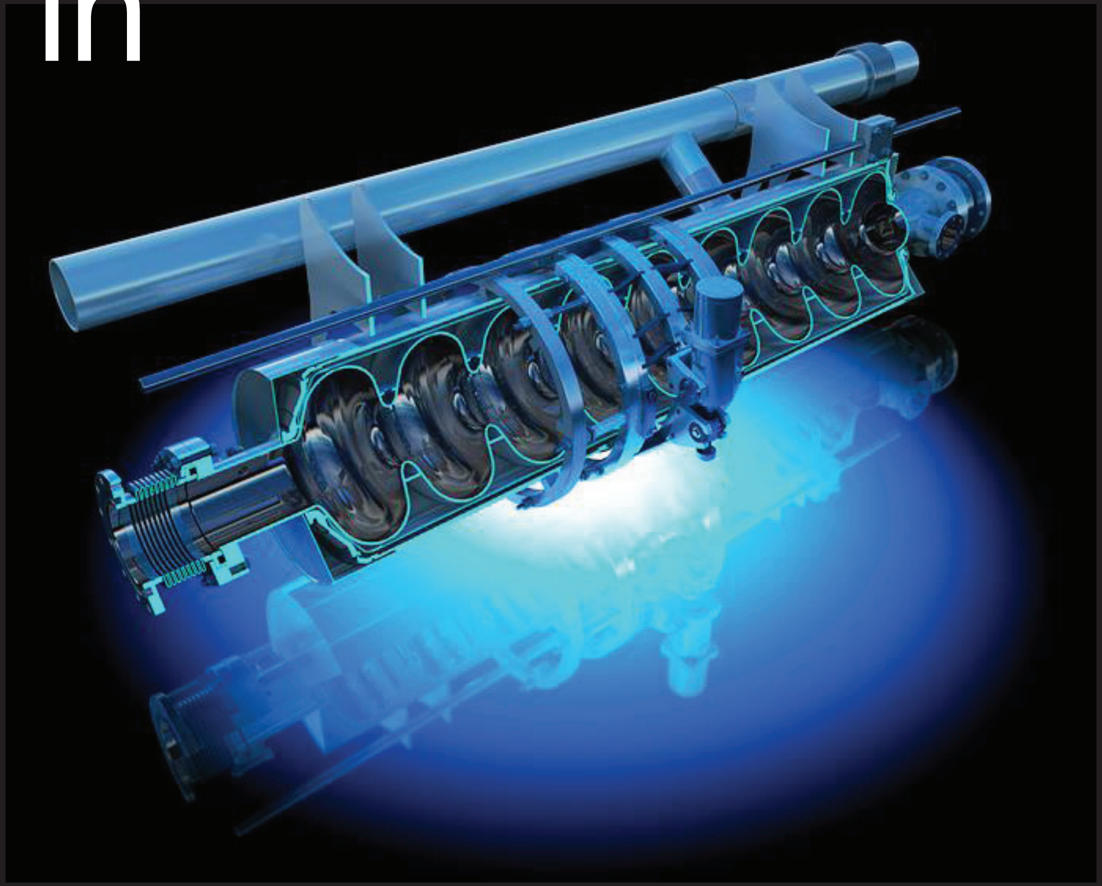
Transition Edge Sensors for quench localization in SRF cavity testing



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SRF2017 – Lanzhou, China – July 2017

Image source: http://www.yk.rim.or.jp/~reyhori/pages/galacc4_e.html

Presentation of our team

Giovanna Vandoni

- BE-RF
- Senior Scientist
- SRF activities coordinator

Torsten Koettig

- TE-CRG-CI
- Senior Cryogenics Scientist
- Cryolab R&D Coordinator

Mentors

Hernán Furci

- BE-RF-SRF
- Senior Fellow
- Cryogenics Scientist
- R&D project responsible

Tobias Stegmaier

- BE-RF-SRF
- Technical Student
- Masters thesis on Cryogenic experimental techniques for SRF

Zsolt Kovàcs

- BE-RF-SRF
- Technical Student
- Finished his bachelor in Material Science with thesis in development of TES films

Project started in March 2016

Quench localization techniques

Quench localization

Future accelerators

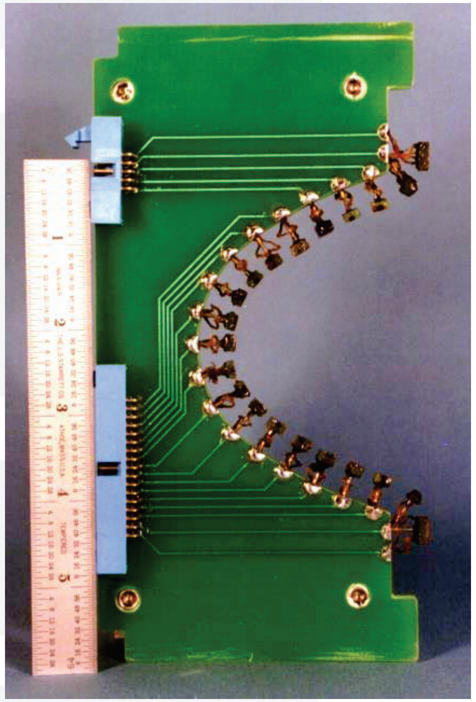
- Need of testing superconducting cavities of variable size and geometry.

QUENCH: limits performance

- Where did the quench start?
- Localized? Magnetic?
- What kind of defect induced the quench?
- Can the problem be corrected?

Contact thermometry

- Placing temperature sensors on the cavity walls
- Requires individual preparation of each cavity



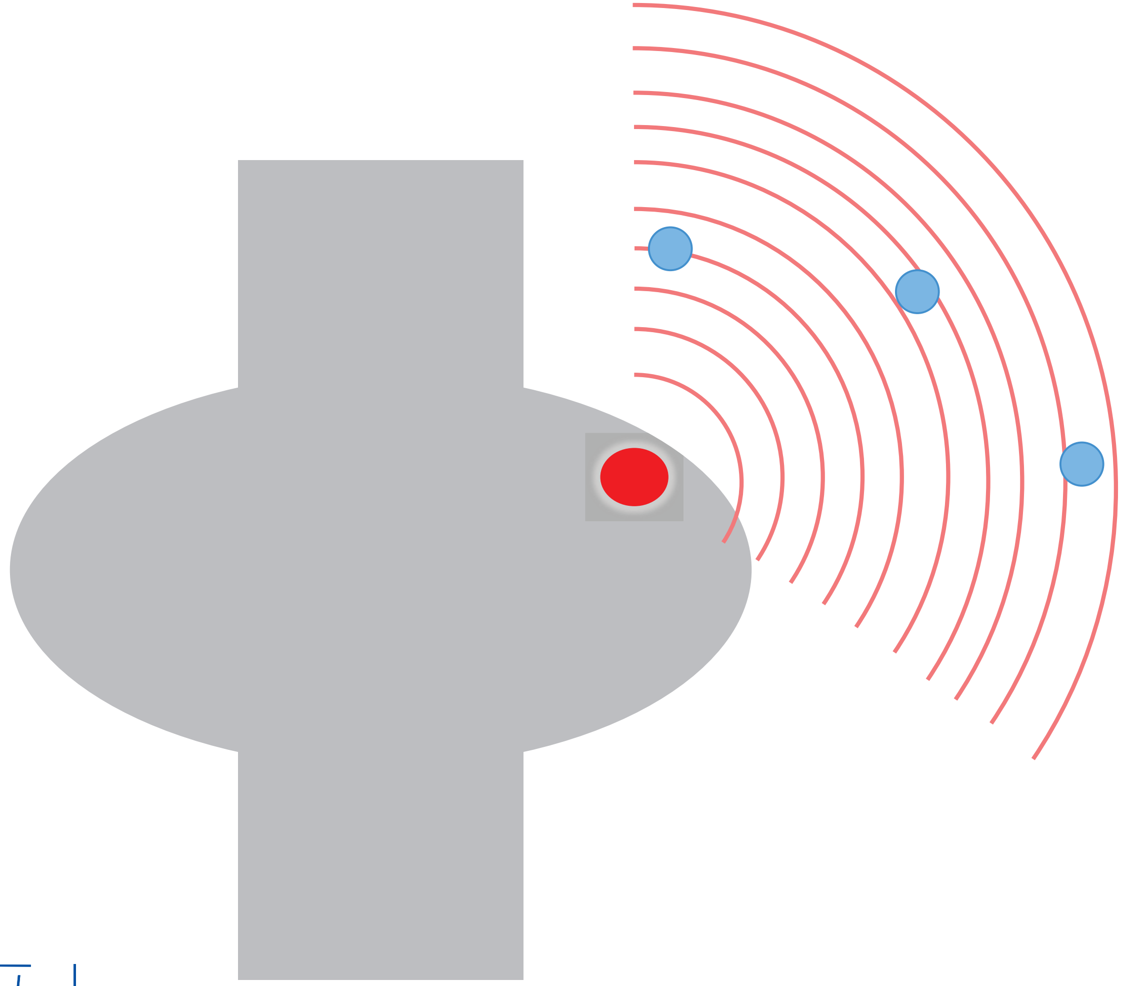
Source: https://www.classe.cornell.edu/Research/SRF/SrfCavitiesAPrimerThree.html

Non- contact thermometry

- Allows systematic and versatile testing of diverse cavities
- Technique based on superfluid helium second sound

Non-contact thermal mapping

(for He-II cooled cavities)



One of He-II many outstanding properties is second sound: temperature-entropy wave

This wave is originated by a **transient heat flux** on a wall in contact with the fluid.

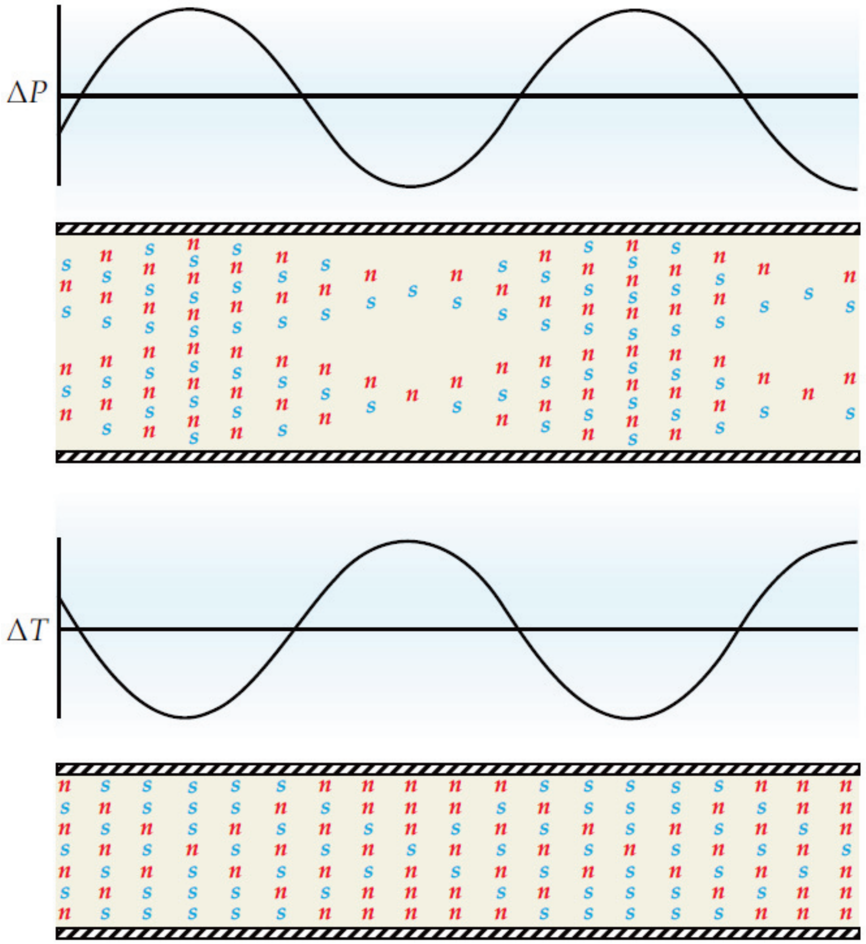
A quenching surface produces second sound!!!

Measuring the difference in time of flight to many sensors, the origin of the wave can be trilaterated (GPS-like).

Second Sound in He-II

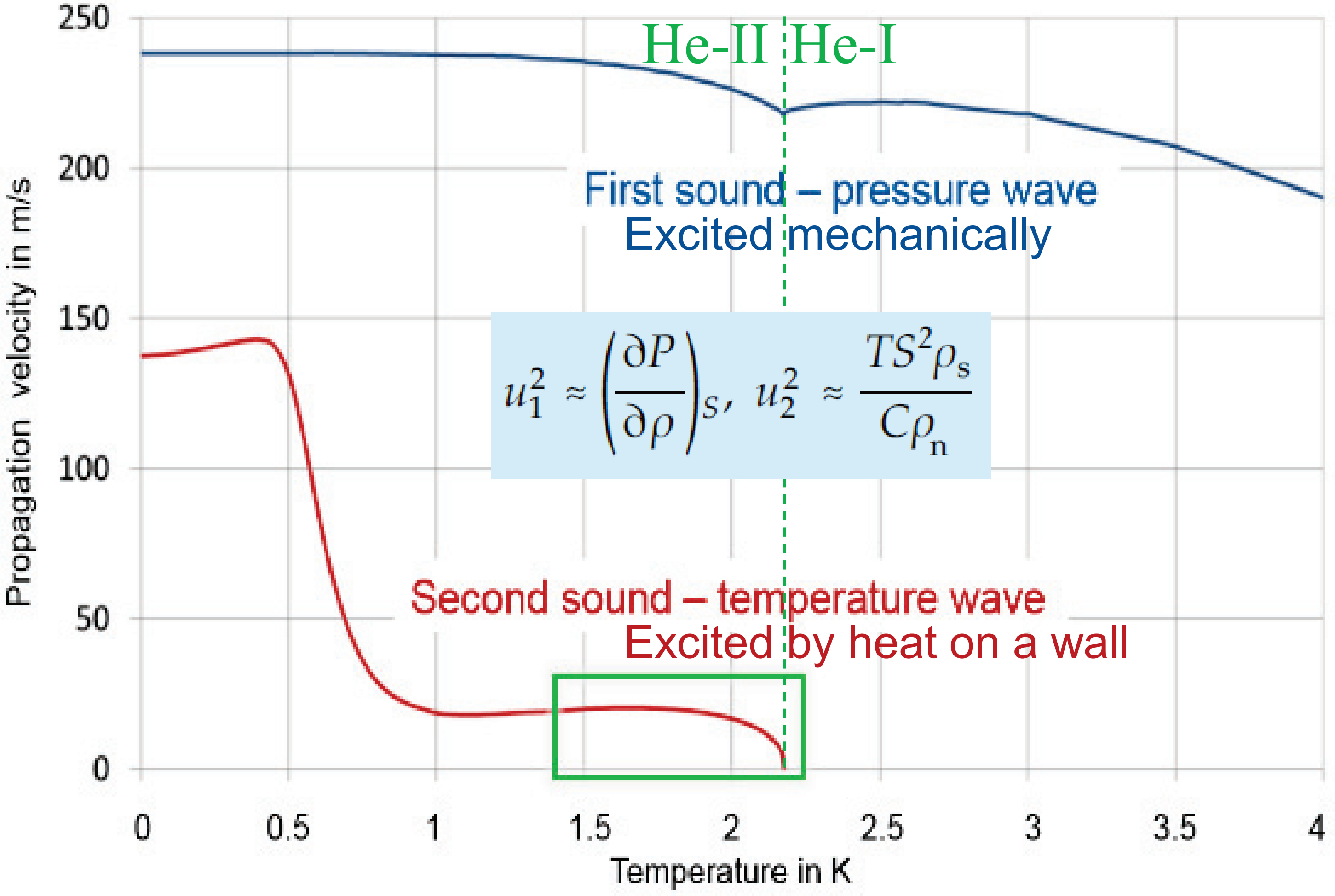
and its detection

He-II and second sound physics



n: normal component particles

s: superfluid component particles

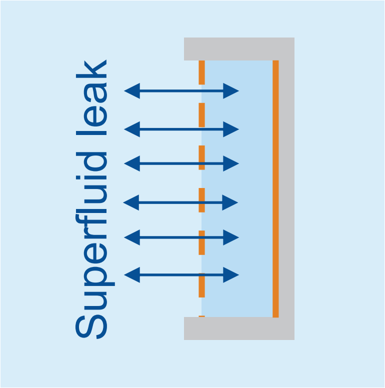


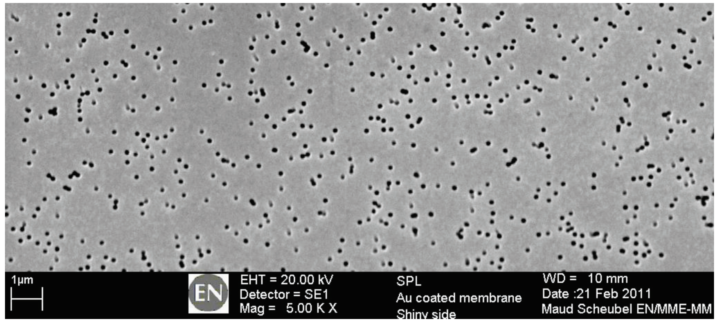
Source: R. J. Donnelly "The two-fluid theory and second sound in liquid helium". Physics Today, Oct. 2009.

