Updates on TESs for PTOLEMY project (PTL-TESs)

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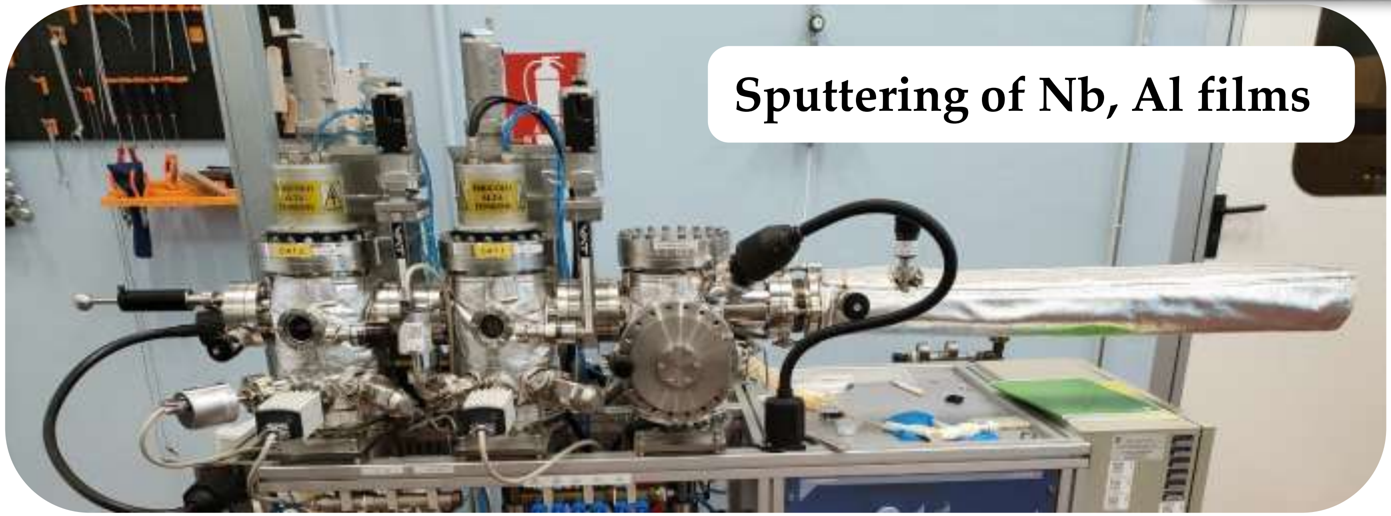
INRiM facilities for TESs

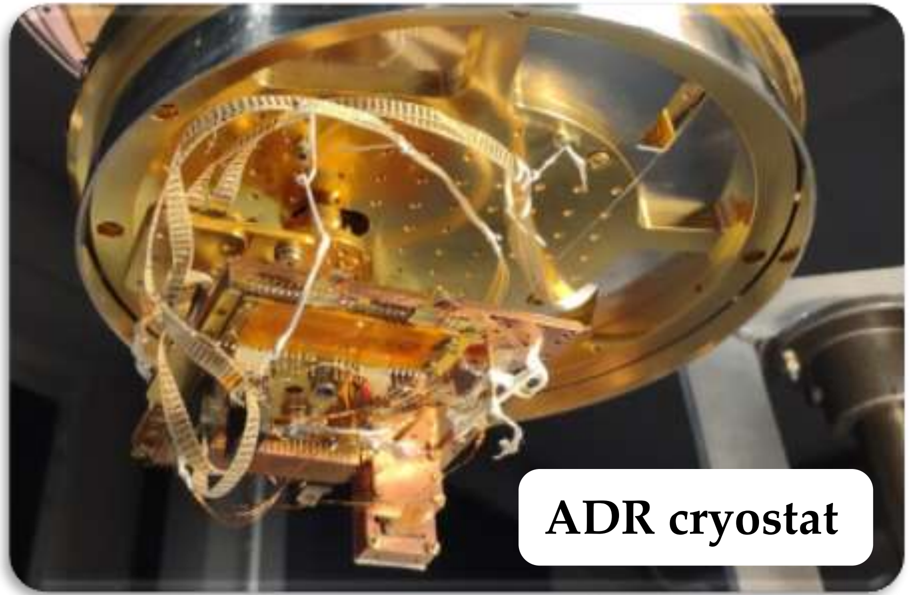
Fabrication

Thermal evaporation of Au ,Ti.
Depositions in rapid sequence.

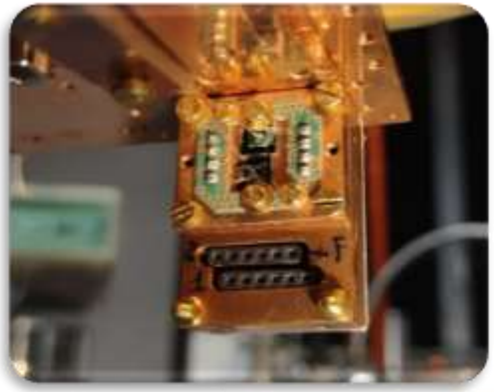


Sputtering of Nb, Al films

Characterization



ADR cryostat



Remarks

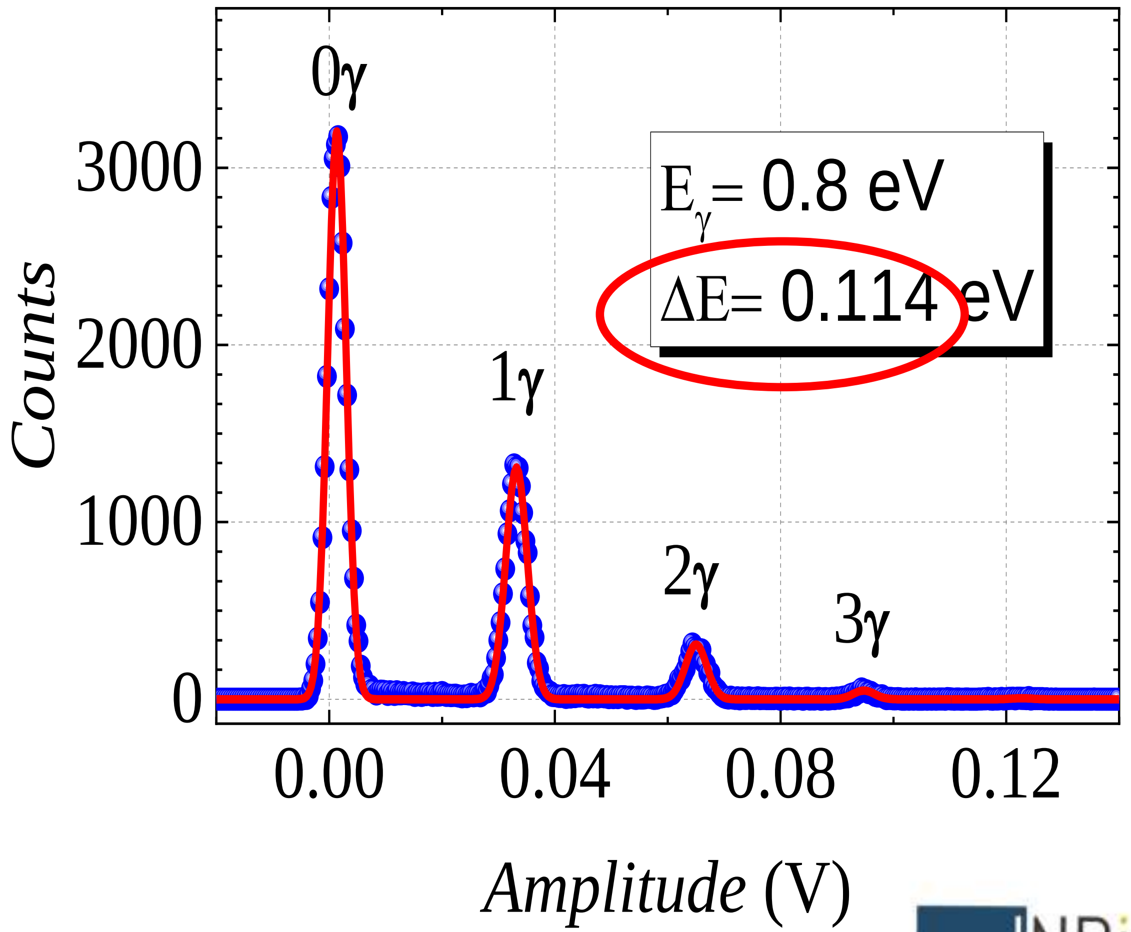
Target:

$\Delta E_{FWHM} = 0.05$ eV
(With e^- @ 10 eV)

Actual result:

$\Delta E_{FWHM} = 0.11$ eV

INRiM BEST ENERGY RESOLUTION



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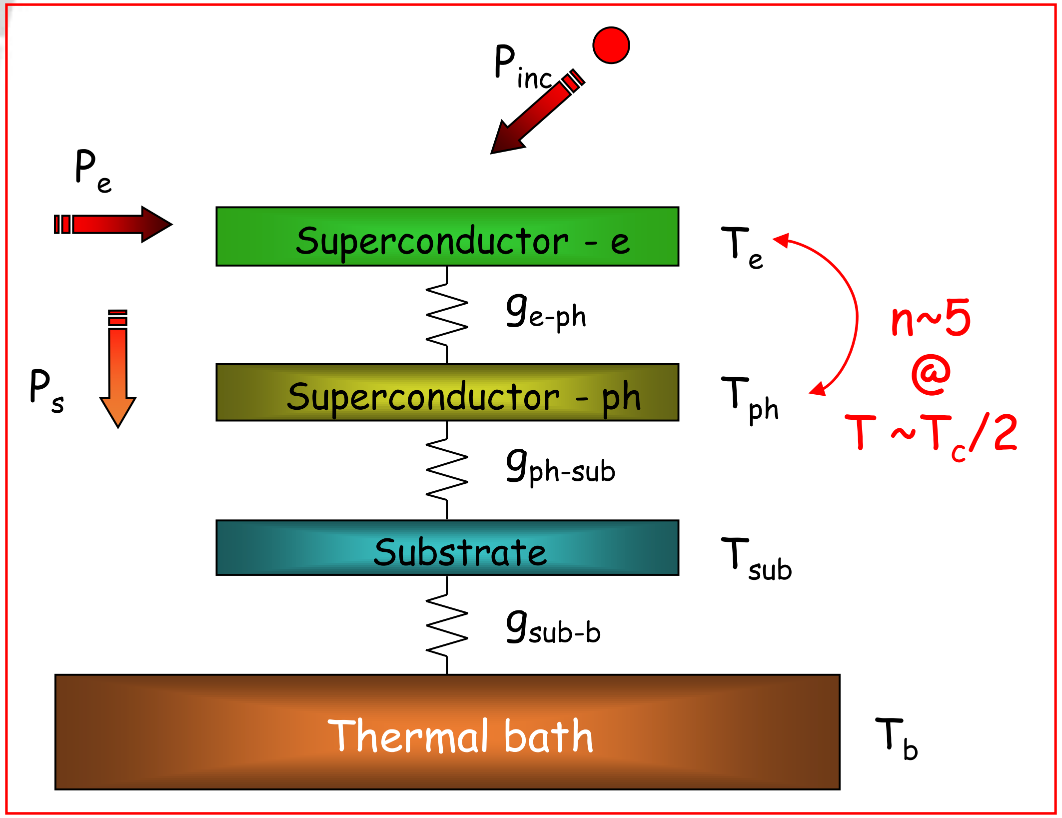
Electro-Thermal Feedback recall

Thermal circuit

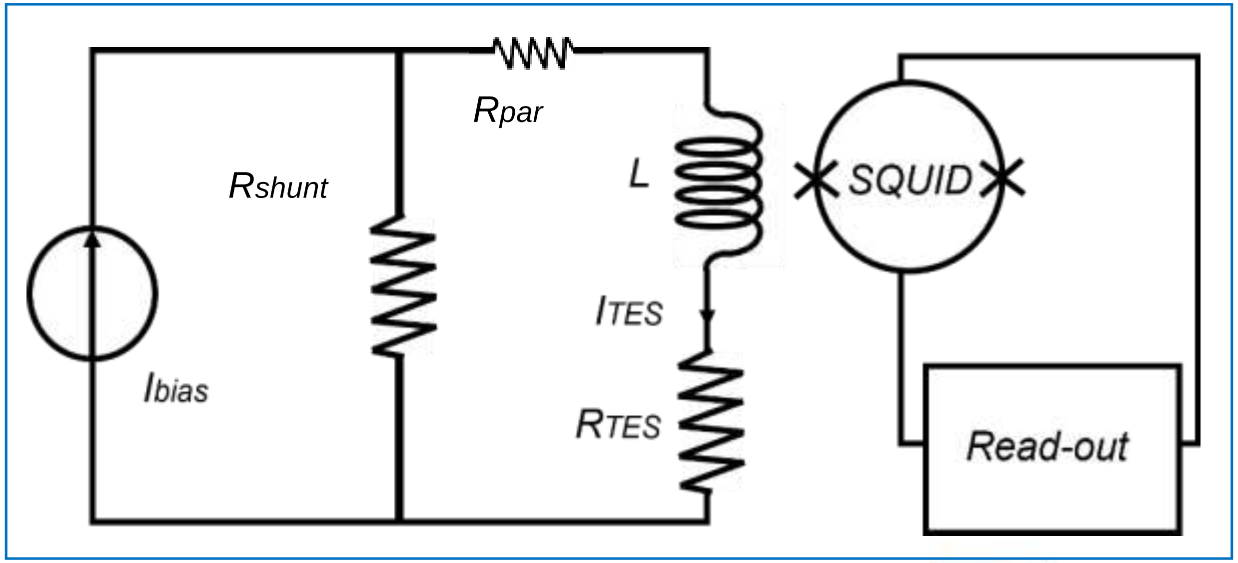


thermal bath $T_b < T_c$

T ⇧ → R ⇧ → $P_e = V^2/R$ ⇩ → T ⇩

T ⇩ → R ⇩ → $P_e = V^2/R$ ⇧ → T ⇧

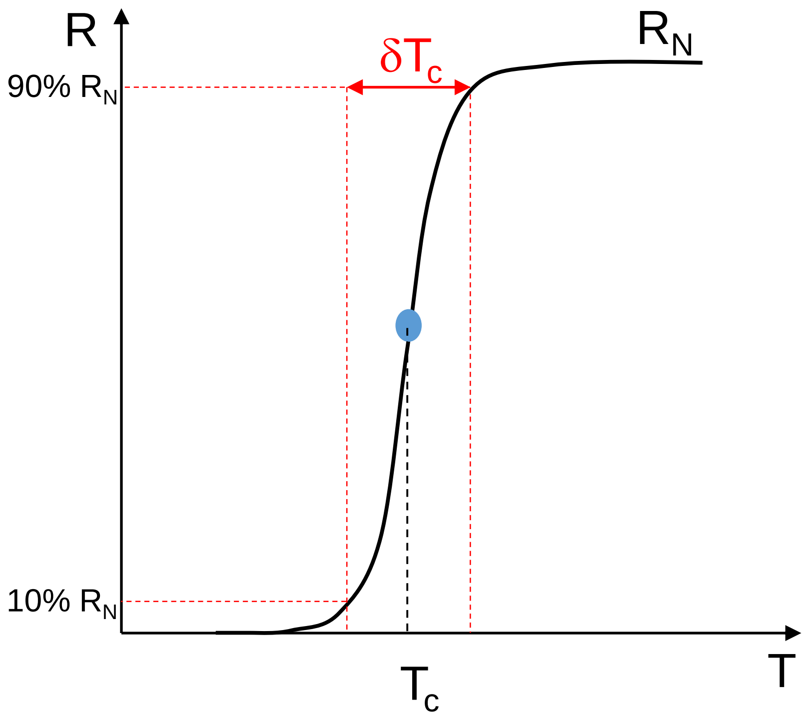
Electrical circuit



Voltage bias

Principle and useful formulas

Superconducting transition



Energy resolution:

$$\Delta E_{FWHM} \approx 2.36\sqrt{4kT_c^2\frac{C_e}{\alpha}\sqrt{n/2}} \propto \sqrt{E_{\max}T_c}$$

