TESs

TES Bolometer for CMB

Flavio Gatti

Università e INFN, Genova

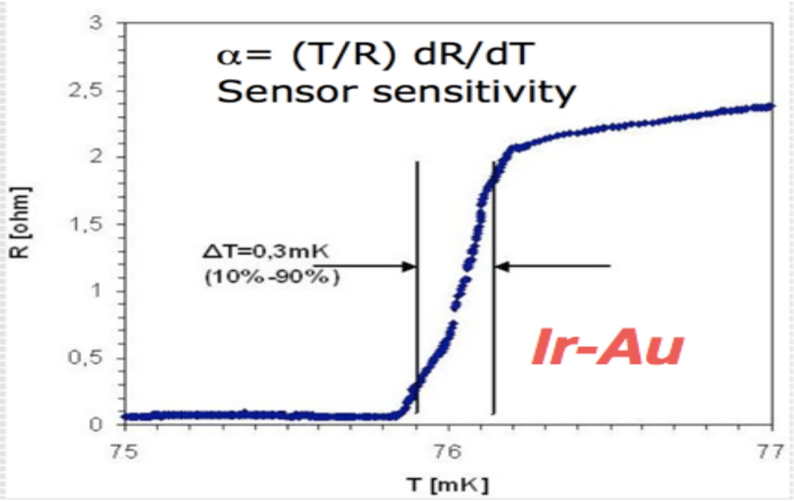
on behalf of the Italian CMB community

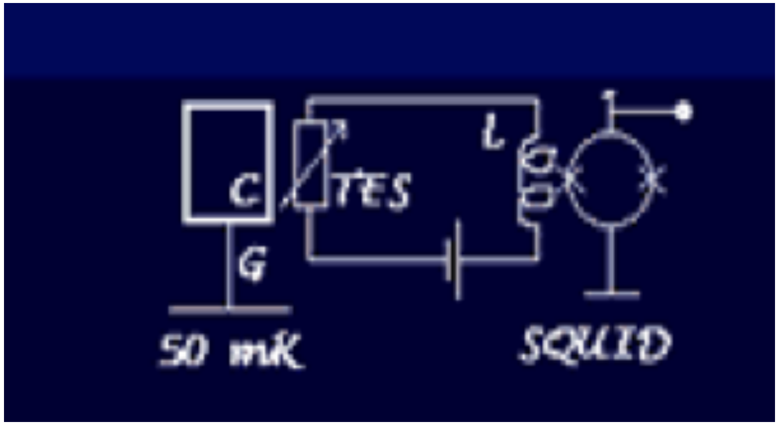
Overview

1. CMB TES Bolometers and Performance
2. Status of the Art
3. TES Bolometers and Readout chain for LSPE
4. Future developments

TES

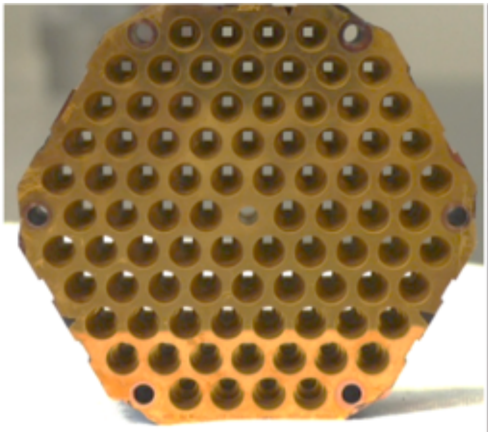
- Superconducting film operated in the s/c to normal transition
- SQUID as best matching current amplifier
- Low T → Low Noise Equivalent Power to input and narrow transitions
- Multiplexing schemes TDM and FDM are suitable

