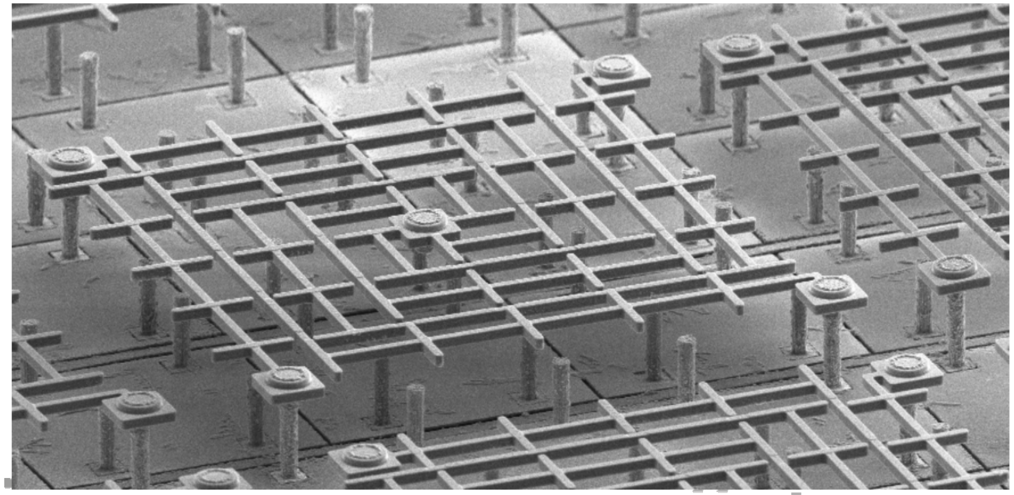

Superconducting Ti/TiN thin films for mm wave absorption

A.Aliane[1], M. Solana[2], V. Goudon[1], C. Vialle[1], S. Pocas[1], E. Baghe[1], L. Carle[1], W. Rabaud[1], L. Saminadayar[2], L. Dussopt[1], P.Agnese[1], N. Lio Soon Shun[1], S. Becker[1], A. Hamelin[1], P. Rodière[2], A. Poglitsch[3],V. Reveret[3], L. Rodriguez[3], S. Bounissou[3], O. Adami[3]

[1]CEA/LETI, MINATEC, 17, avenue des martyrs 38054 Grenoble cedex 9, France

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LTD17 | July 2017, Kurume, Japan

OUTLINE

1 **Introduction**

Background, bolometer principle

2 **Fabrication process**

3 **Superconducting absorbers**

Tc and sheet resistance optimization

Thermal cycling / annealing

Physical characterization

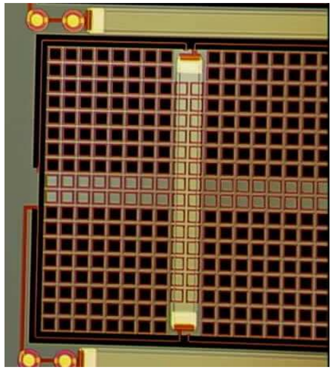
4 **Conclusion**

BACKGROUND

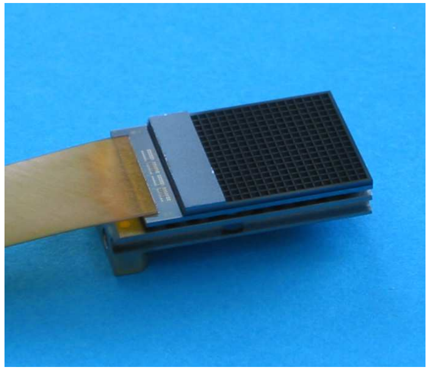
The all-silicon bolometer array developed for PACS in Herschel satellite

- Sub-mm detection (60-210 µm)
- Cooled at 300 mK

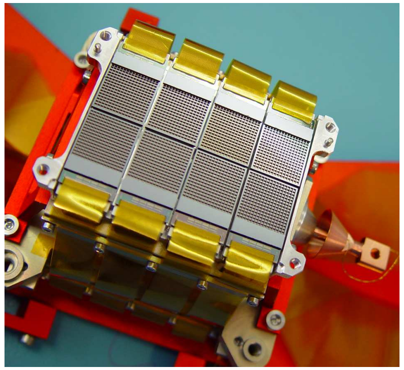
Pixel



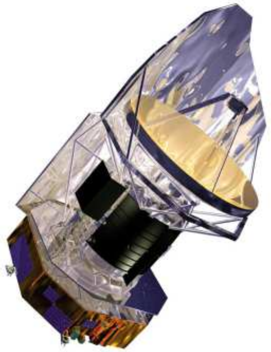
16x16 array



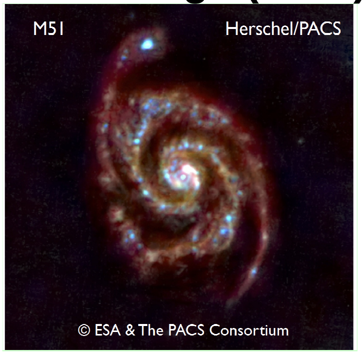
Focal plane array



PACS instrument



First image (2009)



New developments:

- Scalability in sub-mm and mm wave bands
- Dual polarization detection
- Very high sensitivity: 3 aW/√Hz at 100mK
- Targets requirements of future space astronomy missions (e.g. SPICA mission)
  - → Poster of S. Bounissou et al.(A-75)
  - → Poster of L. Rodriguez et al (A-62)

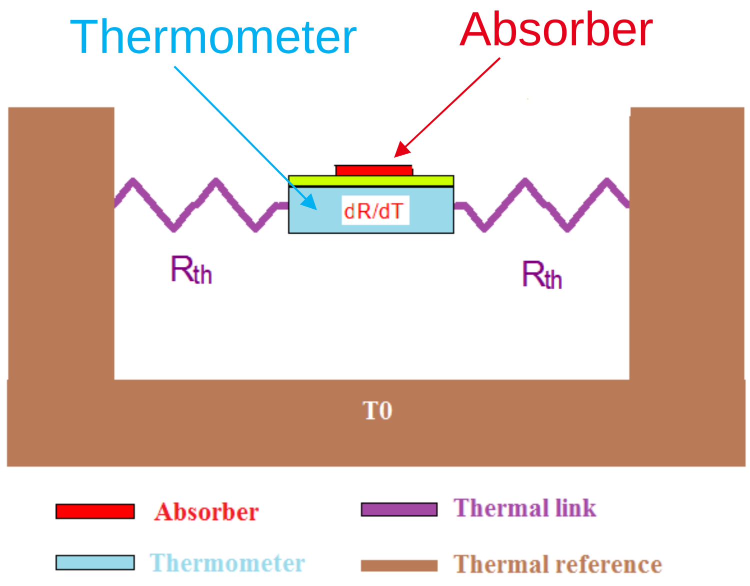
BOLOMETER PRINCIPLE

Thermal link: Meander design to enhance the thermal insulation of the pixel (thermal time constant, NEP)

Thermometer: ion implanted Silicon (P,B) between 50 and 100mK

- good sensitivity: $S = -\frac{T}{R}.\frac{dR}{dT}$
- low specific heat capacity: $C = \gamma T + \frac{A}{\Theta_D^{\,3}} \cdot T^3$

