Development of high-sensitivity TES for next-generation polarimetric millimeter-wave observation instruments

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GDR-DI2I
Groupement De Recherche
Détecteurs et Instrumentation pour les 2 Infinis

Summary

1. The LiteBIRD space observatory

Cold Universe study

The earliest moments of the Universe:

- Polarization of the cosmic microwave background (CMB)

Foreground characterization:

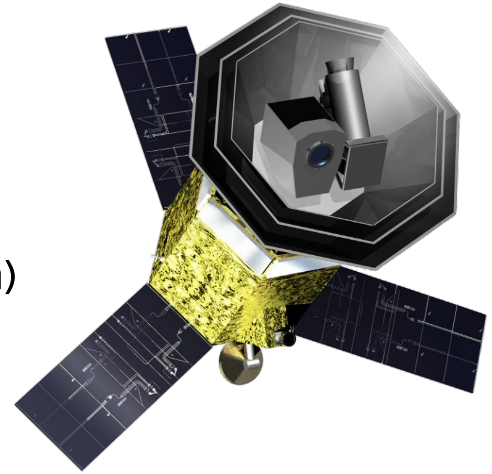
- Interstellar clouds
- Galactic dust polarization

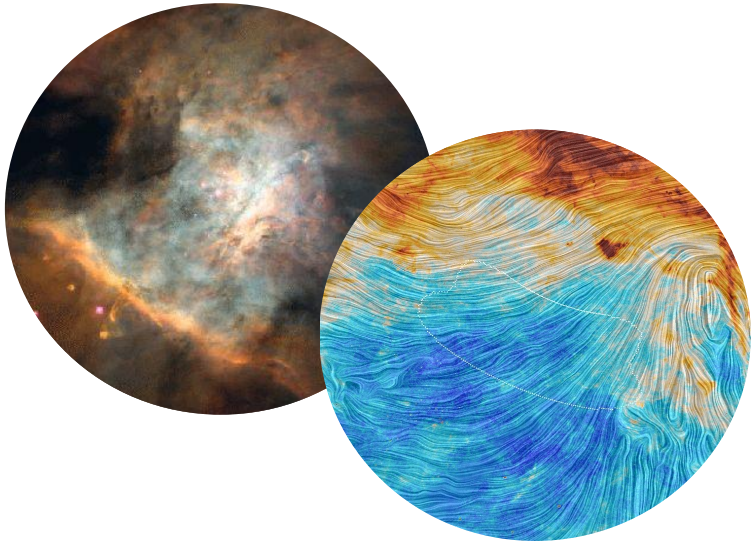
The Mission

- 5 Main contributors

(Japan, France, Netherlands, Italy, Canada)

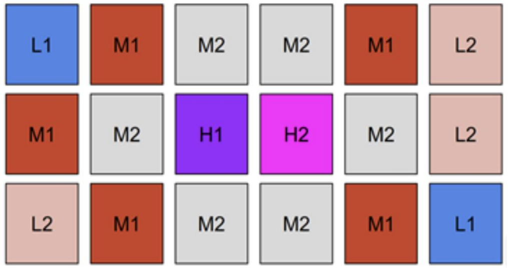
- 3 Years of operation
- Expected Launch: 2037





The Instrument

- 1 focal plane (~4000 detectors)
- 12 frequency bands (40-400 GHZ)
- TES bolometers cooled ~100 mK
- Sensitivity limited by CMB photon noise
- Sensitivity to polarization: horn coupled to antenna and planar superconducting circuit



➔Support for the LiteBIRD project: identified by CNES and IN2P3 as a major priority

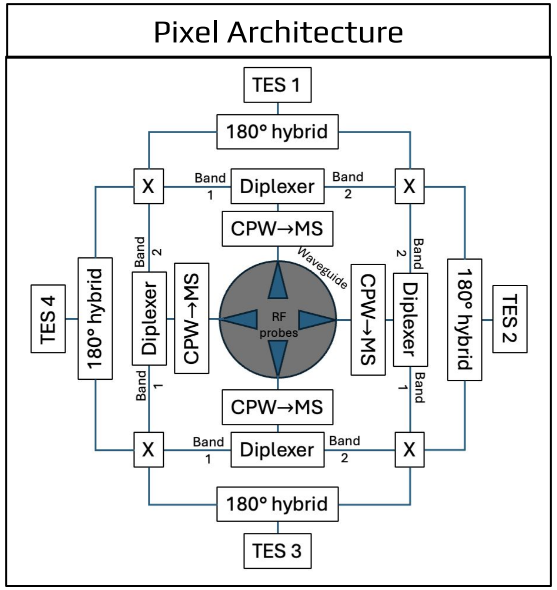
➔Development of the high-frequency (HF) bands not covered by SRON's design plan

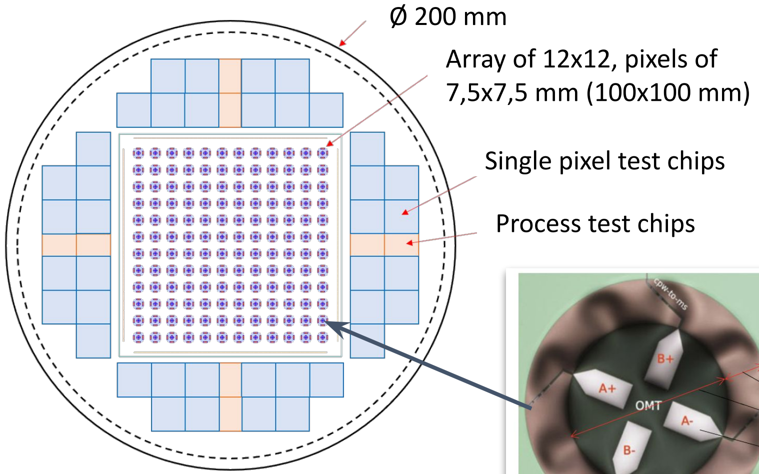
2. Technical objectives

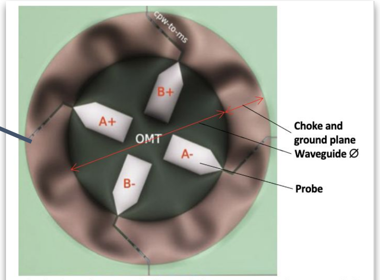
*Develop a **TRL5** prototype of a **dual-polarization, dual-band TES** (Transition Edge Sensor) detector array in the millimeter-wave range for future scientific missions such as LiteBIRD or other ESA missions under the Voyage 2050 program.*

Specifications:

- 12x12 pixels arrays
- Temperature: 100mK
- HF1 LiteBIRD band: 217GHz & 334GHz, $\Delta\nu/\nu$ = 30%
- 2 polarizations
- NEP ~ 6.10^{-18} W.Hz$^{-0.5}$







[Hub22] J. Hubmayr et al., "**Optical Characterization of OMT-Coupled TES Bolometers for LiteBIRD,**" J Low Temp Phys, Nov. 2022.