Second sound detection

Oscillating SuperLeak Transducers (OST)

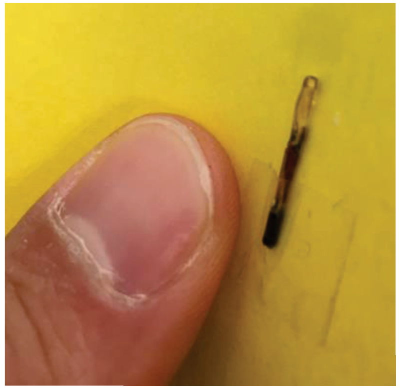
- Sensing of the relative movement of the two components





Thermometry

- Measurement of the temperature variation with fast response, highly sensitive thermometers
  - Commercial sensors like Cernox bare chip sensors



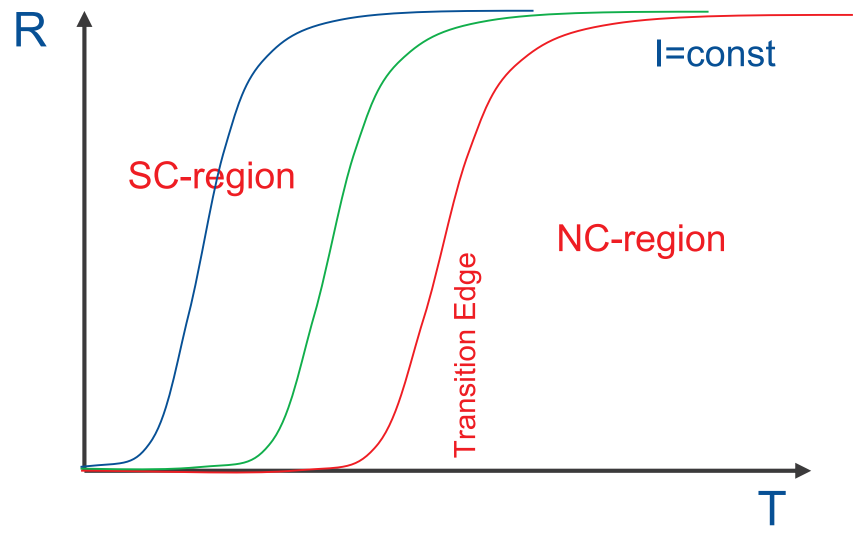
Source:
Lakeshore website

- Transition edge sensors

Image sources:
Koettig et al., IOP Conf. Series: Materials Science and Engineering 101 (2015) 012164
Cornell University website: https://www.classe.cornell.edu/Research/SRF/SrfNews2009.html
Linear Collider Collaboration website: http://newsline.linearcollider.org/2011/04/21/the-sound-of-accelerator-cavities/

Transition Edge Sensors

- Bolometers: tiny and fast temperature variations (≈1 mK, sub-ms range)
- Based on the (gradual) SC to NC transition of a thin film alloy
- Only sensitive in the transition range
- Transition range ‘tuned’ with a bias current



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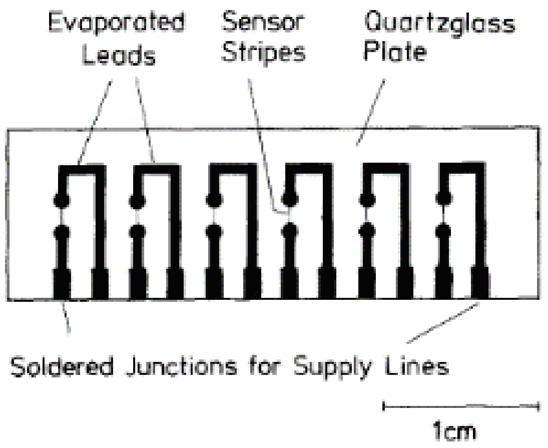
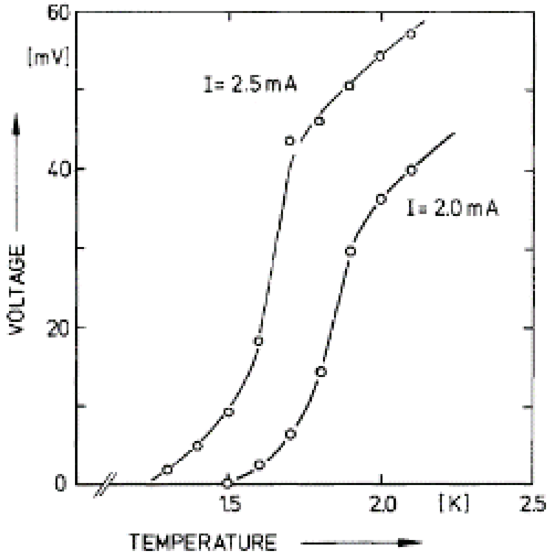
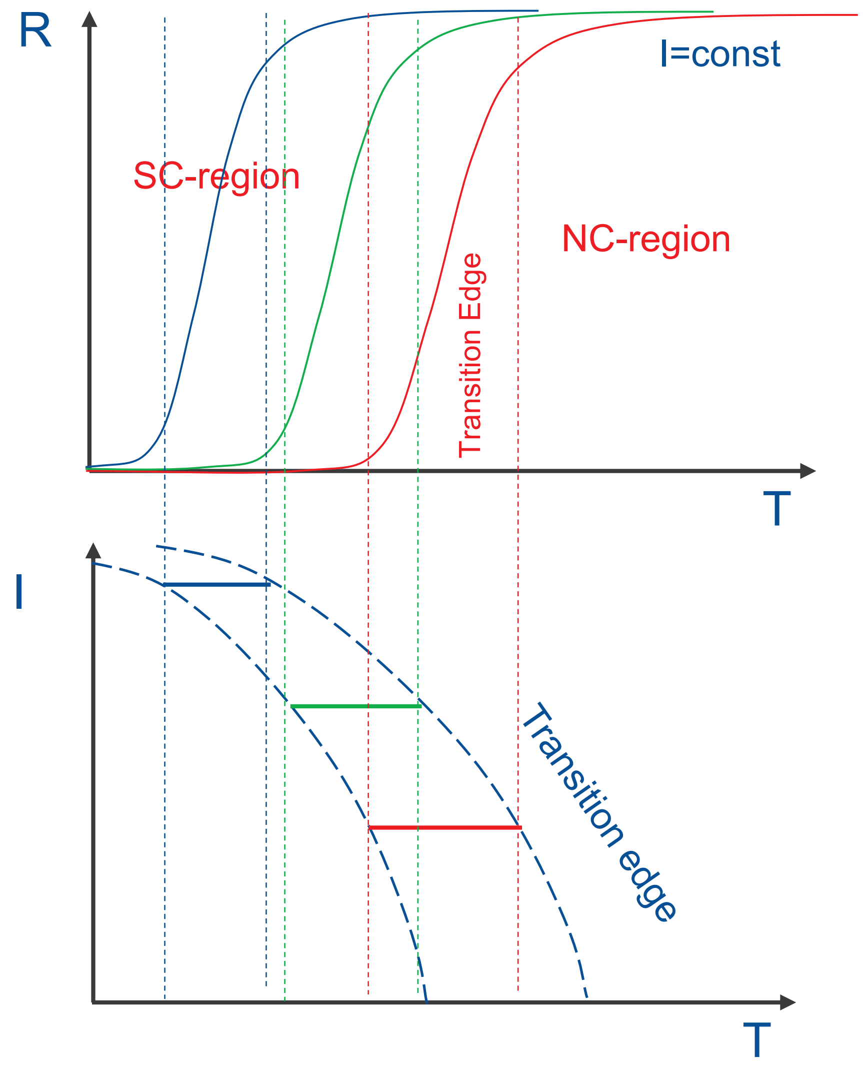


Fig. 1. Sixfold probe chip for second-sound measurement.



Source: H. Borner, Experimental Investigations on Fast Gold-Tin Metal Film Second-Sound Detectors and Their Application



2nd sound detection, Au (20 nm) – Sn (100 nm) thin film alloys are a proven material.

Advantages of TES to OST

Electronics	• Simpler: 4-wire measurement is enough
Space resolution	• One can fabricate them practically as small as desired
Thermometry	• They could provide information on the quench heat flux
Signal	• Not polluted with the mechanical oscillations of the membrane
Reproducibility	• Can all the parameters involved in the fabrication process be controlled?

Project Objectives

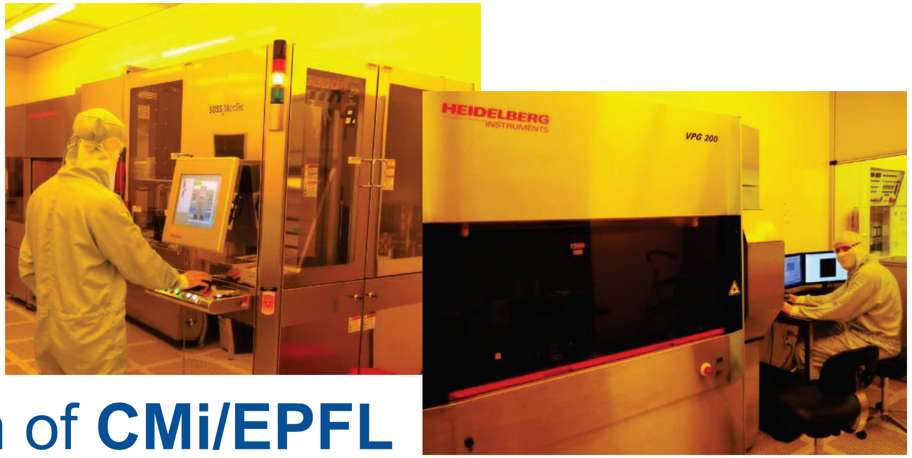
- Establish an in-house production method of TES at CERN → appropriation of the technology
- Produce prototypes of TES
- Cryogenic testing of TES at the Cryolab at CERN
  - Characterisation of the SC transitions
  - Second sound detection by TES
- Deliver a TES sensing device
- Design a large scale TES thermal mapping system
- **Validate TES quench localization on an SRF quenching system**

Fabricating TES Prototypes

in Au-Sn

Fabrication process

Not available commercially – In-house development
Need of an easy-going process to fabricate the TES
We used very up-to-date microfabrication clean room of **CMi/EPFL**



Drawing of the sensors

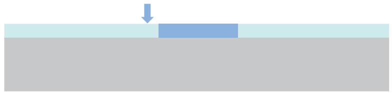
- On any CAD program
- Sensor array on standard wafer (10 cm diameter)

Process flow

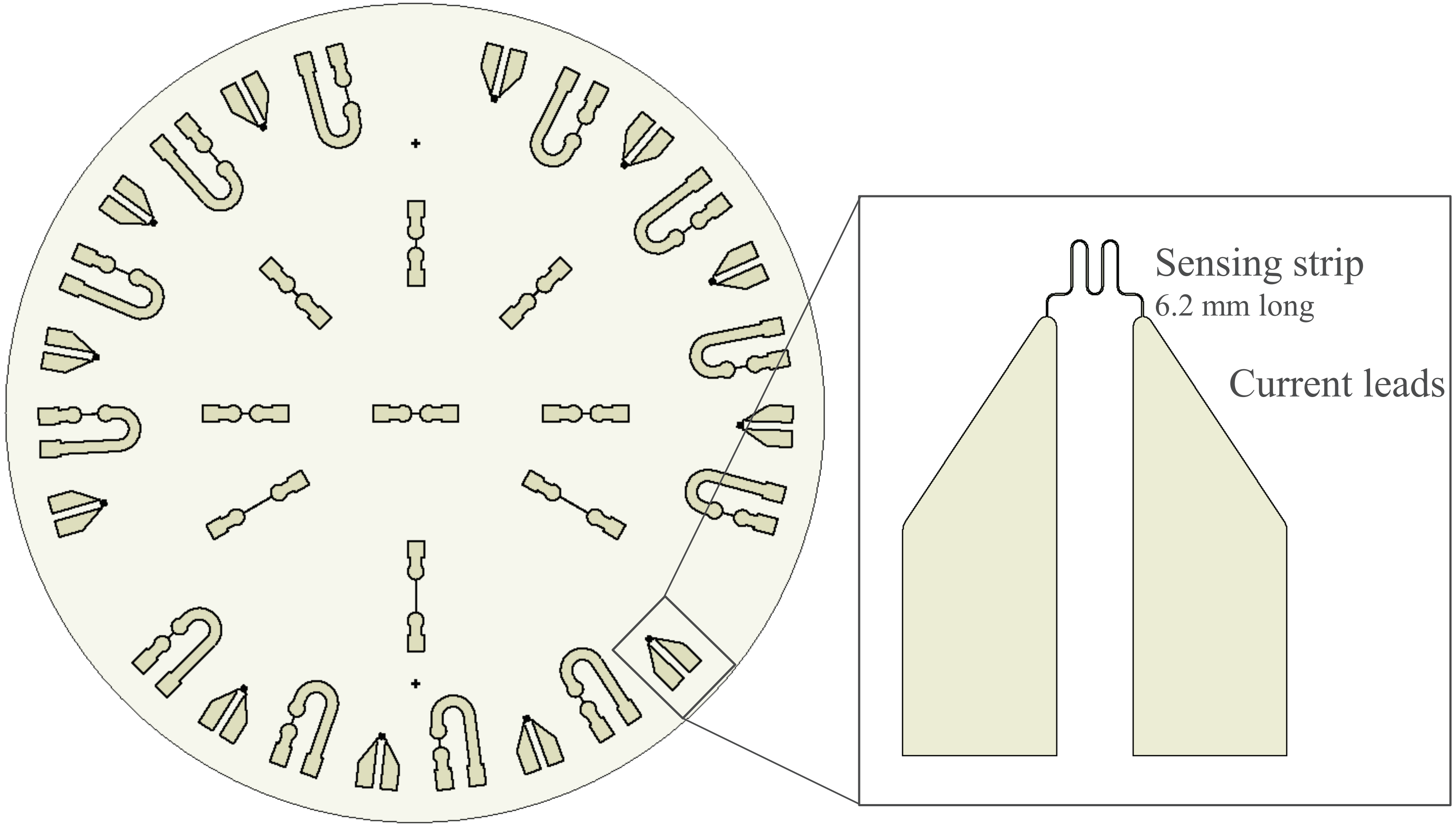
- Automatized photolithography
- Leads and strips of the same material

Cabling

- Soldering with Indium
- Twisted 4-wires, by hand and without heat

Process description	Cross-section after process
Substrate: ***Borofloat 33*** *Coating – positive resist* Machine: *ACS 200*	
LASER Writing Machine: *VPG 200*	
Developing Machine: *ACS 200*	
Metal Evaporation *Metals: Au-Sn*	
Lift-off	

