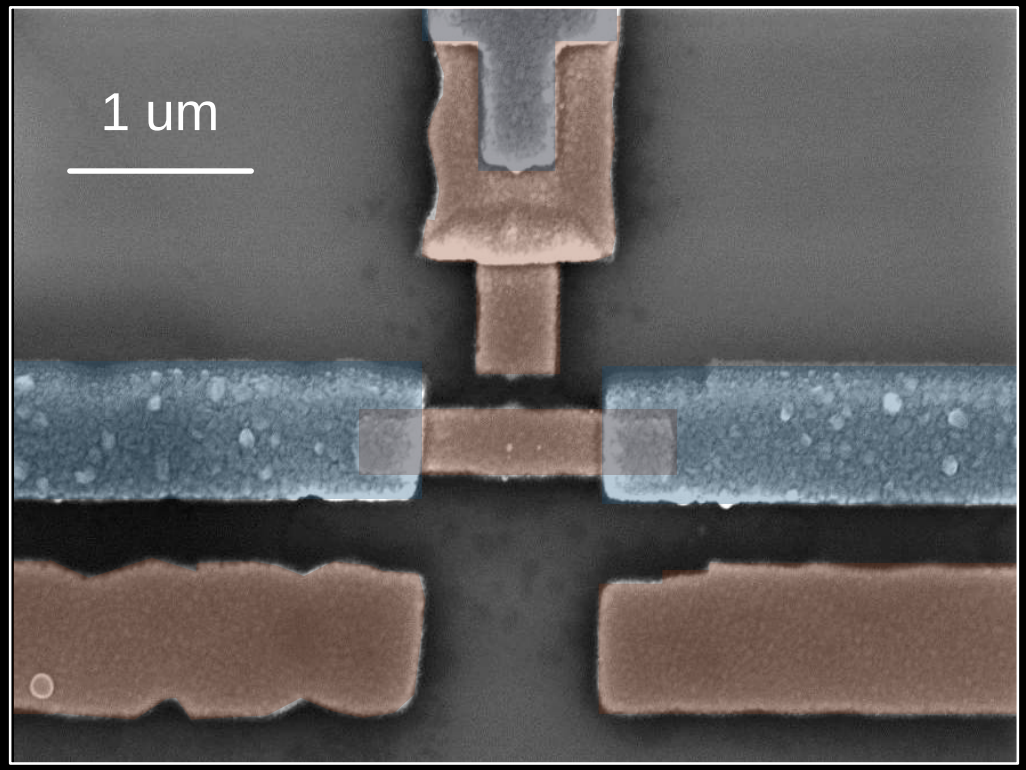


L = 2 um
w = 100 nm
t_{Al} = 10.5 nm
t_{Cu} = 15 nm
t_{banks} = 100 nm

$V_{Active} = L*w*(t_{Al}+t_{Cu}) =$
$= 5.1\text{x}10^{-21}\ m^3 = 5.1\text{x}10^{-3}\ um^3$