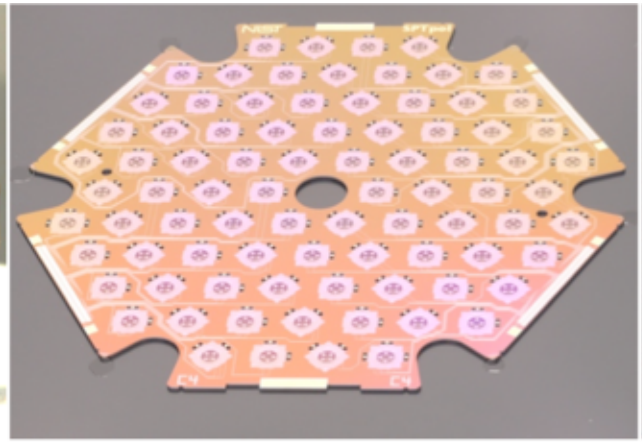


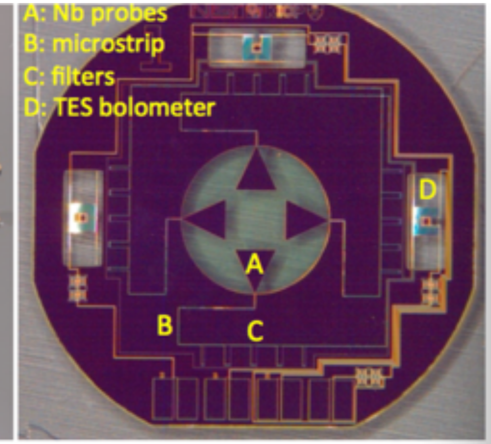


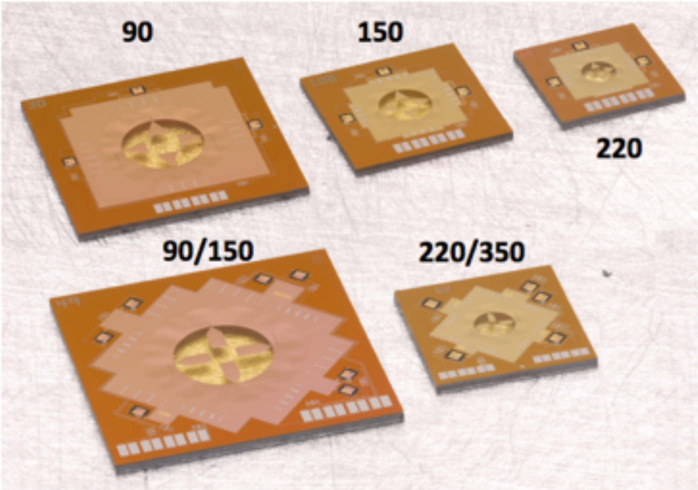
$$NEP = \sqrt{4kTG}$$

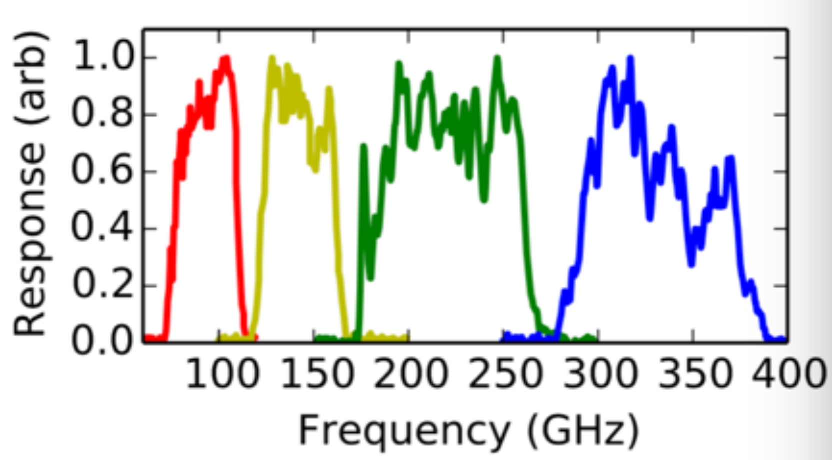
Status of the Art







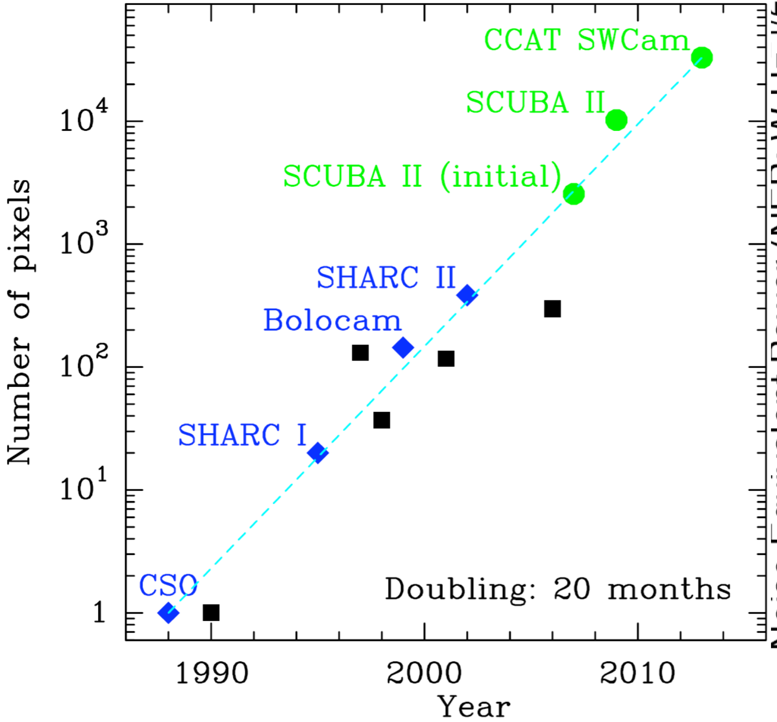


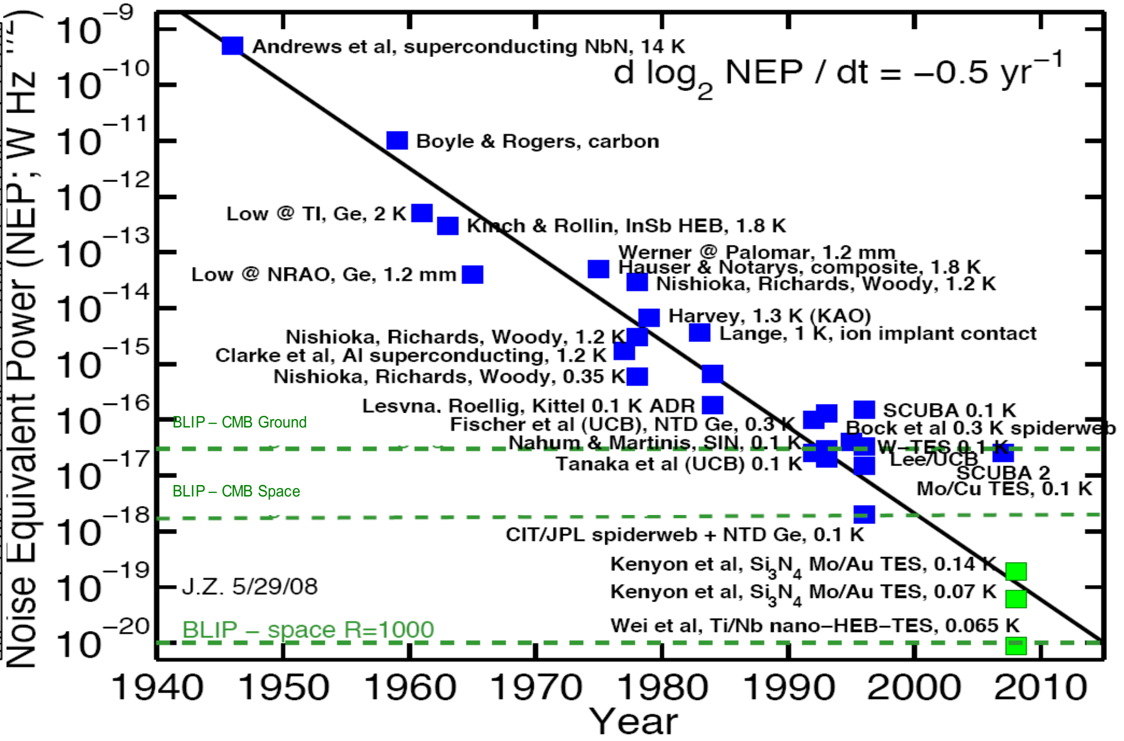


A. Lee, UCB, "Workshop CMB from Space" Tokyo 12 Dec 15

Status of the art

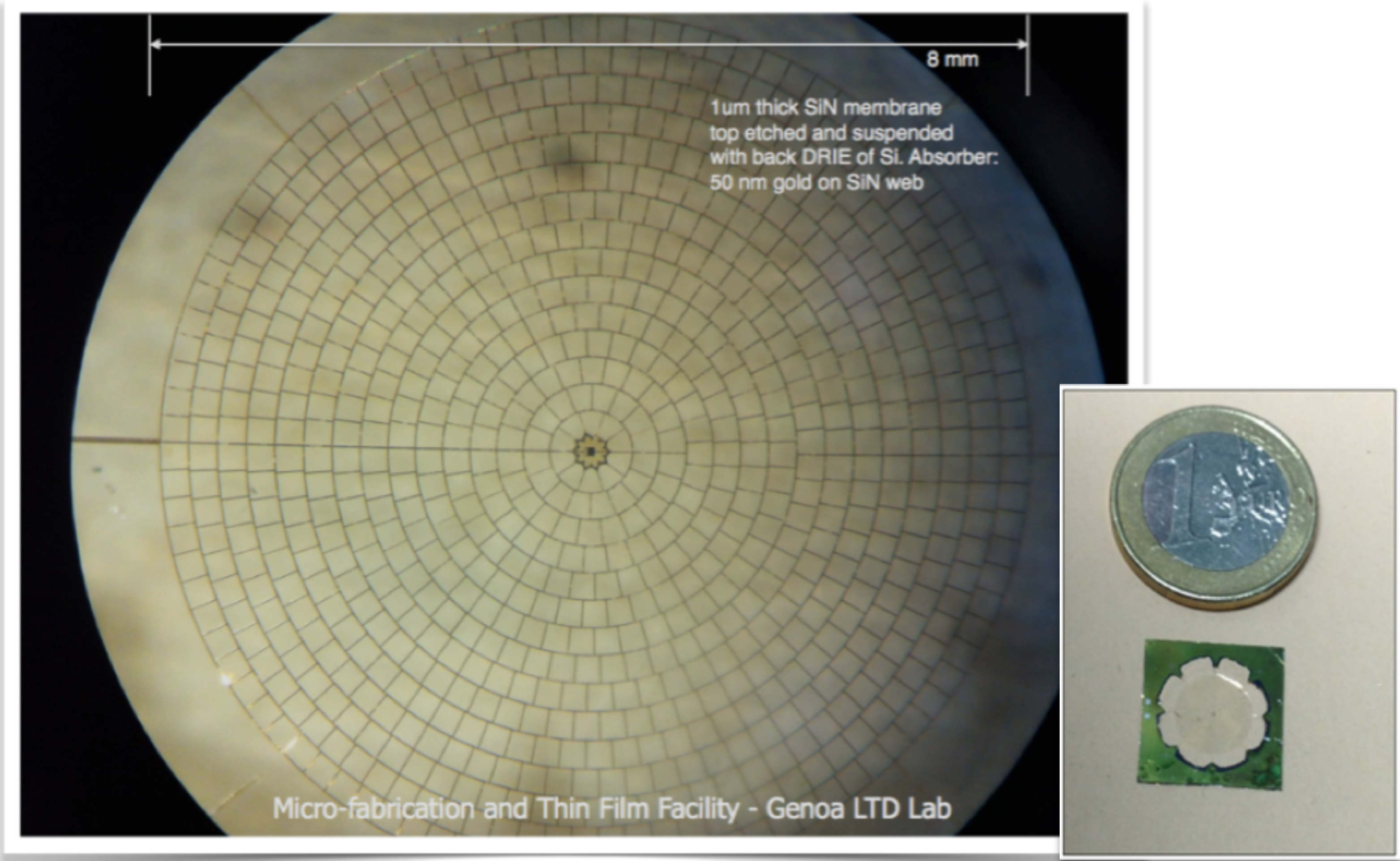
- Array size: doubling time = 20 months
- NEP challenge: improves of about a factor 10 each 10 years