Prototype wafer design



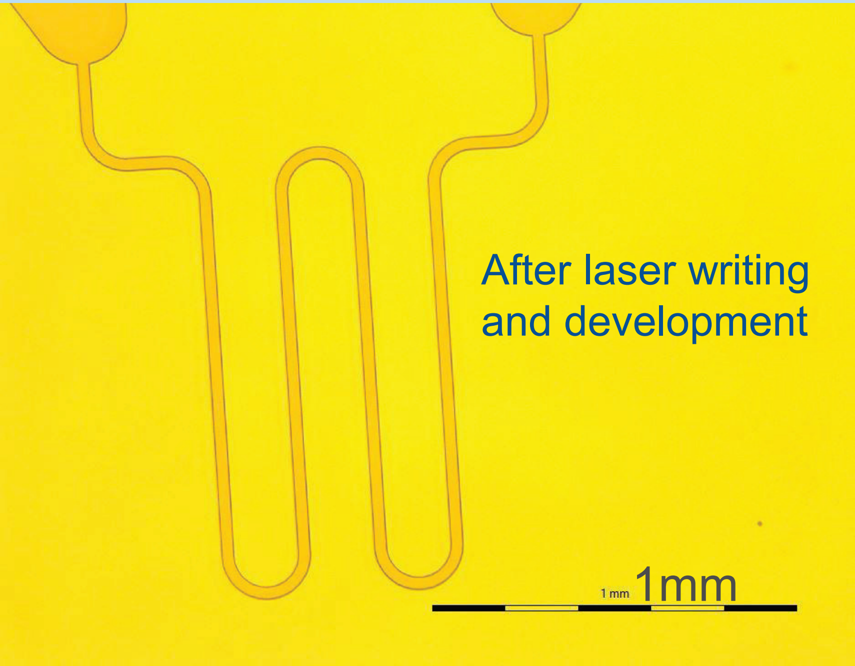
Strips

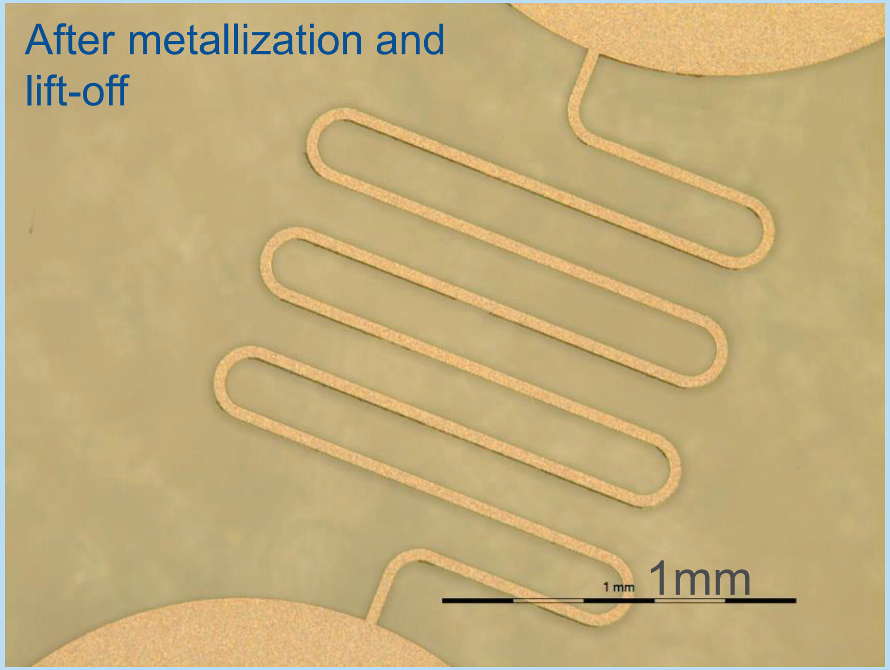
- 30 μm wide
- Variable length (1 to 7 mm)
- Meandering design
- Sensing area ≈ $1\ mm^2$

Leads

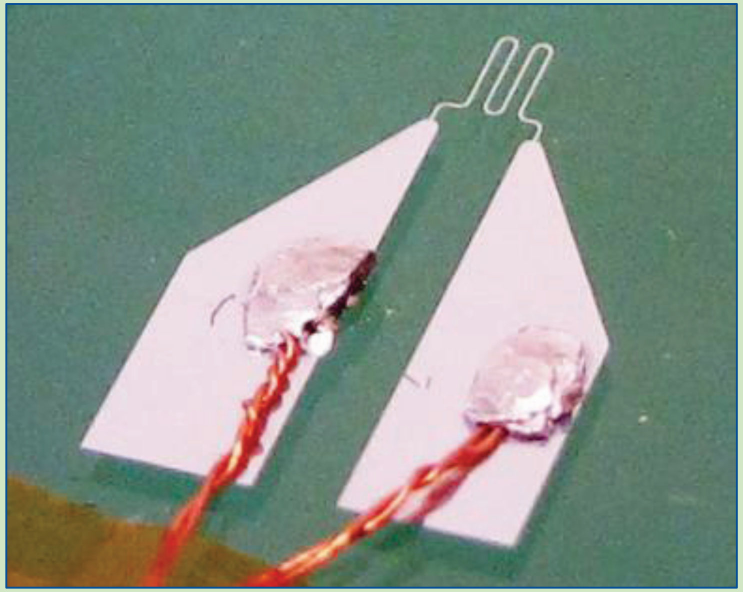
- Oriented for cabling
- Big enough for cabling
- Same material as sensor (low **J** ➔ SC always)
- Pads for Indium cold weld or pressed contact

Fabrication results





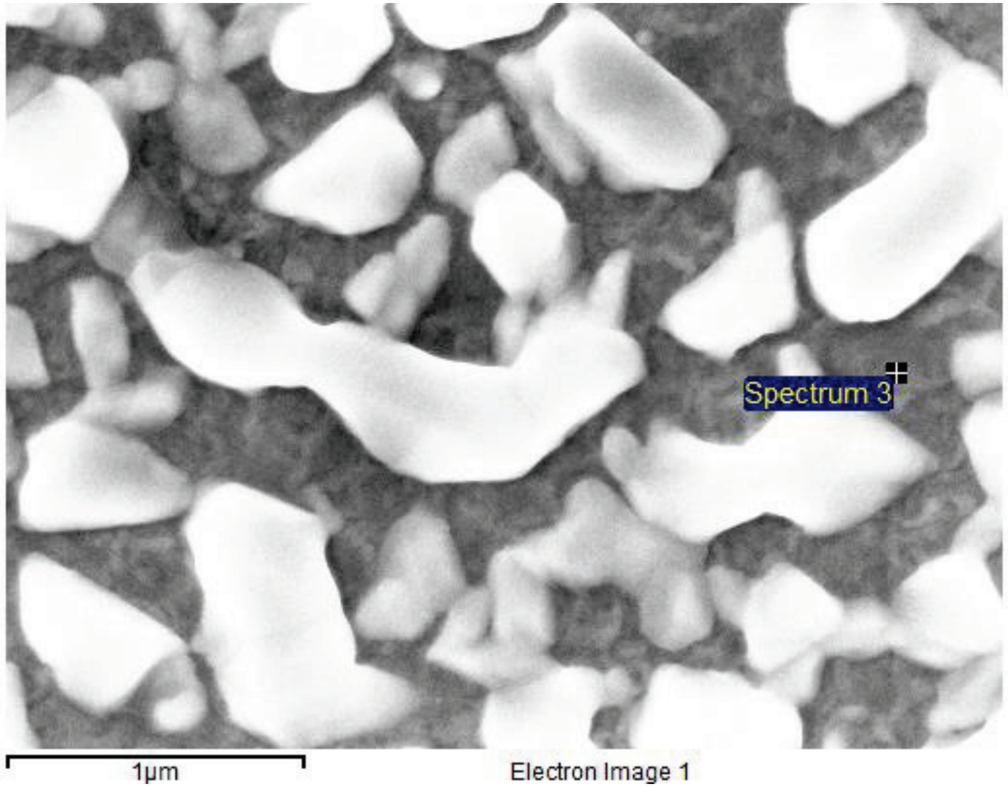
Sensor cabling



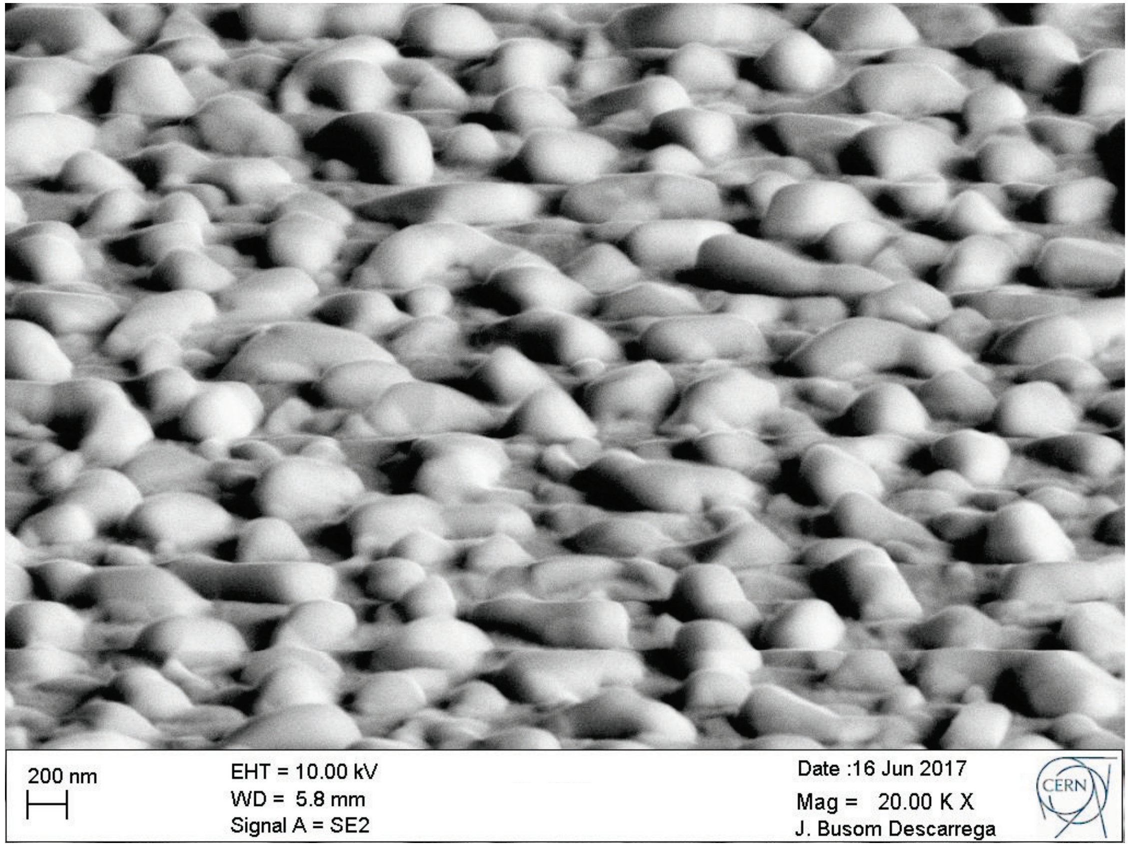
Instrumented wafer
4 wire measurement configuration

Indium soldering

Thin film microstructure

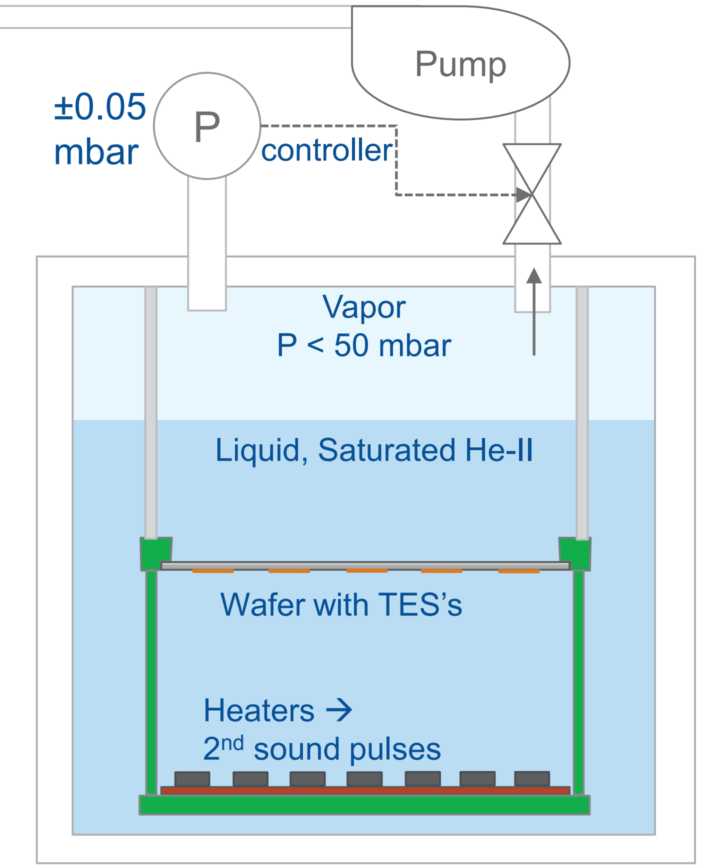


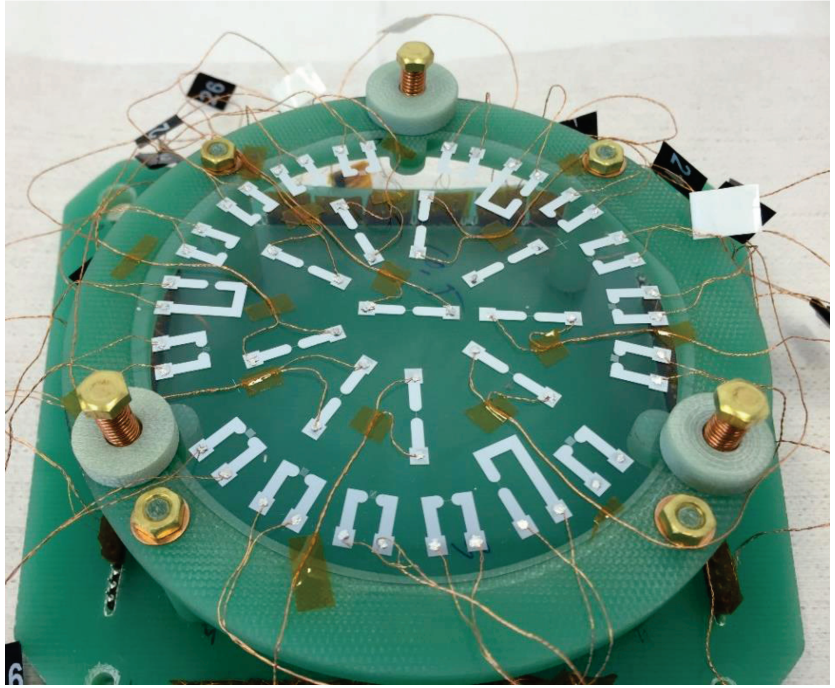
The bright structures have a much higher content of Sn ($AuSn_4$ or Sn) than the dark background ($AuSn_2$)