Saturation energy:

$$E_{\max} \approx \frac{C_e T_c}{\alpha}$$

$$\alpha = f(\delta\ T_c, I)$$

Irwin K. D. , Appl. Phys. Lett. **66** 1998 (1995)

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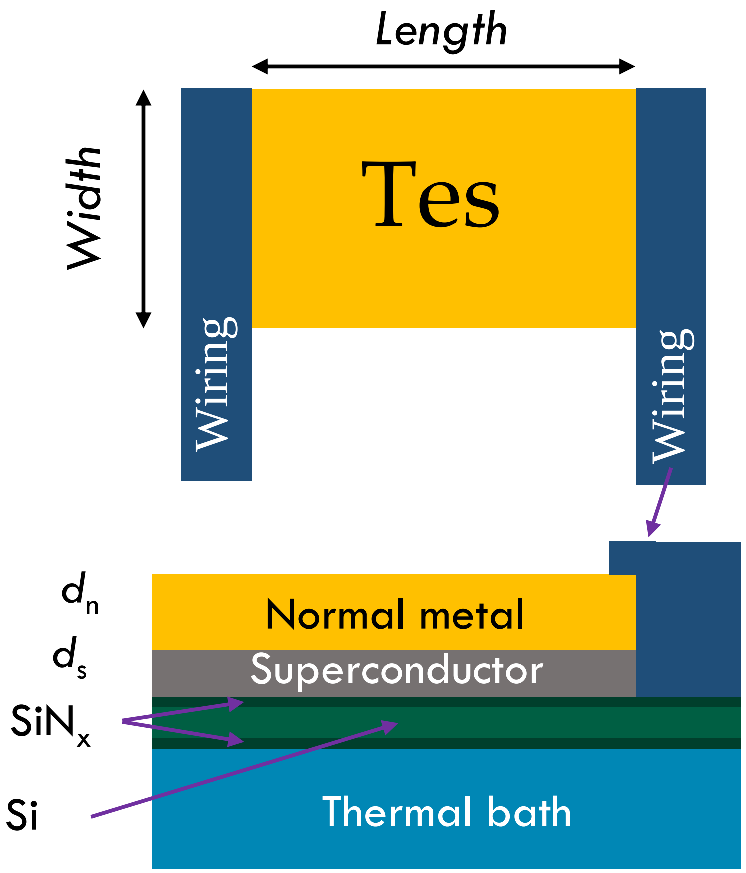
Proximity effect without wiring



$$T_C = T_{C0}\left[\frac{d_s}{1.13\, d_0\left(1+\frac{d_s n_s}{d_n n_n}\right) t}\right]^{\frac{d_n n_n}{d_s n_s}}$$

n_n , n_s ≡ electron state densities,
λ_F ≡ Fermi wavelength,
T_{C0} ≡ intrinsic critical temperature,
s_n ≡ normal layer conductivity,
t ≡ transmission coefficient.

$$d_0^{-1} = \frac{\pi}{2} k_B\, T_{C0} n_s \lambda_F^{2}$$

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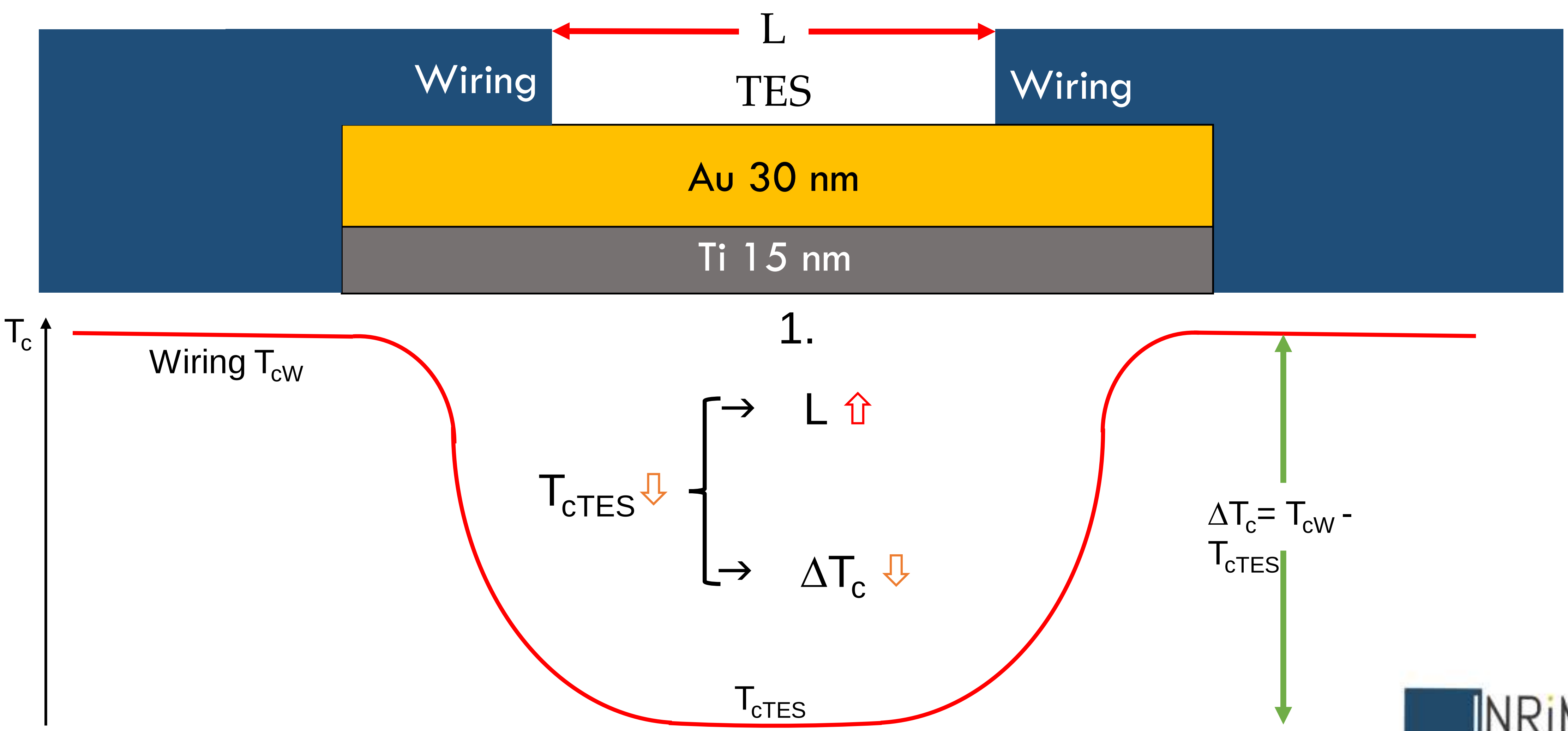
Proximity effect - wiring 1



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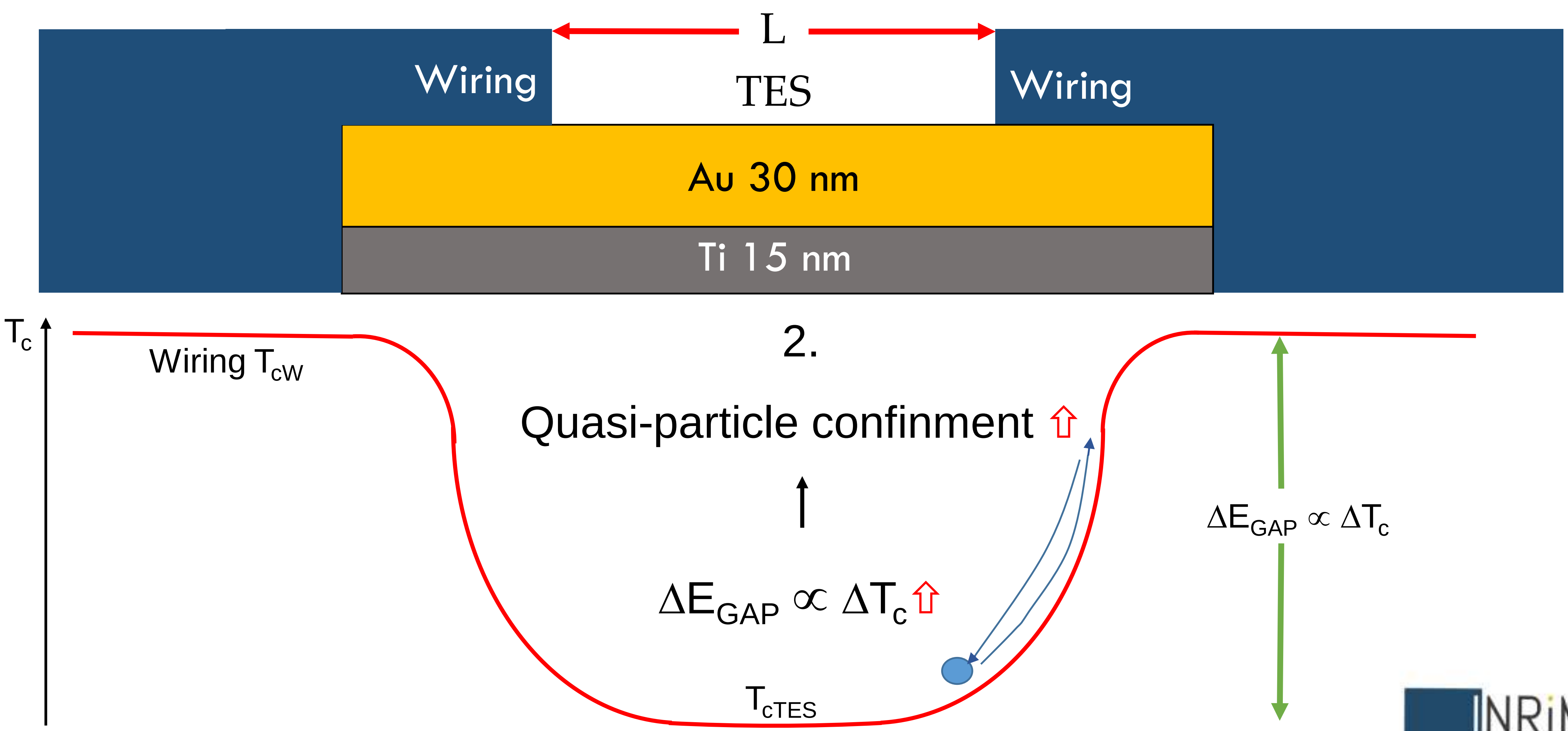
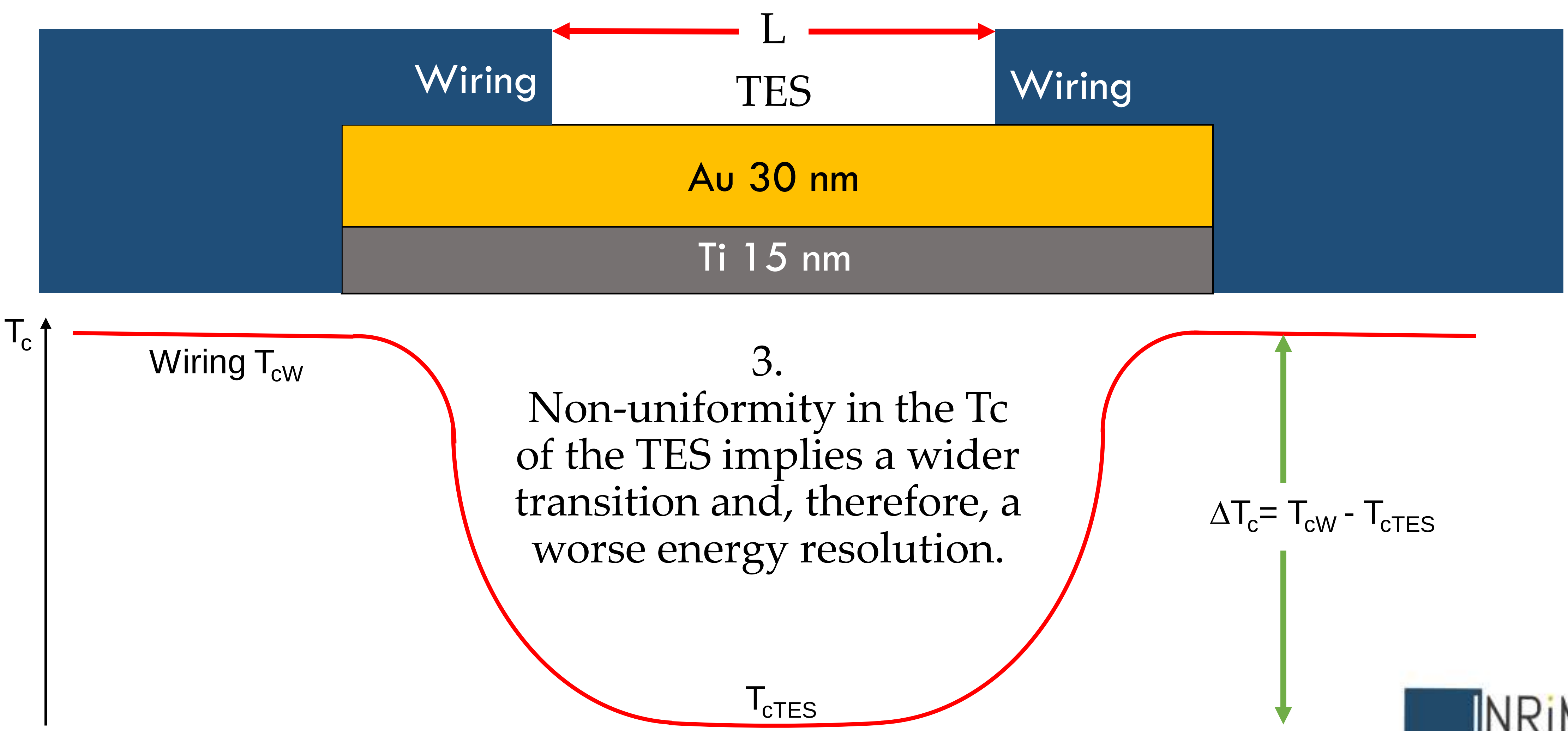
Proximity effect - wiring 2