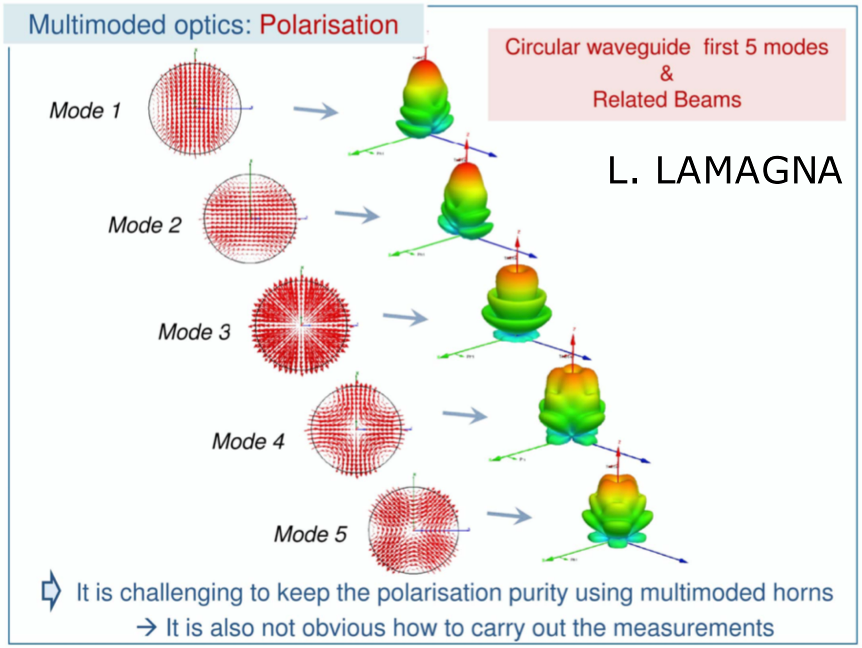


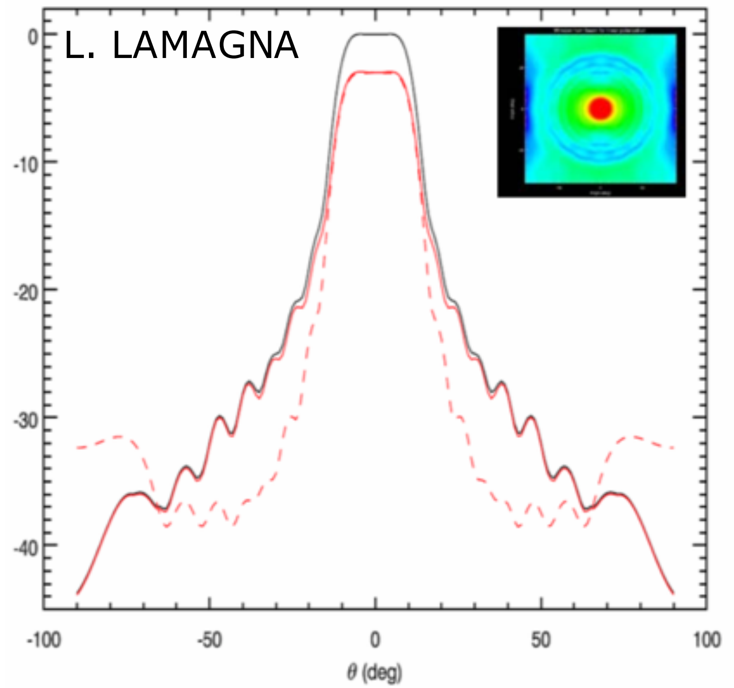
TES Large Area Bolomter for LSPE

Bolometers: starting point (Genova)



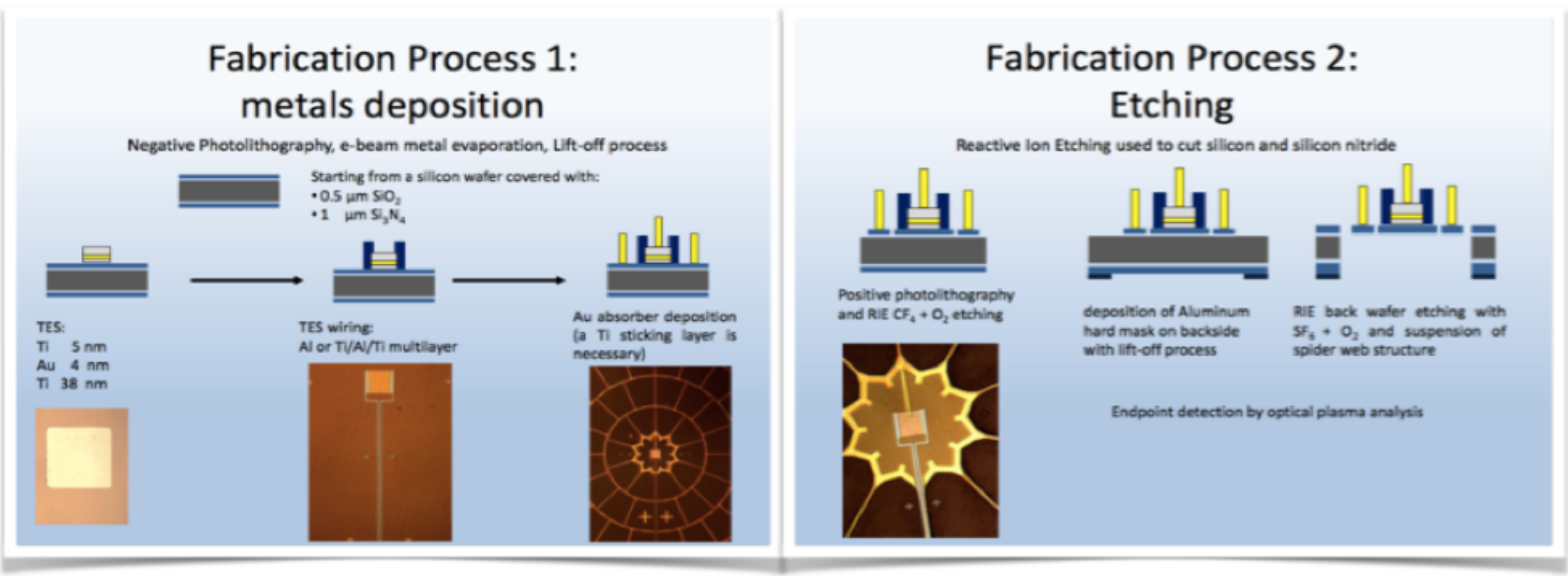
- LSPE based on Multi-Mode detection: Bolometers must couples with several tents of cavity modes (P.de Bernardis)
- This is the motivations of a such large area
- Expected performance of comparable experiment with 10^3 single mode detector
- Top flat beam is within the required angular resolution of LSPE





Fabrication Process @ Genova

Full fabrication in the Genova Facilities



Fab and Test Facility in Genova

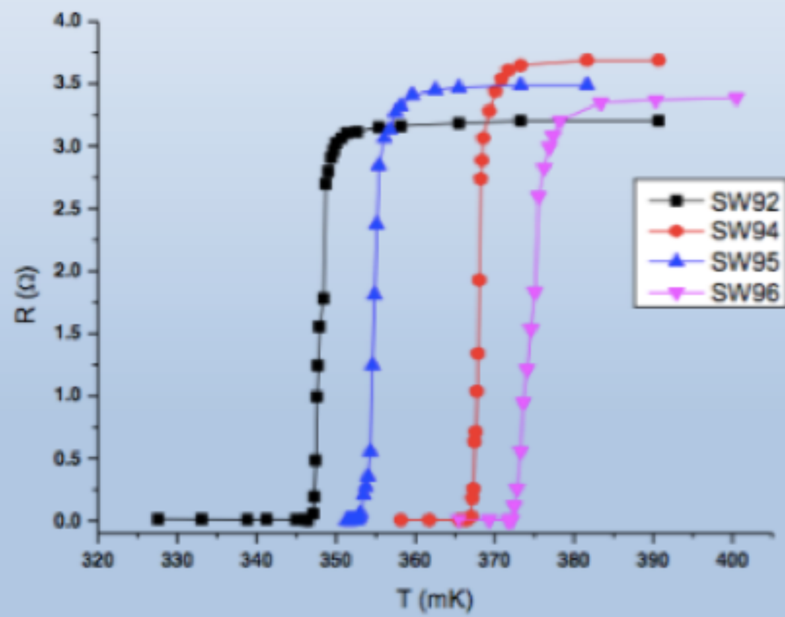
1. Fab Facility with Thin Film growth system (PVD, RF/DC Sputtering, PLD)
2. Optical micro-lithography
3. Micromachining
4. Low T fridges with SQUID for testing
5. “Flexible” for fast prototyping not very well suited for large production

Clean room for litho and thin films evaporation system facilities

Test facilities (3 dilution fridgew)