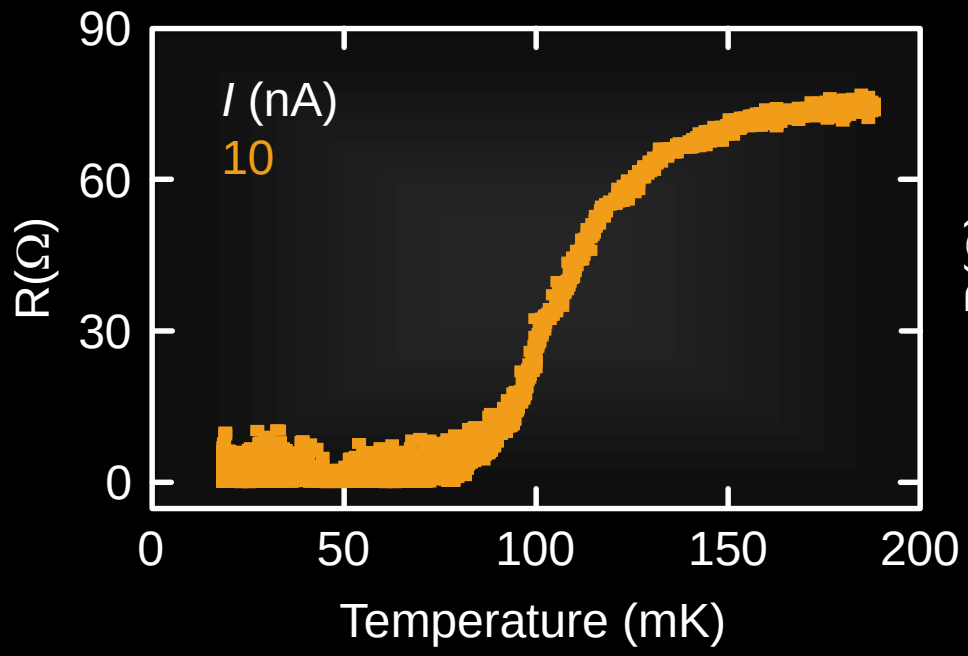
Andreev Mirror: $\Delta_{Super} \gg \Delta_{Active}$
Heat is confined in the active region
Appl. Phys. Lett. **63**, 3075 (1993)

- Low critical temperature;
- Low critical current;
- Limited proximity effect from banks;
- High heat confinement.