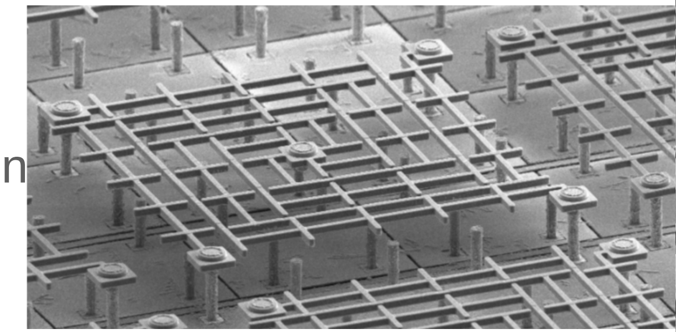
➢ Poster of O. Adami et al. A-74

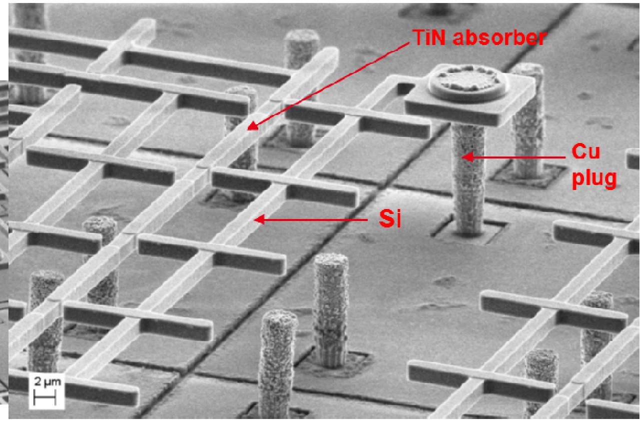


$$\frac{dE}{dt} = C \cdot \frac{dT}{dt} = P_{ray} + \mathrm{R(T).I}^2 - \int_{T_b}^{T} G_{th}(T)dT$$

Absorber: superconducting bi-layer metals for low specific heat and good absorption

➢ Focus of this presentation

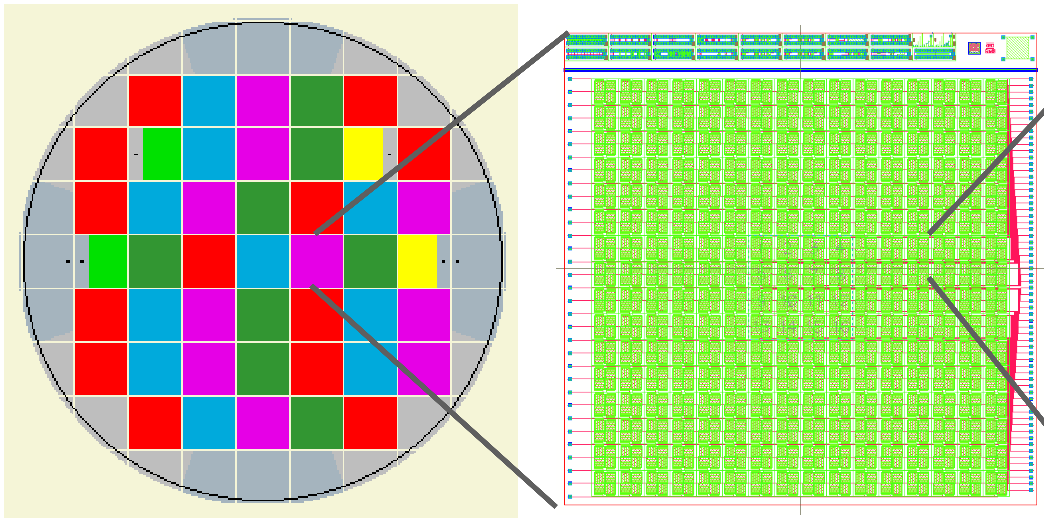


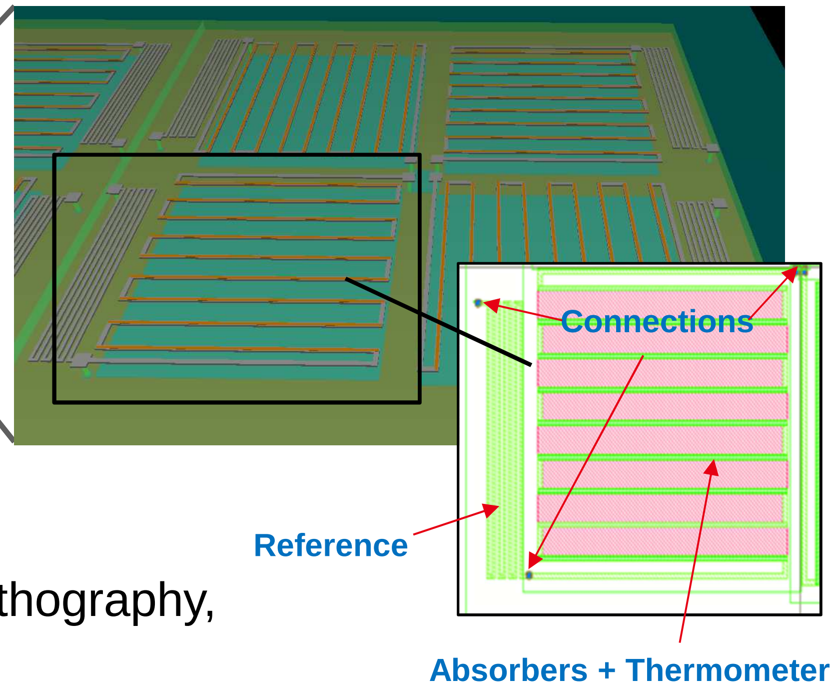


FABRICATION PROCESS (1)

Collective manufacturing realized in standard 200mm silicon technology at CEA-LETI clean rooms

- Above-IC technology implemented on a readout circuit
- Electrical arrays of 16x16 pixels are being processed