TES performance test

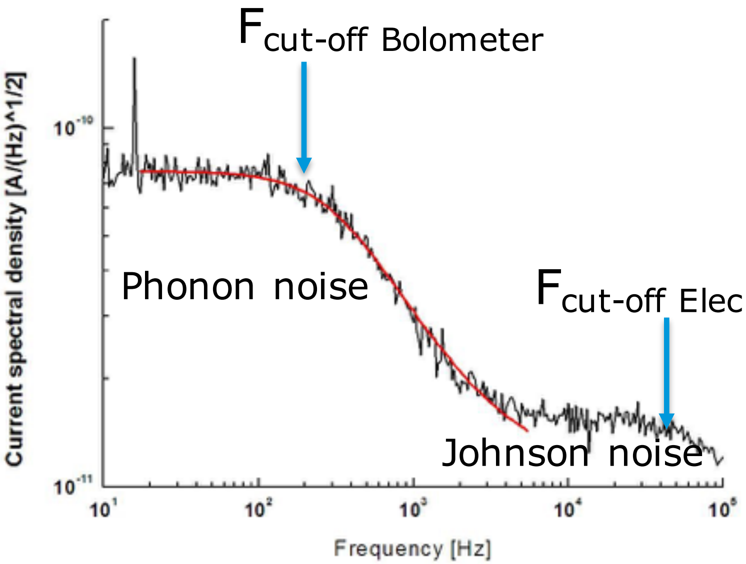
- Bilayer TES Ti-Au studied for covering 0.3 -0.4 K
- Larger temperature range requirements: bilayer Mo-Au

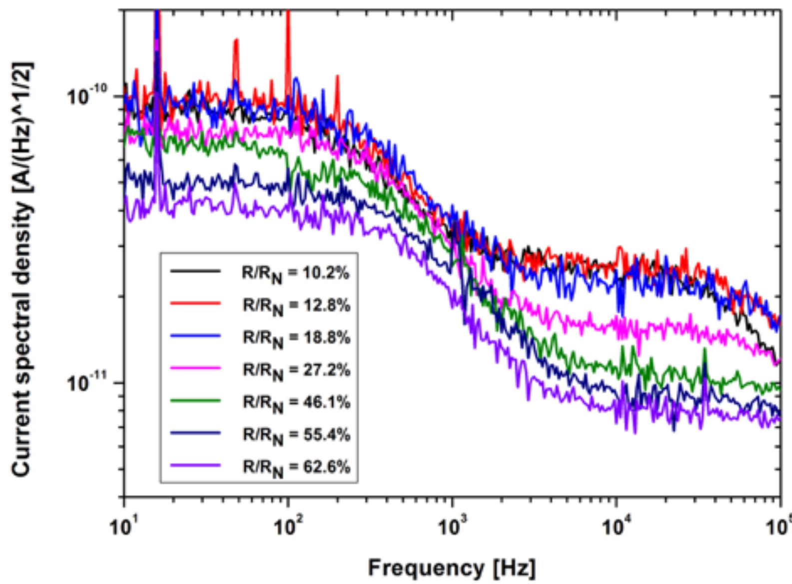


	Ti (nm)	Au (nm)	Ti (nm)
SW92	5.0	4.4	37.2
SW94	5.0	4.4	38.0
SW95	5.0	3.8	37.2
SW96	5.0	3.8	38.0

TES Performance tests

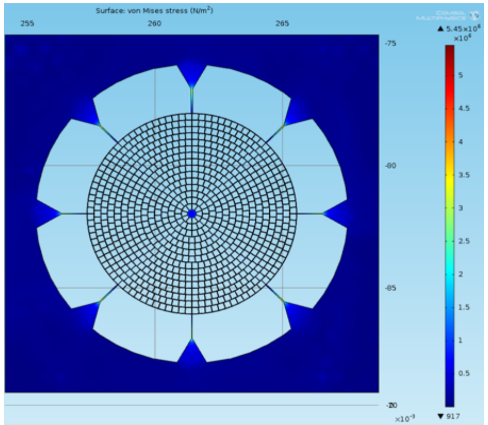
1. Bolometer in isothermal box at low T (no external EM radiation)
2. TES at several operating points (R/Rn)
3. Current Noise as composition of [phonon noise x bolometer gain] and Johnson noise; SQUID noise at $1x10^{-12}$ A/Hz.

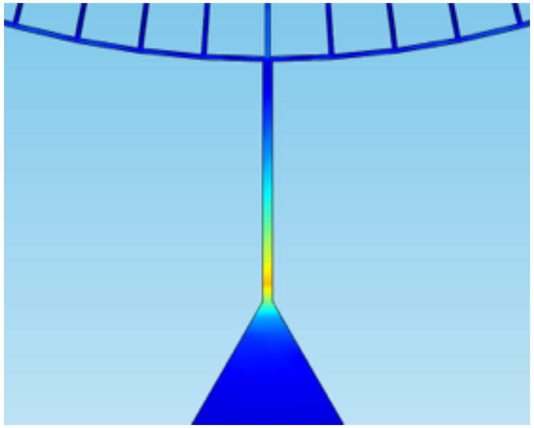


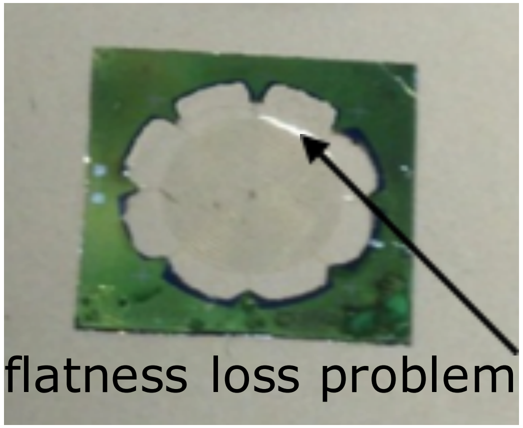


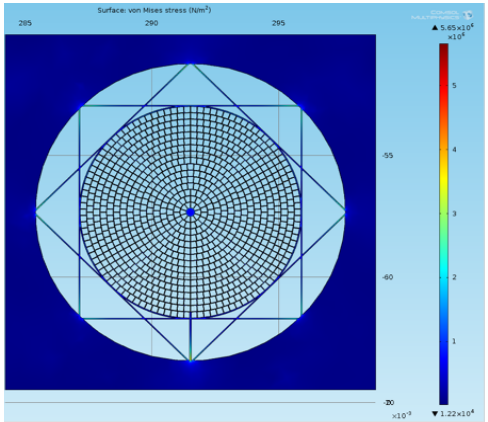
Design Review and upgrade

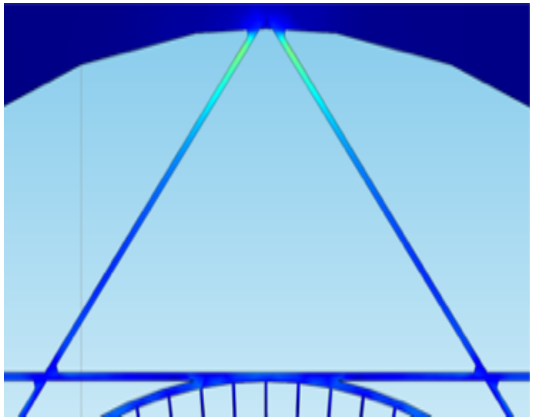
- Largest spiderweb bolometers even built: Metal film-SiN stress release → wavy shape at the edges
- Reduction of von Mises stress at the supporting beam → more than a factor 3