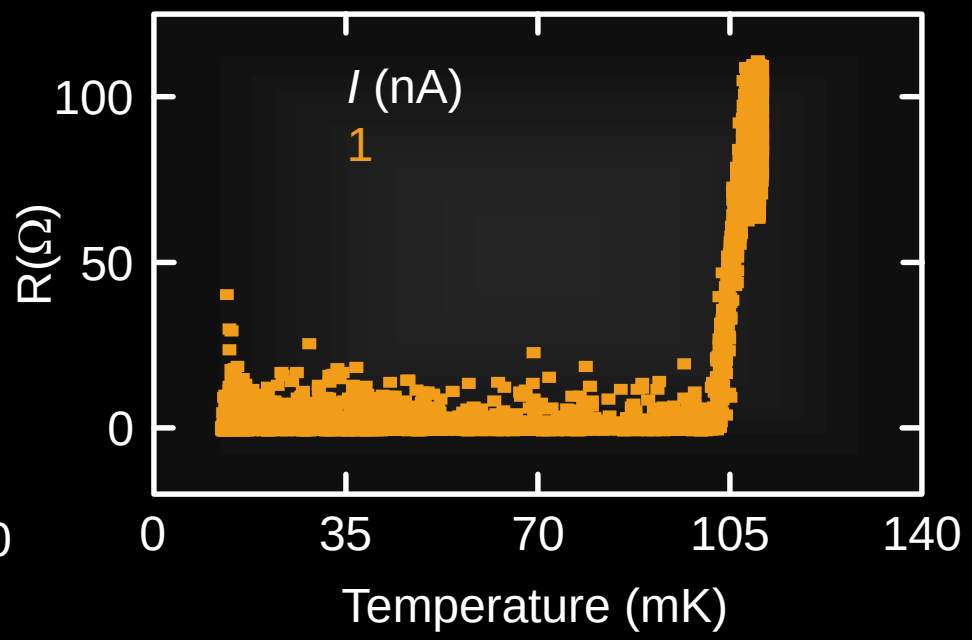


TES Critical Temperature

Sample A



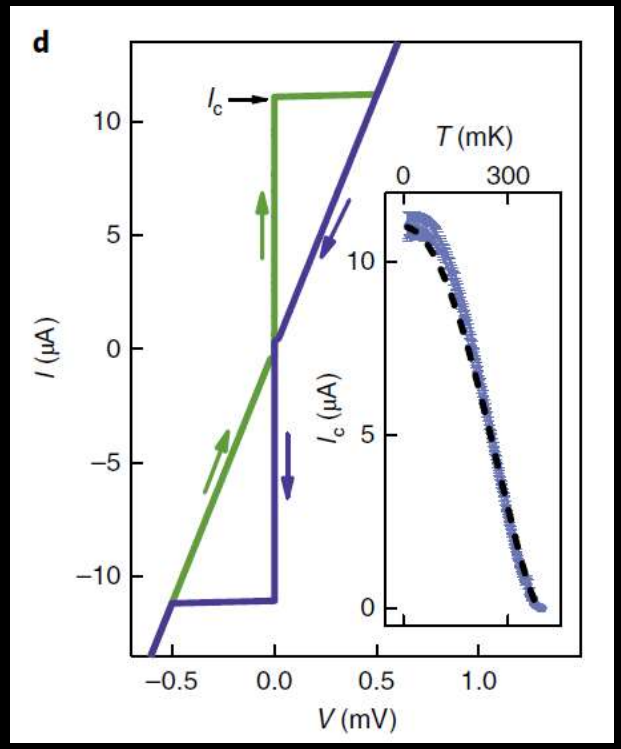
Sample B



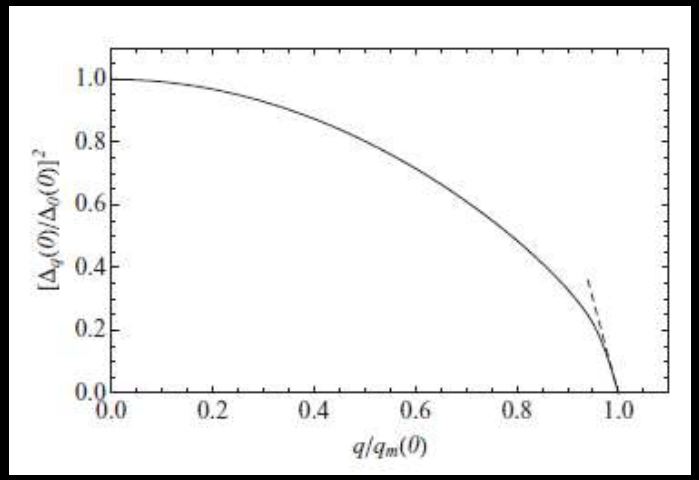
I (nA)	$T_{C,0}$ (mK)	$T_{C,50}$ (mK)	ΔT_C (mK)
10	80	110	105

I (nA)	$T_{C,0}$ (mK)	$T_{C,50}$ (mK)	ΔT_C (mK)
1	103	105	7

Tuning T_C by Current Injection

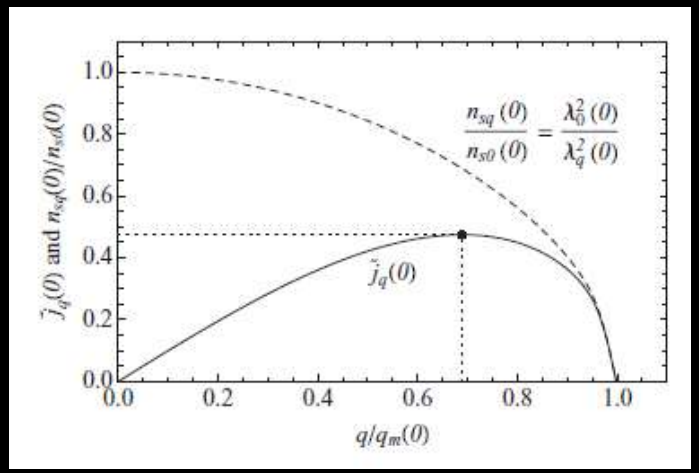


Nat. Nanotech. **13**, 802 (2018)