Deliverable:

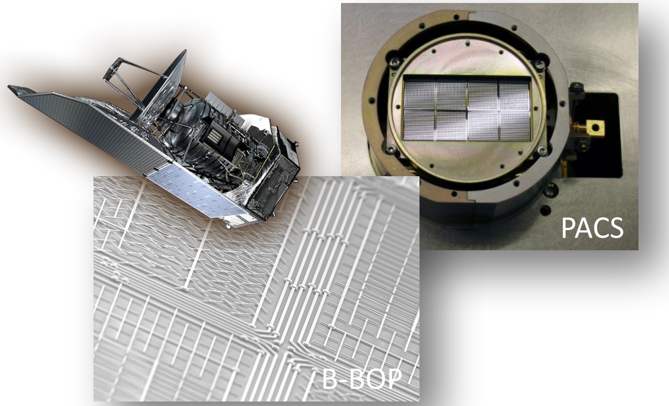
- Two fabrication lots, each consisting of 12 (200 mm) wafers with:
  - 144-pixel array (100×100 mm²)
  - Process test chips
  - ~40 single pixels and RF structures for testing technological variants to optimize and validate the design
- Process-level testing of each wafer
- Electrical testing at 100 mK
- Optical measurements

3. The collaboration Team

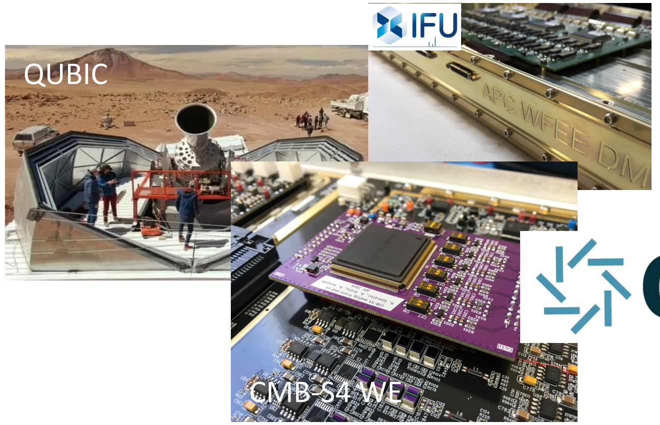
CEA leti	CEA irfu	APC	irap	Berkeley Lab
Laurent Dussopt Abdelkader Aliane	Louis Rodriguez Vincent Revéret	● Michel Piat Damien Prêle Manuel Gonzalez Timothée Tollet Paul Tagnon	● Ludovic Montier	Aritoki Suzuki Oliver Jeong

Key projects:

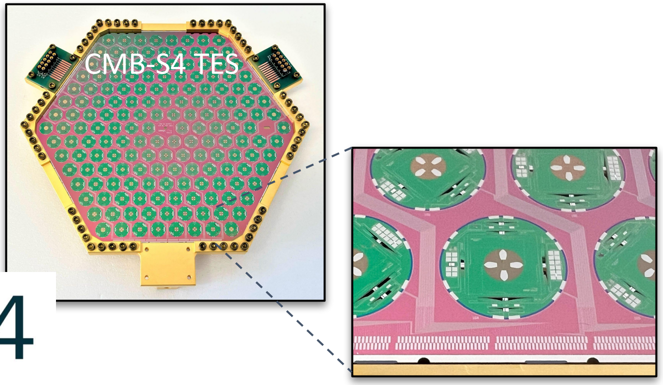
Bolometer development for: **Herschel/PACS**, **APEX/Artemis** and **SPICA/B-BOP**



QUBIC's TES design and tests
Athena/X-IFU and **CMB-S4** readout development



CMB-S4 TES design, fab and test, new **Hf TES** techno development



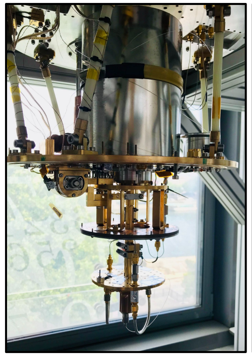
● *Member of the LiteBIRD collaboration*

3. The collaboration Team

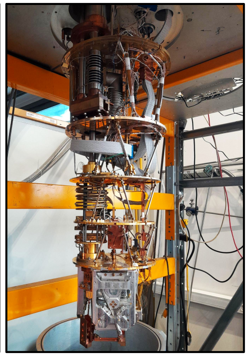
The fabrication and test facilities

- Semi-industrial lab in Grenoble
- Cleanrooms: 11000 m²
  - 200mm and 300mm wafers
  - characterization,
  - prototyping,
  - validation,
  - testing capabilities

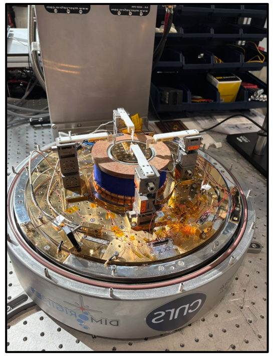
- DRTBT Lab
  - Dilution fridge with TDM readout (from CMB-S4) → To be opened for optical tests
- Cryo-Mat sub-K characterization platform
  - Electrical properties (2025)
  - Thermal properties (2026)
  - Mechanical properties (2027)
- Low Noise Room: electric tests & integration