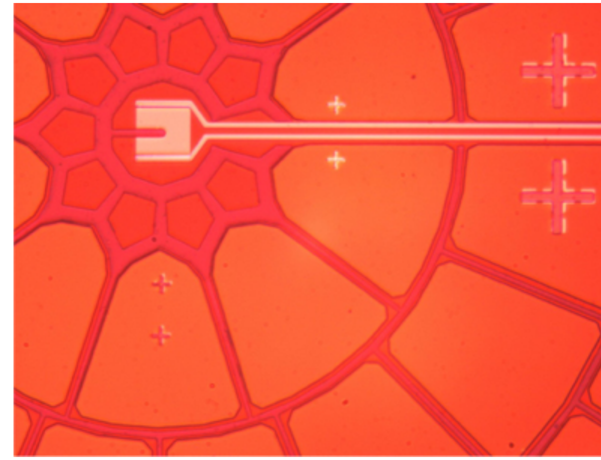


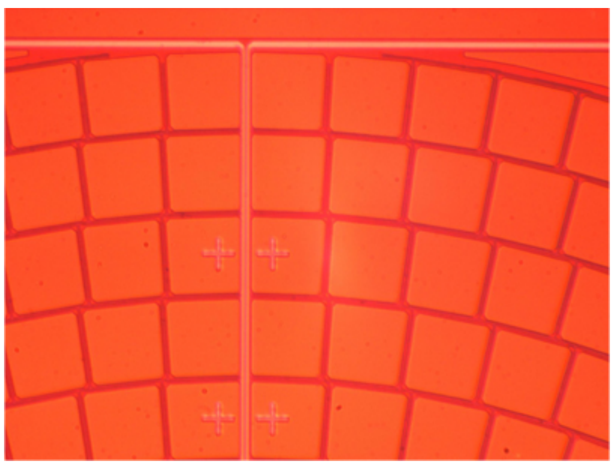


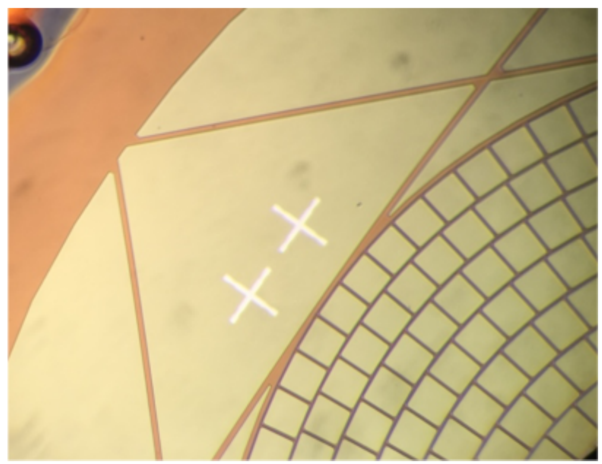


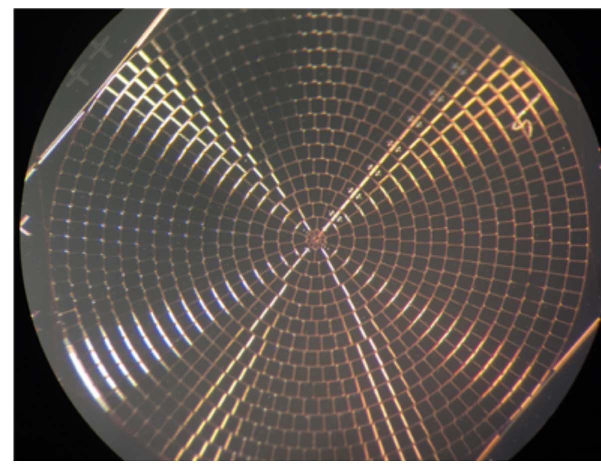
Design Review and upgrade

1. New TES: MoAu
2. New Wiring: Nb
3. New mechanical structure
4. Fabrication done and micro-etching under way

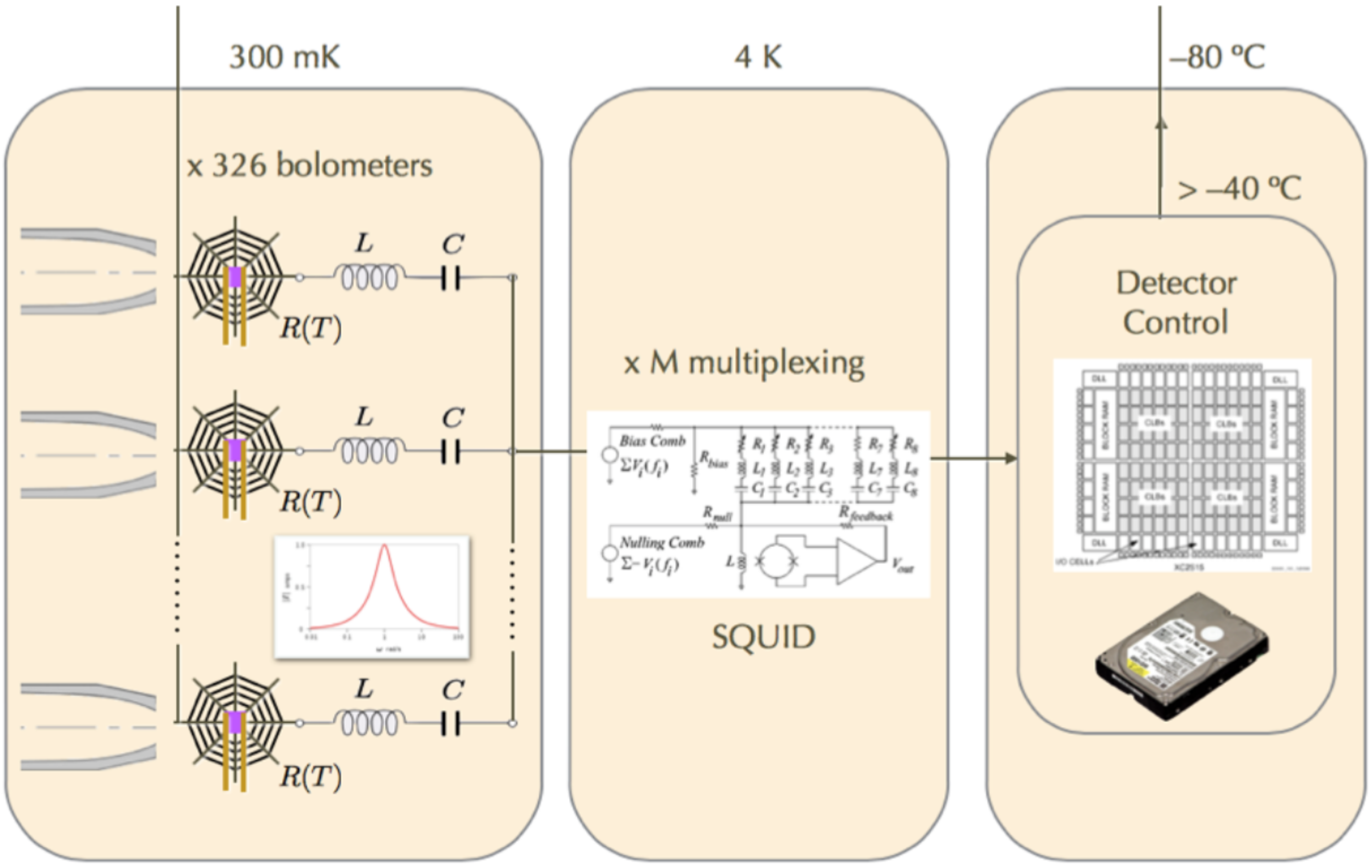






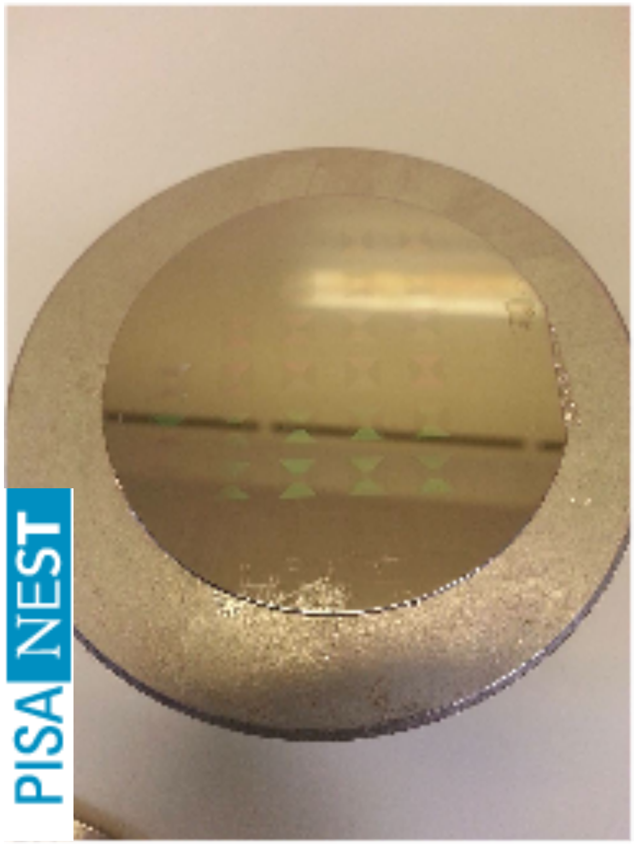


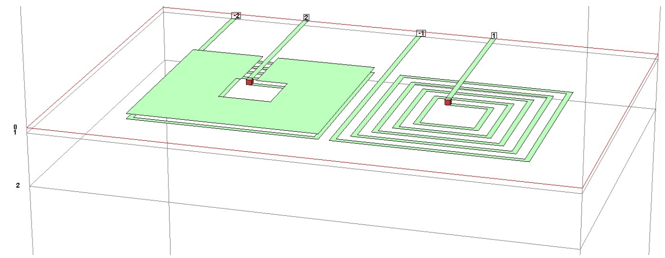
Frequency Division Multiplexing

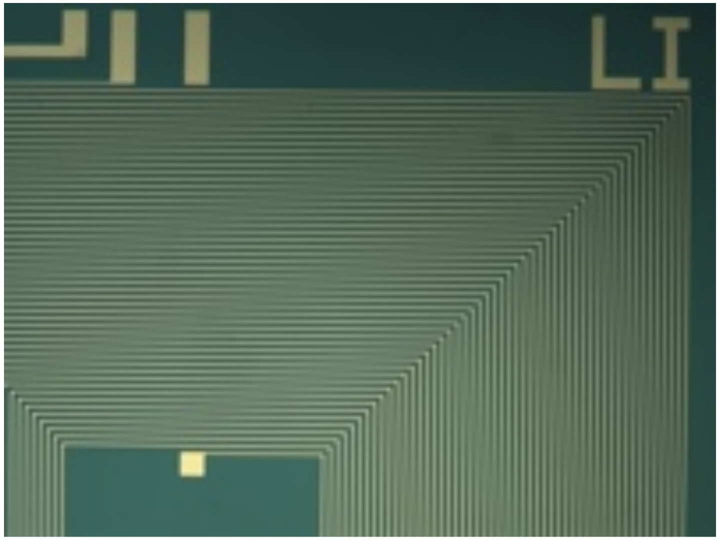


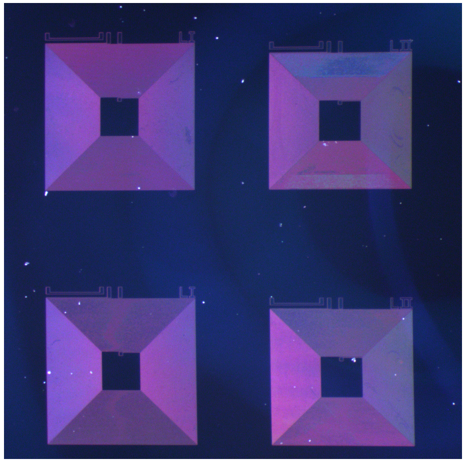
Custom LC circuits for FDM resonators