$q = 2mv_s/\hbar$

v_s: superfluid velocity

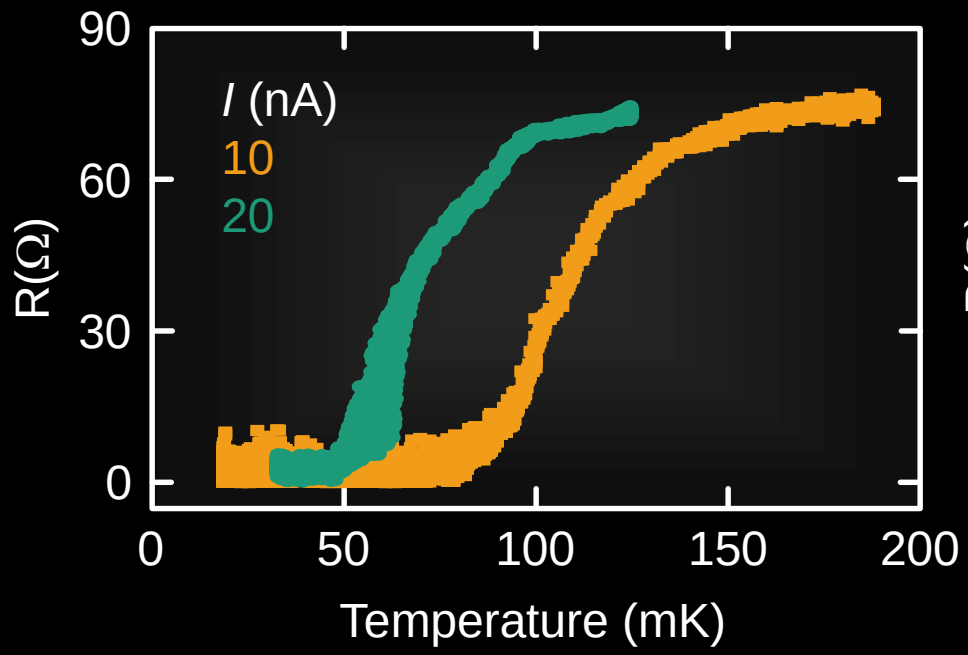


Phys Rev. B **86**, 174521 (2012)

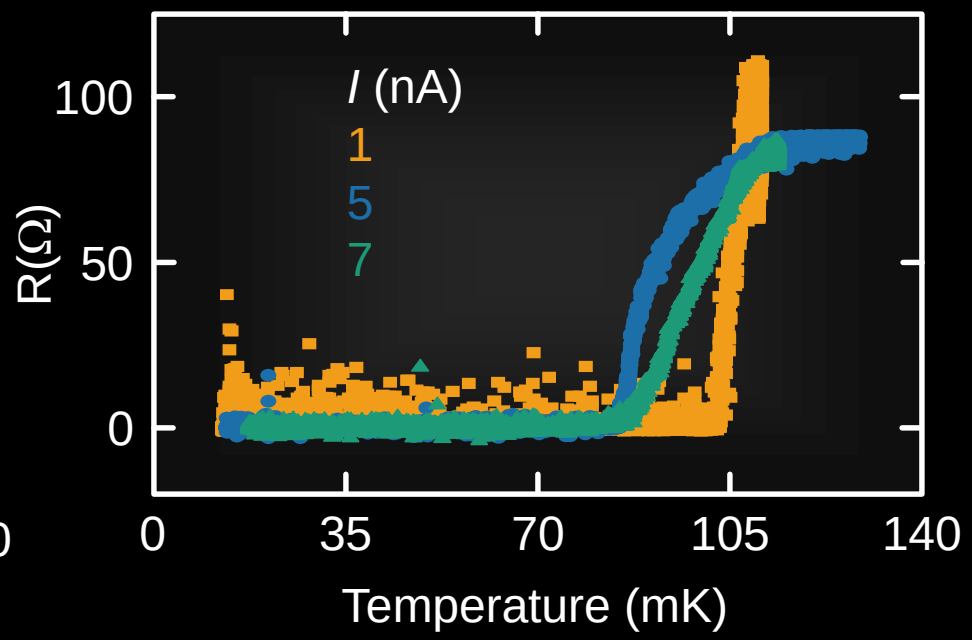
Minimum critical temperature is ~$0.6T_{C,0}$