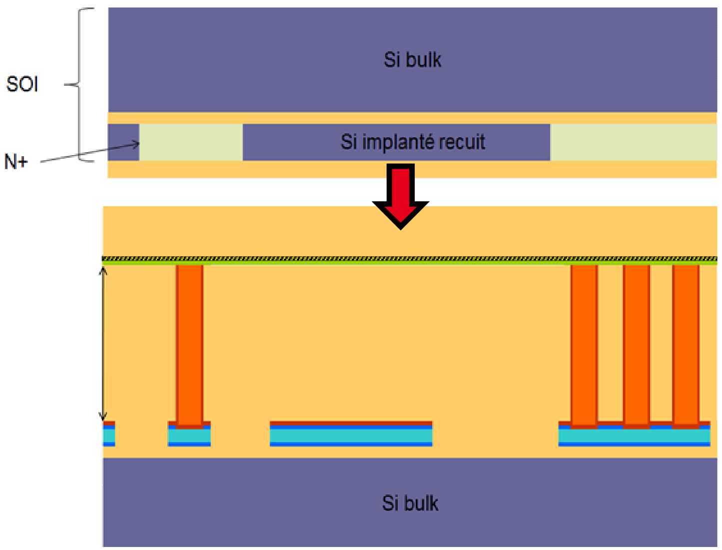




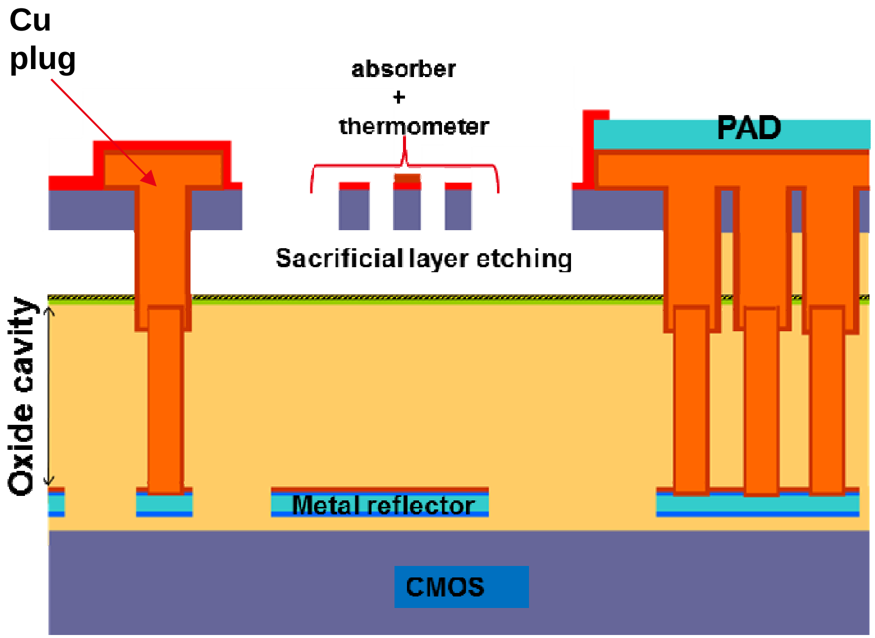
~ Different process steps (deposition, photolithography, etching, electroplating, CMP…)

FABRICATION PROCESS (2)

- Cavity and thermometers on separate wafers
- Oxide-oxide molecular bonding
- Copper via filling by electroplating
- Sacrificial layer etching:
  - ➢ **Requires residual stress relaxation in thermometer and absorber layers**

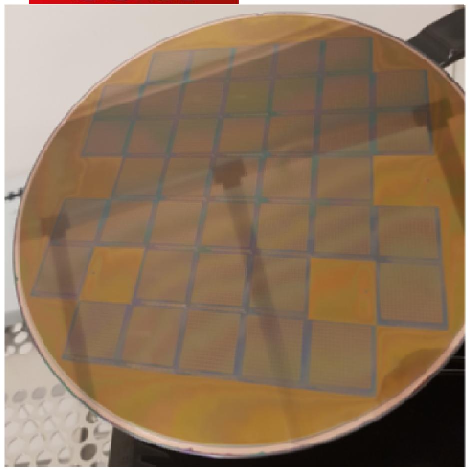


T° of molecular bonding <450°C



Released pixel structure

FABRICATION PROCESS (3)



200mm wafer with different arrays

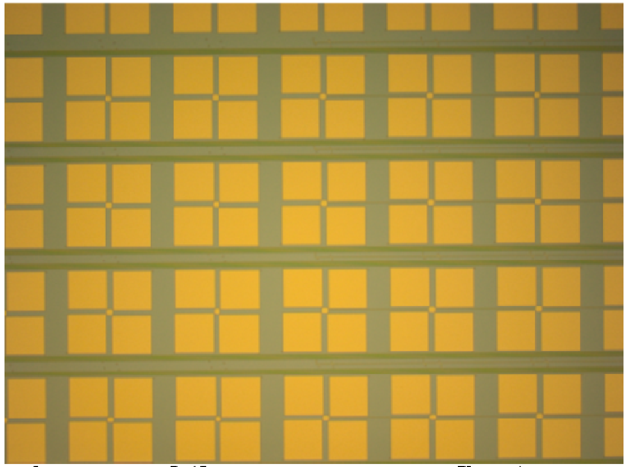
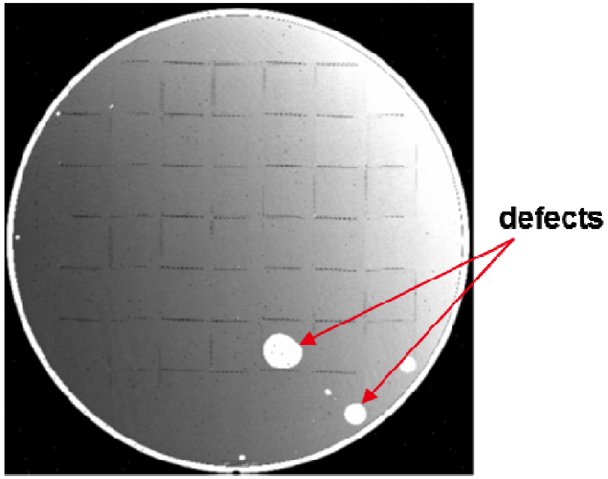
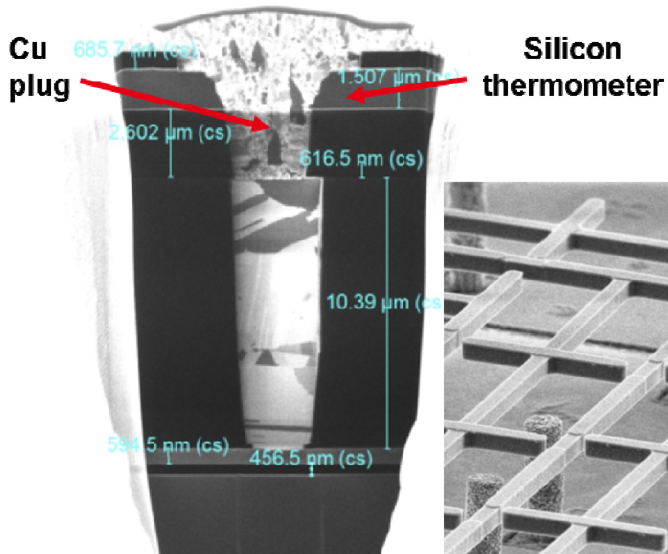


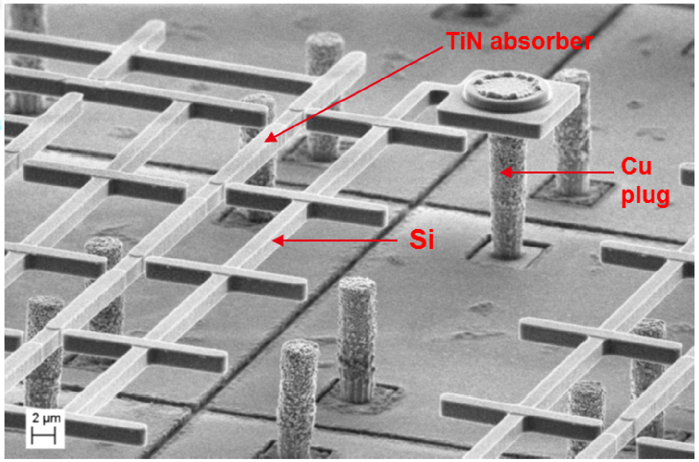
Image of the mm-wave reflectors



Acoustic image (140MHz) of the molecular bonding of two wafers



SEM cross section of Cu electrical Connections



SEM image of the Pixel structure

SUPERCONDUCTING ABSORBER (1)