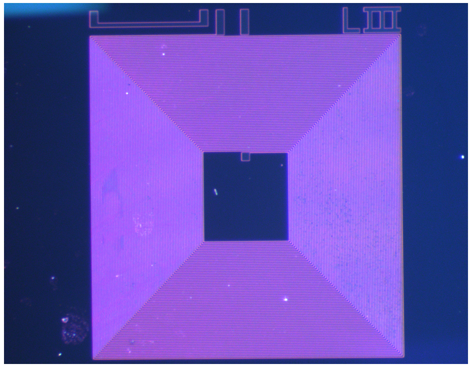
- Niobium inductors produced on 2” Si wafer
- Designed, simulated and tested at INFN Pisa- Fabricated at CNR-NANO PISA and INFN PISA





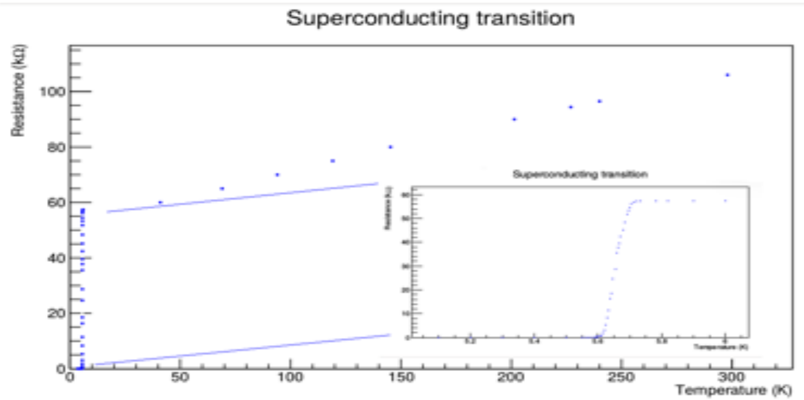


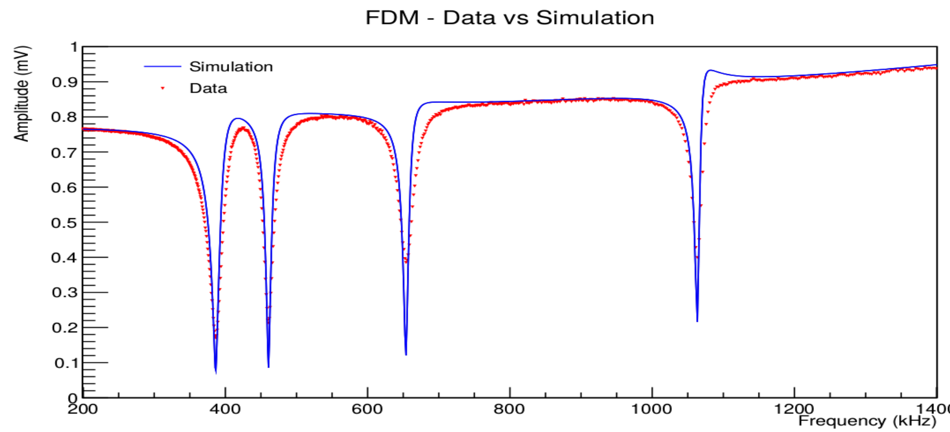


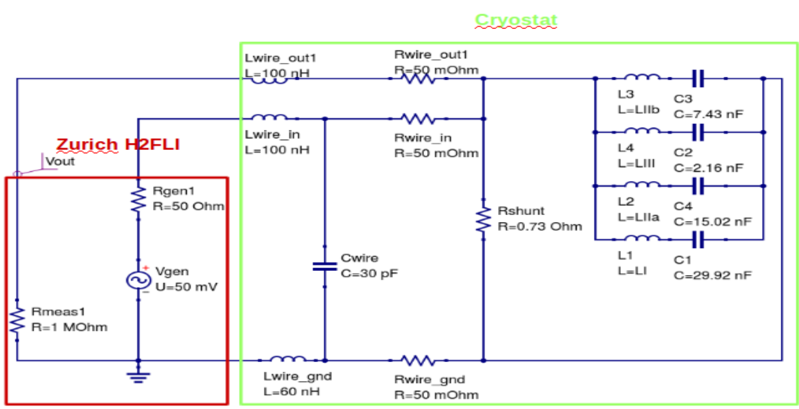


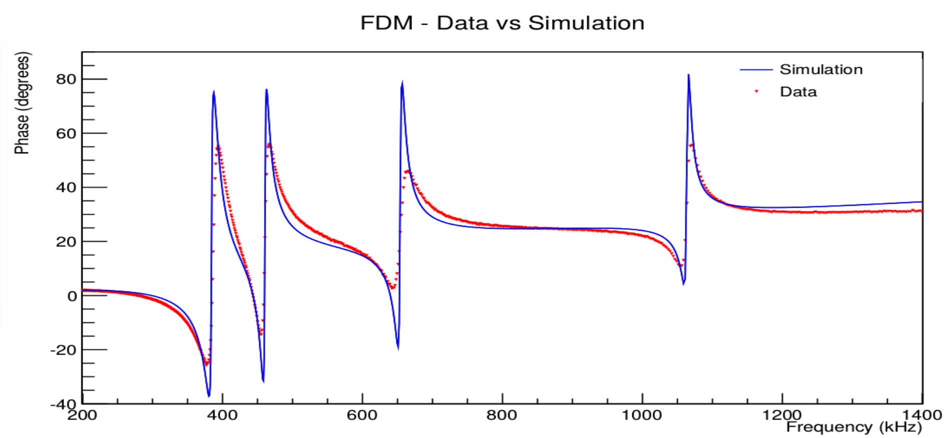
Custom LC circuits for FDM resonators

- Pack 16 carriers in 0.2 -2 MHz frequency band for the LSPE bolometers
- Nb quality test: Tc=5.6 K , RRR=2
- 4-resonator test at 4.2: amplitude and phase (data vs simulation)