Tuning T_C by Current Injection

Sample A



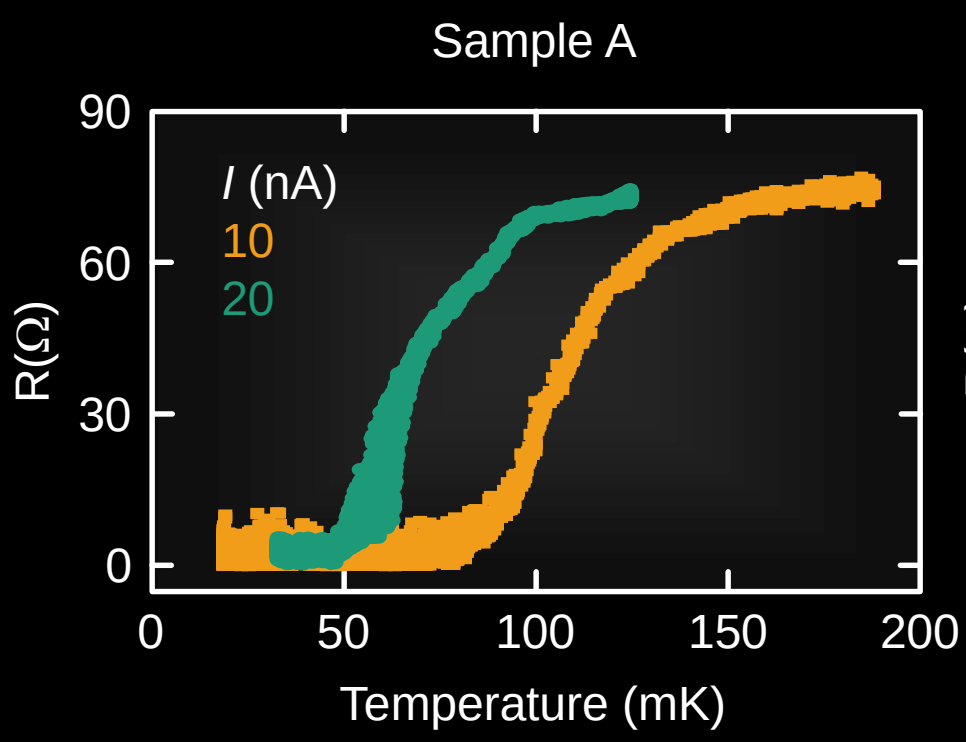
Sample B

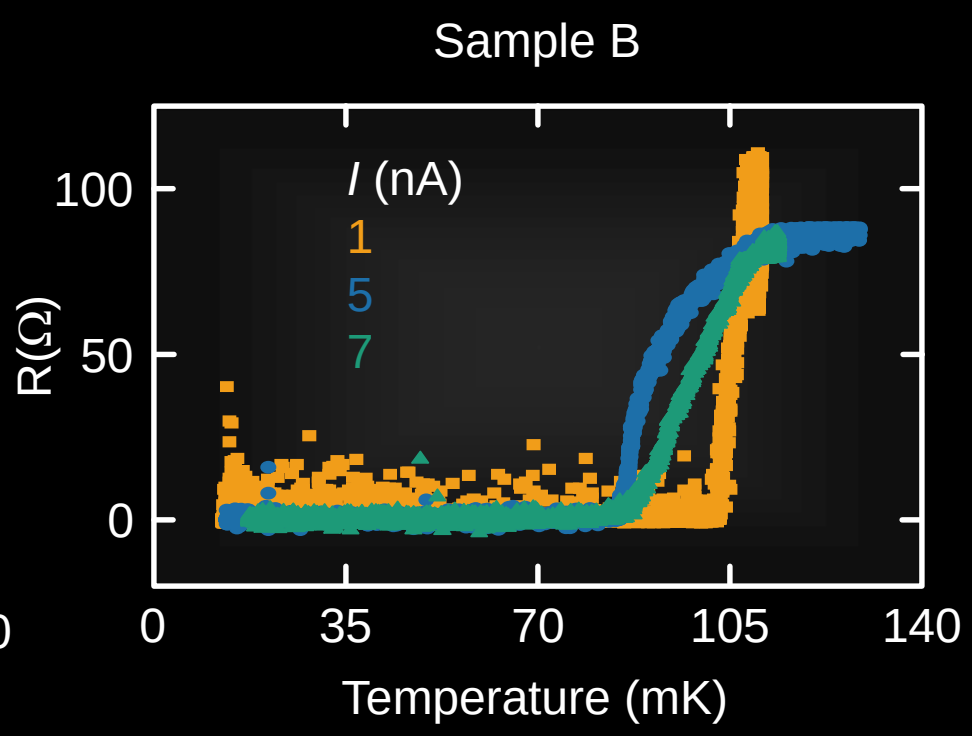


I (nA)	$T_{C,0}$ (mK)	$T_{C,50}$ (mK)	ΔT_C (mK)
10	80	110	105
20	50	70	75

I (nA)	$T_{C,0}$ (mK)	$T_{C,50}$ (mK)	ΔT_C (mK)
1	103	105	7
5	80	90	40
7	80	95	40

Tuning T_C by Current Injection





T_C = 50 mK -> f = 1.04 GHz

Frequency resolution σ_E ~ 1-2 GHz

Bolometer