Proximity effect - wiring 3



3.
Non-uniformity in the Tc of the TES implies a wider transition and, therefore, a worse energy resolution.

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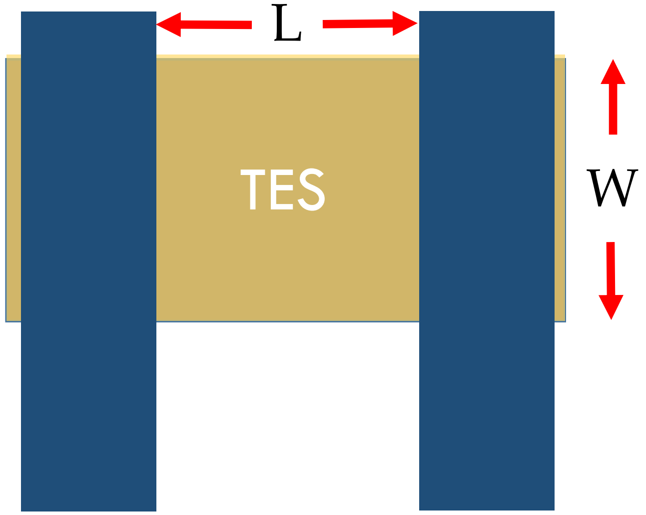
Proximity effect due to the wiring



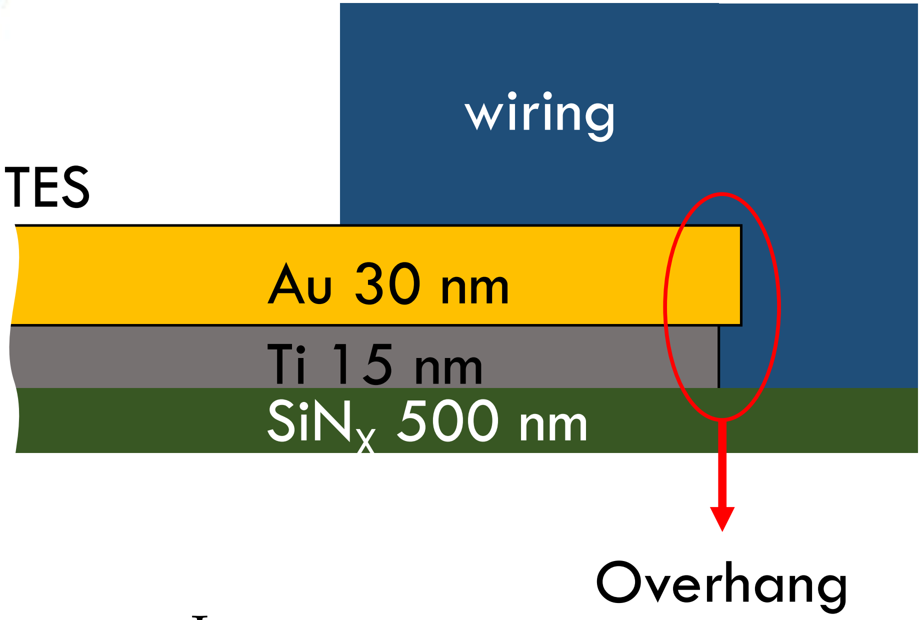
REF:
Ridder, M. L., et al. "Study of TES Detector Transition Curve to Optimize the Pixel Design for Frequency-Division Multiplexing Readout." *Journal of Low Temperature Physics* 199 (2020): 962-967.

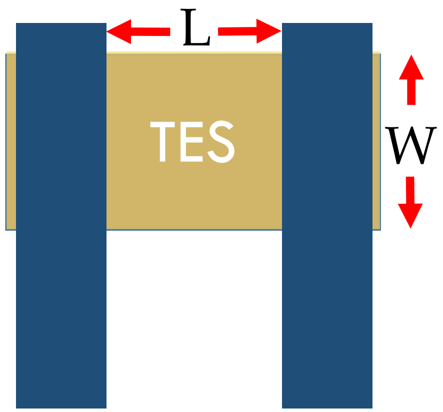
$\delta T_c \alpha\ -L^{-2}$

$T_c\ \alpha\ -L^{-2}$

Saturates @ L ~ 100 μm

Edge effects: overhangs





REF:
Nagayoshi, K., et al. "Lateral Inverse Proximity Effect in Ti/Au Transition Edge Sensors." *Journal of Low Temperature Physics* (2022): 1-8.

$T_c \propto -W^{-2}$

Saturates @ W ~ 30 μm

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Recent design modification attempts

T_C non-uniformity in the TES:

- Edge effect (overhangs);
- Proximity effect due to the wiring.

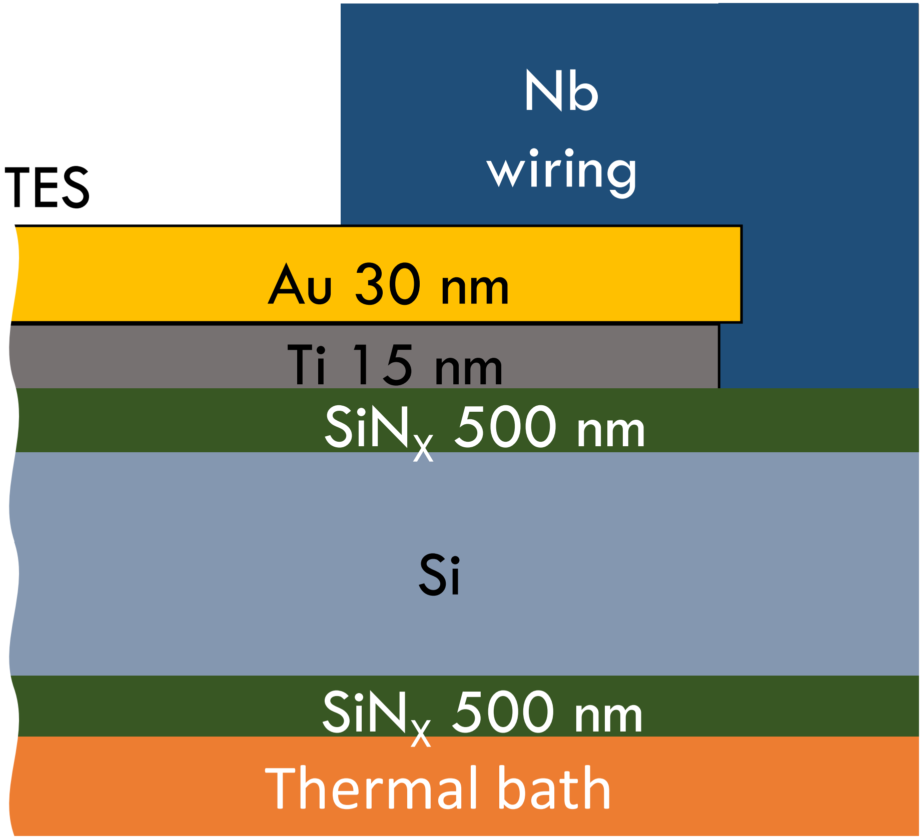
Design solution attempts:

1. Wiring of *titanium* instead of *niobium*:
   Pro: lower wiring T_C may reduce the transition width.
   Con: a lower energy gap between wiring and TES could reduce the energy resolution?

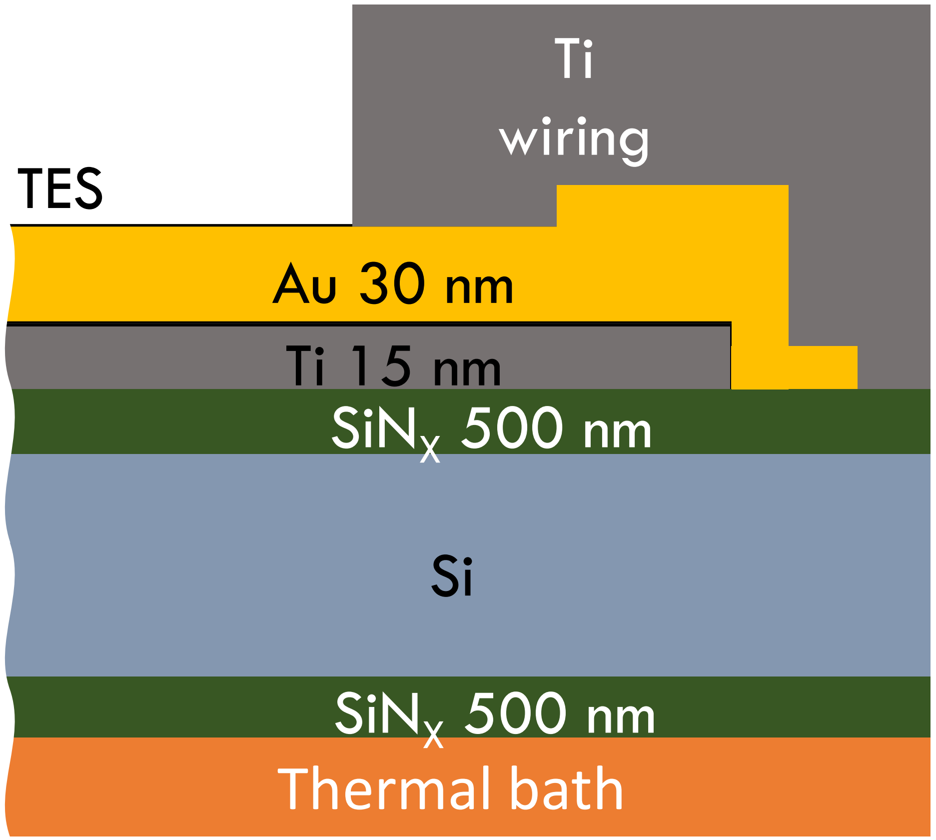
2. Ring of gold that surrounds the edges of the TES:
   Pros: Reduction of the edge effect, Ti of the TES protected from oxidation.
   Con: Increased fabrication complexity due to a major number of steps.