- Superconductors: very low heat capacity below the transition

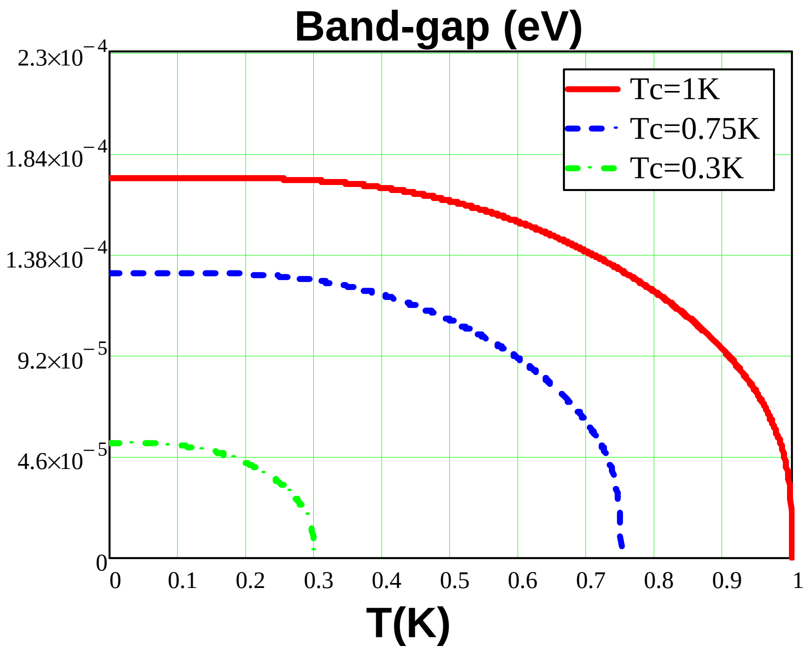
$$C = 8{,}5 \cdot \gamma \cdot T_c \cdot \exp\left(-1{,}44 \frac{T_c}{T}\right) + \frac{A}{\Theta^3} \cdot T^3$$

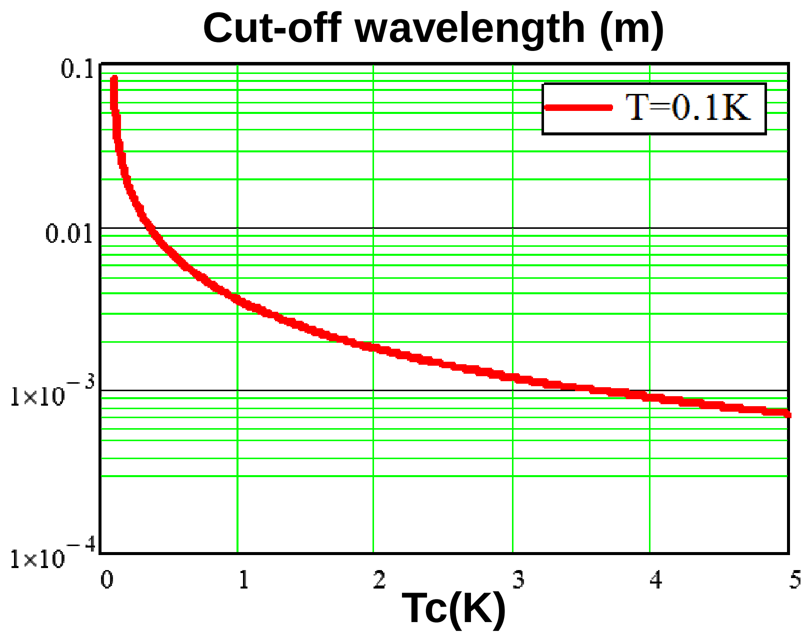
- Absorption at mm-waves if $h\nu > 2\Delta(T)$

  $\rightarrow \lambda < \frac{hc}{2\Delta(T)}$

$$\Delta(T) := 2 \cdot \frac{kb}{q} \cdot Tc \cdot \left(1 - \frac{T}{Tc}\right)^{0.3\left(\frac{Tc}{T}\right)}$$

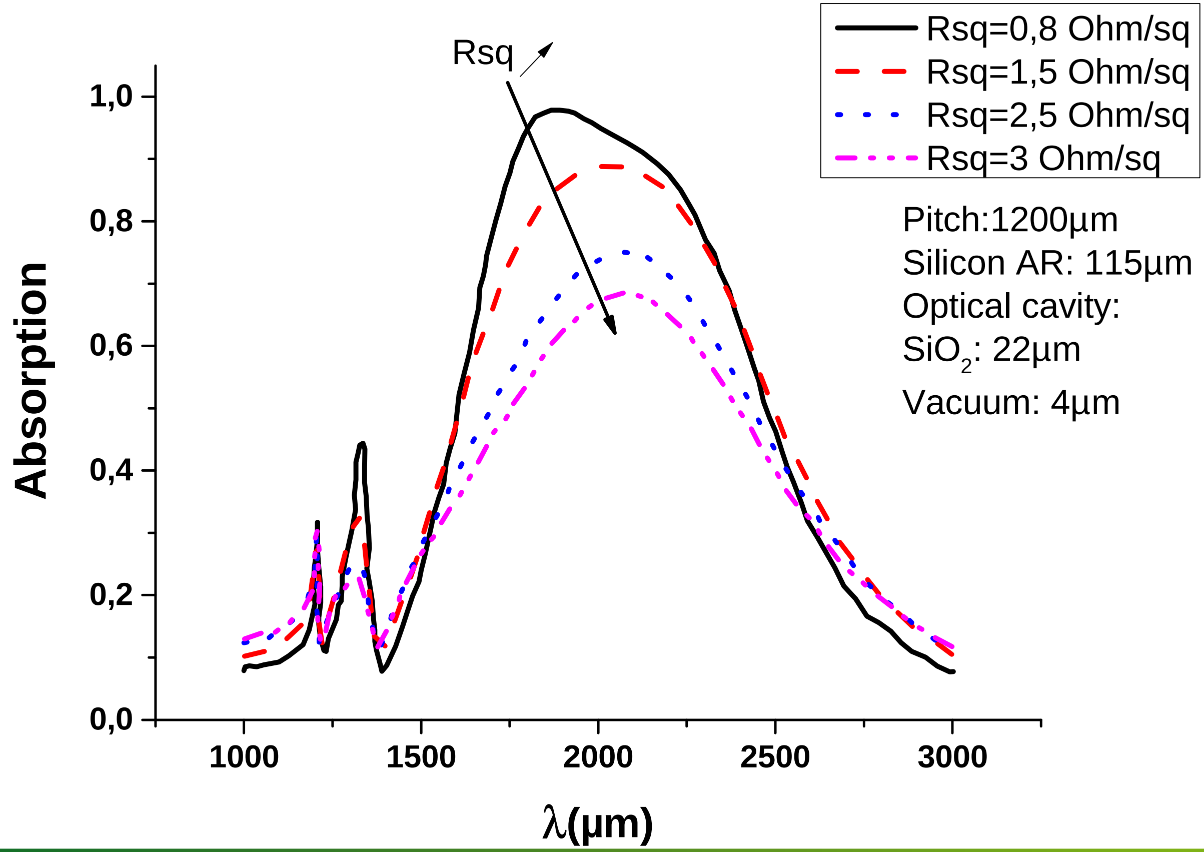
- Need to tune T_c through proximity effects in bi-layer metals; Ti/TiN selected for microelectronics compatibility