Electron-phonon thermal exchange in metals:

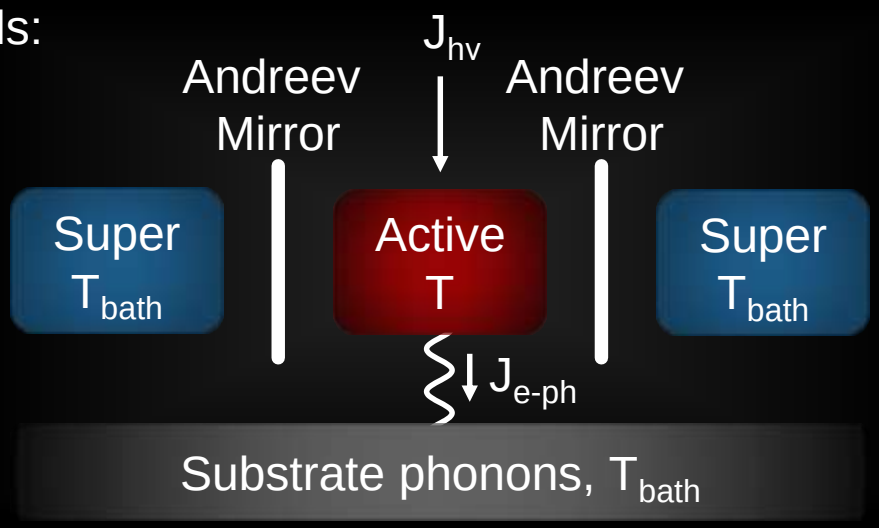
$$J_{e-ph} = \Sigma V_{Active}\left(T_e^5 - T_{bath}^5\right)$$

Rev. Mod. Phys. **78**, 217 (2006)

Determine the volume of the active region V_{Active}, by solving the energy balance equation:

$$J_{hv} - J_{e-ph} = 0$$

Rev. Mod. Phys. **78**, 217 (2006)



Considering
L = 2 um
w = 100 nm
t_{Al} = 10.5 nm
t_{Cu} = 15 nm
$T_e = 50mK$
$T_{ph} = 10mK$