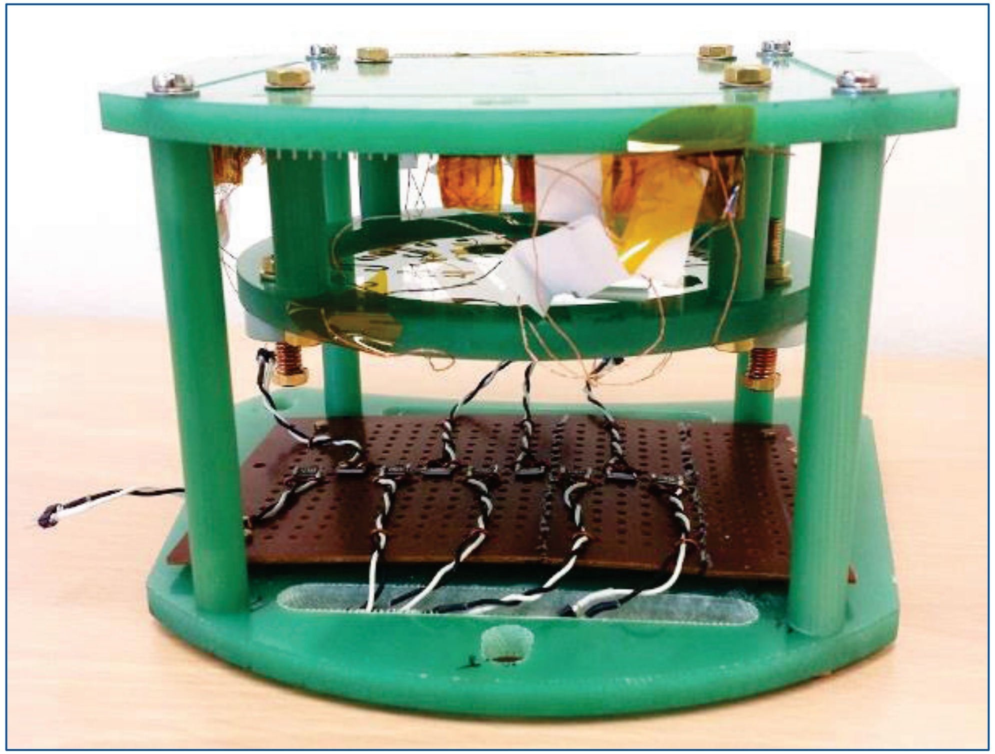


Cryogenic testing

Testing of TES at the Cryolab







Helium p-T curve is the T standard (IST90) in the LHe range

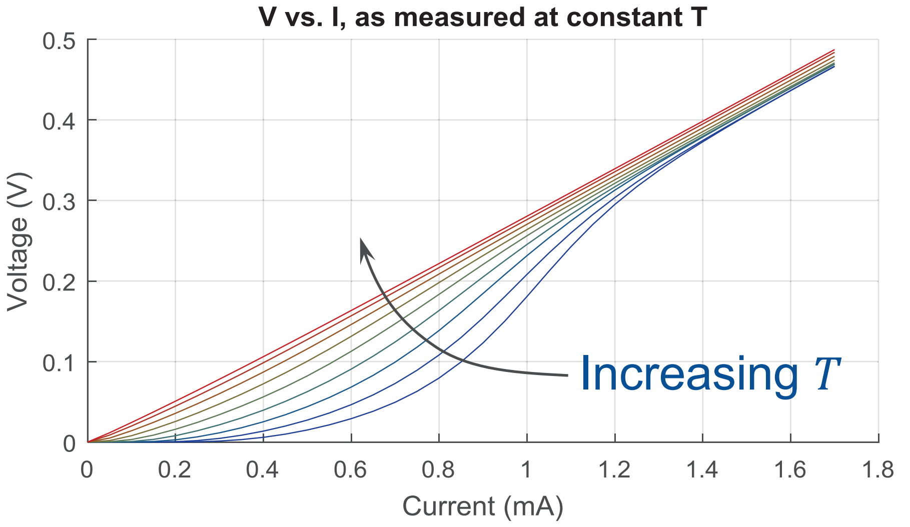
TES Characterization

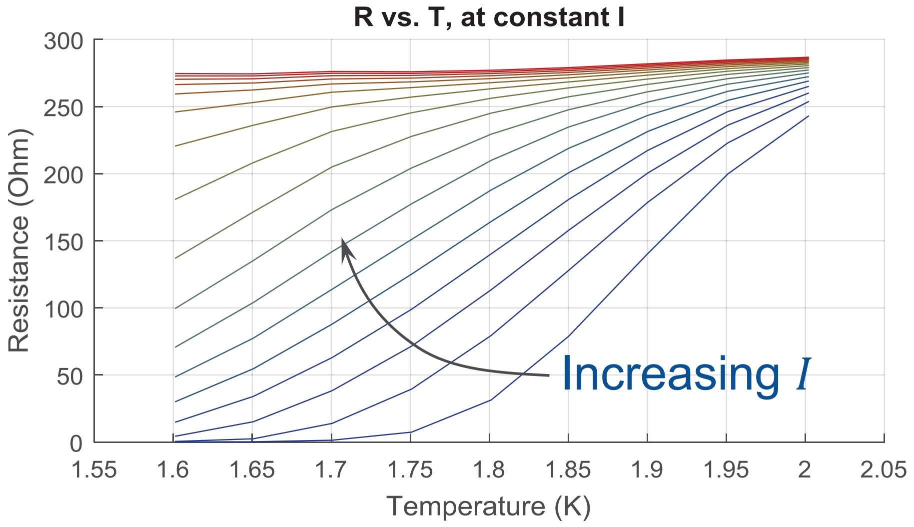
Pressure steps:
750 to 3150 Pa
(1.6 to 2.0 K)

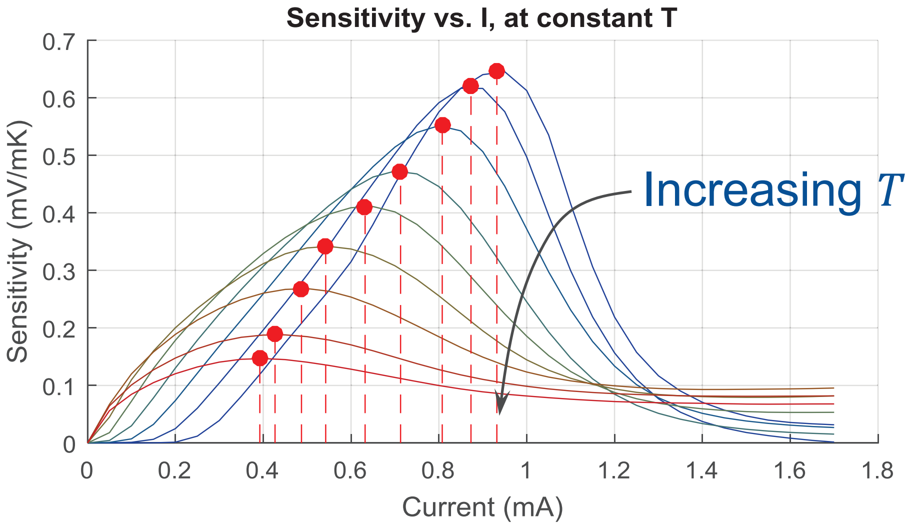
Current sweeps:
0 to 1.7 mA

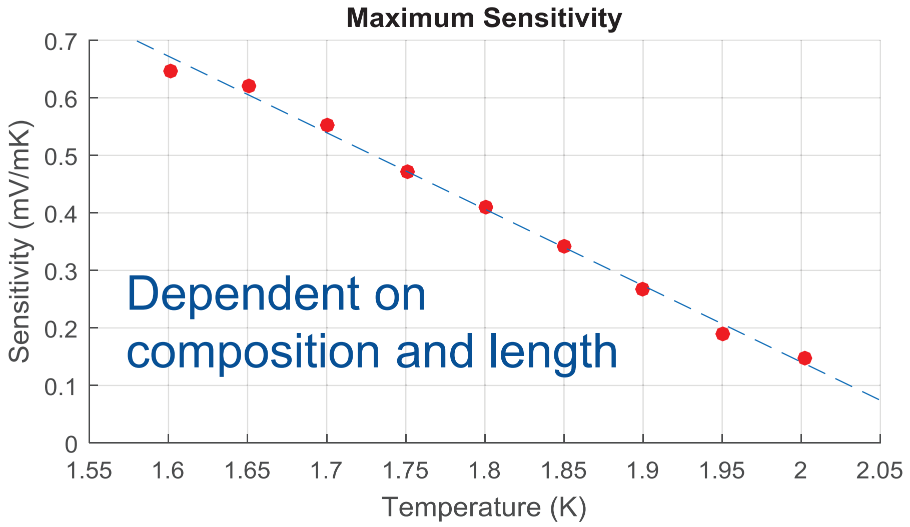
Voltage recording =>
Resistance

Sensor strip
20 nm Au –
100 nm Sn







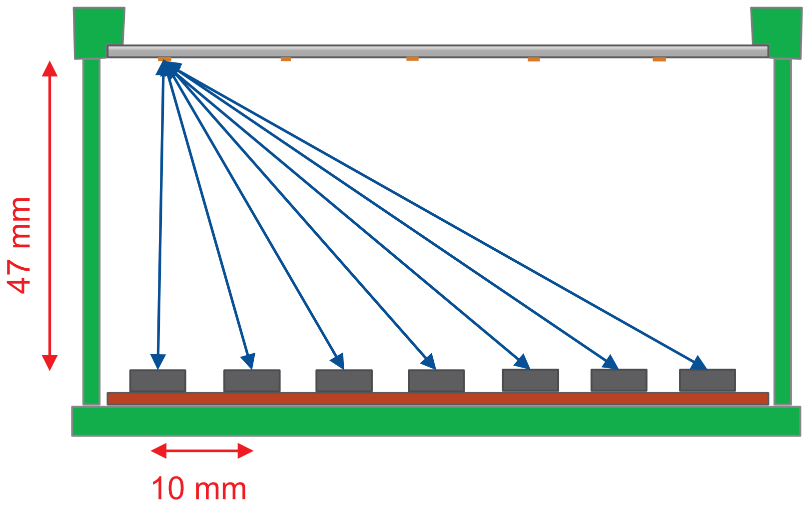


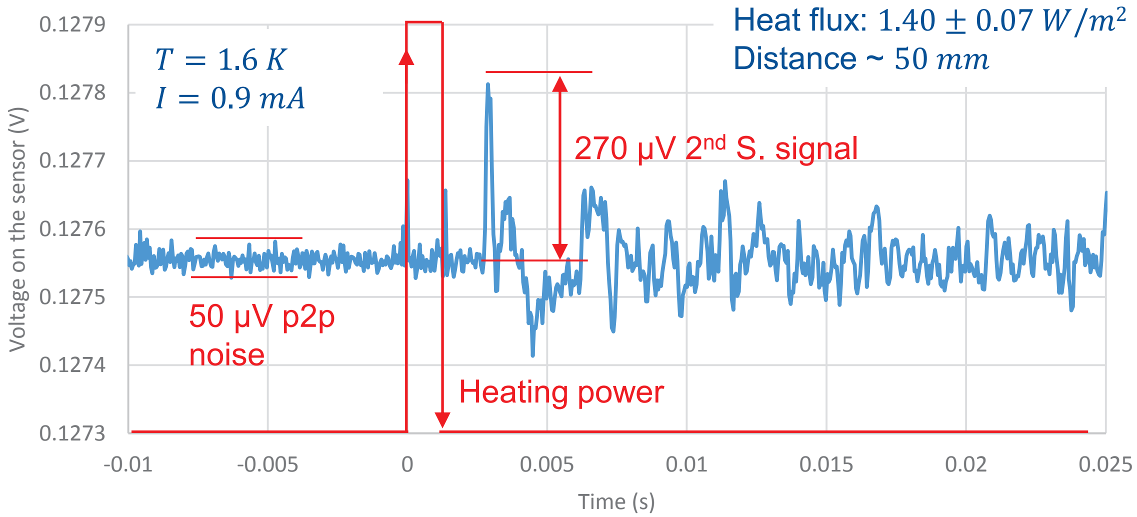
Second sound measurements with TES

Pulses by resistive heaters

Different distances

Sensors biased at constant current

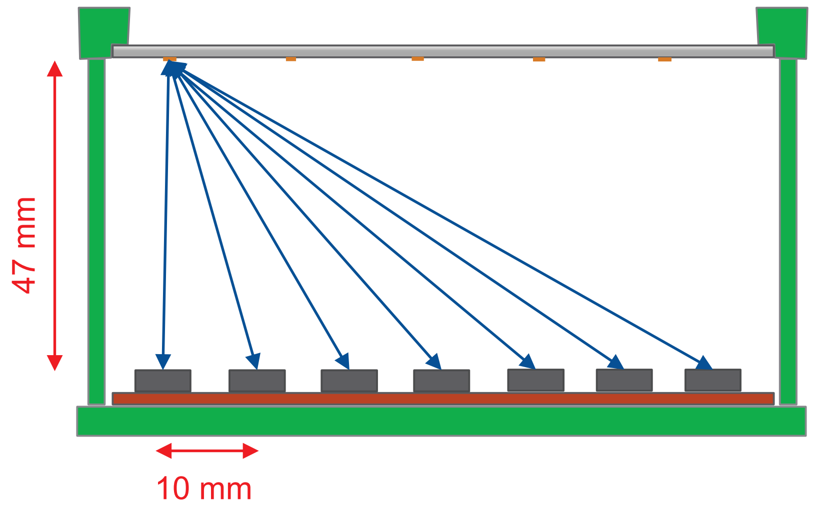


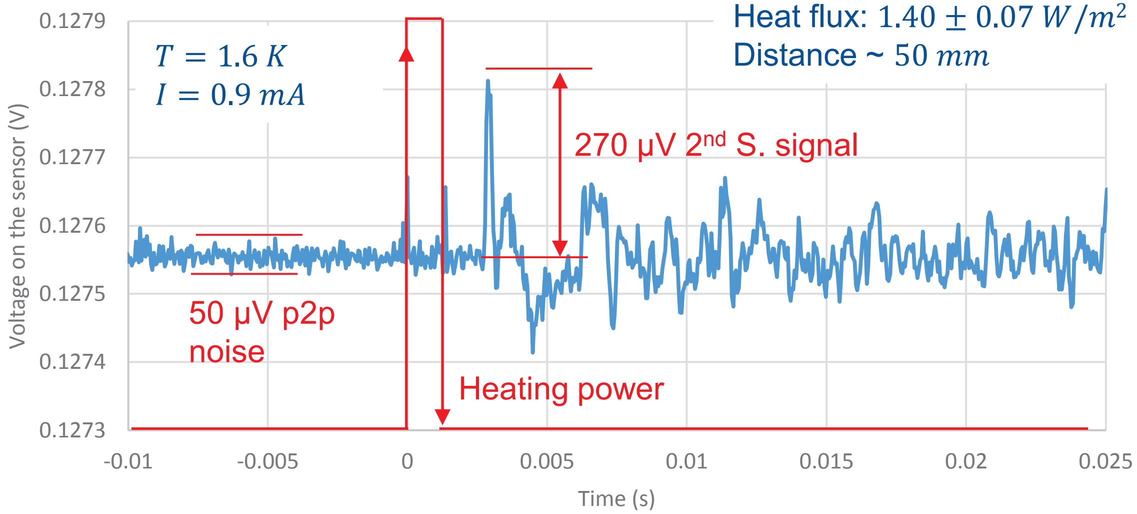


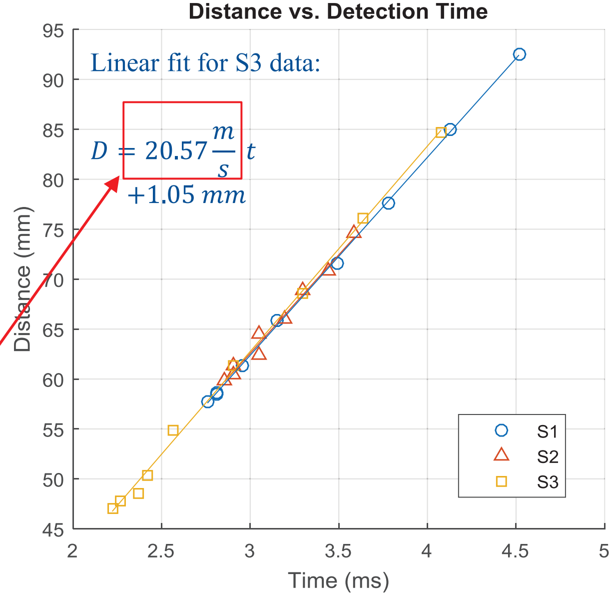
The signal was measured WITHOUT any electronic treatment (20 kHz sampling rate on NI compact DAQ)

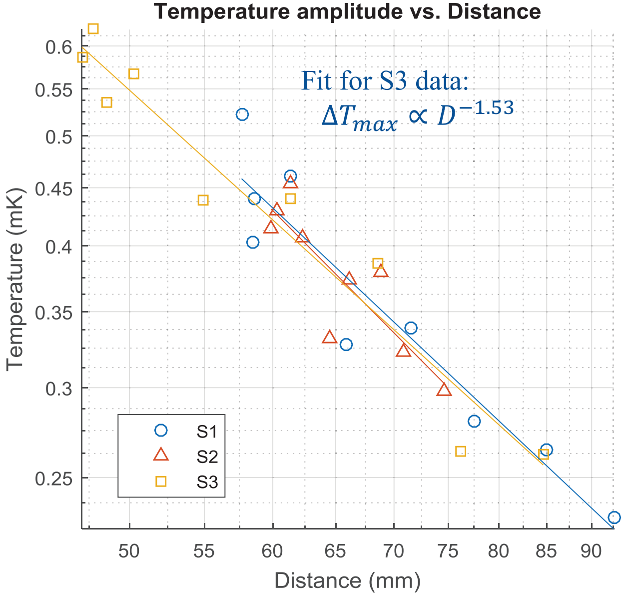
Second sound measurements with TES

- Pulses by resistive heaters
- Different distances
- Sensors biased at constant current









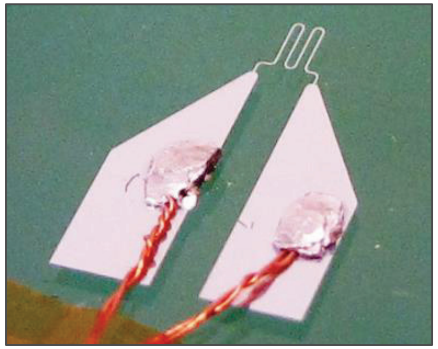
The second sound signal is clearly identified and the velocity value corresponds to literature.