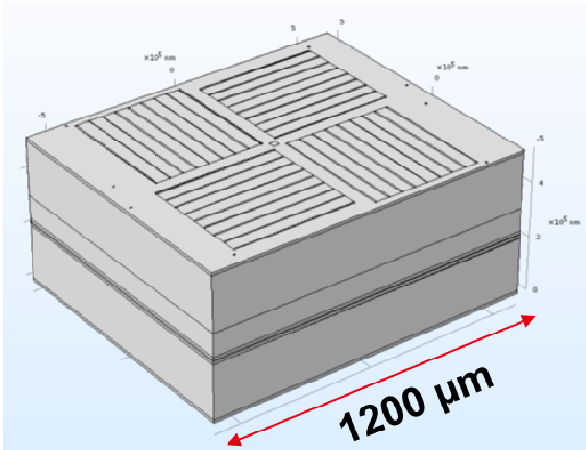




SUPERCONDUCTING ABSORBER (2)

- Pixel design optimized through multiple parameters: pitch, cavity height, absorber resistance, …
- For the 2 mm wavelength:
  - Sheet resistance ~ 0.5-0.8 Ω/sq. (dipoles of 100 squares)
  - Working Temperature ~100 mK → T_c ~ 0.75 K

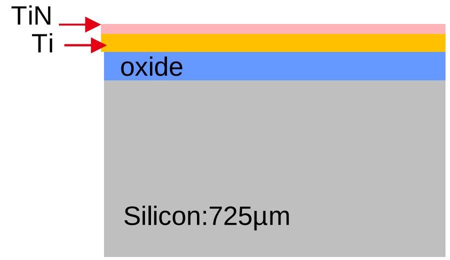




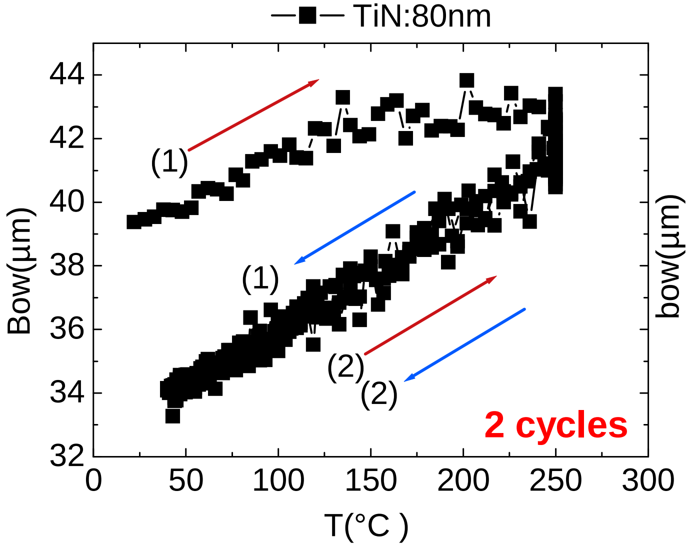
Simulated structure with COMSOL

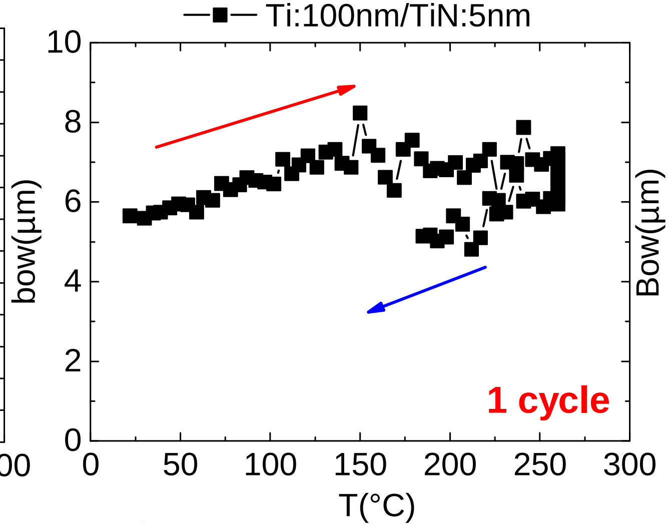
THERMAL ANNEALING / CYCLING (1)

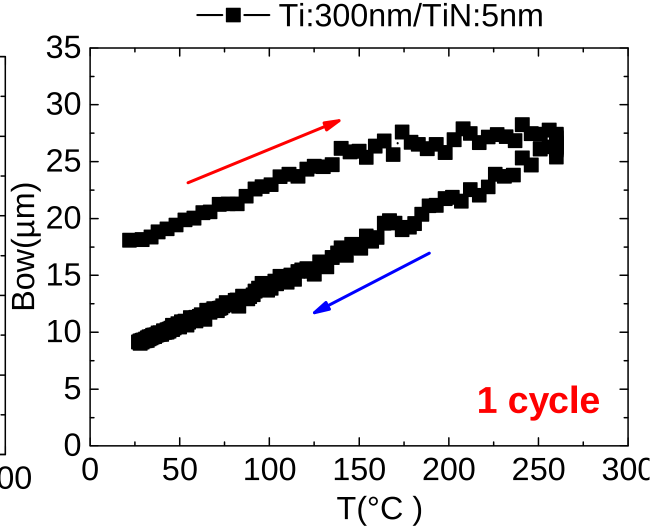
Thermal cycling: relaxation of residual stresses in the bi-layer



- Ti/TiN layers deposited at 100°C on 500nm SiO_2
  - Sample 1: Ti/TiN = 100/5 nm
  - Sample 2: Ti/TiN = 300/5 nm
- Annealing temperature: 20-250°C







Stoney formula

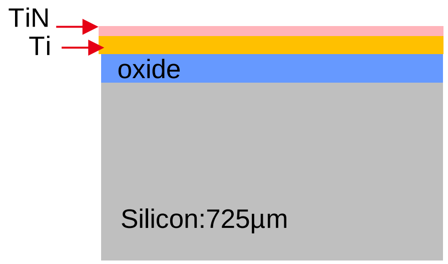
$$\sigma^{(f)} = \frac{E_s h_s^2 \kappa}{6h_f(1-\nu_s)}$$