ADR
35mK



Dilution
20mK

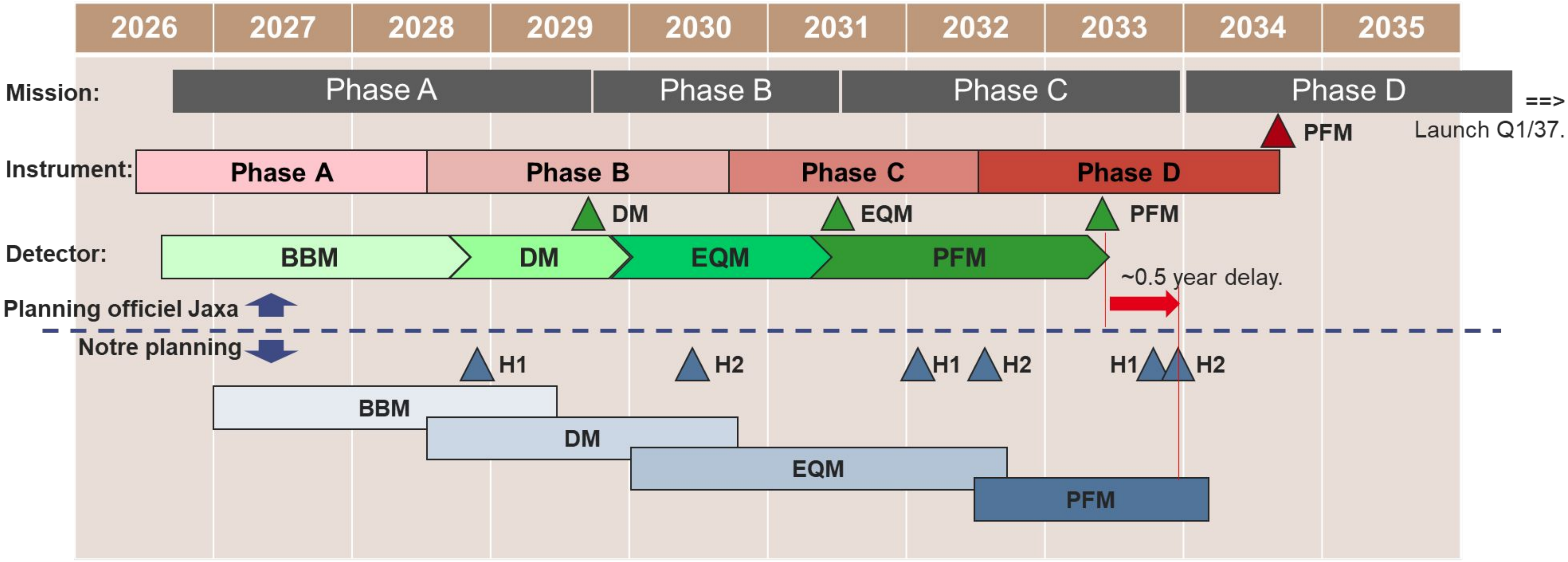


Cryomat
electrical cryostat

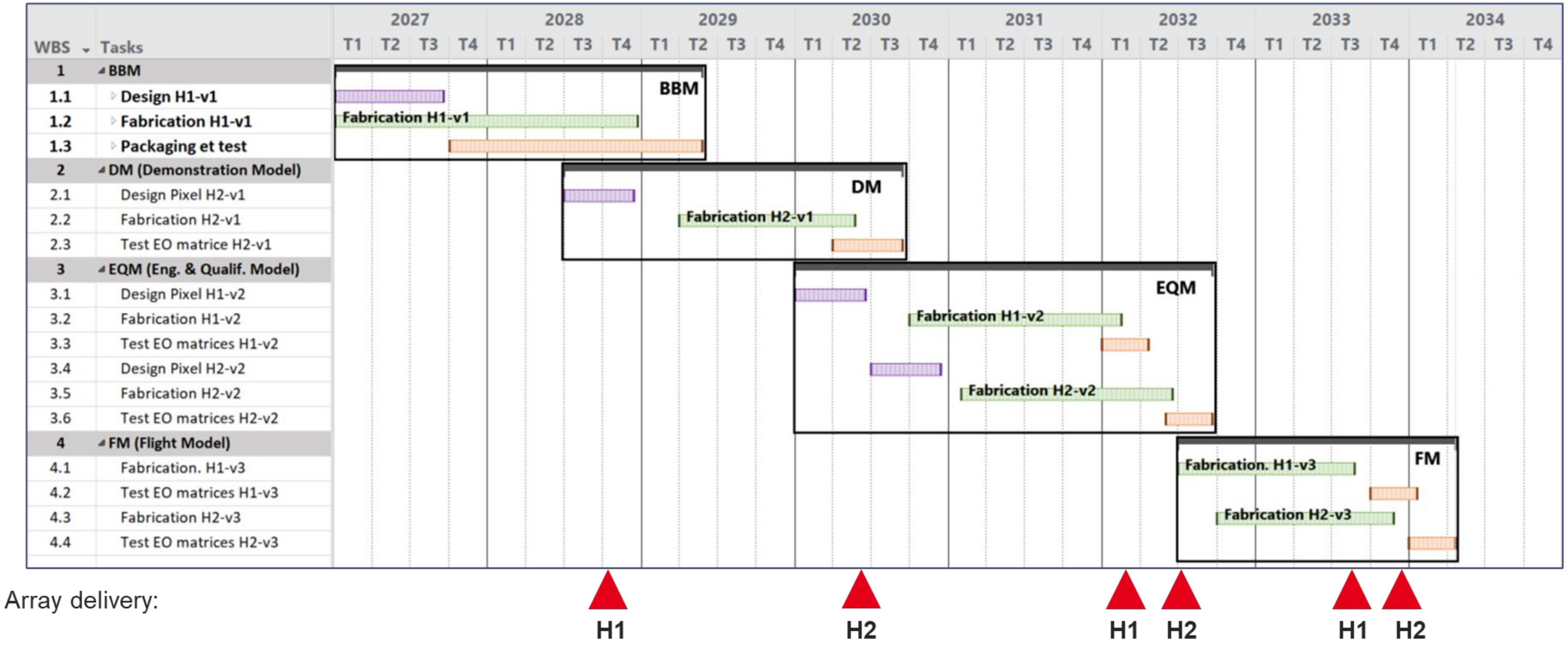
Low Noise Room

4. Development plan

ORFPM: Optical and RF Prototype Model
DM: Demonstration Model
EQM: Engineering and Qualification Model
PFM: Flight Model
FS: Flight Spare



4. Development plan



<u>Proposed project</u>

WP1: Management

WP2: Pixel and prototype design

- ➢ Design report

WP3: Technology

- ➢ Year 1: Fabrication process study runs
- ➢ Year 2:
  - o **Two prototype runs**
  - o Full DC testing at 300K
  - o First low-Temperature DC tests
  - o **DC fabrication and test report**

<u>Supporting activities with LiteBIRD partners</u>

WP4: Packaging

Design and fabrication of mounts, feedhorns, and test interfaces.