TES structure with and without ring

TES without the ring



TES with the ring



TES structure with ring

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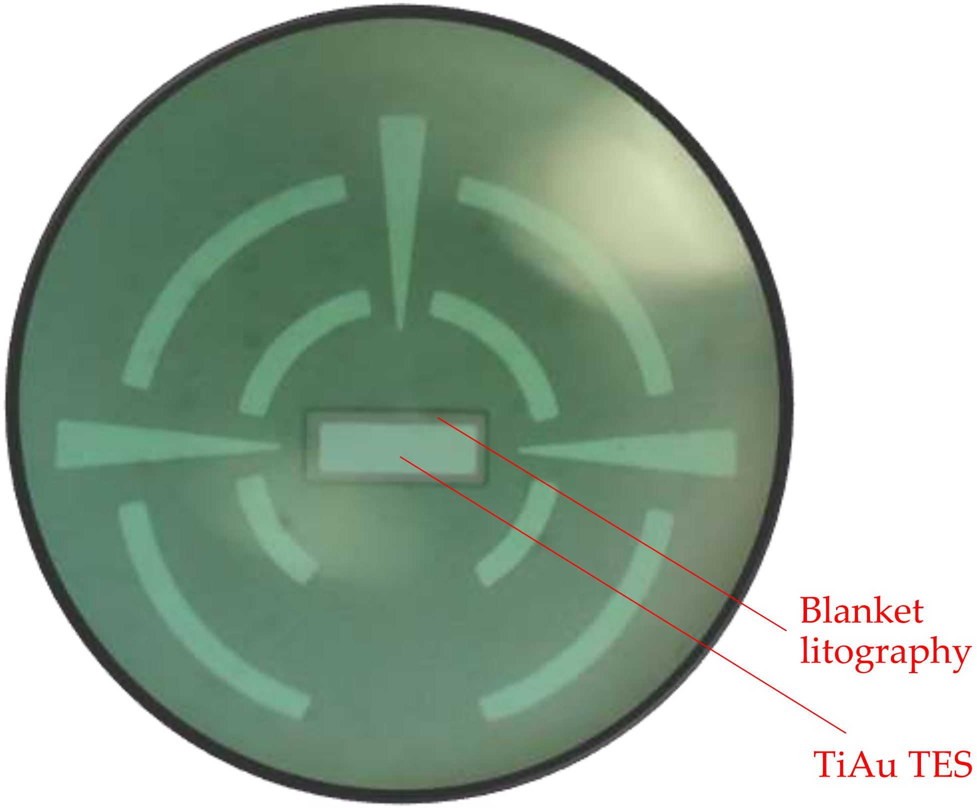
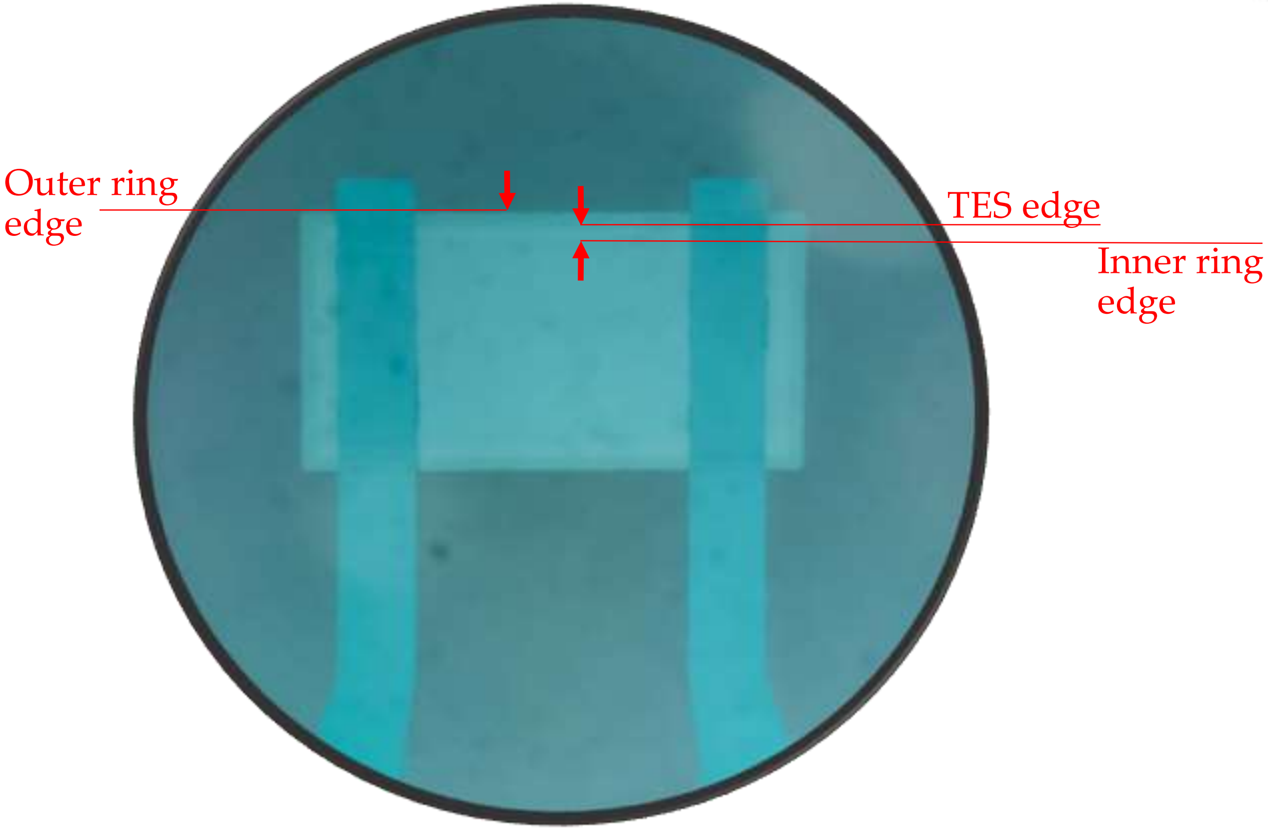
TES structure with and without ring

TiAu TES 10x10



TiAu TES 100x100



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Results table for sample 1 (Lito10)

Sample name	chip	Area[μm^2]	T_c[mK]	δT_c[mK]
Lito10 Ti: 15 nm Au: 30 nm Wiring: Ti	A	12x12	102	1
		20x20	103	1.5
		60x60	103	2
		100x100	104.6	1
	B	All	No Tc	
	C	60x60	102	1.5
	F	60x60	94	1

Chip A: No Ring

Chip B: All blankets

Chip C: I: 2 μm O: 3 μm

Chip F: I: 5 μm O: 5 μm

Only for TESs 60x60 and 100x100

I: Inner part of the ring, overlapping the TES.

O: Outer part of the ring, overlapping only the wiring.

Only for TESs 12x12 and 20x20

Results table for sample 2 (PTL1)

Sample name	chip	Area[μm]	T_c[mK]	δT_c[mK]
PTL1 Ti: 15 nm Au: 20 nm Wiring: Ti	A	10x10	168.8	1.2
		20x20	170.5	0.75
		60x60	173	0.9
		100x100	175	2.5
	B	10x10	162.2	5
		20x20	168.5	2
		60x60	168	1
		100x100	172.3	1.4
	C	All	No Tc	
	F	10x10	160.3	4.3
		20x20	163.9	1.93
		60x60	161.3	1.33
		100x100	161.8	1.4

No Ring

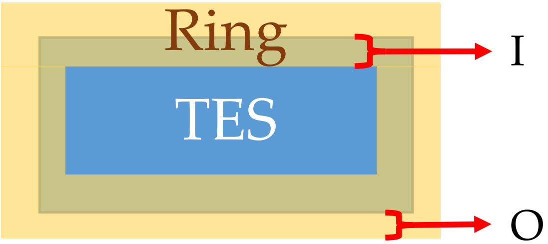
I: 1 μm O: 2 μm

I: 2 μm O: 3 μm

I: 1 μm O: 1 μm

I: 5 μm O: 5 μm

For all the TESs



Results table for sample 3 (PTL3)

Sample name	chip	Area[μm]	T_c[mK]	δT_c[mK]
PTL3 Ti: 15 nm Au: 30 nm Wiring: Ti	A	10x10	105.2	9.25
		20x20	100	3.5
		60x60	97.8	1.95
		100x100	104	1
	B	20x20	91.5	1.3
		100x100	93	1.3
	C	10x10	69.4	5.3
		20x20	68.3	1.7
		60x60	96.5	1.8
	F	20x20	88.4	0.9
		60x60	87	1.3
		100x100	88.7	1.6

As sample 2

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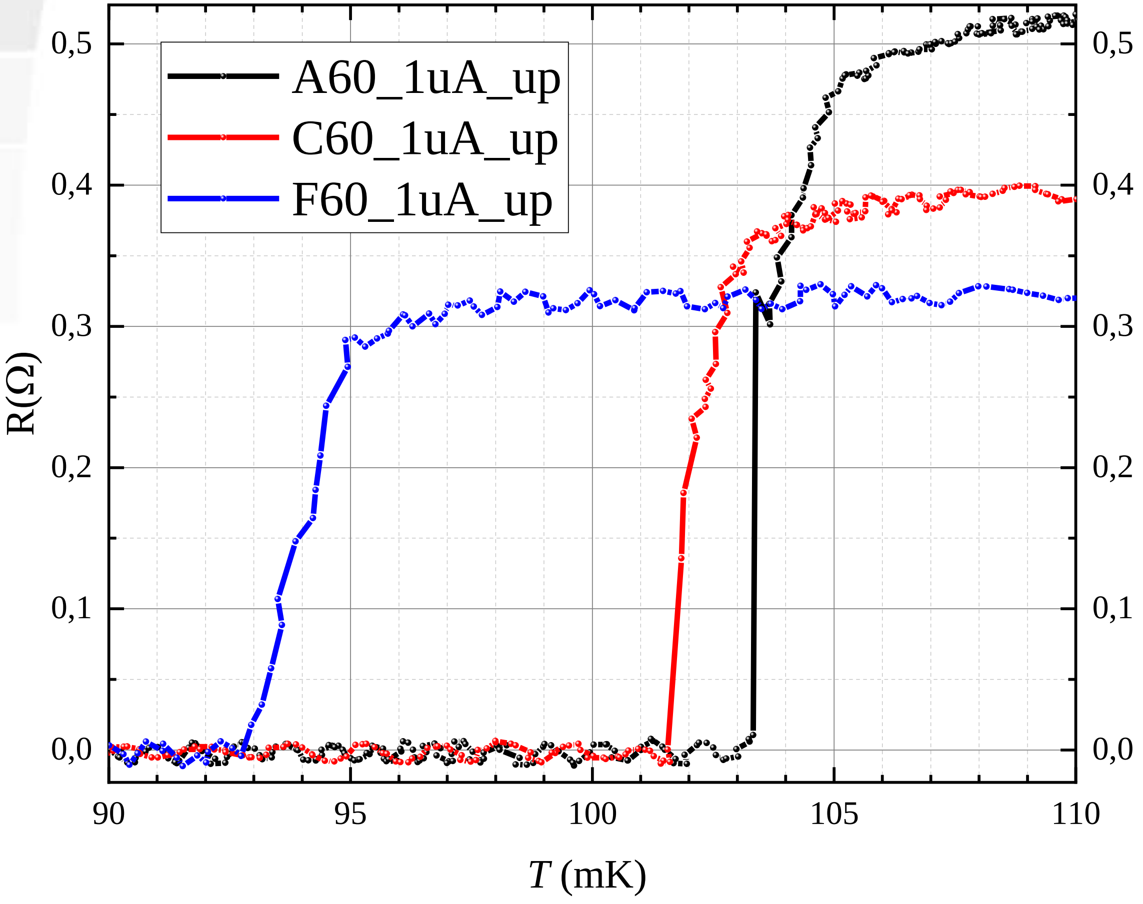
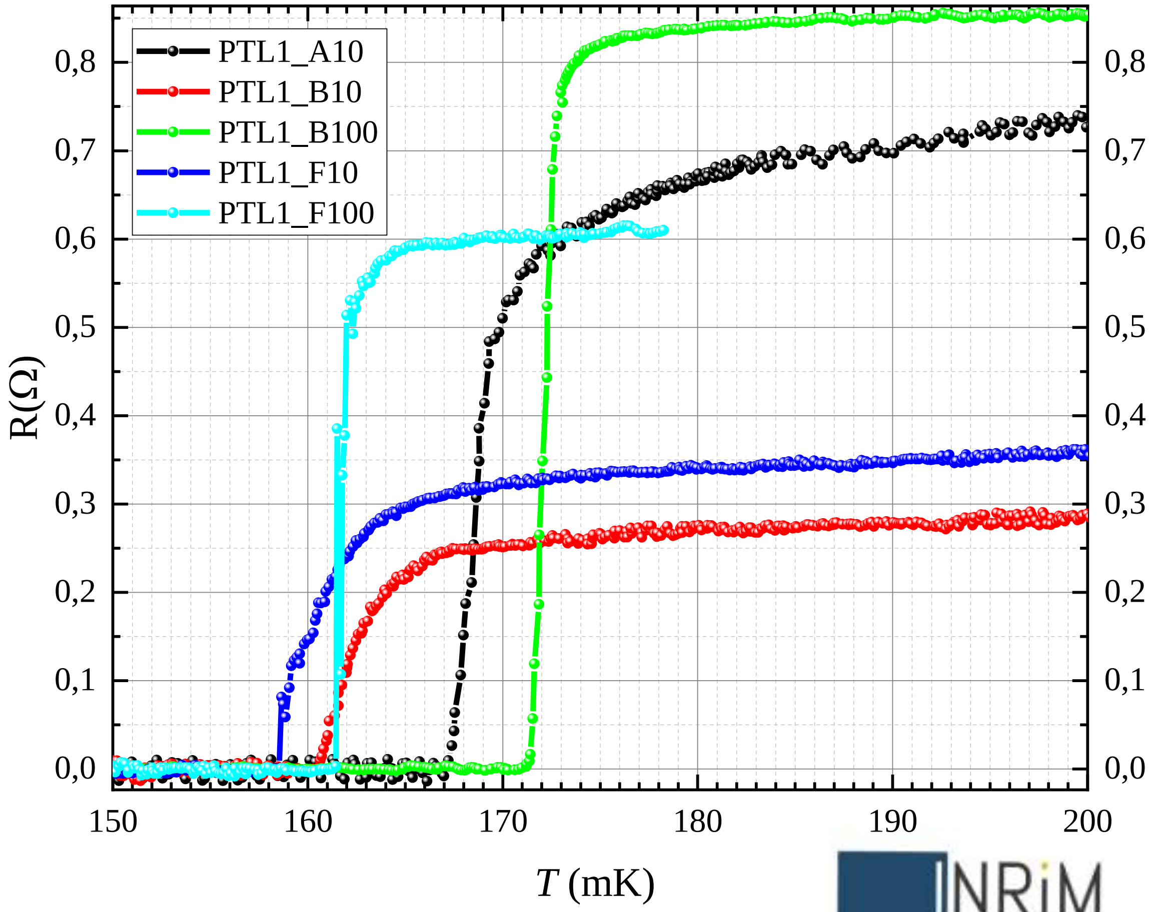
sample 1 and sample 2 : comparisons