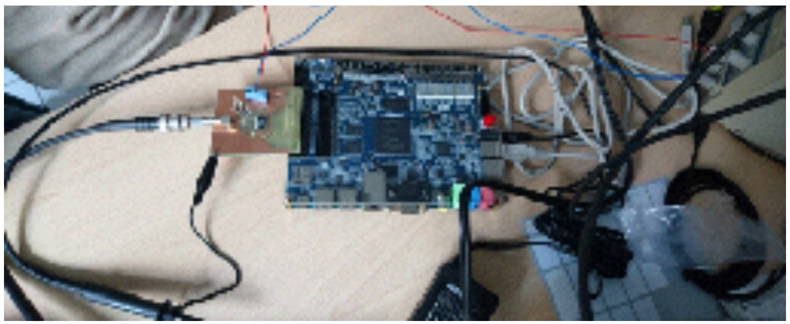


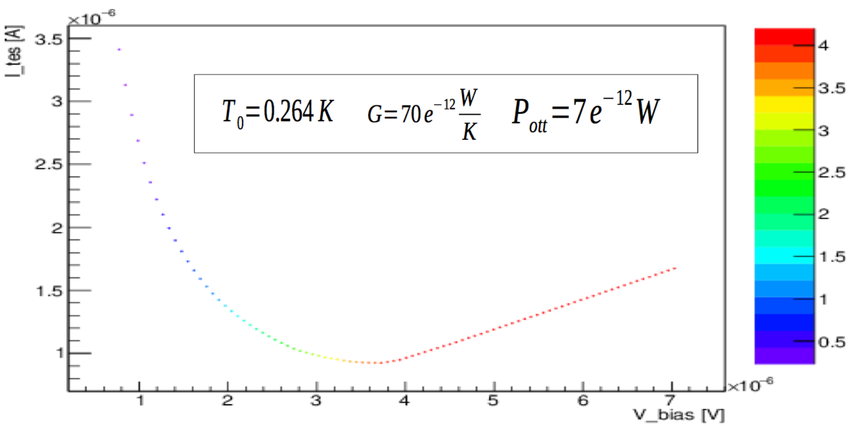


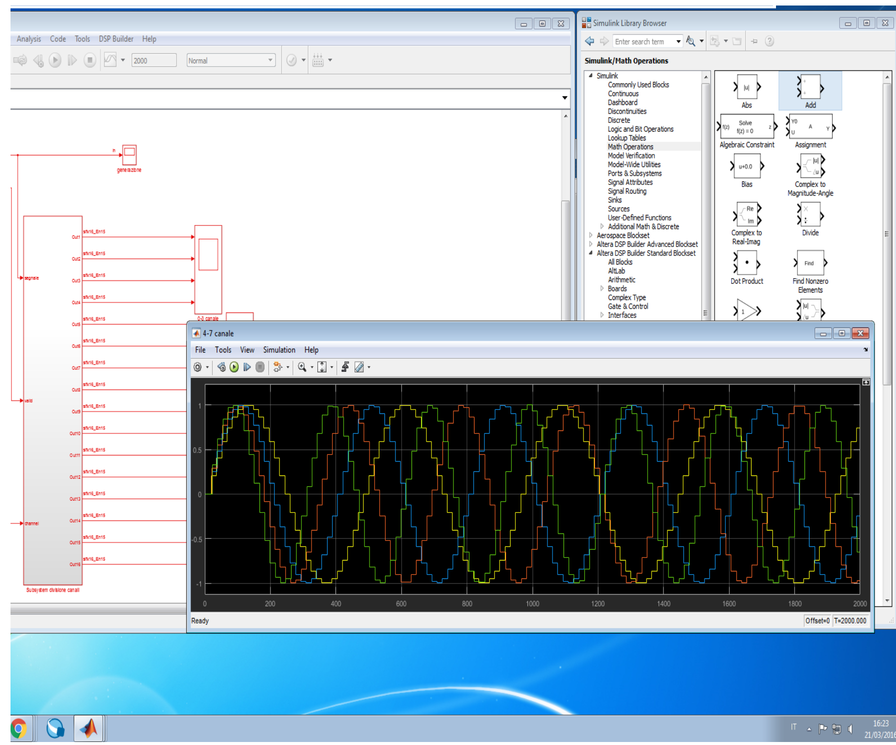


Custom LC circuits for FDM resonators

- FPGA controls the carrier frequencies generation and de-MUX
- Provide operating set-point tuning of TES bolometers
- Firmware test done with Altera CicloneV FPGA for DAC/Carrier gen.
- Foreseen migration to MicroSemi SmartFusion2





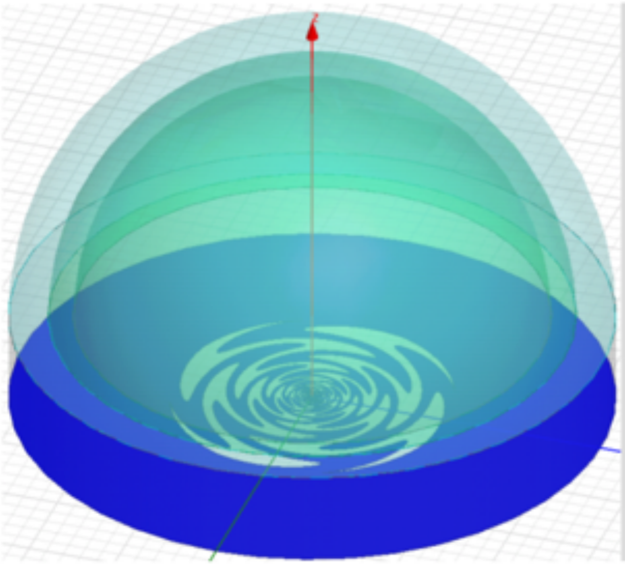


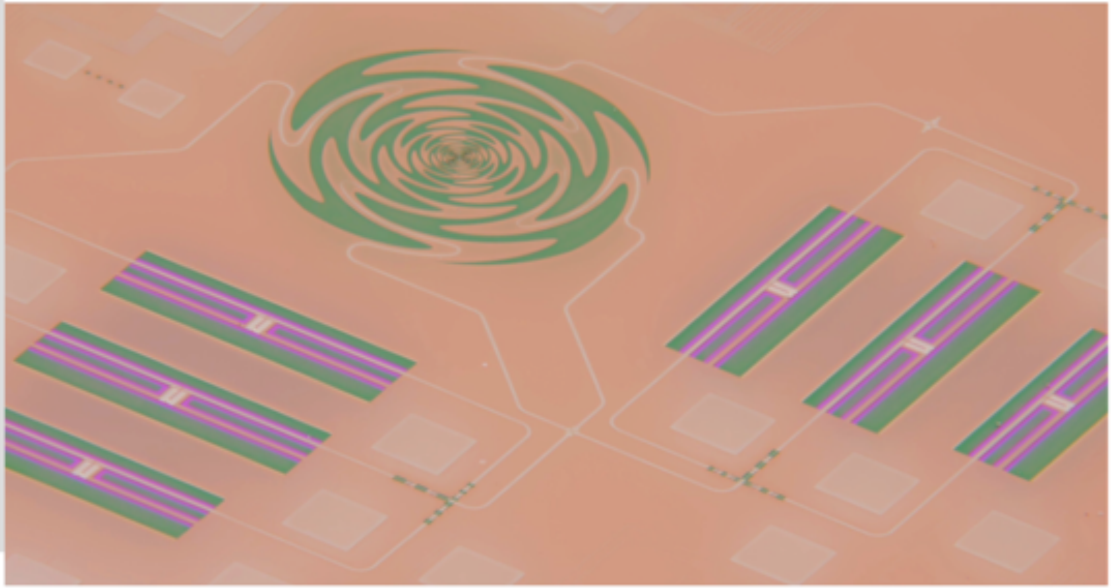
Future Developments

1. Goals:
   a. Antenna Coupled Bolometers
   b. High Multiplicity GHz FDM (developed for the HOLMES project-INFN by NIST)
2. R&D:
   a. Planar Antennas (multicrhoic and polarization saving)
   b. HF Striplines and Filters
   c. Small TES bolometer (10^{-2} um)
   d. High multiplicity FDM (several 1010^{3})
3. Teaming up with Uni. Trento - TIFPA and FBK
   a. Antenna design
   b. HF striplines and Filters (FBK)
   c. Large scale production (FBK)

Future Developments

A snapshot of the possible future development for the Italian CMB community: multiband and polarization saving antenna coupled bolometers





A. Lee, UCB, “Workshop CMB from Space” Tokyo 12 Dec 15

CONCLUSIONS

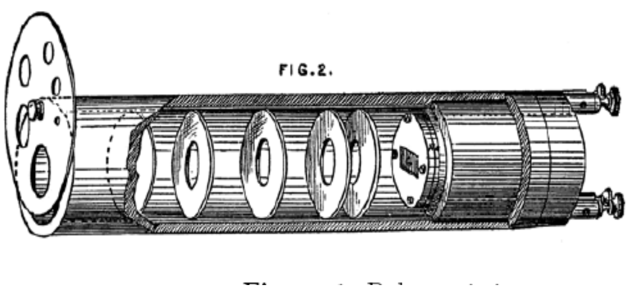
1. Almost 3 decades expertise in Low Temperature Detectors in INFN and 2 decades in TES detectors.
2. Presently a INFN groups are committed for providing the full detector-electronic chain (300 bolometers channels) for LSPE.
   a. Upgraded design of LSPE bolometers is completed and the fabrication of the bolometer under way
   b. The FDM electronics (resonators and Mux-deMux chain) prototypes are in advanced phase of testing.
3. We hope for a successful ballon mission in the winter 2017-18.
4. Involvement in future projects is under the INFN plans.
5. Teaming up with Uni.Trento-TIFPA and FBK could allow:
   a. Expertise exchange and design/fab. capability improvement
   b. Large array productions