Further studies on TES thin film

- Variation of composition and its impact of TES quality
- Other material combinations
- Reproducibility
- Effect of adhesion-improving pre-layer on the TES performance

Next steps in R&D

Comparative study TES-OST



Fully characterise the two types of sensors

- in a common set-up
- in the same conditions

Appreciate differences in…

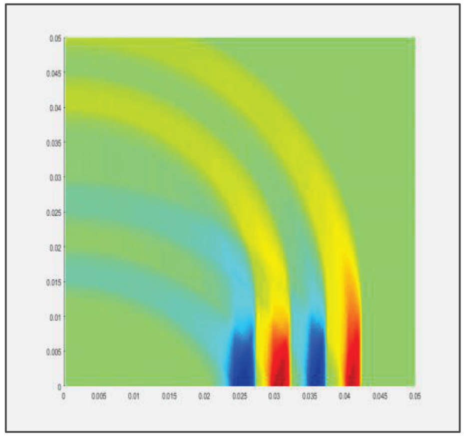
- Angular response
- Effect of distance from the source
- Response to source intensity
- Time response features

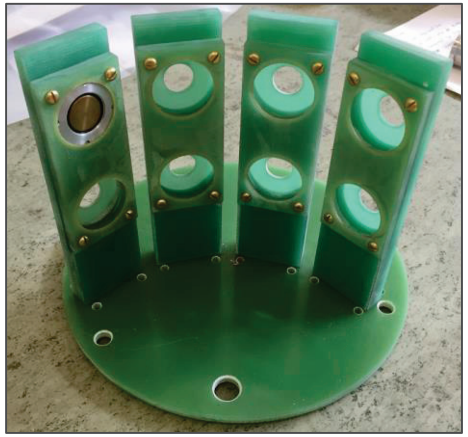
Assess the advantages and drawbacks of each of them

Second sound 3D propagation study

Spatial structure of a second sound wave from planar heater

- Modelling
- Experimentally

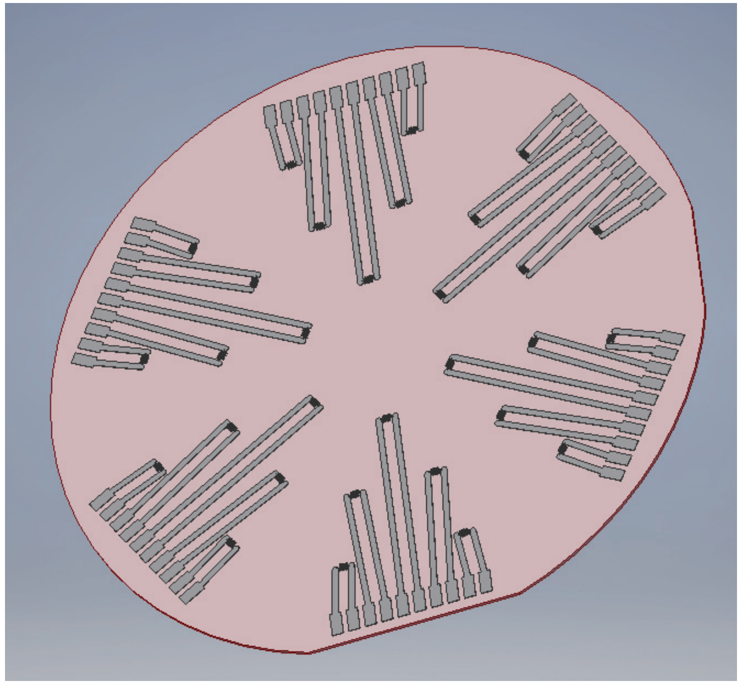


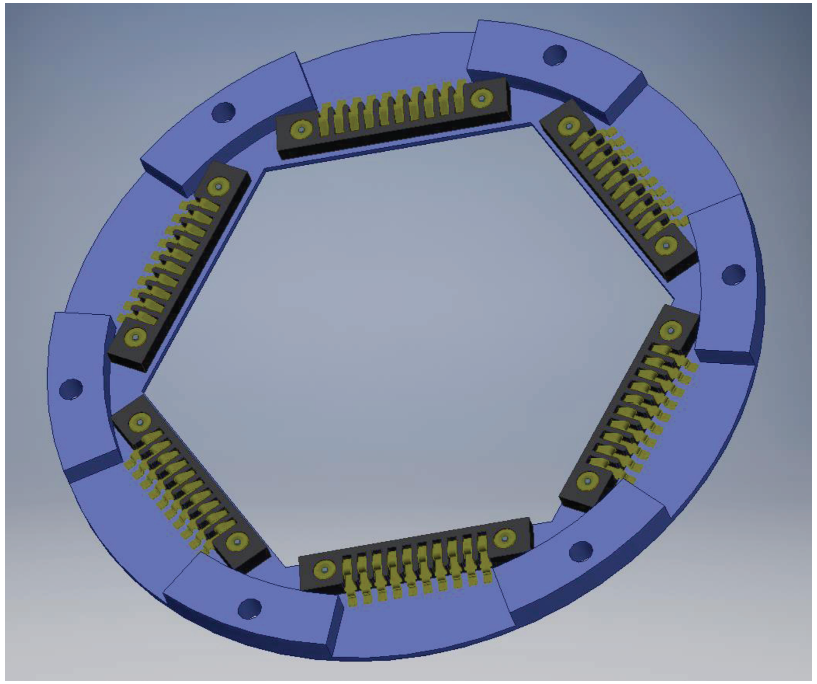


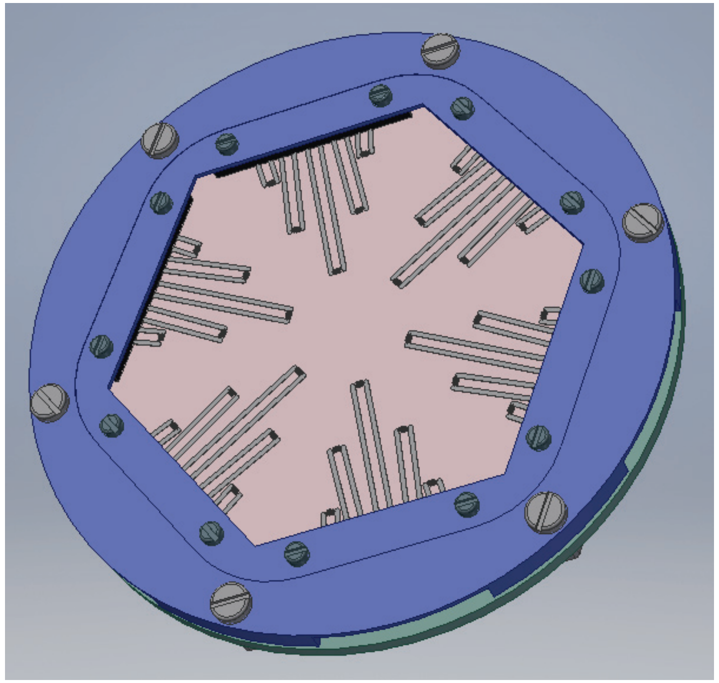
Towards
Thermal Mapping Instruments

TES camera array

A compact multi-sensor device of sufficient size to do thermal mapping with.
A network of independent sensors is proposed.
The robustness is provided by a GFE frame. The connection is simplified with spring connectors. The fragility of the film needs to be dealt with, specially at electrodes.





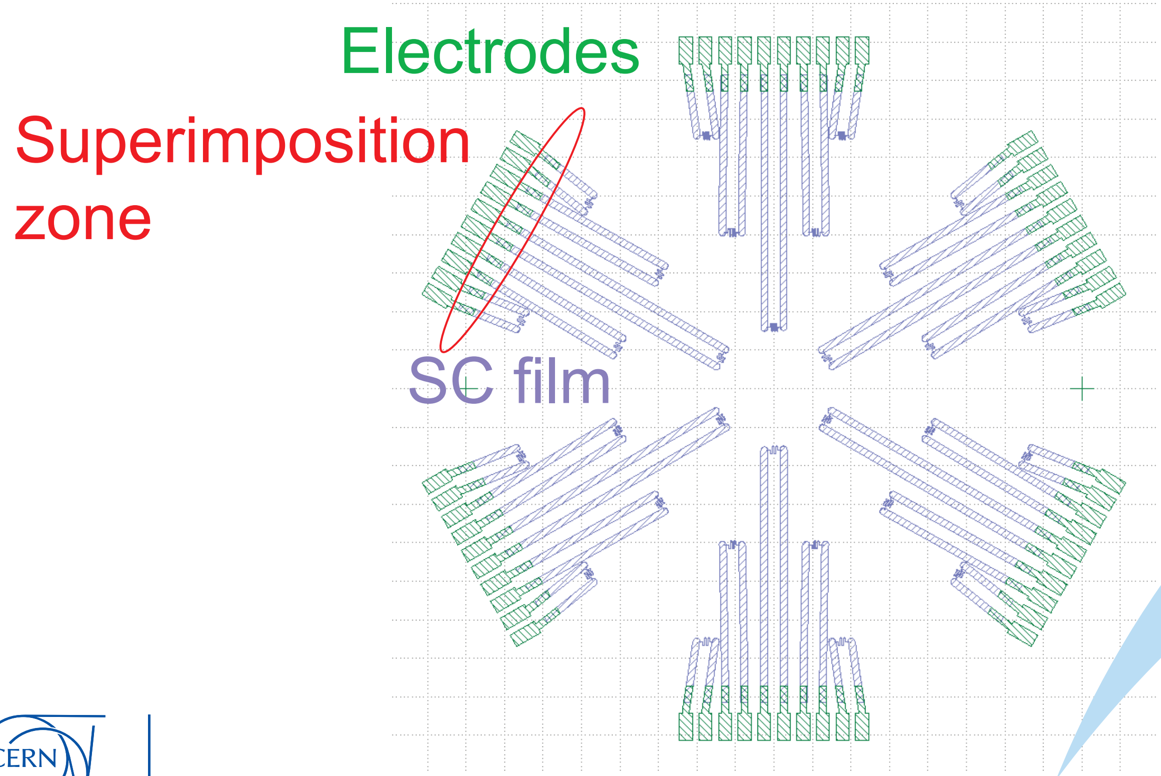


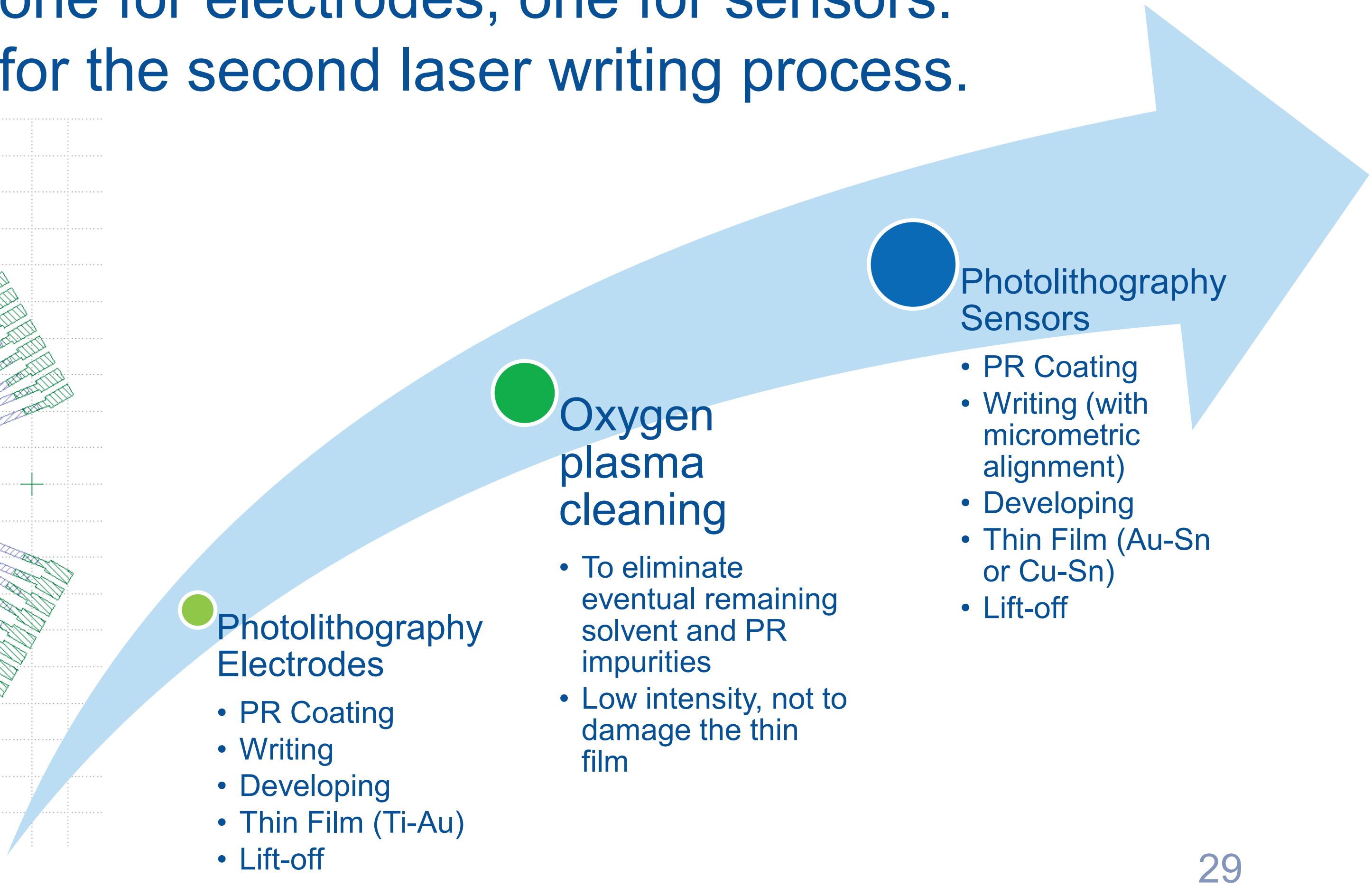
TES camera array: electrodes

More resistant electrodes can be obtained with a thin film of Ti and Au: we tested 20 nm – 80 nm thickness. The adhesion is sufficient.