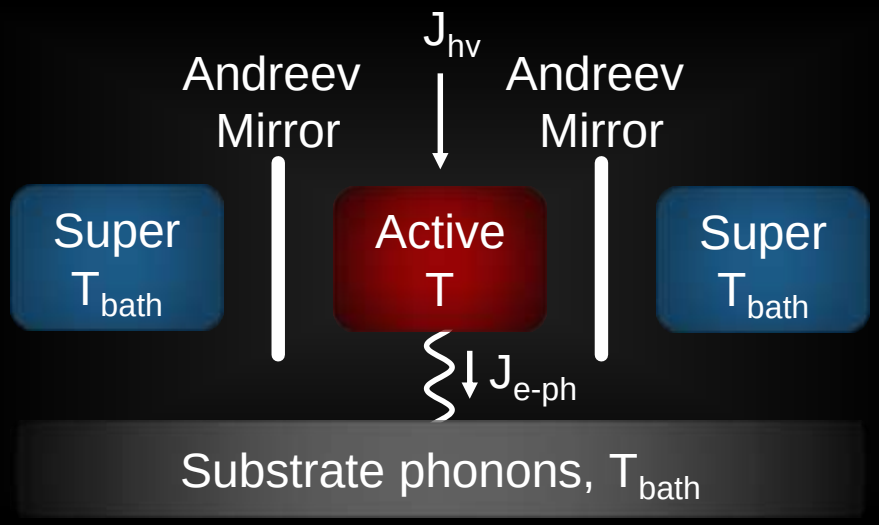
$$J_{e-ph} = J_{e-ph,Cu} + J_{e-ph,Al} \approx 1.87 \times 10^{-18}W + 2 \times 10^{-19}W = \\ = 2.07 \times 10^{-18}W$$

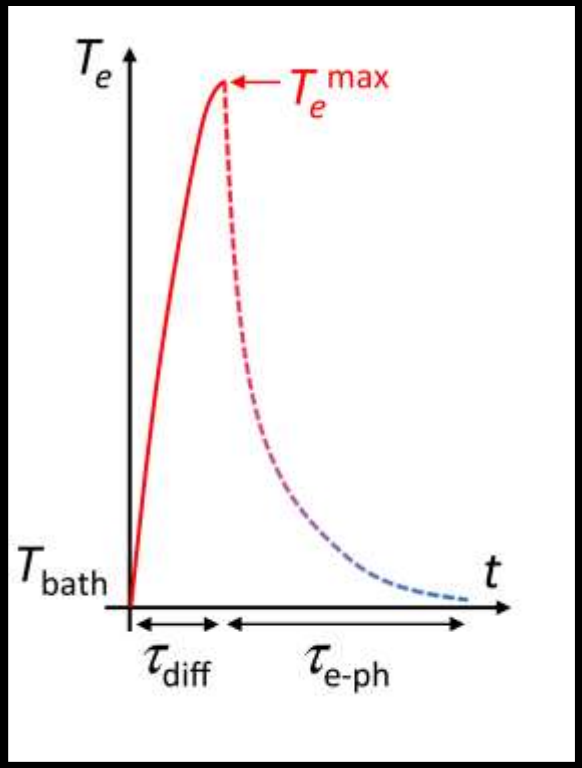
Considering the superconductor electron-phonon coupling the minimum detectale heating is on the order of **10^{-19}-10^{-20} W**

Calorimeter

Power of single-photon: $J_{h\nu} \sim 10^{-20}\mathrm{W}$

Phys. Dark Universe **12**, 37 (2016)



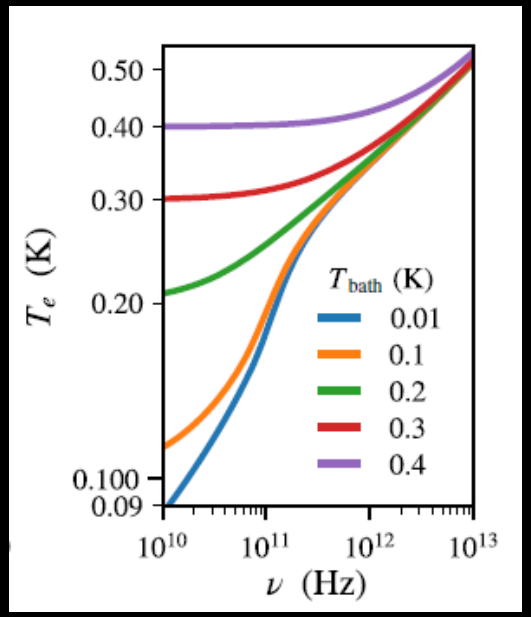


Phys. Rev. Appl. **9**, 054027 (2018)