WP5: Tests

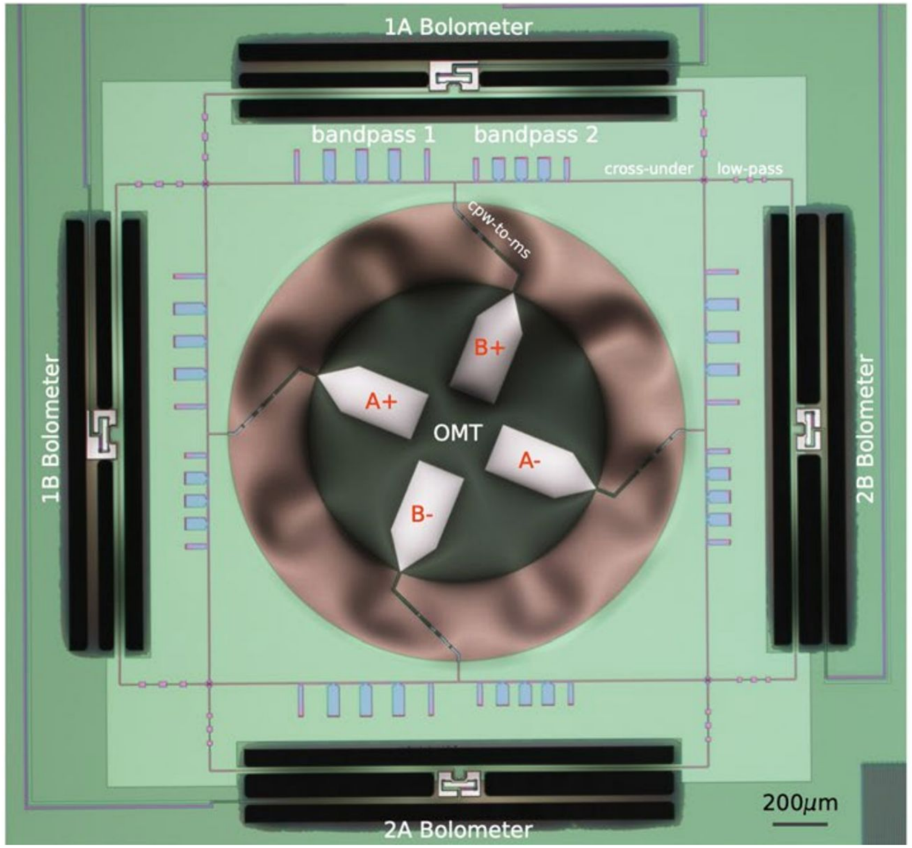
Preparation and performance of cryogenic optical tests.

5. Development status

TES pixel design:

- OMT design
- RF lines design
- TES characteristics and expected performance
- Choice of materials
- Mechanical Study