Two photolithography processes: one for electrodes; one for sensors.

Micrometric alignment performed for the second laser writing process.





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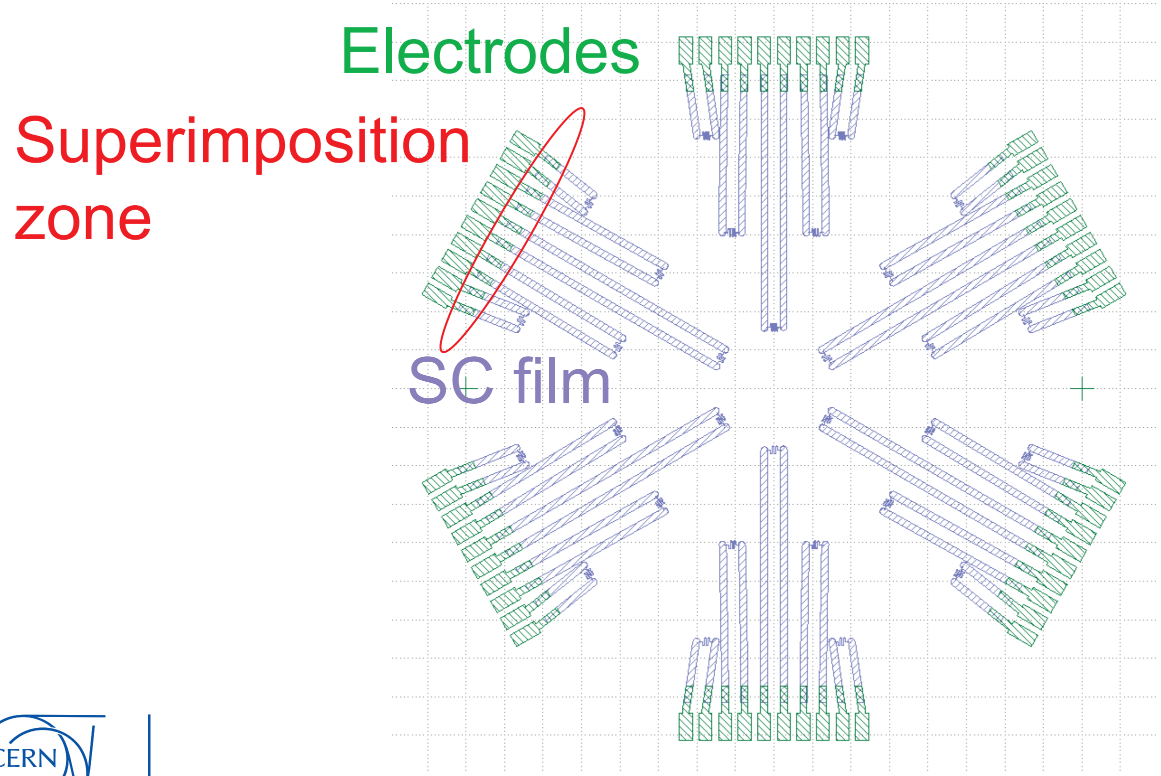
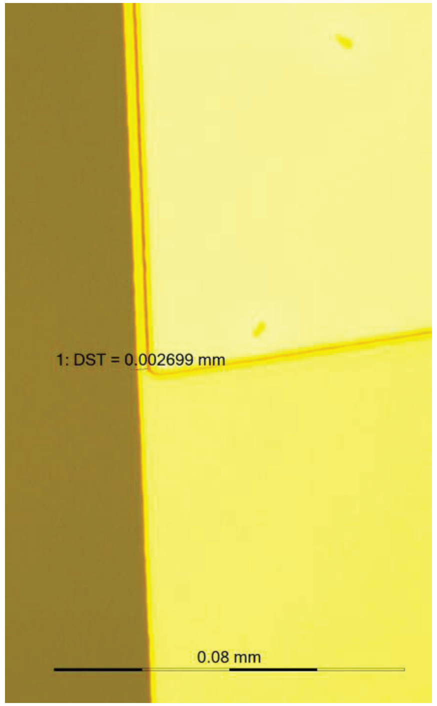
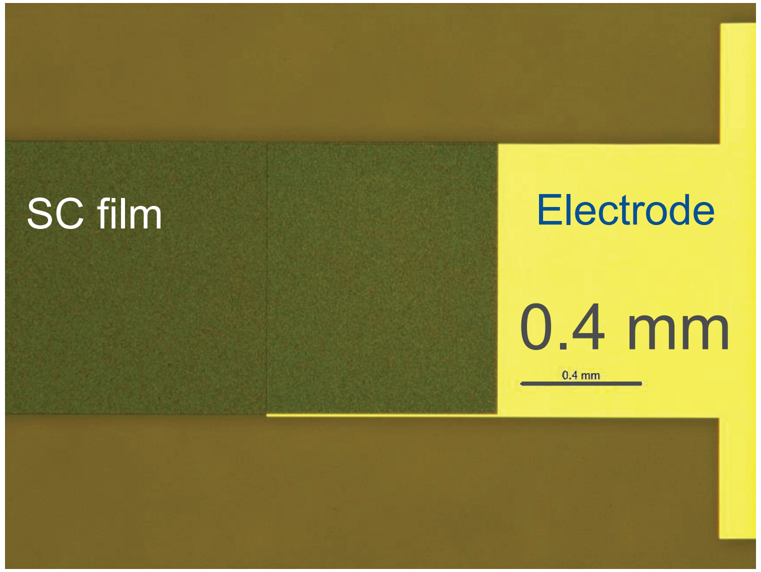
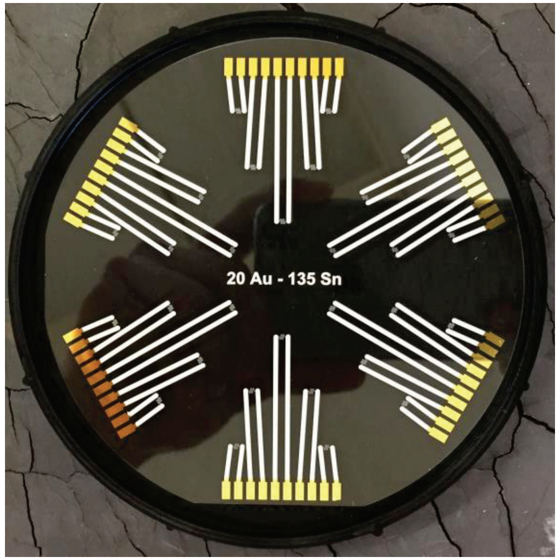
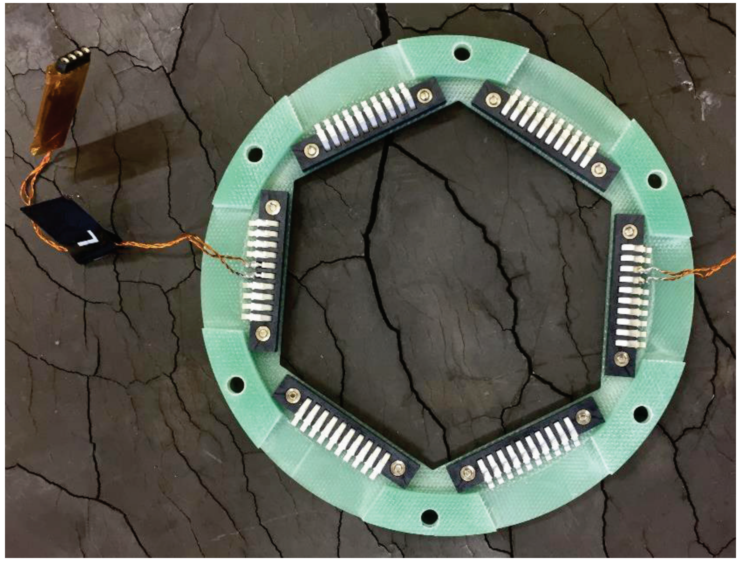


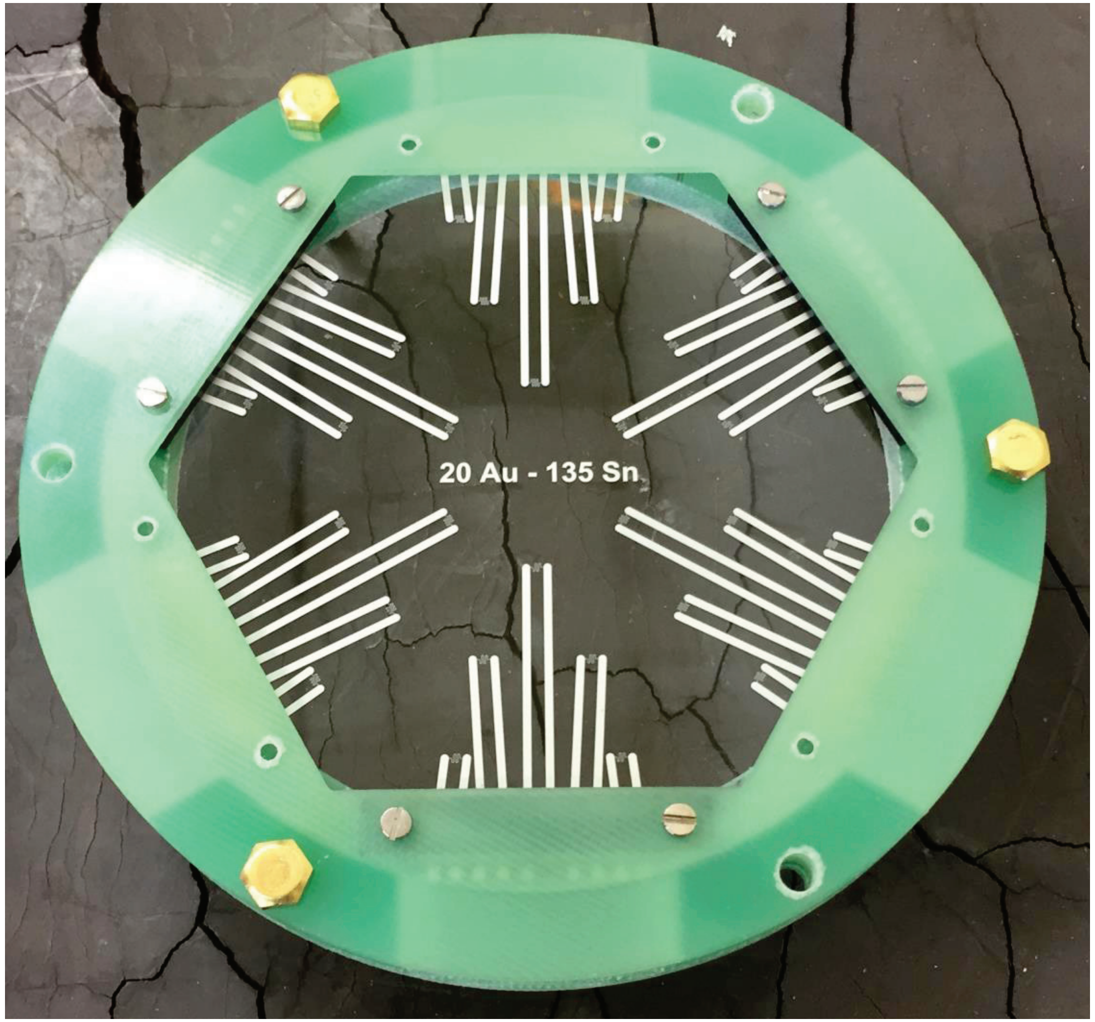




TES camera array: prototype







Stand-alone TES chips

Wafers have already been produced to test the method

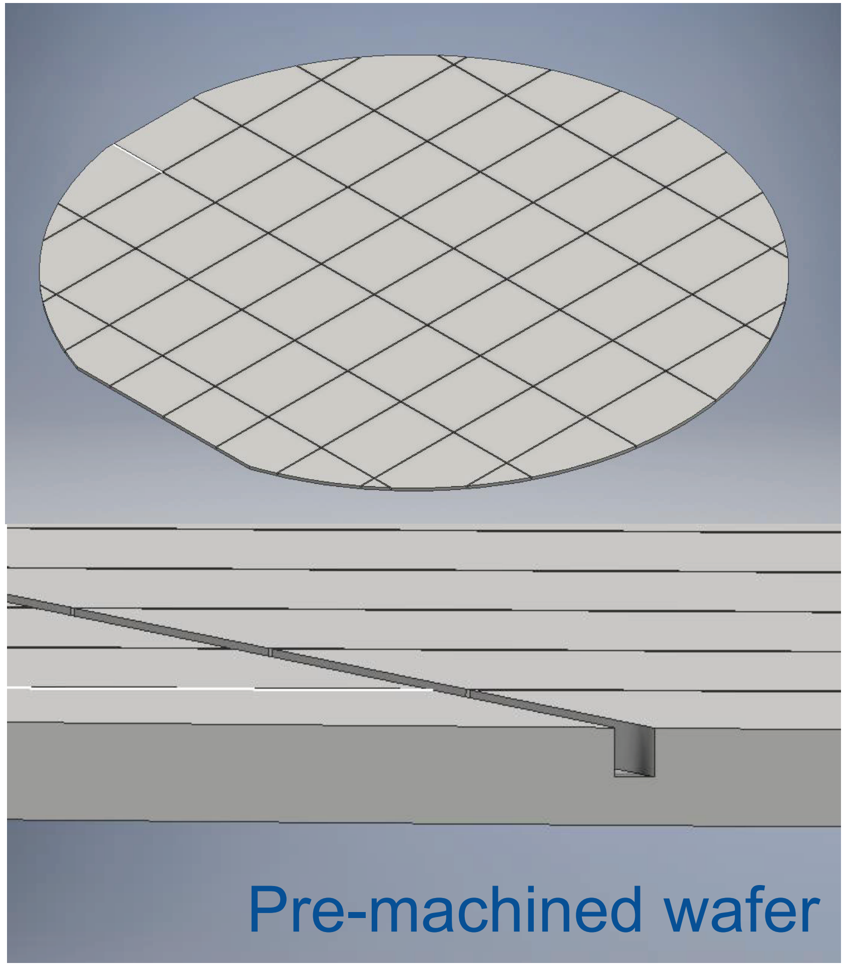
- Pre-diced cutting lines
- Thicker coating
- Laser more intense
- Careful manipulation

The results is satisfying

- Good geometrical quality
- Easy to separate

CERN

Stand-alone TES chips



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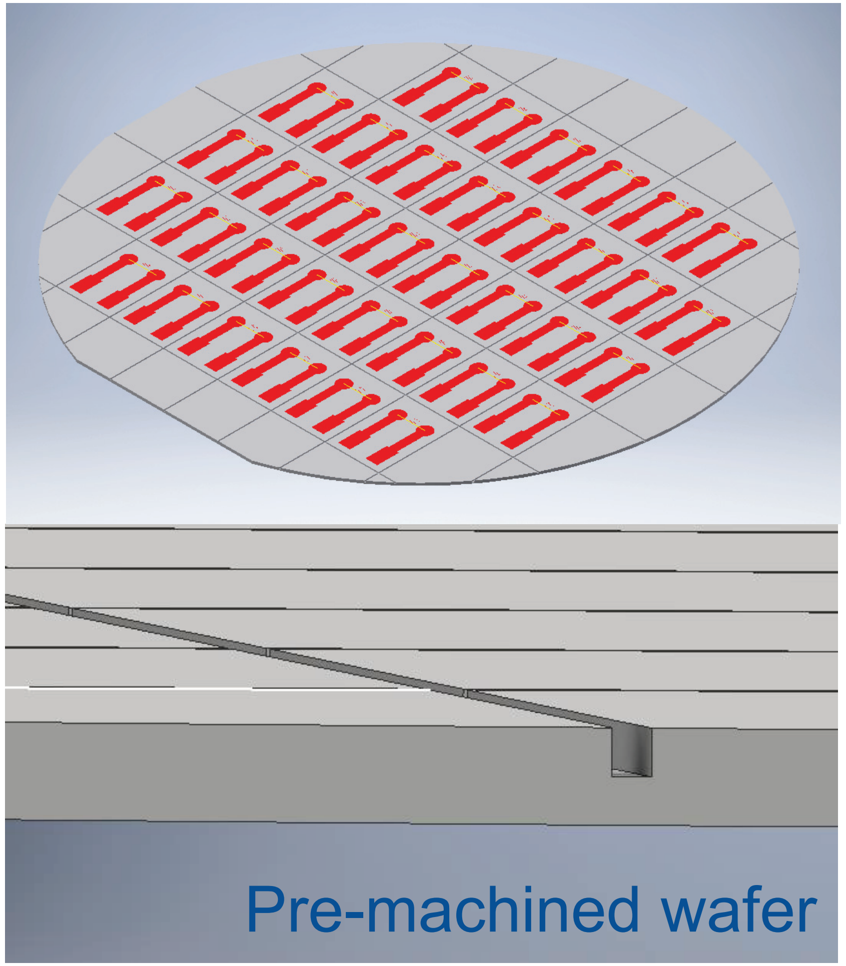