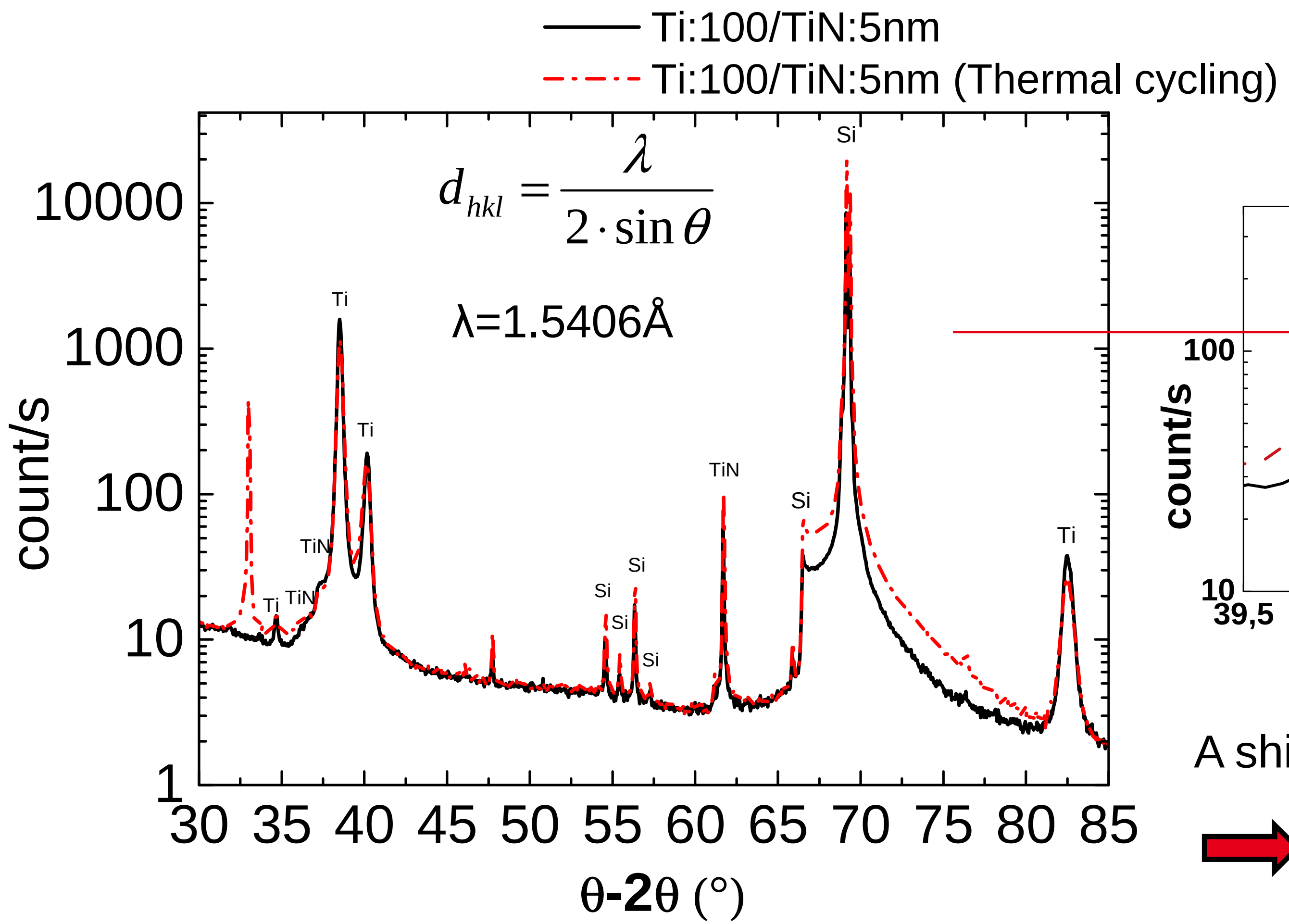
Bow measurements on 200-mm wafers

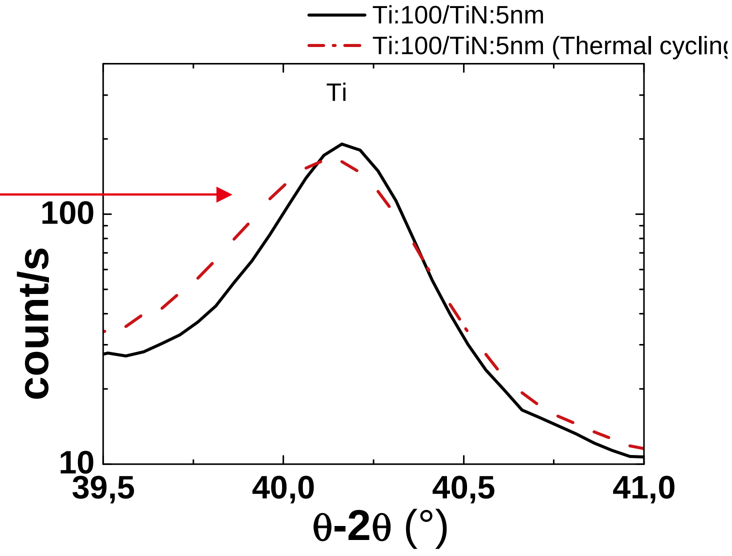
THERMAL ANNEALING / CYCLING (2)

XRD analysis

- Presence of a stress in the deposited thin films
- Confirms the bow measurements







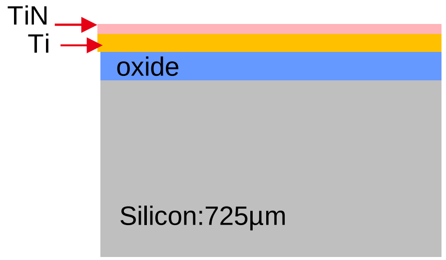
A shift of the diffraction peak

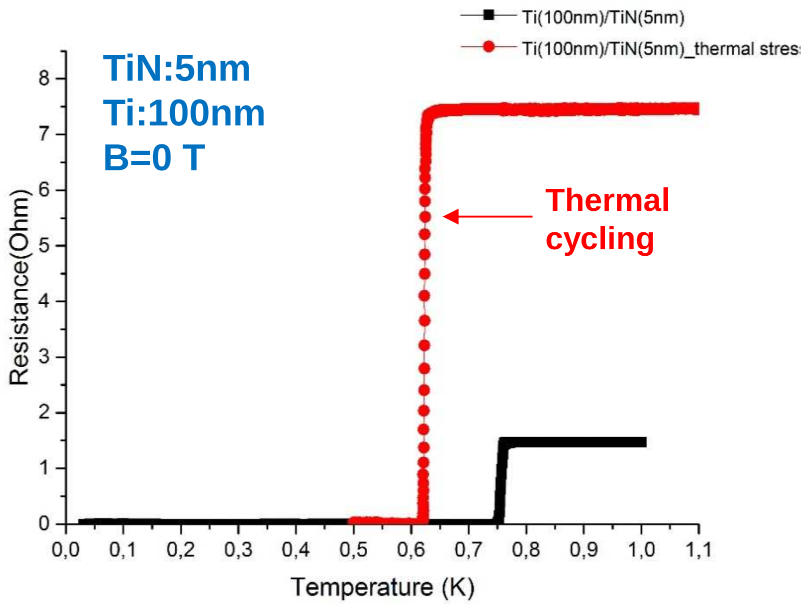
Effect of the residual stress

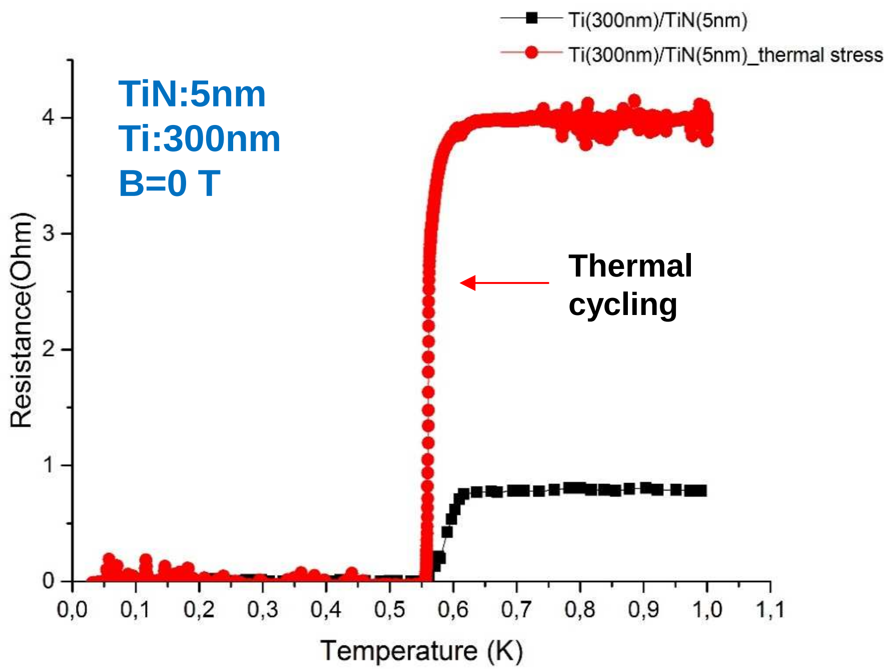
THERMAL ANNEALING / CYCLING (3)

Impact on the critical temperature

- For Ti/TiN : 100nm/5nm : Tc shifts from 0.75K to 0.63K
- Modify the proximity effect between TiN and Ti
- Presence of oxidized states at the interfaces preventing the cooper pairs diffusion from TiN to Ti ?