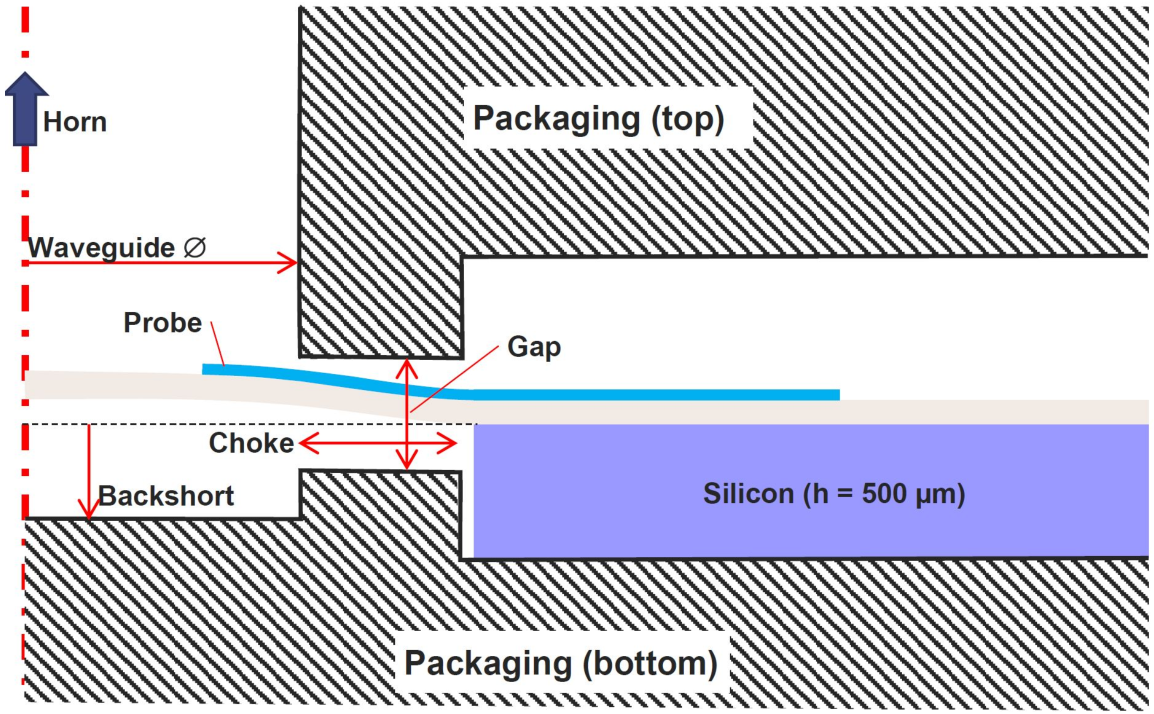
NIST Pixel



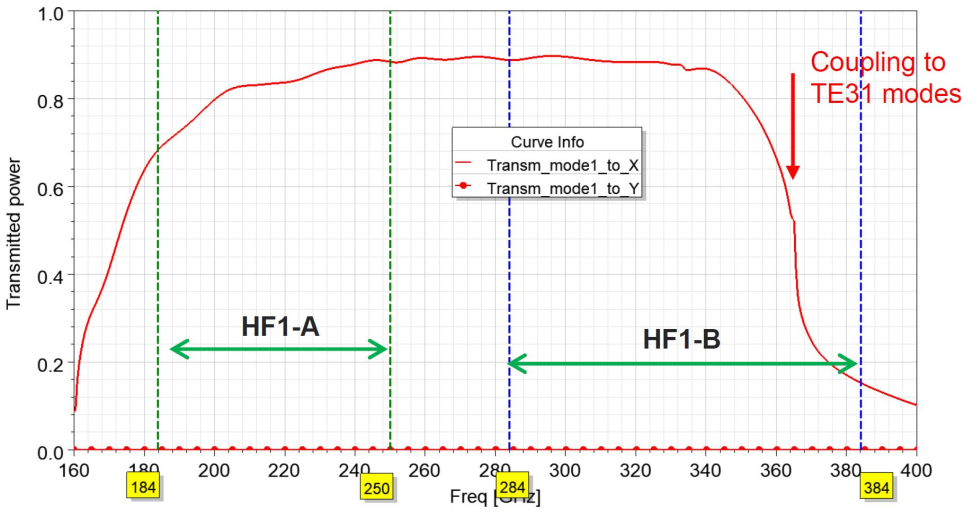
J. Hubmayr et. al 2022

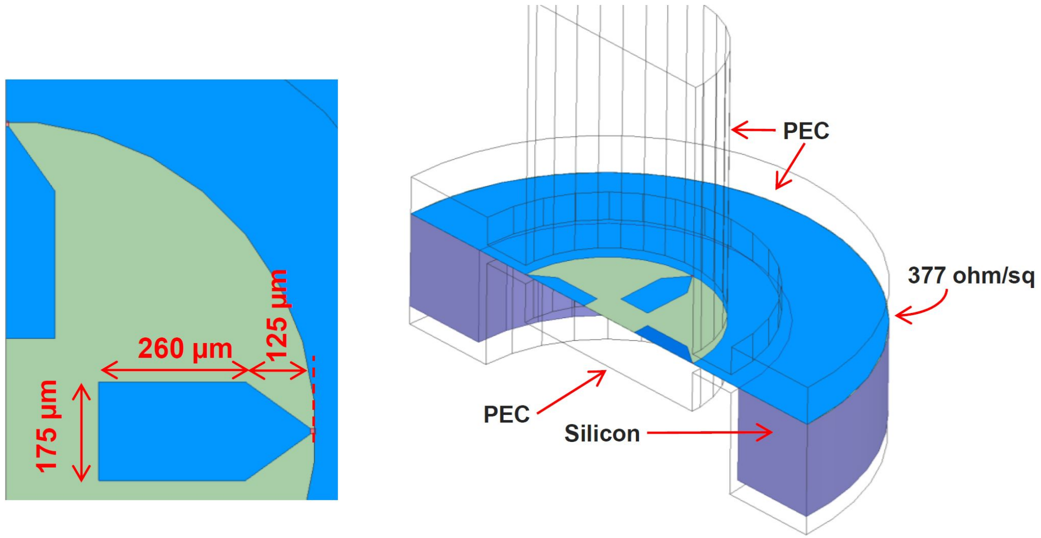
5. Development status - OMT design

<u>Preliminary design based on published examples:</u>
- Waveguide : 1.1mm => mode TE11 ~160 GHz
- Backshort: 260 µm
- Choke: 250 µm
- Gap: 100 µm (±50 µm wrt to the wafer top surface)
- Probe port impedance: 200 ohms (not optimized)



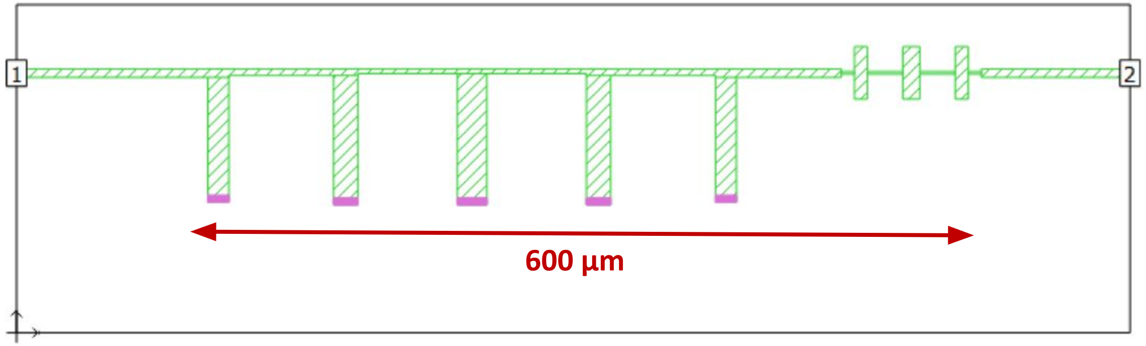
Transmission from the waveguide (TE11 mode, X pol.) to the 2 X-probes and the 2 Y-probes.