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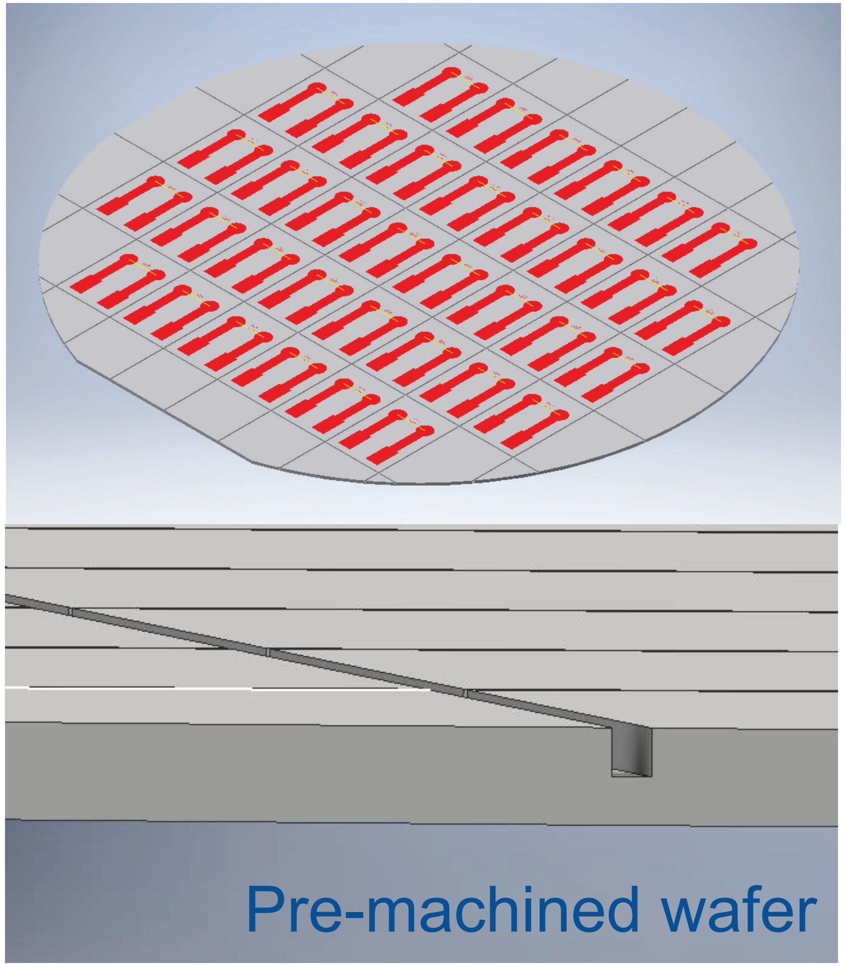

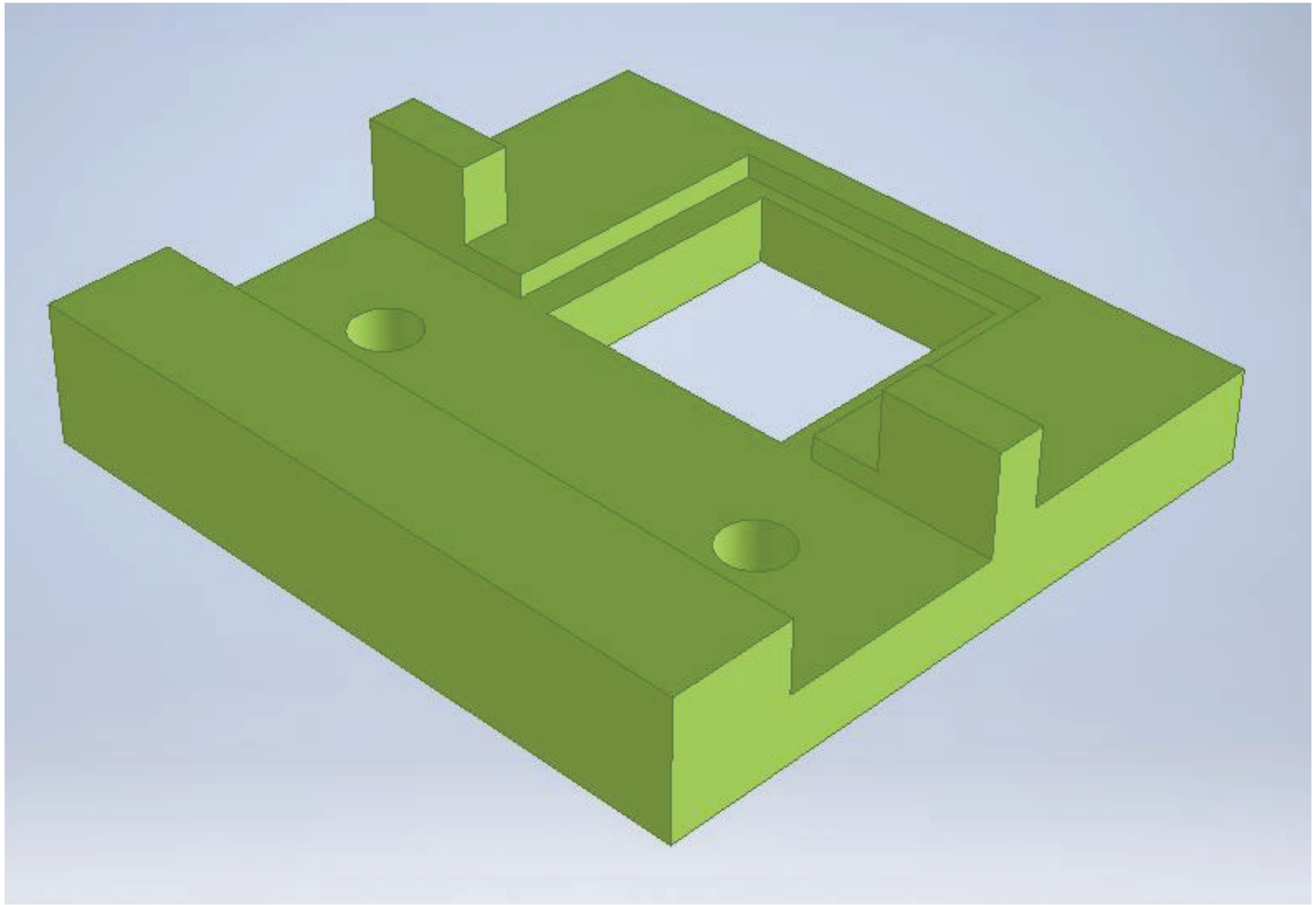

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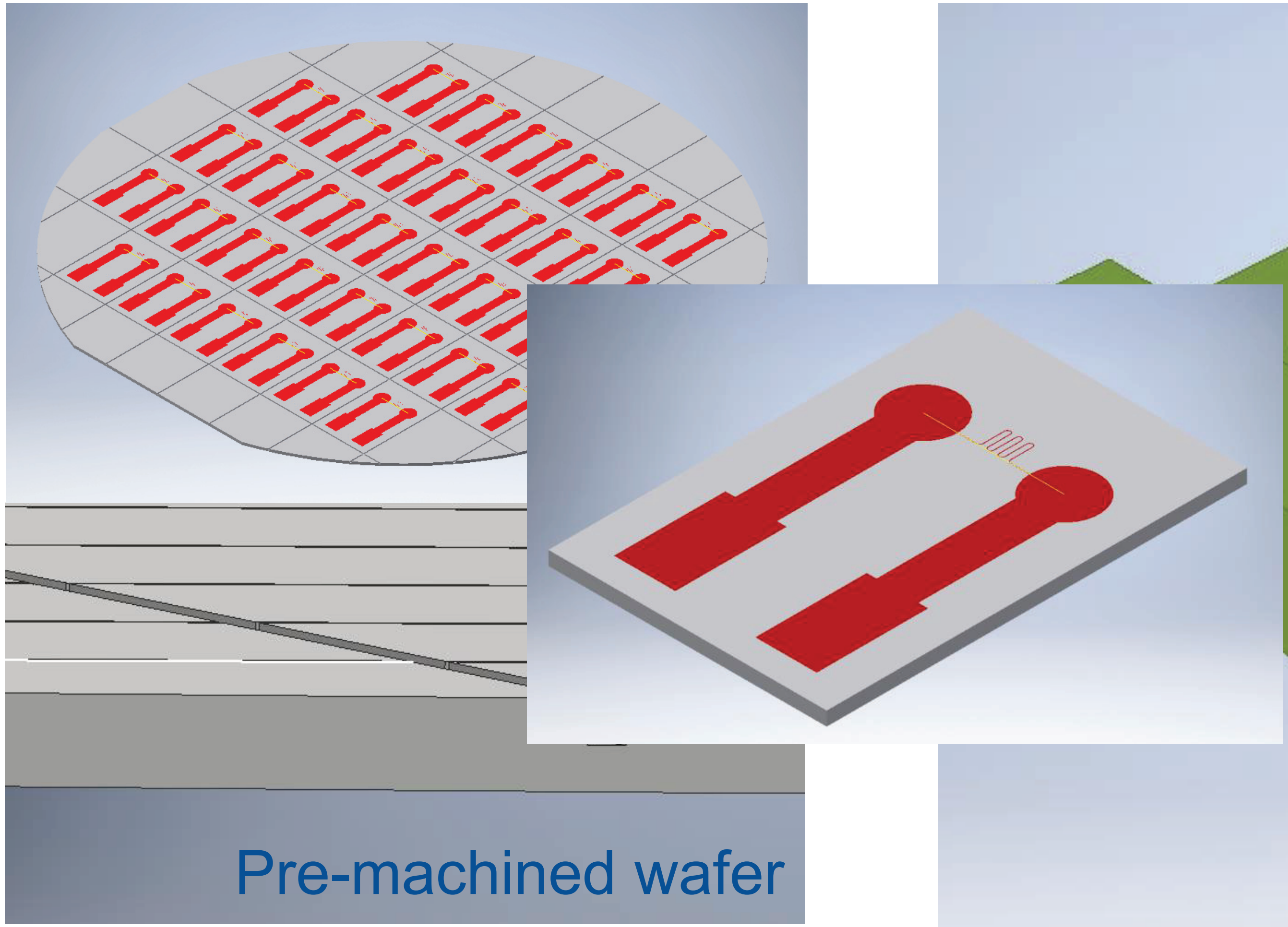

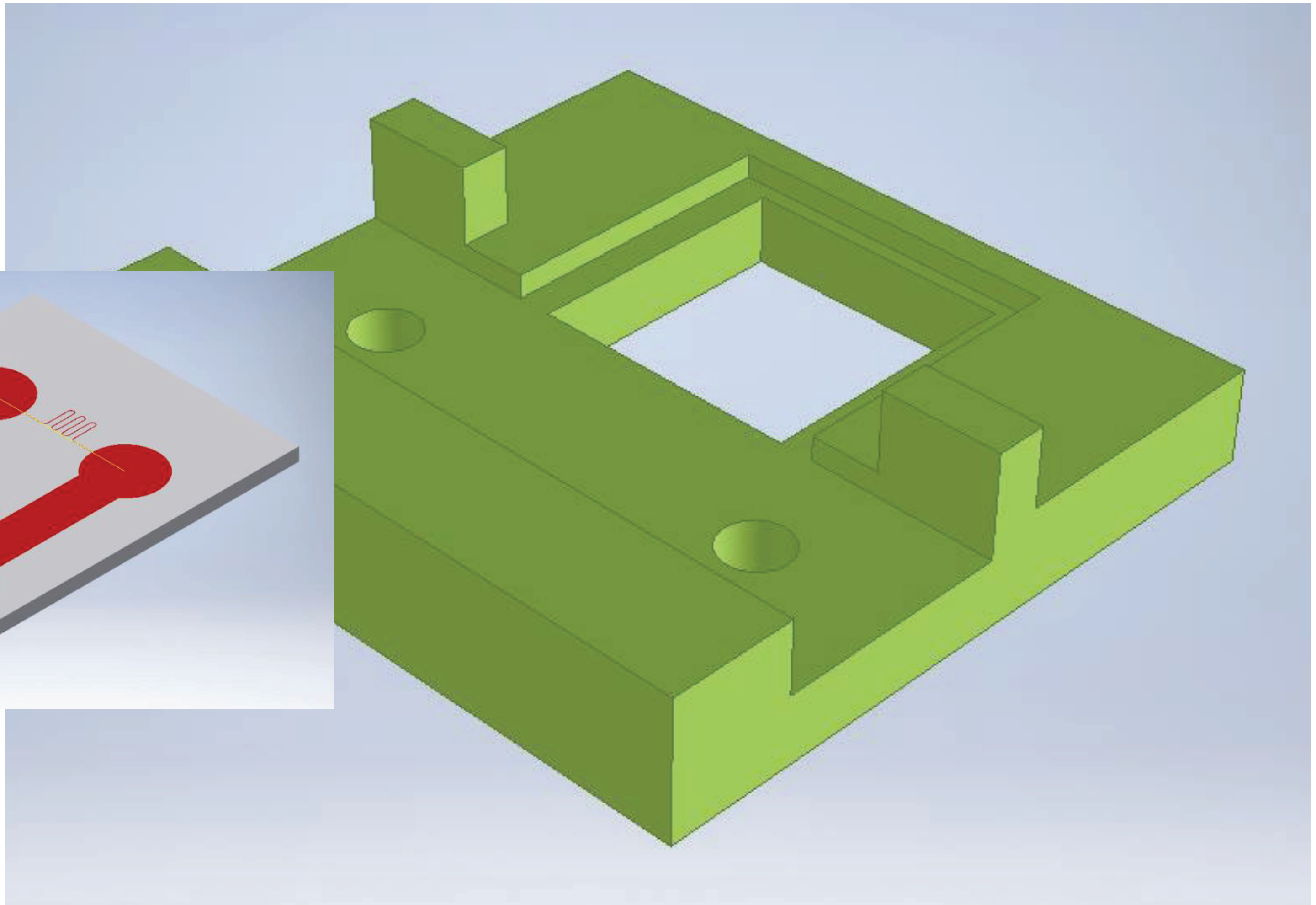

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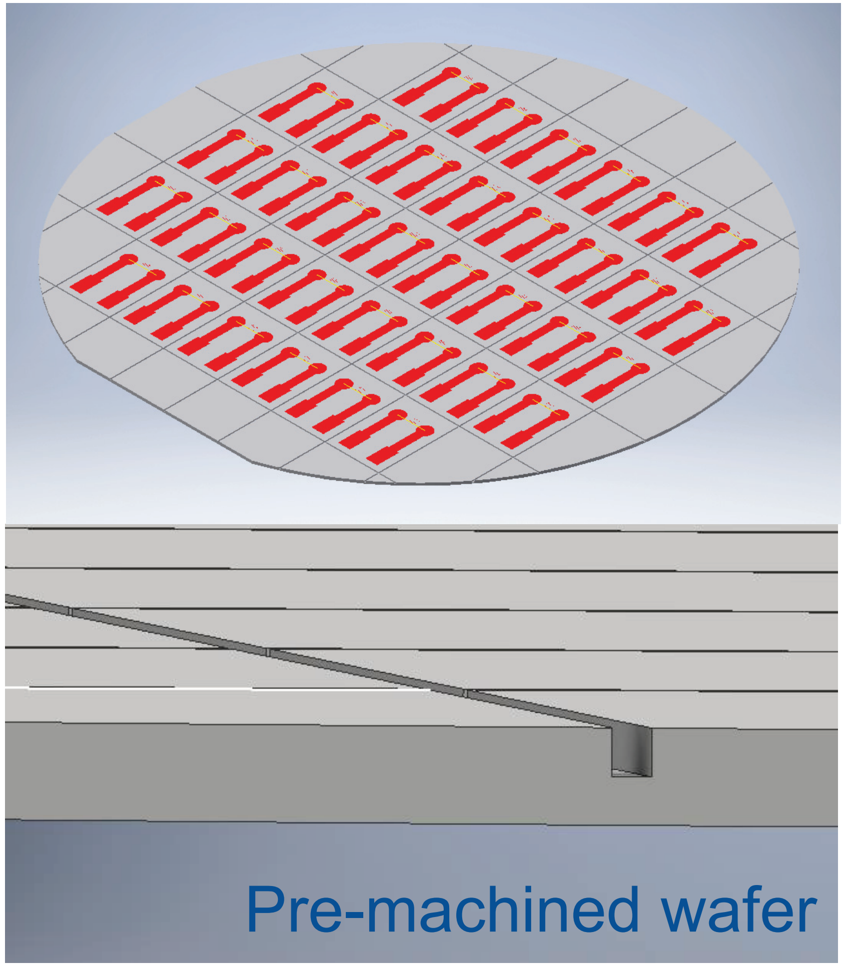