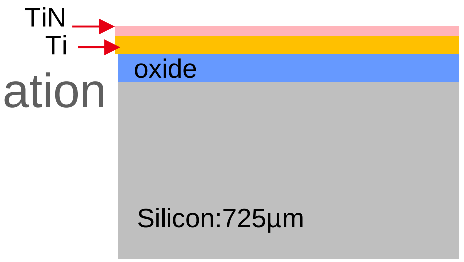


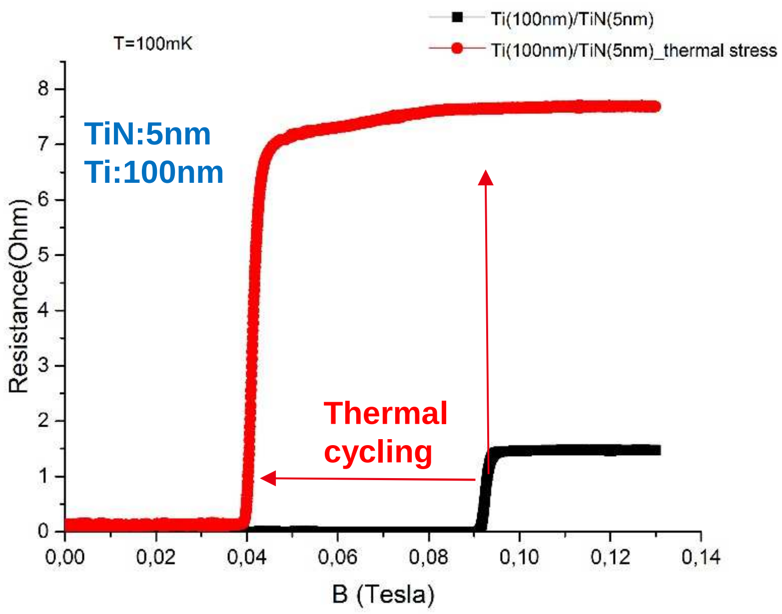


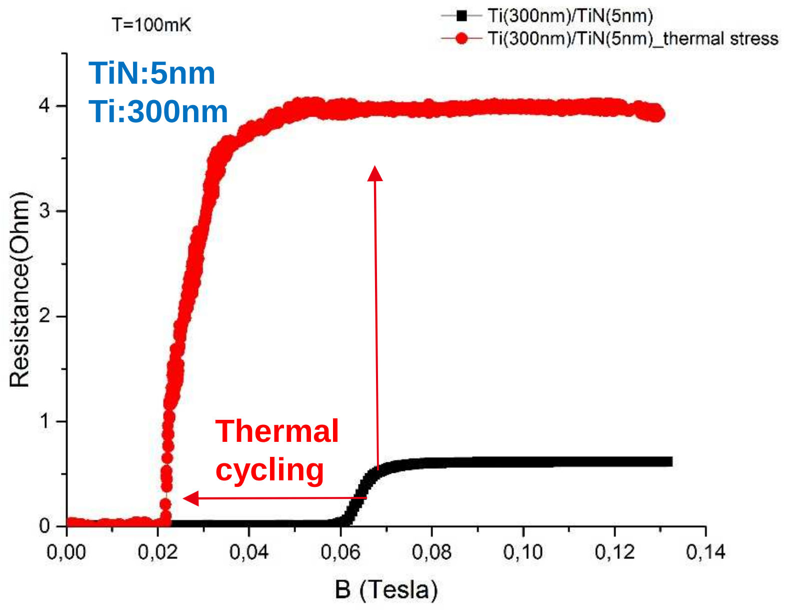
THERMAL ANNEALING / CYCLING (4)

Impact on the critical magnetic field

- For Ti:100nm/TiN:5nm → B_c decreases from 93mT to 40mT at 100mK
- Critical magnetic field is related to the critical temperature
- Defects (oxidized states) in the Ti/TiN layer causing the degradation of the critical magnetic field