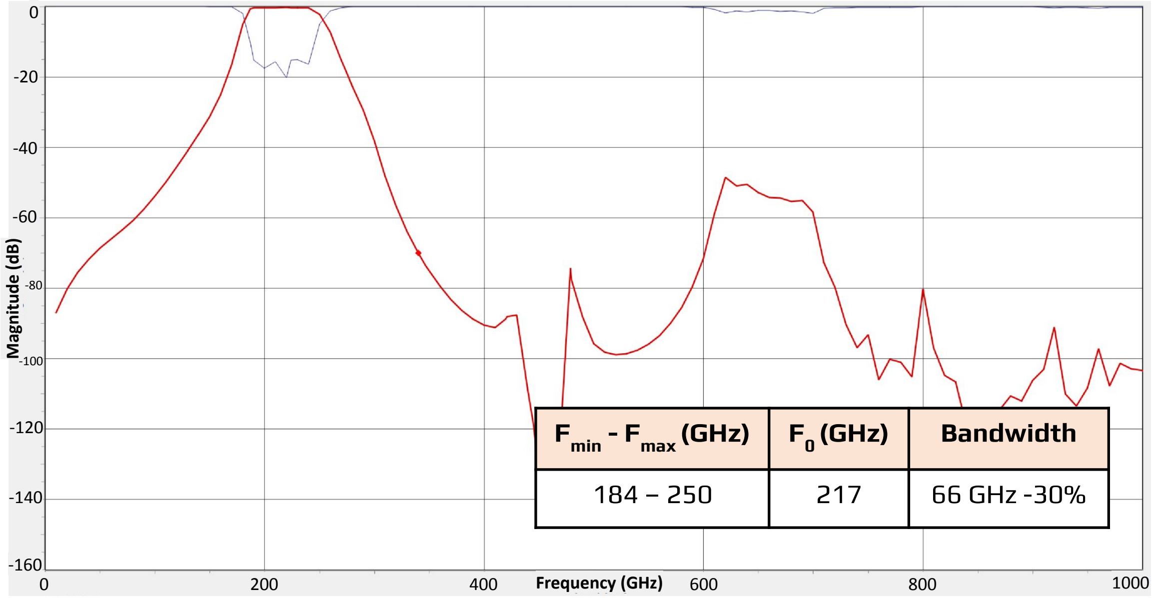




5. Development status - RF Filters

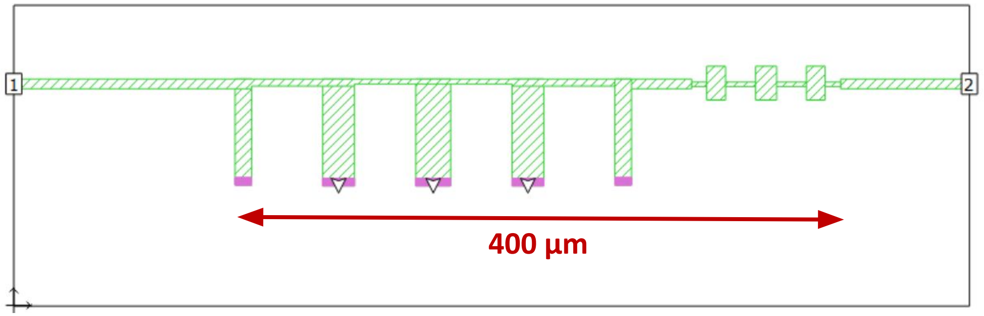
217 GHz band

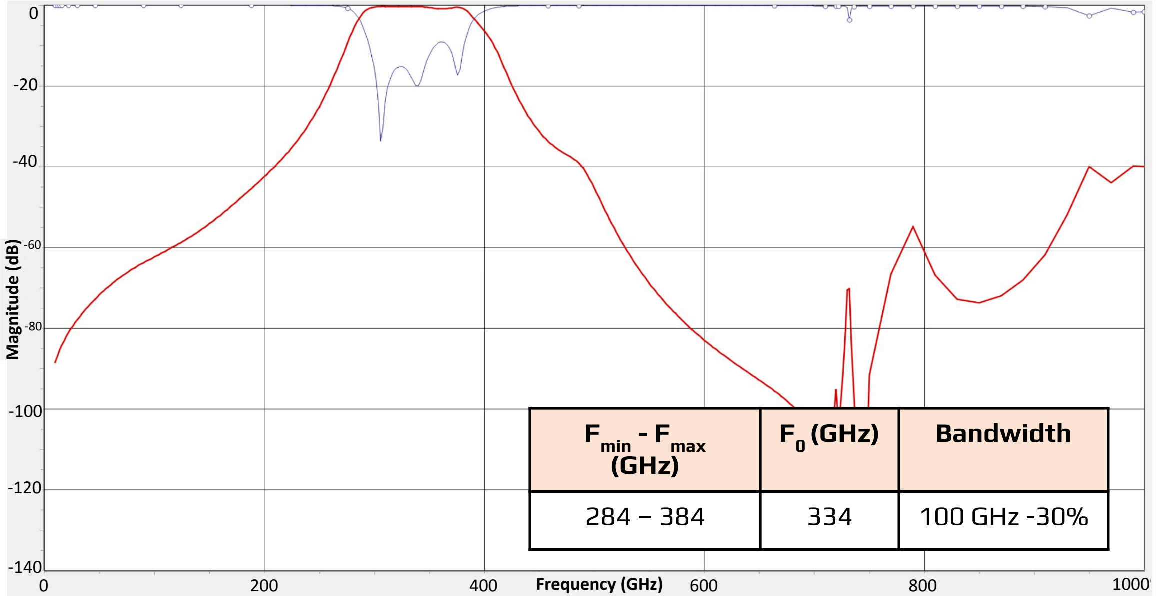




F_{min} - F_{max} (GHz)	F_0 (GHz)	Bandwidth
184 – 250	217	66 GHz -30%

334 GHz band

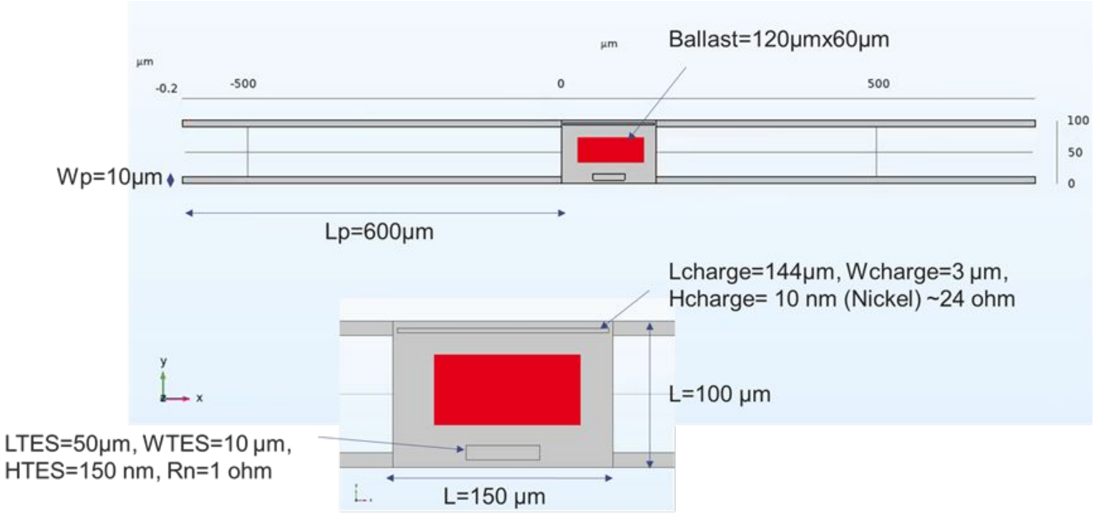


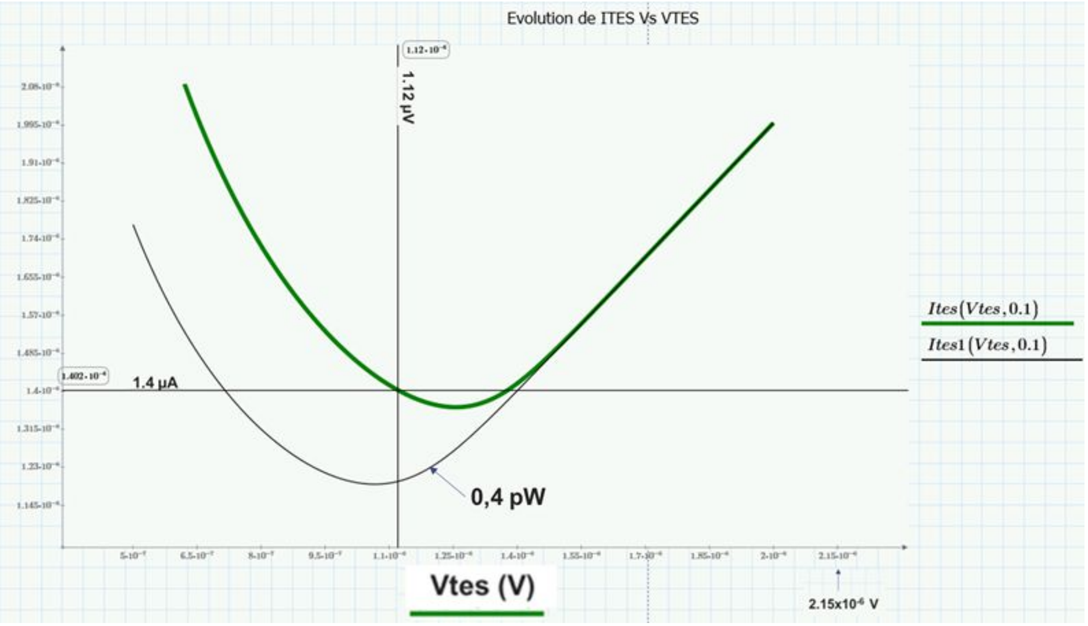


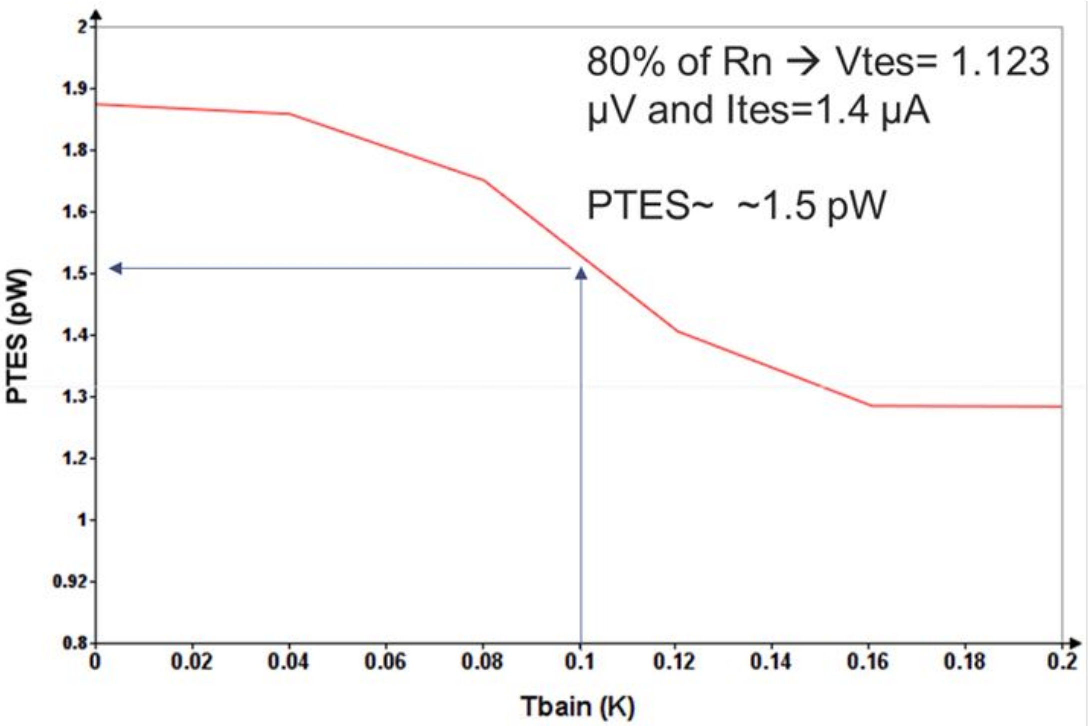
F_{min} - F_{max} (GHz)	F_0 (GHz)	Bandwidth
284 – 384	334	100 GHz -30%

PRELIMINARY RESULTS

5. Development status - TES design







$$Gthtot\_nb\_poutres(Tc) = 3.098 \cdot 10^{-11} \ \frac{W}{K}$$