Lito10 60x60μm² 1μA up measurement 23/01/23



PTL1 1uA up measurement 03/03/23



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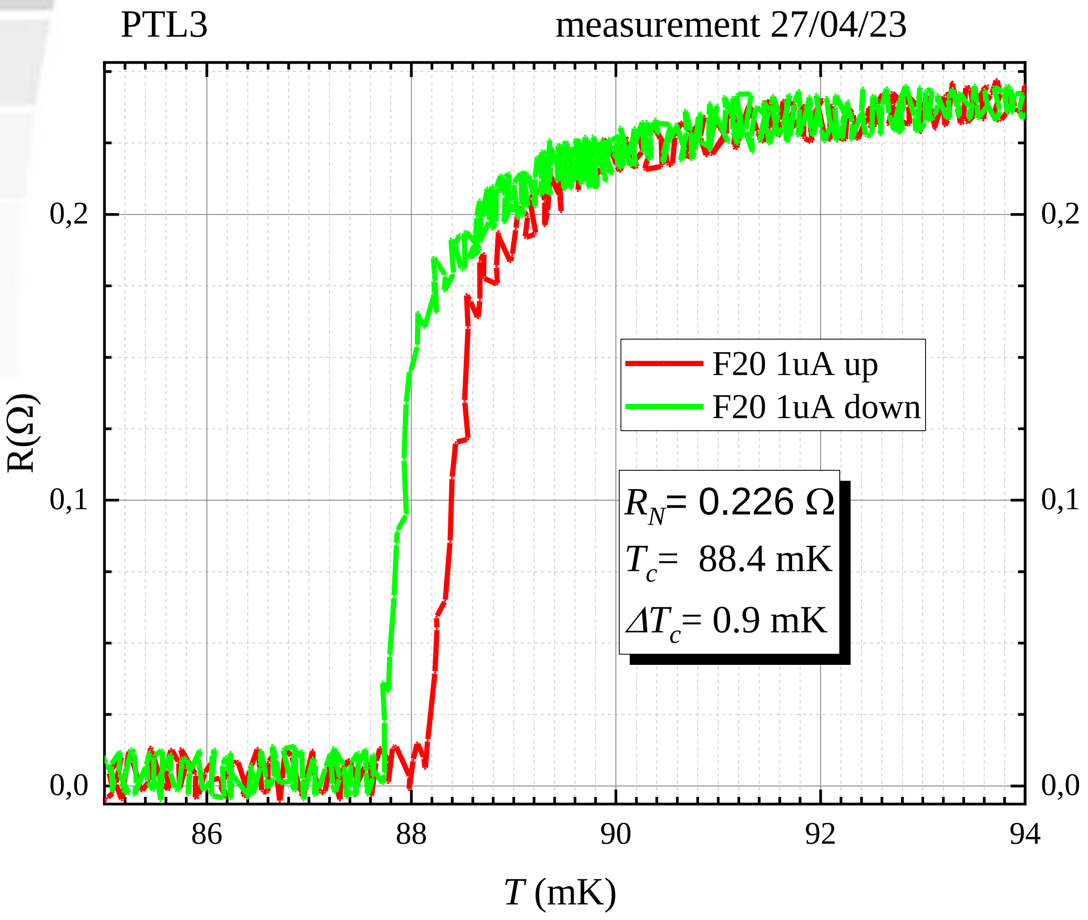
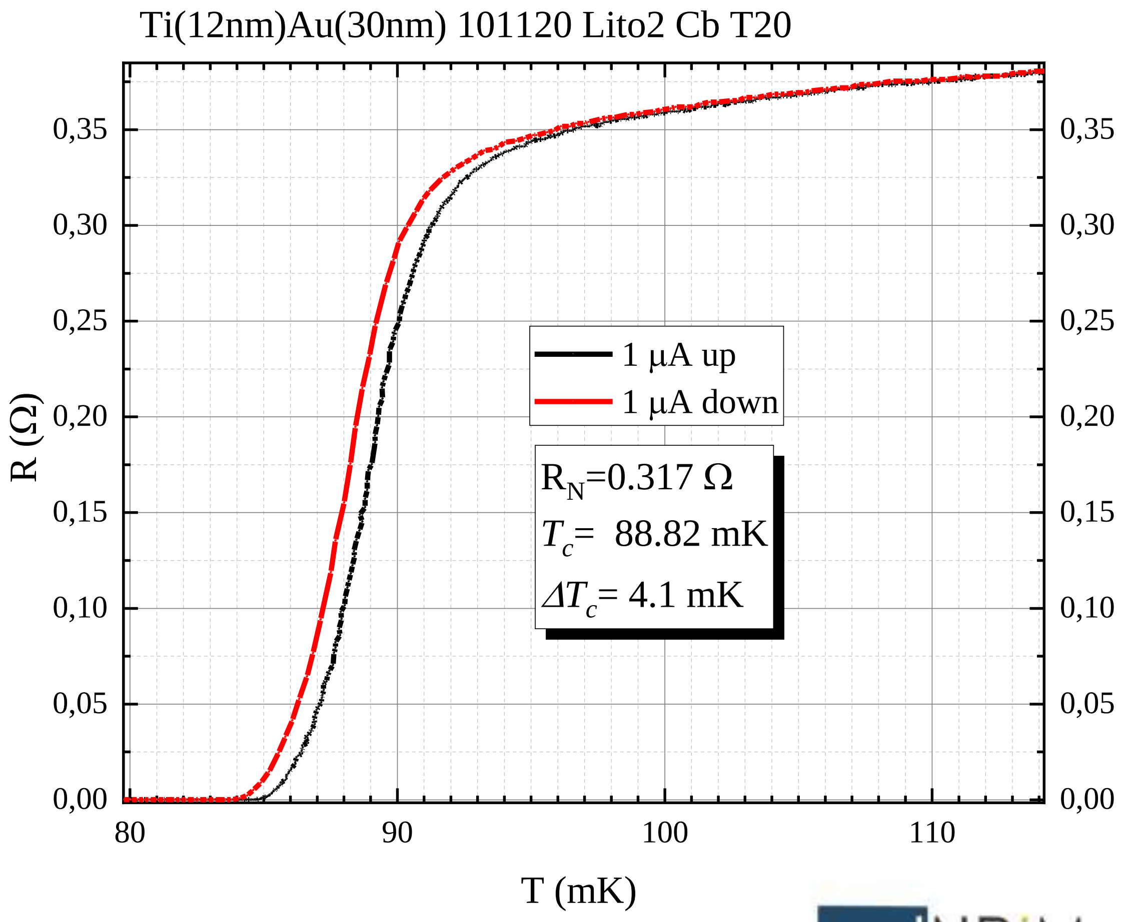
Best result (sample 3 F20)

Sample 3 VS Old good result (no ring)





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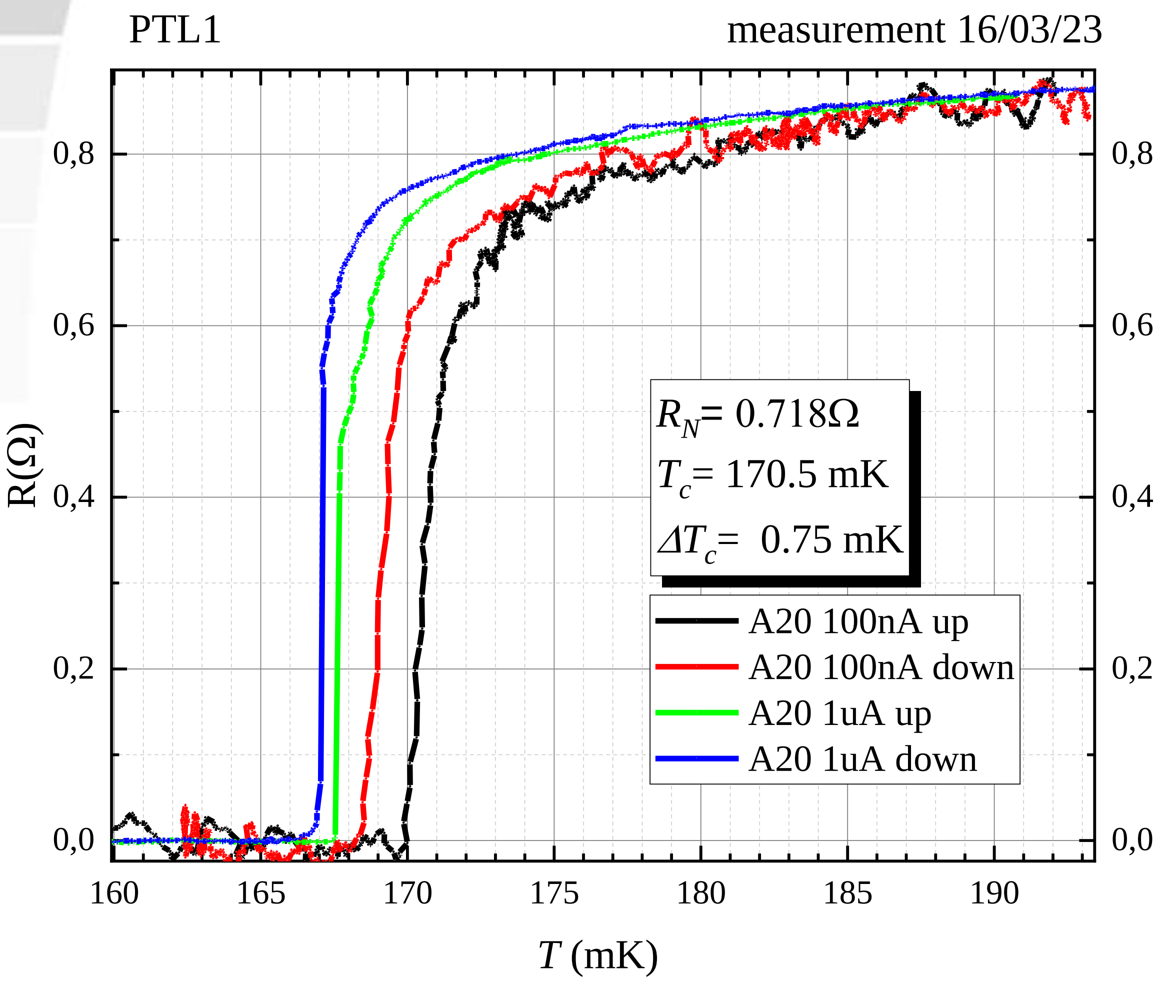
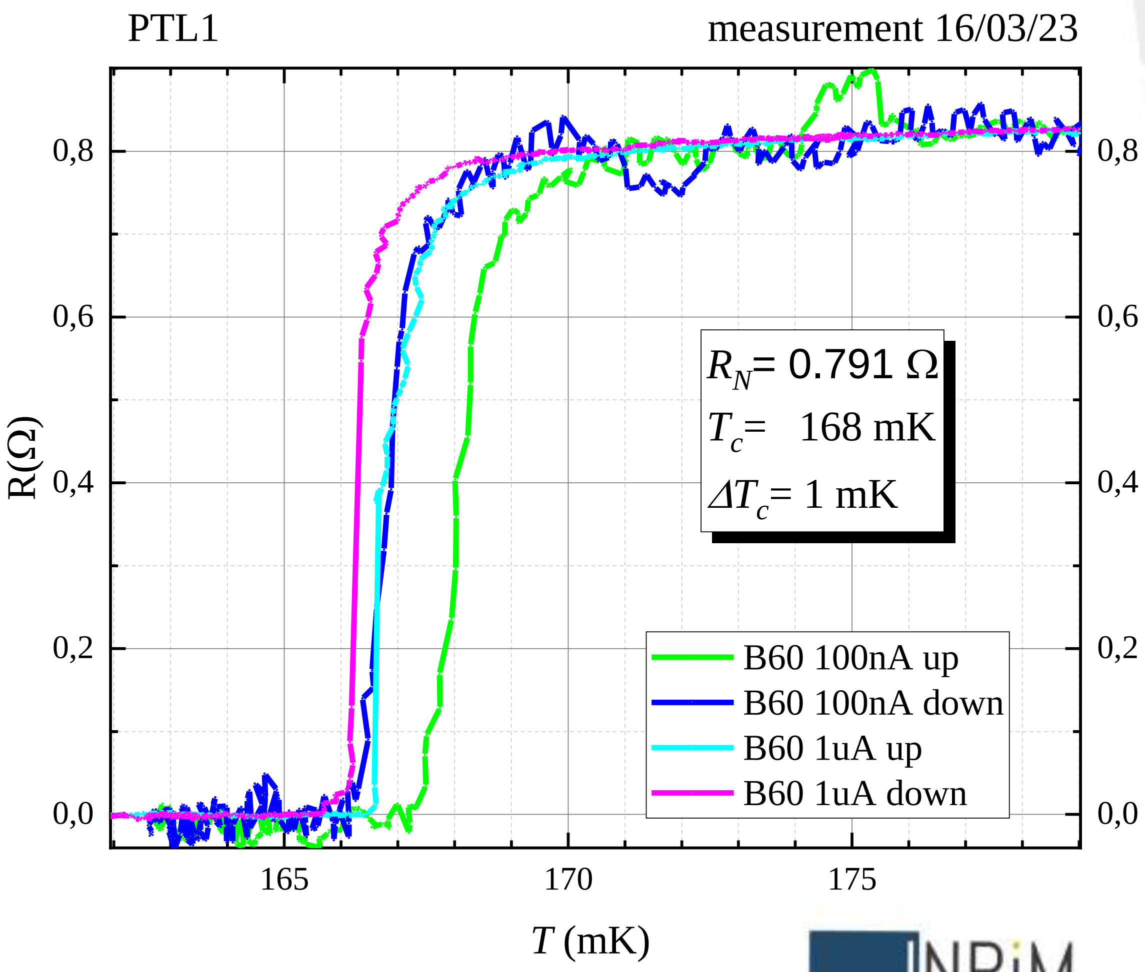
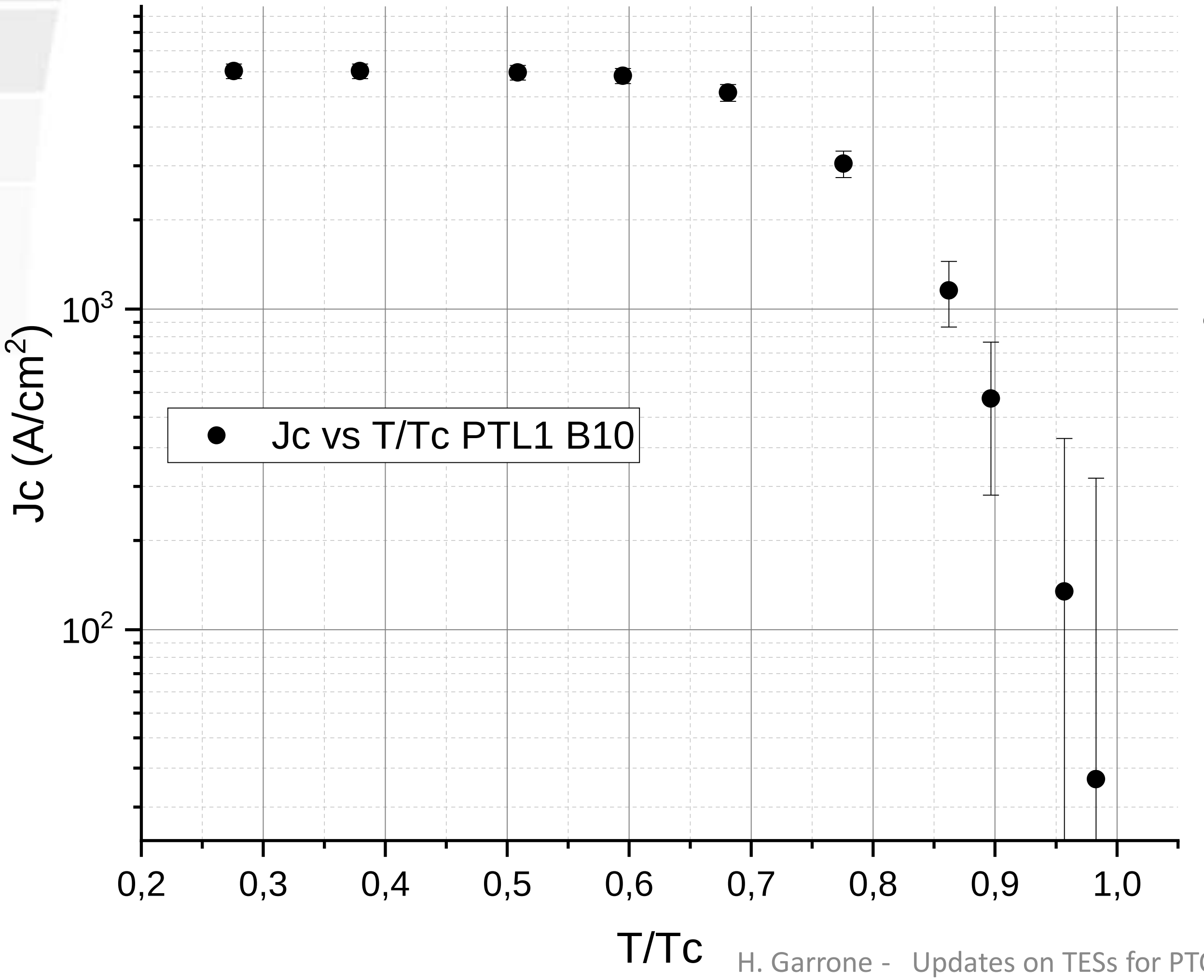
Other good results (sample 2 A20 - B60)