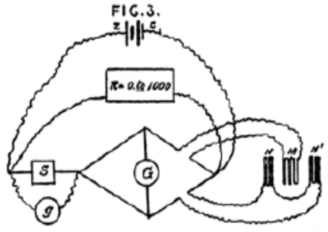
END

Back up slide

History

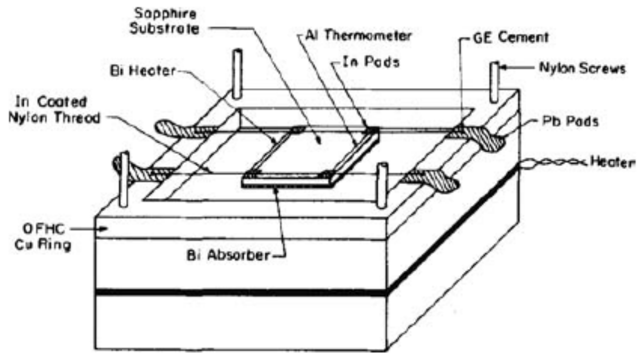
S. Langley, "The Bolometer," *Nature*, vol. 25, p. 14, 1881.





Clarcke et al. 1977

NEP $10^{-13} – 10^{-12}$ W/Hz



A Superconducting Bolometer as a High Sensitivity Detector for Molecular Beams

M. CAVALLINI, G. GALLINARO, and G. SCOLES

Istituto di Fisica Sperimentale dell'Università, 16132 Genova, Italy

Gruppo Nazionale di Struttura della Materia del C.N.R.

(Z. Naturforsch. 24 a, 1850—1851 [1969]; received 31 July 1969)

The construction, operation and calibration of a superconducting bolometer is reported. Operated as a molecular beam detector the bolometer has, for Argon, a maximum sensitivity of $7 \cdot 10^{6}$ molecules sec^{-1} corresponding to a N.E.P. of $3 \cdot 10^{-13}$ Watt $Hz^{-\frac{1}{2}}$.

The use of a liquid He cooled Ge infrared detector as a high sensitivity bolometer detector for molecular beams has been recently reported [1] and its usefulness in molecular scattering experiments has been shown [2, 3].

The present note is intended to report on the construction, operation and calibration of a superconducting bolometer which, operated as a molecular beam detector, showed an order of magnitude improvement in signal to noise ratio compared with the previously used Ge bolometer.

A superconducting bolometer has been reported, almost ten years ago, by MARTIN and BLOOR [4] which showed a noise equivalent power (N.E.P.) of about $3 \cdot 10^{-12}$ Watt $Hz^{-\frac{1}{2}}$ (reflection coefficient $\alpha = 0.1$) with a time constant of about $50 \cdot 10^{-3}$ sec. The sensitive element was an evaporated tin film maintained at a fixed temperature, to within 10^{-5} °K, in its superconducting transition (around 3.7 °K). In this condition the film has a very large temperature coefficient of resistance that can be used to transduce a chopped power imput to a voltage output which may then be integrated with standard techniques.

Up to the present time the superconducting bolometer has not been widely adopted in infrared spectroscopy for two main reasons. The first is the difficulty of thermo-regulating the sensitive element within 10^{-5} °K, and the second is the extreme delicacy of its construction.

Taking into account that the N.E.P. of Martin and Bloor's bolometer was reported to be limited by the electronics available at that time, we undertook the development of a superconducting bolometer with the aim of solving the mechanical ruggedness problem by relaxing the requirement that the film, when operating, should be homogeneous in temperature.

Indeed the possibility of a superconducting thin film acting as a non isothermal bolometer is qualitatively quite obvious and has also been quantitatively discussed theoretically in the literature by FRANZEN [5].

A superconducting bolometer of the non isothermal kind has also been reported by V. A. KONOVODCHENKO et al. at the 11th Low Temperature Conference (St. Andrews 1968). With respect to this point it should be noted, however, that it is not clear whether or not a non isothermal bolometer can be operated only in the way described by FRANZEN [5]. Indeed the transition curves obtained by us (see Fig. 1) were of the kind expected for a non isothermal element. Two types of operations are then possible: namely in the region a or in the region b. Region b corresponds to the type describec by Franzen. If sufficient thermal stability is available one can operate in region a which, in our opinion, corresponds to a different non isothermal kind of opera-

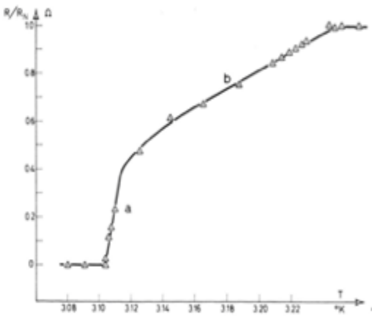


Fig. 1. Transition curve of a typical bolometer.

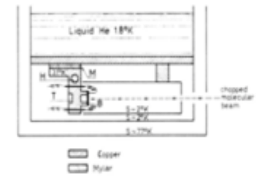


Fig. 2. Schematic experimental set-up.

Reprint requests to Dr. G. SCOLES, Istituto di Fisica Sperimentale dell'Università di Genova, Viale Benedetto XV, 5, *I-16132 Genova*, Italy.

1 M. CAVALLINI, G. GALLINARO, and G. SCOLES, Z. Naturforsch. **22 a**, 413 [1967].

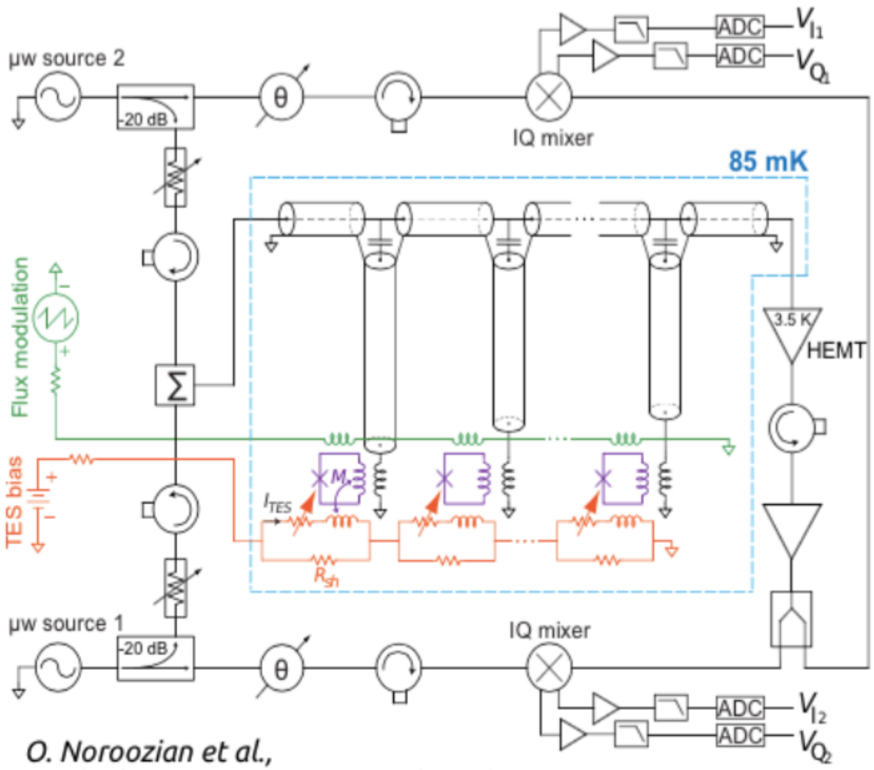
2 P. CANTINI, M. CAVALLINI, M. G. DONDI, and G. SCOLES, Phys. Letters **27 A**, 284 [1968].

3 M. G. DONDI, G. SCOLES, F. TORELLO, and H. PAULY, J. Chem. Phys. **51**, 392 [1969].

4 D. H. MARTIN and D. BLOOR, Cryogenics **1**, 159 [1961].

5 W. FRANZEN, J. Opt. Soc. Am. **53**, 596 [1963].

Back up slide



O. Noroozian et al., Appl. Phys. Lett. 103, 202602 (2013), arXiv:1310.7287v1 [physics.ins-det]