$$Cth\_tot\_pixel(Tc) = 3.156 \cdot 10^{-14} \ \frac{J}{K}$$

PRELIMINARY RESULTS

5. Development status - Superconducting materials

Target: Tc ~160 to 180 mK and Rn~0.1 Ohm

Deposition at CEA/Leti, measurement at Irfu and APC

Different Metals were used for the study:

→ **Tungsten (W)** 200 nm thick, deposited by sputtering at 50, 250, 350, 450 °C

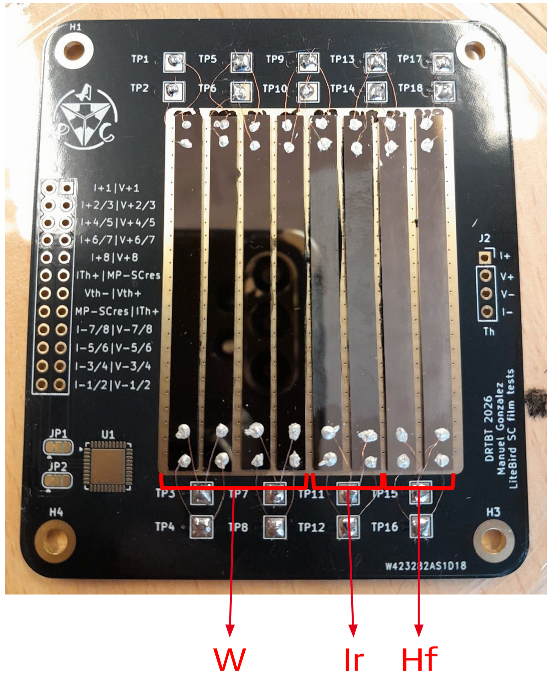
Not superconducting down to 25 mK

→ **Hafnium (Hf)** 150 nm thick, deposited by sputtering at RT: Rsq ~6.3 Ohm/sq @RT
(+Post deposition annealing to reduce and stabilize the Tc)