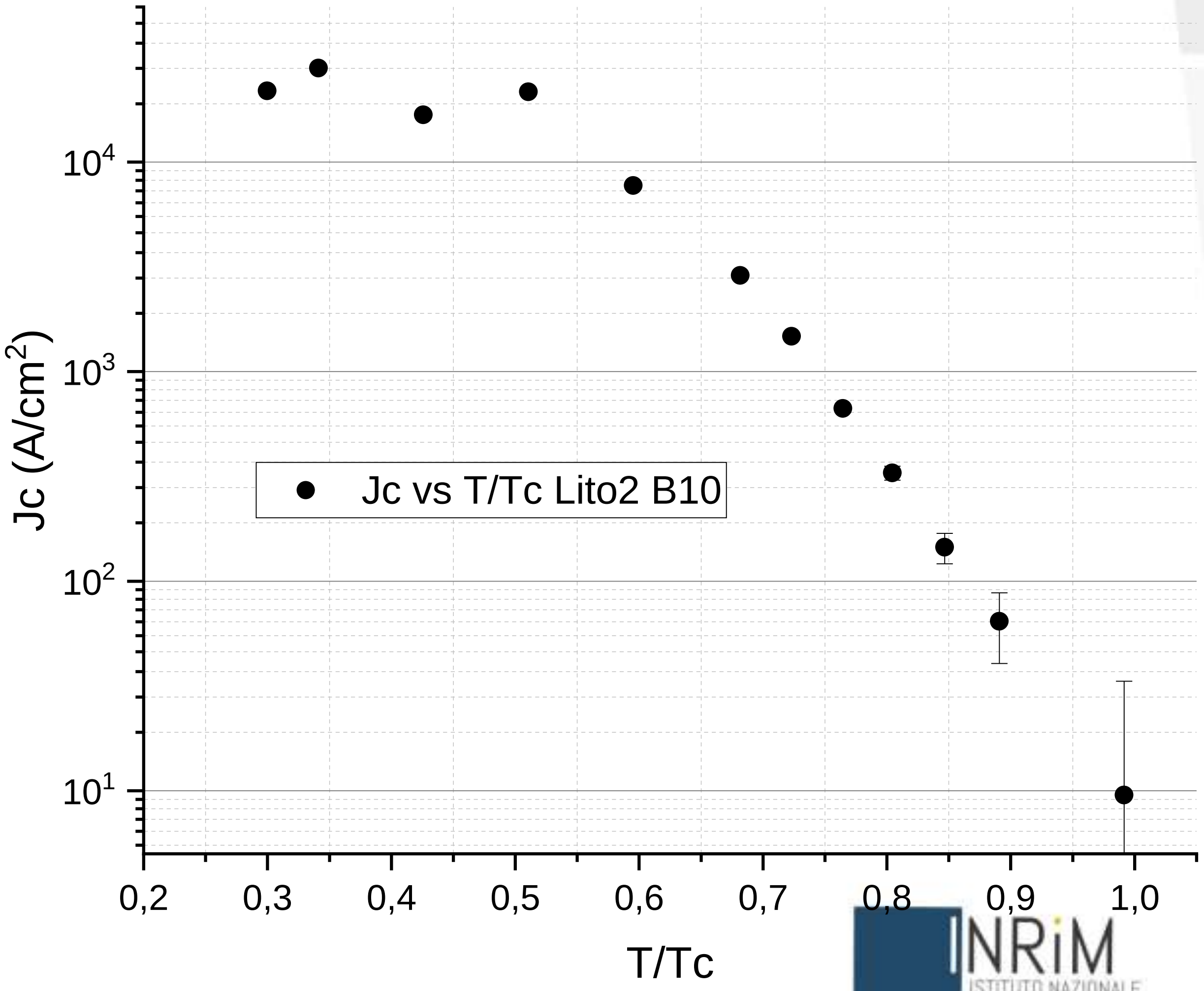




Critical current density comparison

Sample 2 VS Old good result (no ring)





Recent design modification attempts

T_C non-uniformity in the TES:

- Edge effect (overhangs);
- Proximity effect due to the wiring.

We noticed a reduction in the amplitude of the signal generated by photons detected by the TES.

Design solution attempts:

1. Wiring of *titanium* instead of *niobium*:
   Pro: lower wiring T_C may reduce the transition width.
   Con: a lower energy gap between wiring and TES could reduce the energy resolution?

2. Ring of gold that surrounds the edges of the TES:
   Pros: Reduction of the edge effect, Ti of the TES protected from oxidation.
   Con: Increased fabrication complexity due to a major number of steps.

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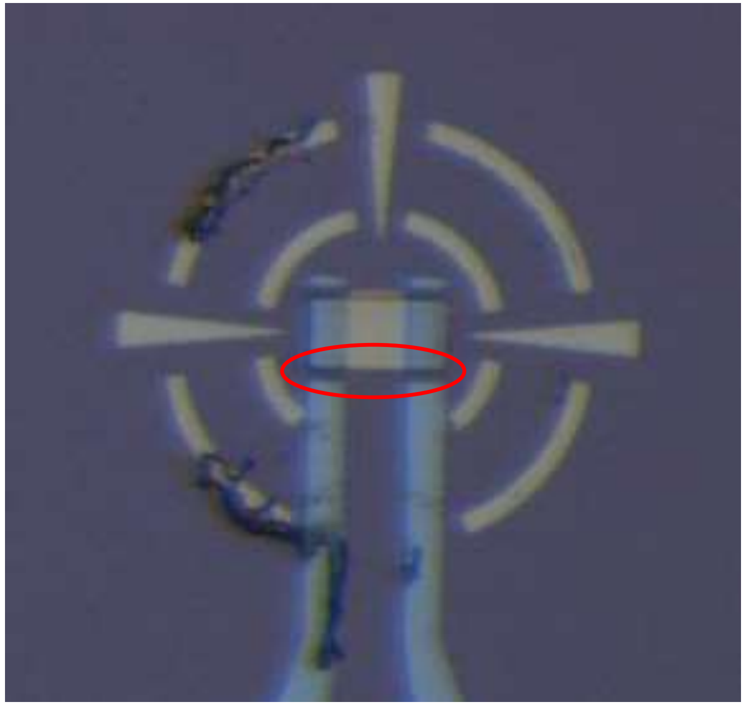
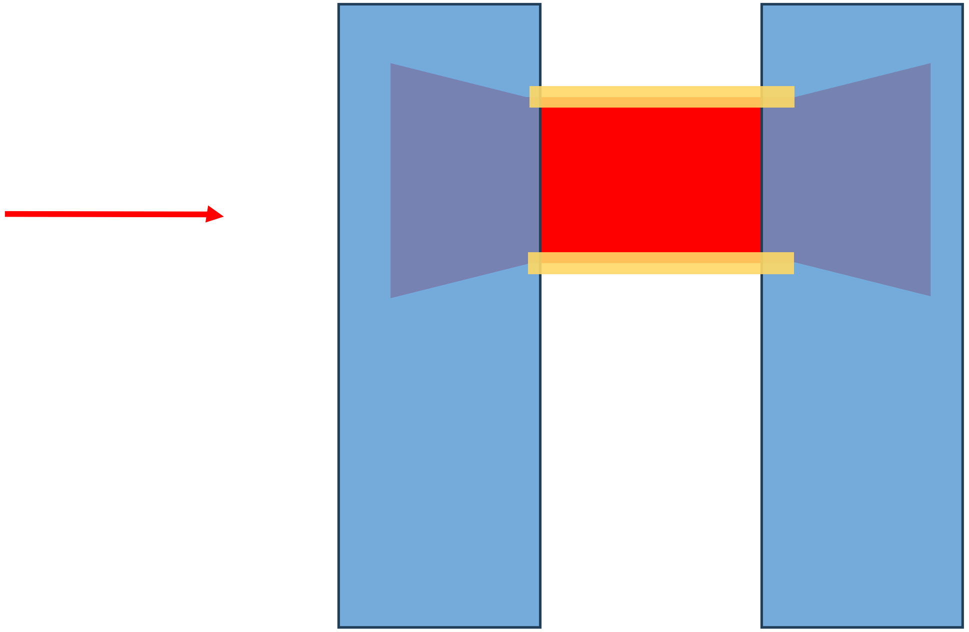
Adhesion of the gold

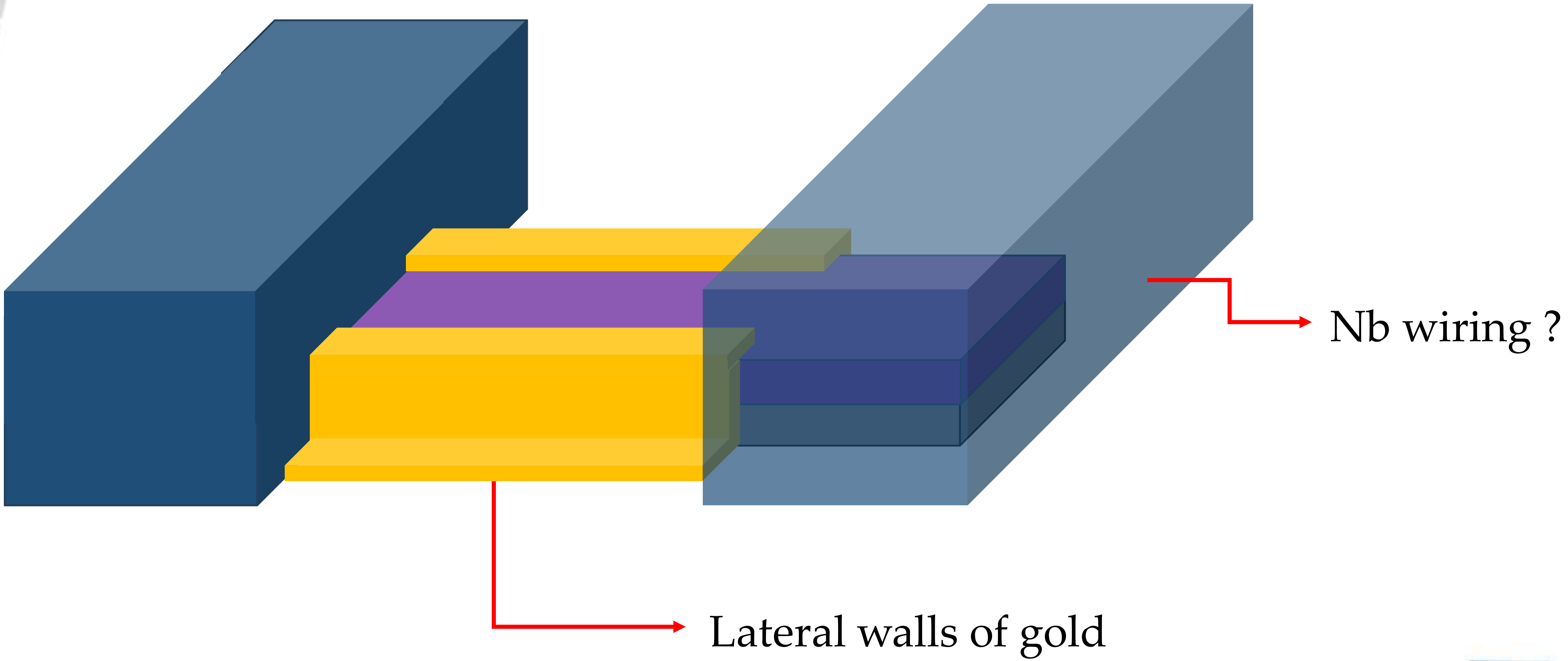
Low adhesion of the gold to the SiN substrate.
Detachment the glue could remove even the gold.

Solution: from rings to bars.





Conclusions ?