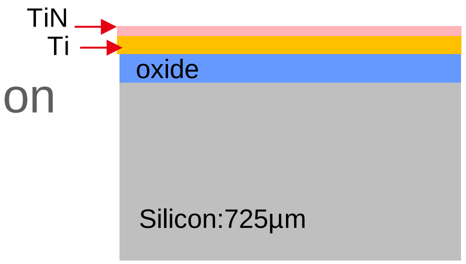




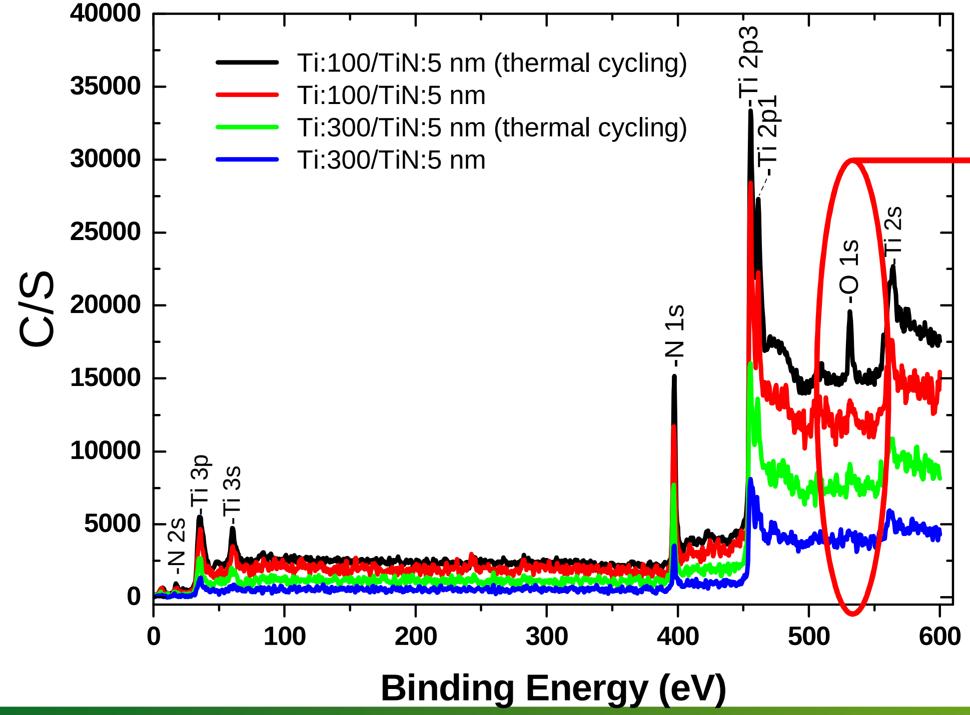


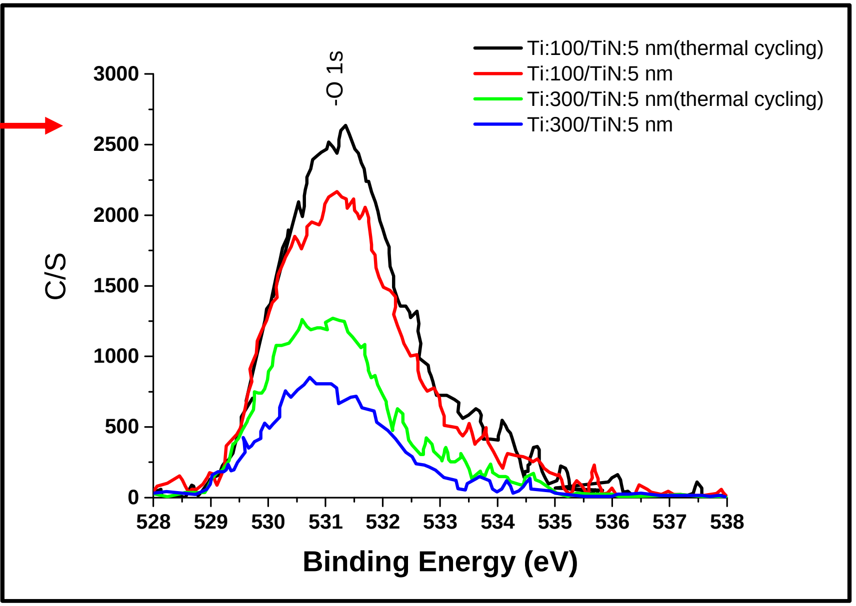
PHYSICAL CHARACTERIZATION (1)

Surface analysis with XPS

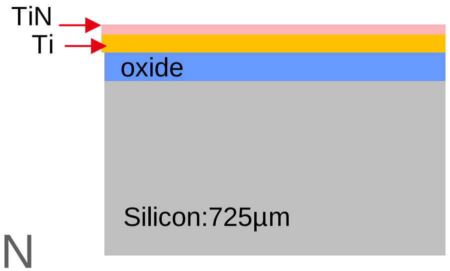


- O 1s increases with the thermal cycling: residual surface oxidation
- The binding energy of the O1s peak reflects a typical chemical state: sub-oxide or oxide-nitride



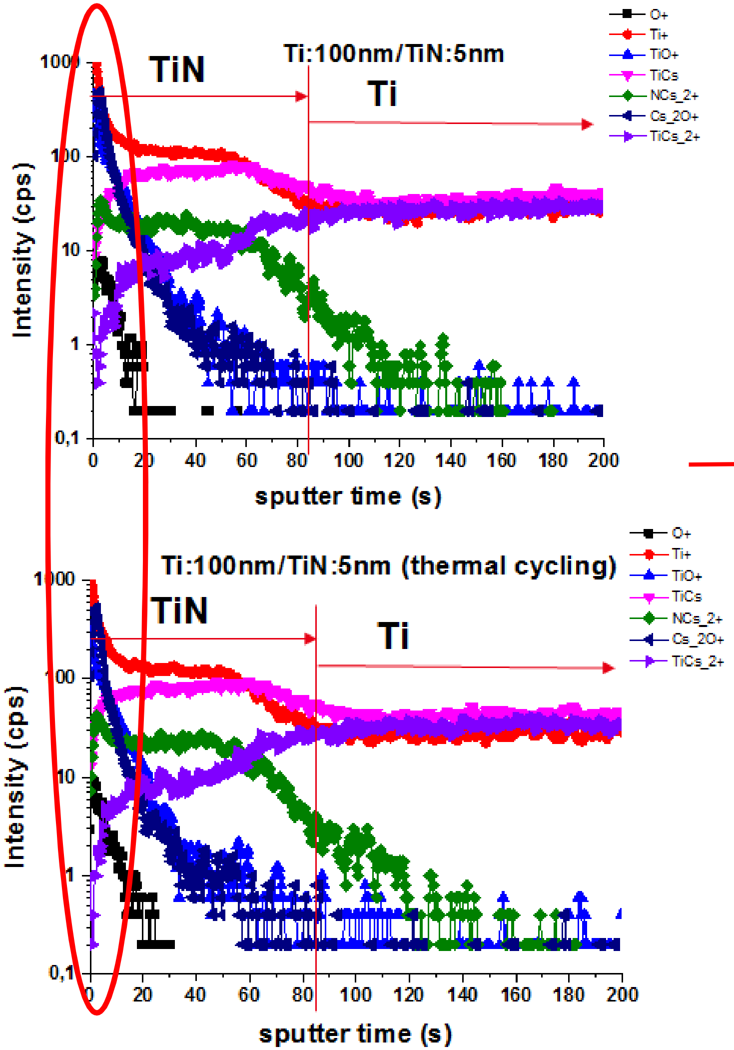


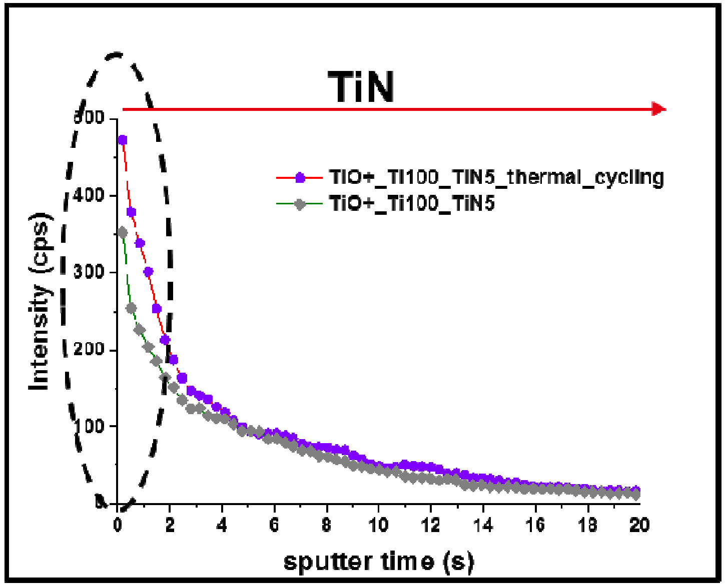
PHYSICAL CHARACTERIZATION (2)



SIMS analysis

- Presence of oxidized states at the surface of the TiN
- Confirms the XPS analysis





→ **An effect on electrical properties**

CONCLUSION

- Collective fabrication on 200mm wafer with an above IC integration.
- We have designed an innovative pixel using doped silicon thermometers between 50 and 100mK to absorb in sub-mm and mm waves.
- We have studied and integrated a compatible superconducting absorber.
- We used the proximity effect between Ti (T_c=0.4K) and TiN (T_c=2.2K) to adapt the T_c for mm wave applications.
- For the final pixel structure, we have to take into account stress and oxidized effects in superconducting absorbers to keep good electrical and optical properties.
- We have to control these effects by adapting annealing steps and passivation layers.

Thank you for your attention

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