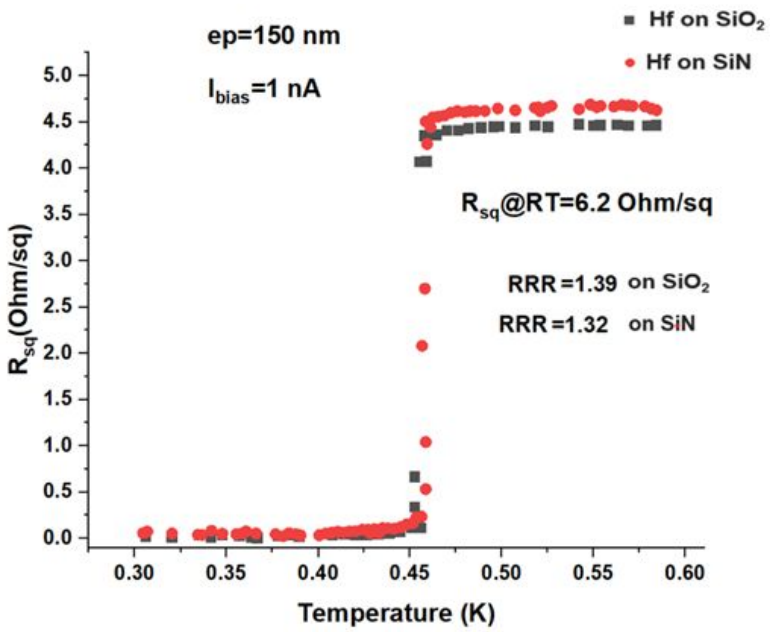
Tc ~450 mK

→ **Iridium (Ir)** 150 nm thick, deposited by sputtering at RT: Rsq ~1.3 Ohm/sq @RT

Tc ~158 mK

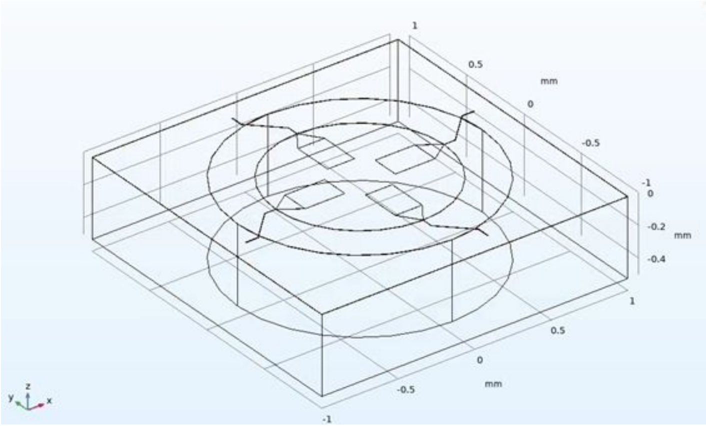


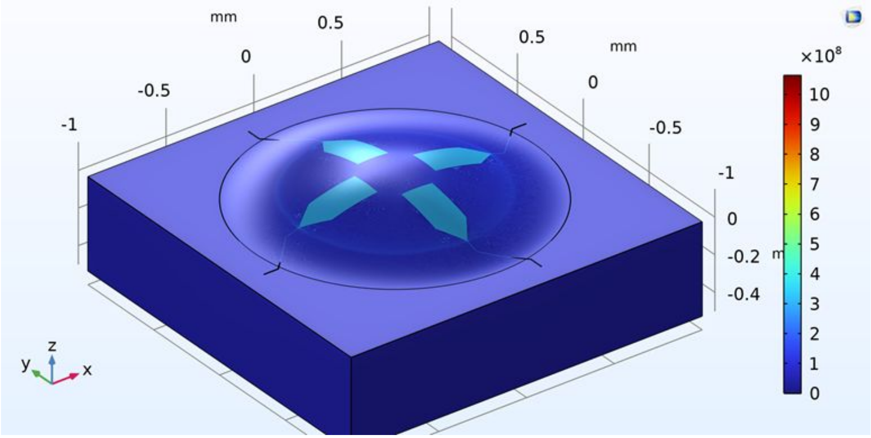
Hafnium As-deposited



PRELIMINARY RESULTS

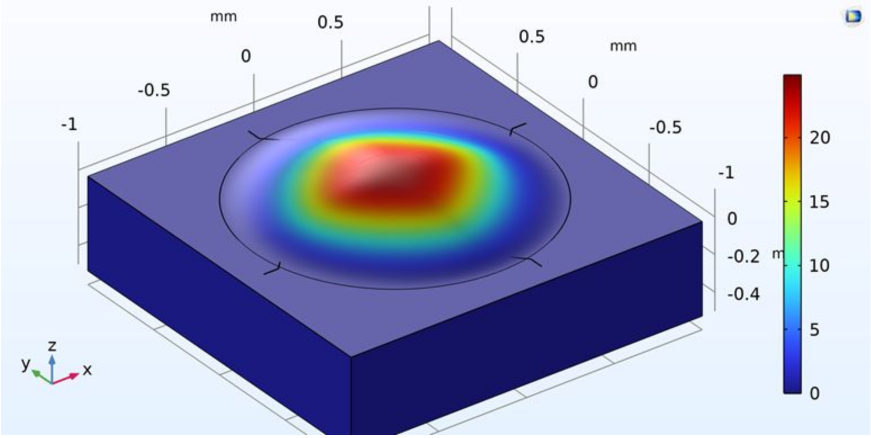
5. Development status - OMT Mechanical Simulation





Stack:

- SiN membrane (thickness: 500nm with a residual stress (~100 MPa)
- Nb ground (thickness: 200nm with a residual stress (~350 MPa)
- SiN insulator (thickness: 350nm, with no residual stress
- Nb Metal 2 (thickness: 400nm with a residual stress (~350 MPa)



→ **Max displacemnt: 23 µm upward**

PRELIMINARY RESULTS

6. Perspectives

- Fundings by ESA and CNES ?
- Technology process development
- Complete pixel design
- Wafers fabrication at CEA/Leti
- Pixel performance demonstration at APC and CEA/Irfu
- Official integration in the LiteBIRD project and collaboration

- New french expertise and TES manufacturing capability for future ground- and spaceborne (sub)-mm observatories

LiteBIRD Focal Plane

Wafer type		Freq [GHz]
LF	LF1	40
		61
	LF2	50
		77
MF	MF1	94
		145
	MF3	118
		182
HF	HF1	217
		334
	HF2	261
		402

Focal Plane Layout and polarisation orientations