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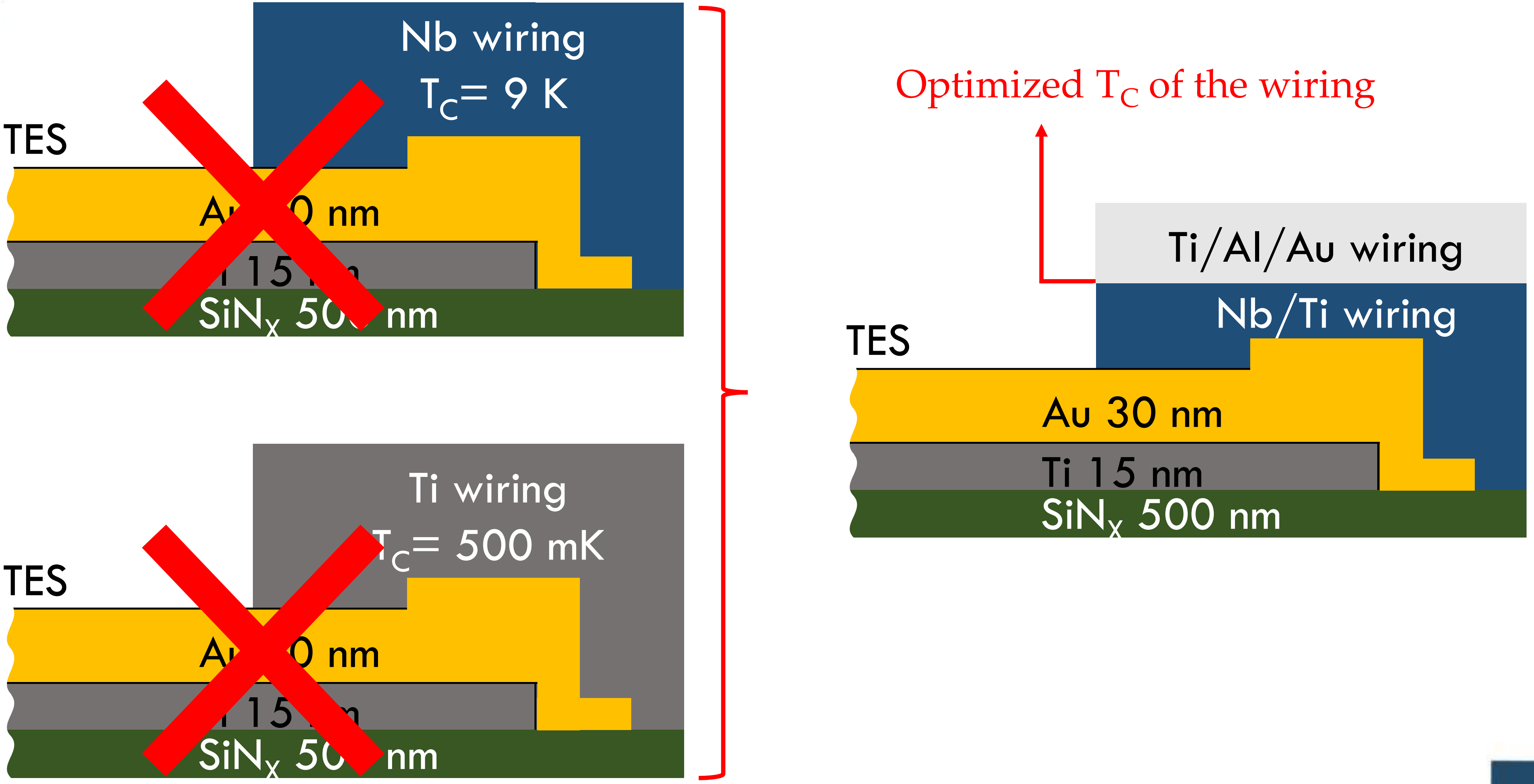
Conclusion: proximazed wiring



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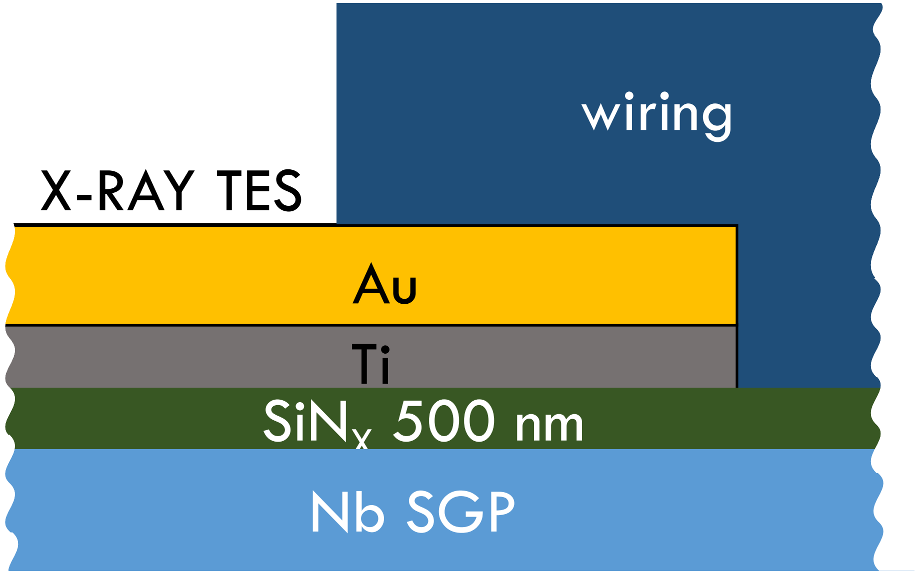
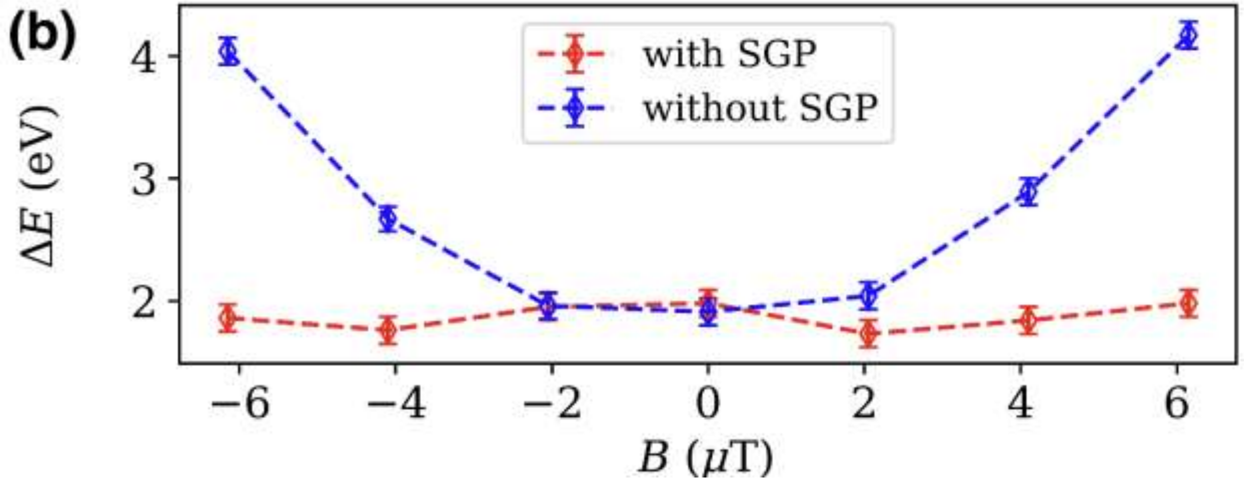
Remarks from SRON's X-ray TESs in B-fields



REF:
de Wit, Martin, et al. "Mitigation of the Magnetic Field Susceptibility of Transition-Edge Sensors Using a Superconducting Groundplane." *Physical Review Applied* 18.2 (2022): 024066.



Superconducting GroundPlane (SGP) can mitigate B field effects of several tens of μT

The end for now

That’ all for now.

Thank you for the attention!

Sample 2 (PTL1) annealed

Sample name	chip	Area[µm]	T_c[mK]	δT_c[mK]
PTL1 Ti: 15 nm Au: 20 nm Wiring: Ti After annealing process @ 130°C for 2 hours	A	10x10	118	2.5
		20x20	No Tc	
	B	10x10	116	5
		20x20	120	3
	C	10x10	89	2
		20x20	107	3

- Chip A: No Ring
- Chip B: I: 1 µm O: 2 µm
- Chip C: I: 2 µm O: 3 µm

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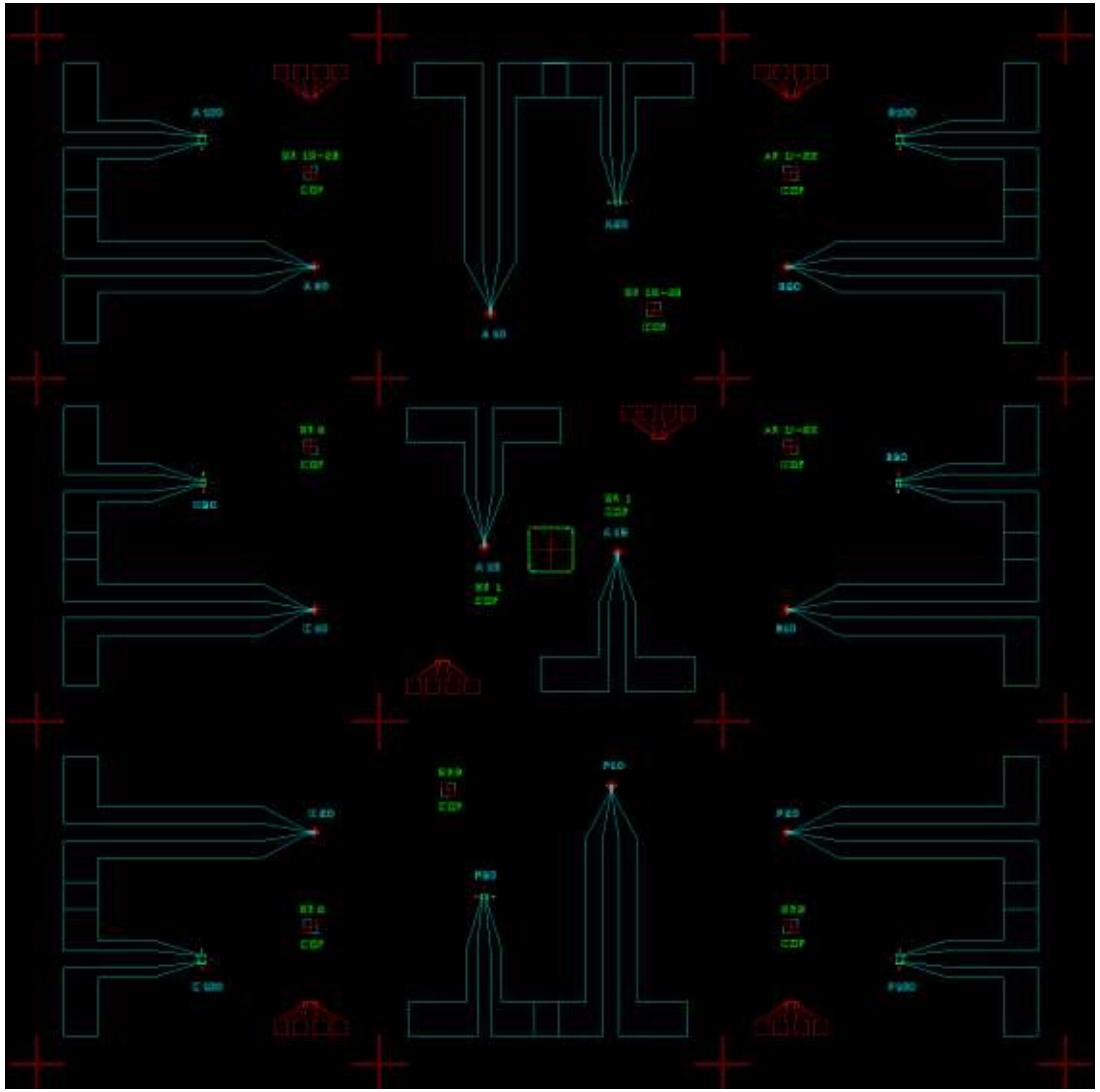
New mask for faster measurements



The new mask will allow:

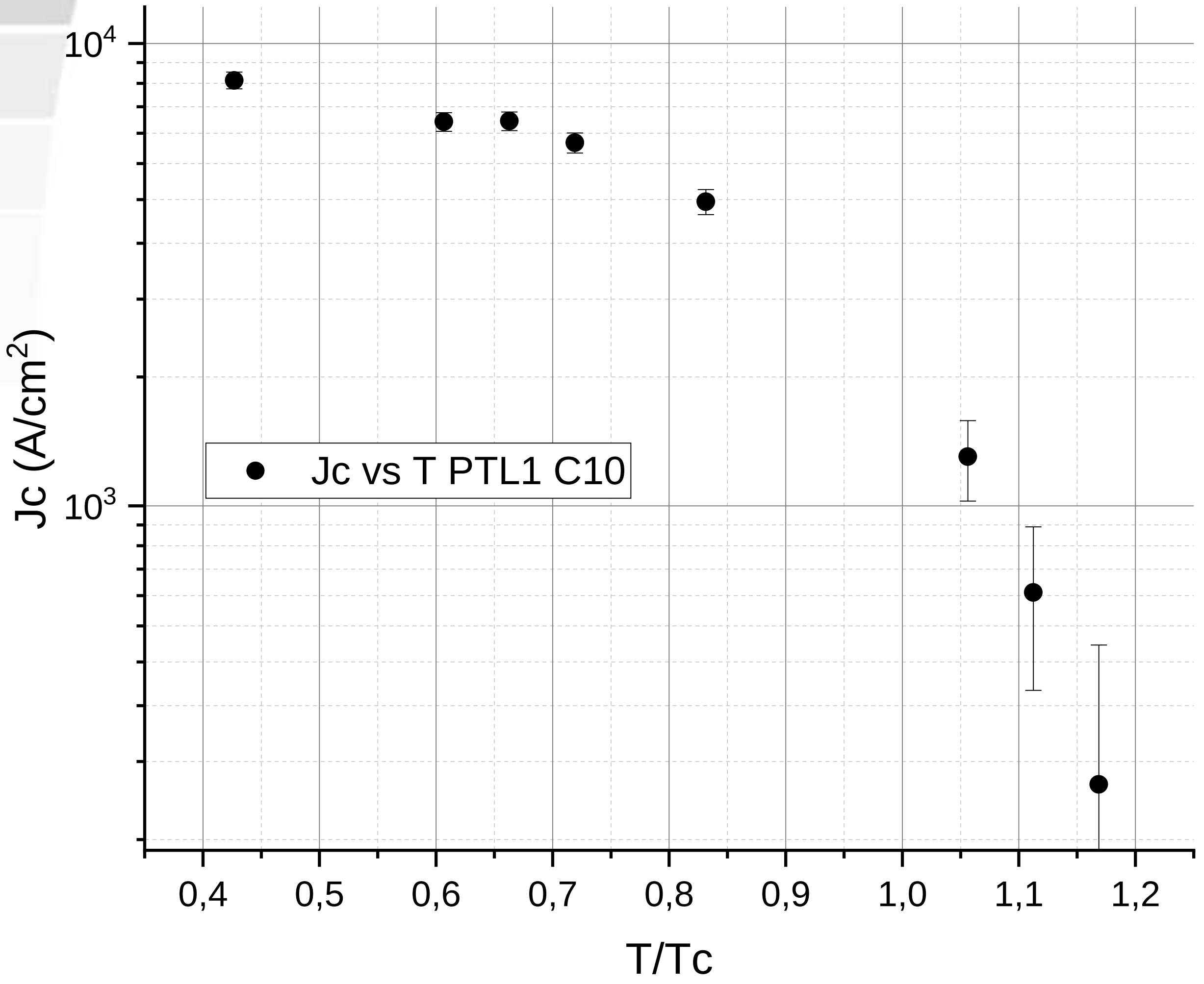
1. Faster transition measurements. Since almost all the TESs can be bonded in series easily.