$$\tau_{diff} = {L^2}/{D} \approx 10^{-10}s$$

con D ~ 100 cm²/s

$$\tau_{e-ph} \approx \left[{(k_B^2 v_F)}/{(0.34\Sigma)}\right] T_{bath}^{-3} \approx 10^{-6} - 10^{-7}s$$



Phys. Rev. Appl. **9**, 054027 (2018)

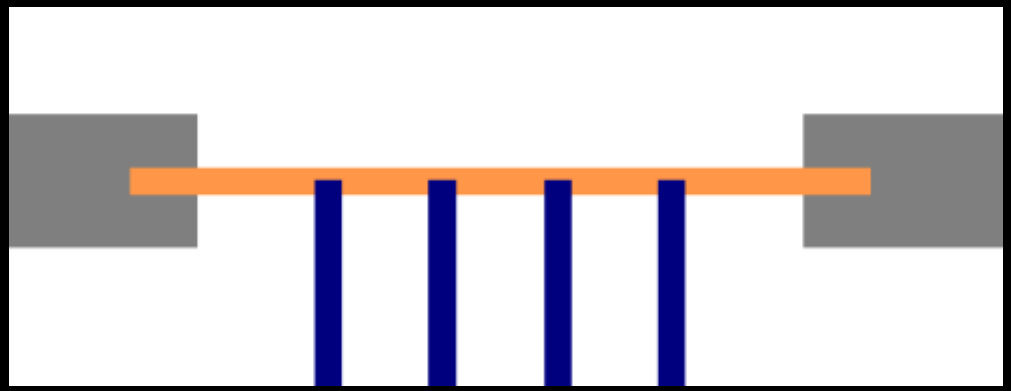
Suitable for single photon detection

Resume of Results

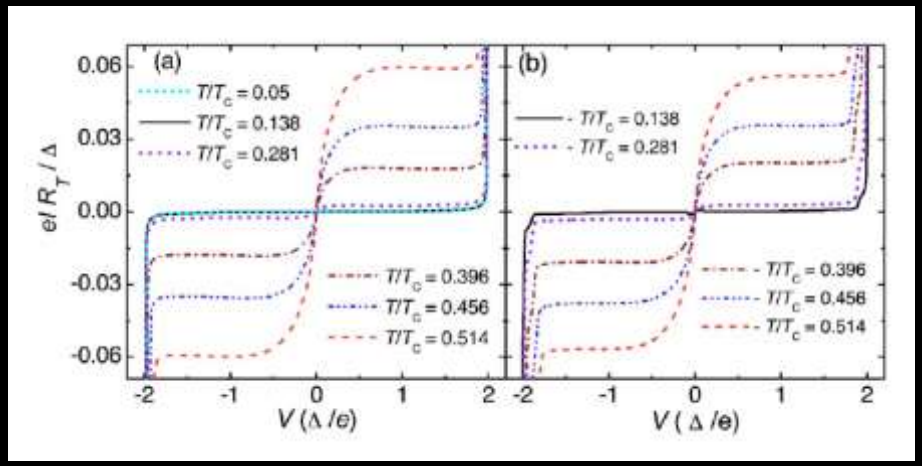
- Fabrication of TES without antenna
- T_C tunable in the range 50 – 103 mK
- Sensible to 1 GHz
- Energy resolution 1-2 GHz
- Bolometer: sensitivity 10^{-19}-10^{-20} W
- Calorimeter: suitable for a few GHz single photons

Future Work

- Include heaters and thermometers



Al banks
Cu/Al active
Al tunnel



Rev. Mod. Phys. **78**, 217 (2006)

- Active region made of Ti/Cu?