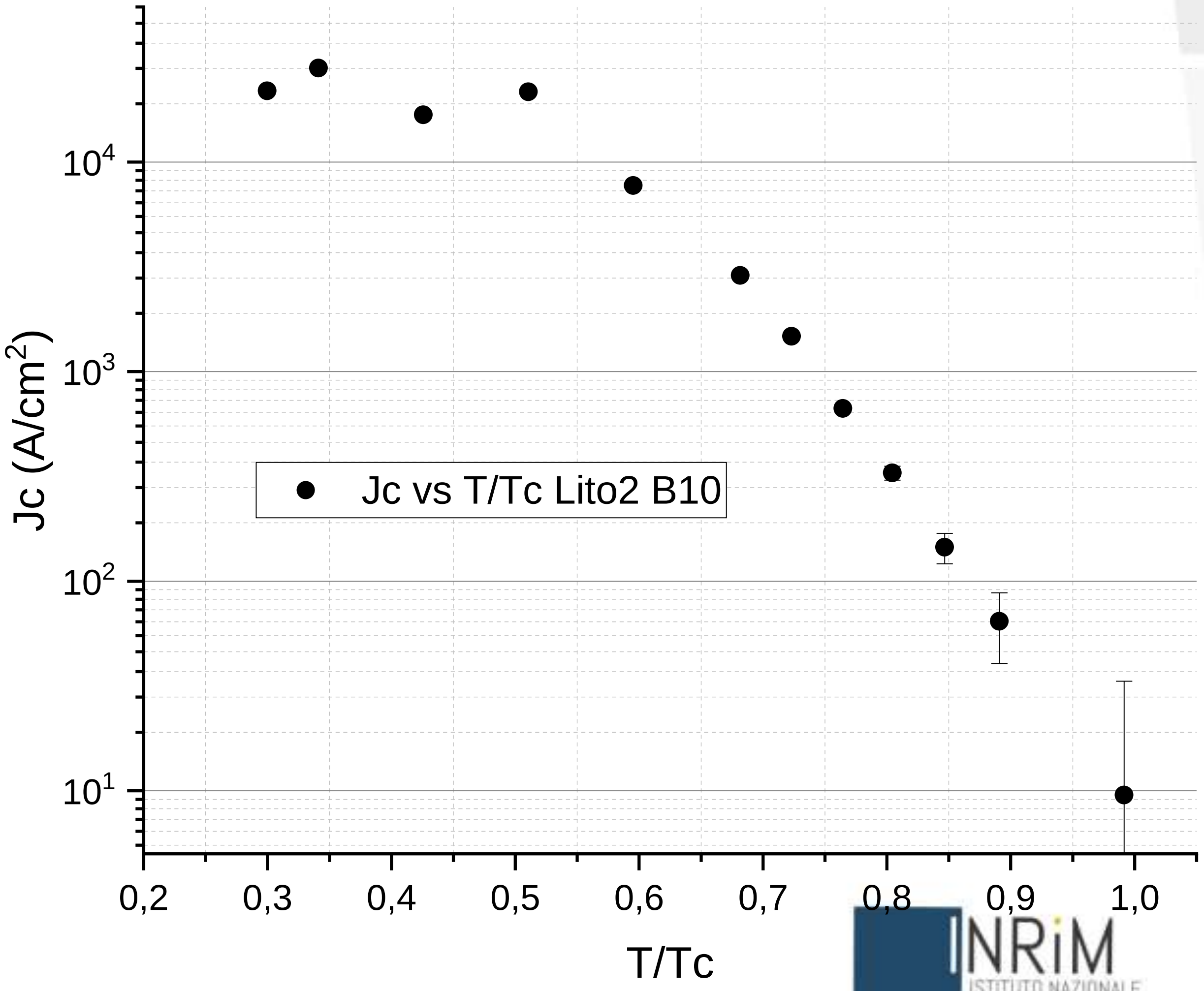
2. Faster fiber coupling. Since the mask is already divided into 9 rectangle, each of them contains 2 TESs.

*Not the final design

Critical current density comparison

Sample 2 VS Old good result (no ring)





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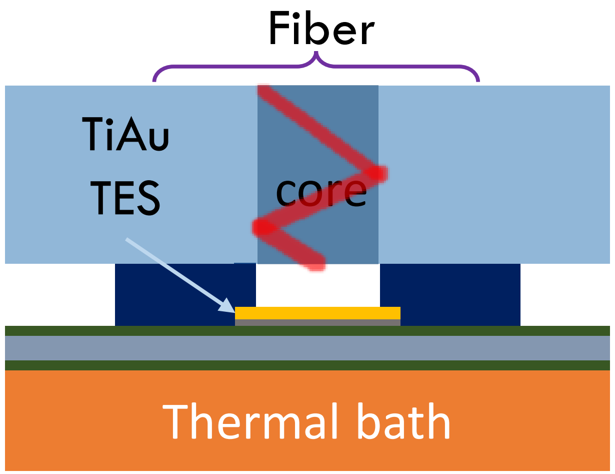
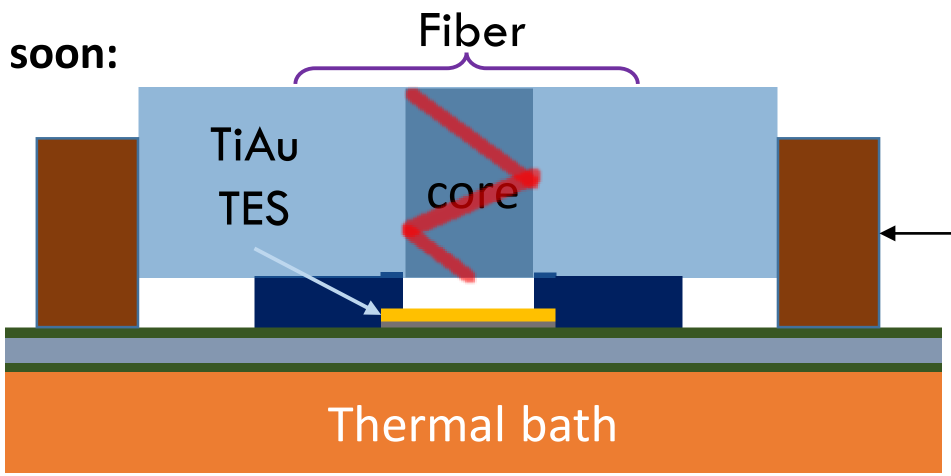
Photoresist cylinder for TES-fiber coupling

Now:



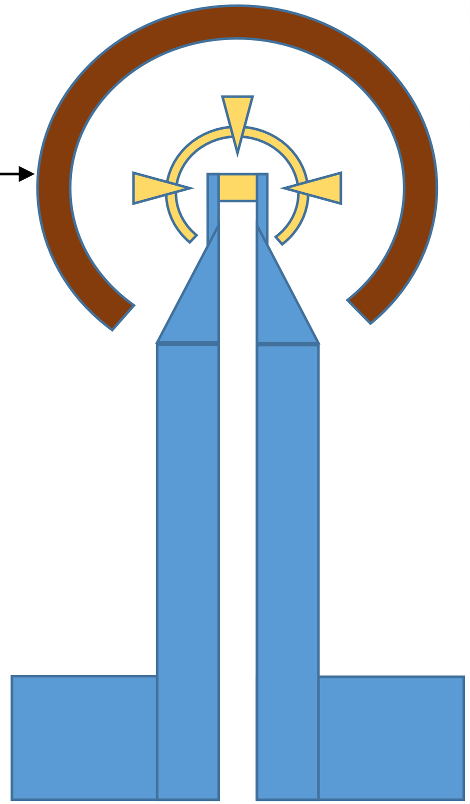
Trying soon:



Photoresist hollow cylinder

Near future implementation.
Hollow cylinder in photoresist that will:

1. serve to help in fiber alignment,
2. reduce the amount of glue under the fiber,
3. partially support the fiber in the next operations.

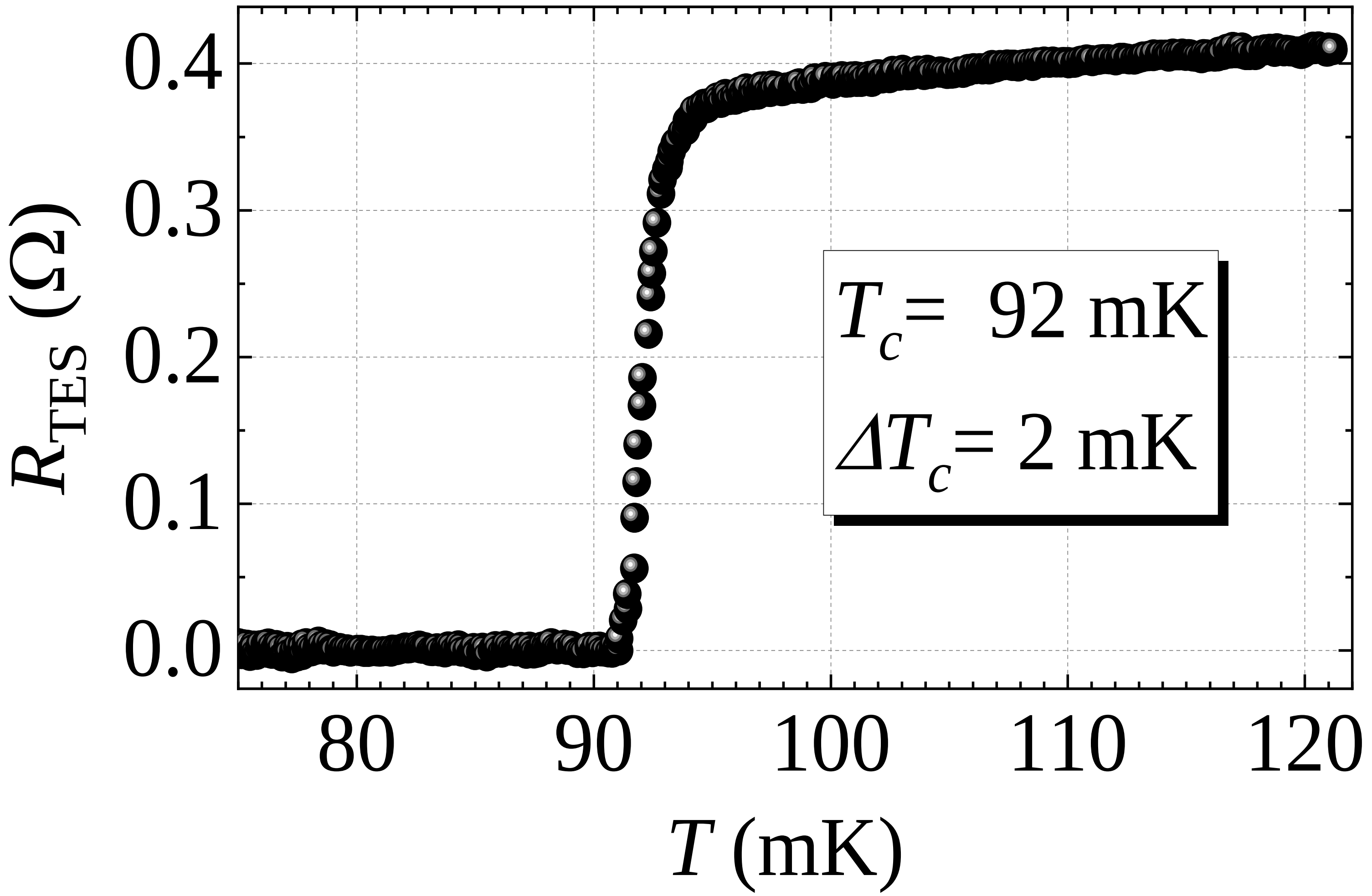


REF:
Ma, Pei-Sa, Hong-Fan Zhang, and Xingxiang Zhou. "Fiber-sensor alignment based on surface microstructures." *Optics Express* 31.1 (2023): 737-744.

Results table for PTL2

Sample name	chip	TES	T_C[mK]	ΔT_C[mK]
PTL2 Ti: 15 nm Au: 30 nm Wiring: Ti	A	T10	140.8	10.9
		T20	107.4	3.1
		T60	161.7	1.4
	B	T10	122.2	24.9
		T20	98.4	10.7
	C	T60	133	6.4
	F	T20	130.5	9.4
		T100	99.4	1.8

Old best result



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