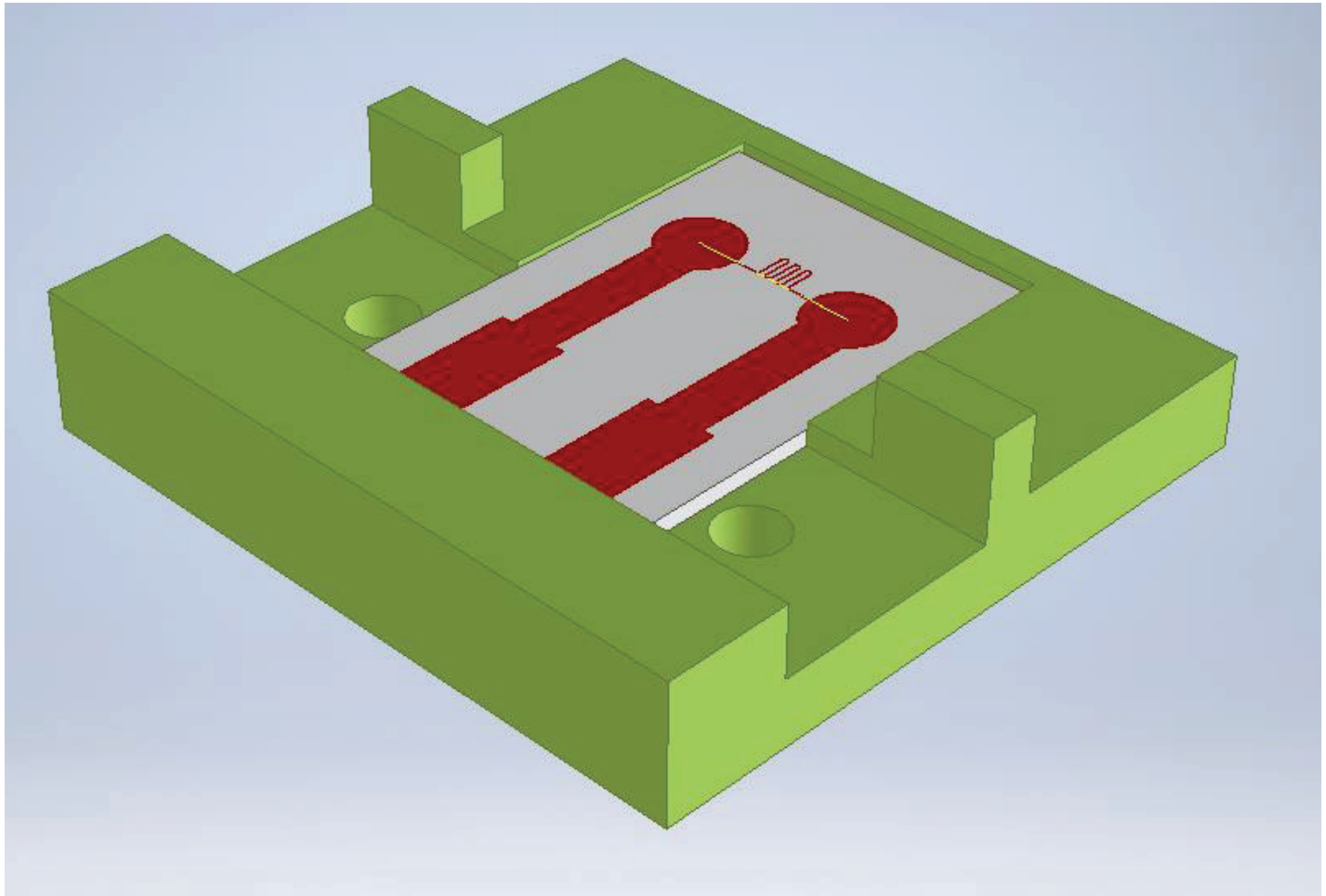

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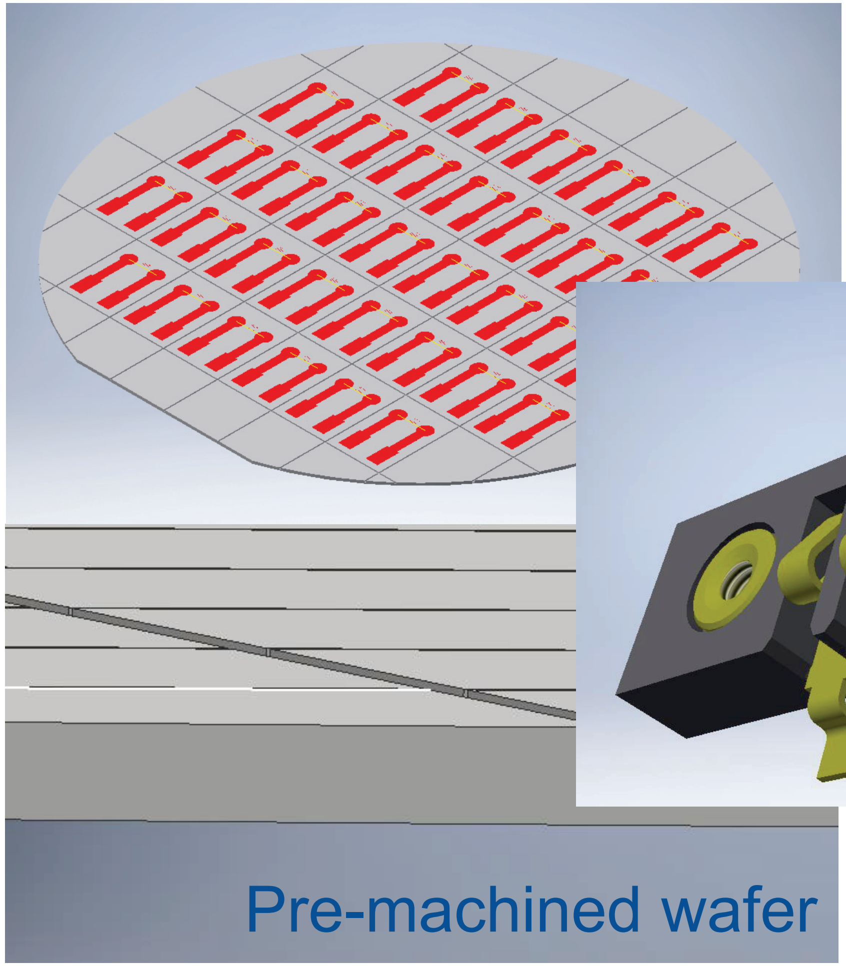
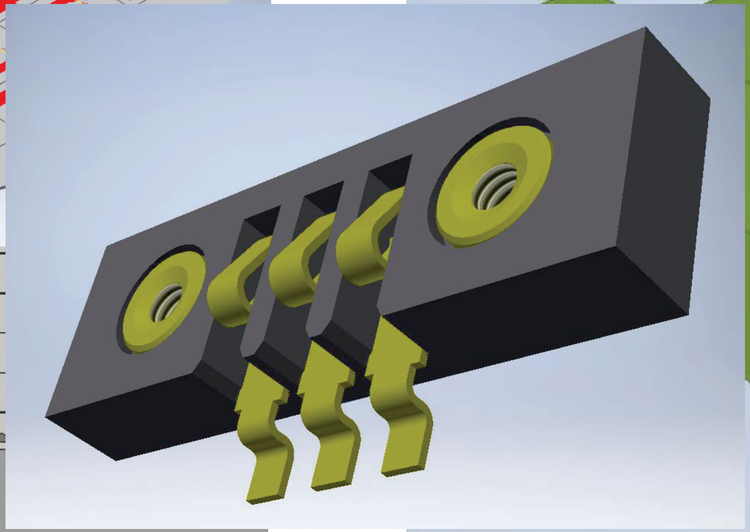
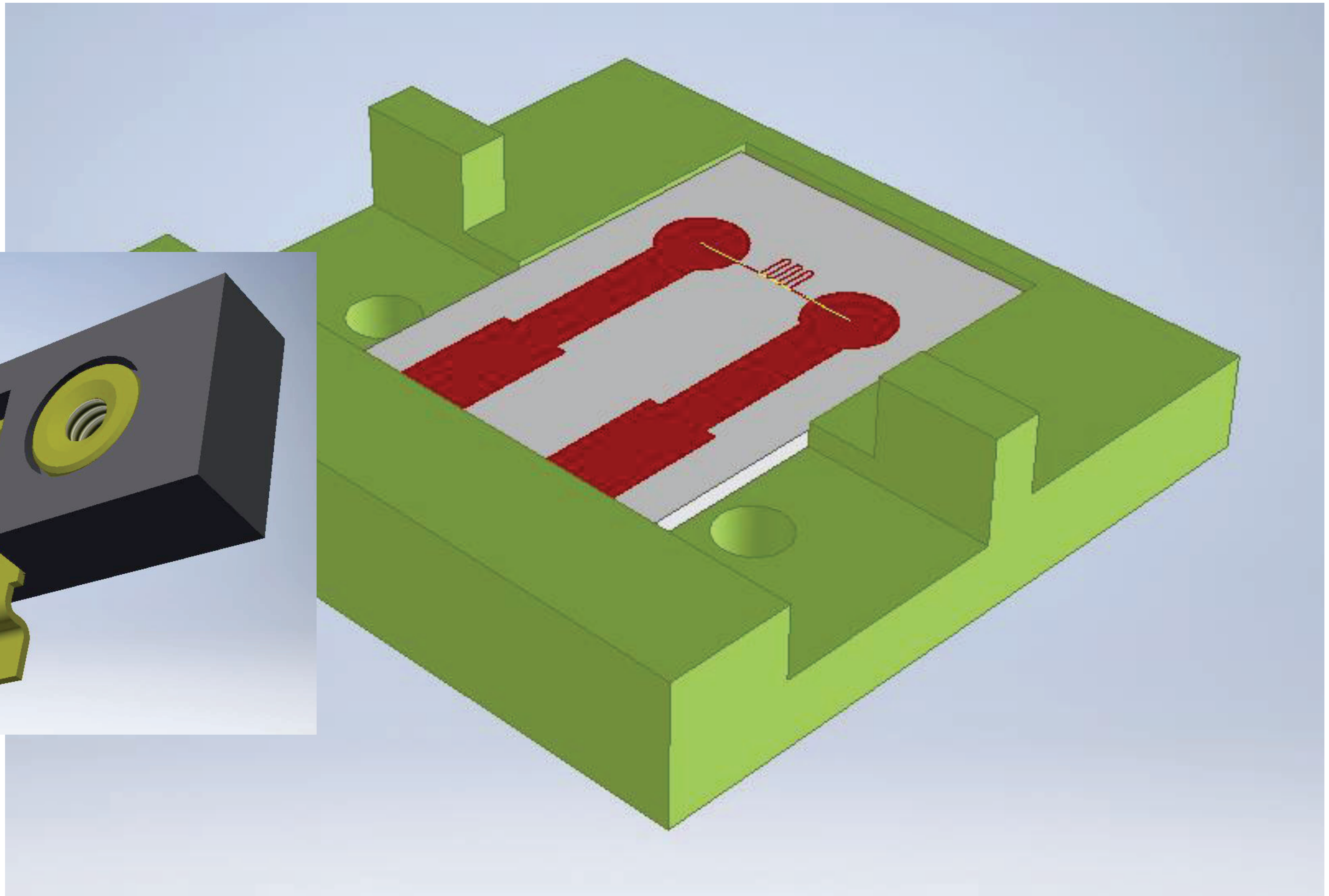
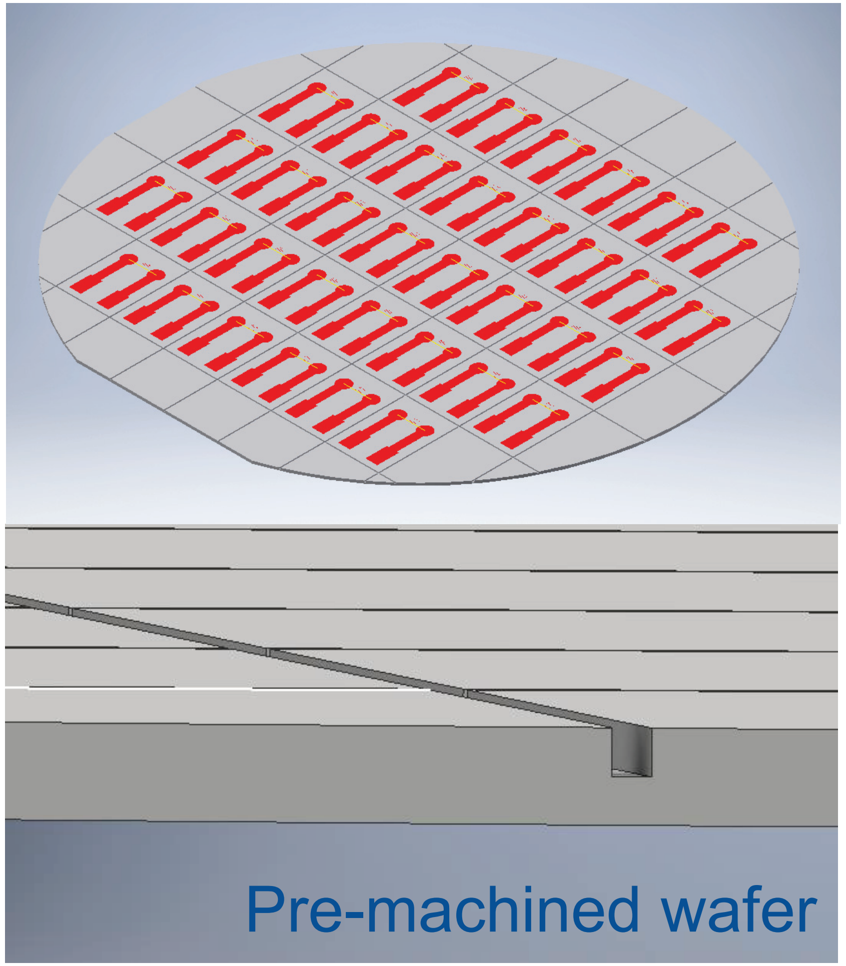


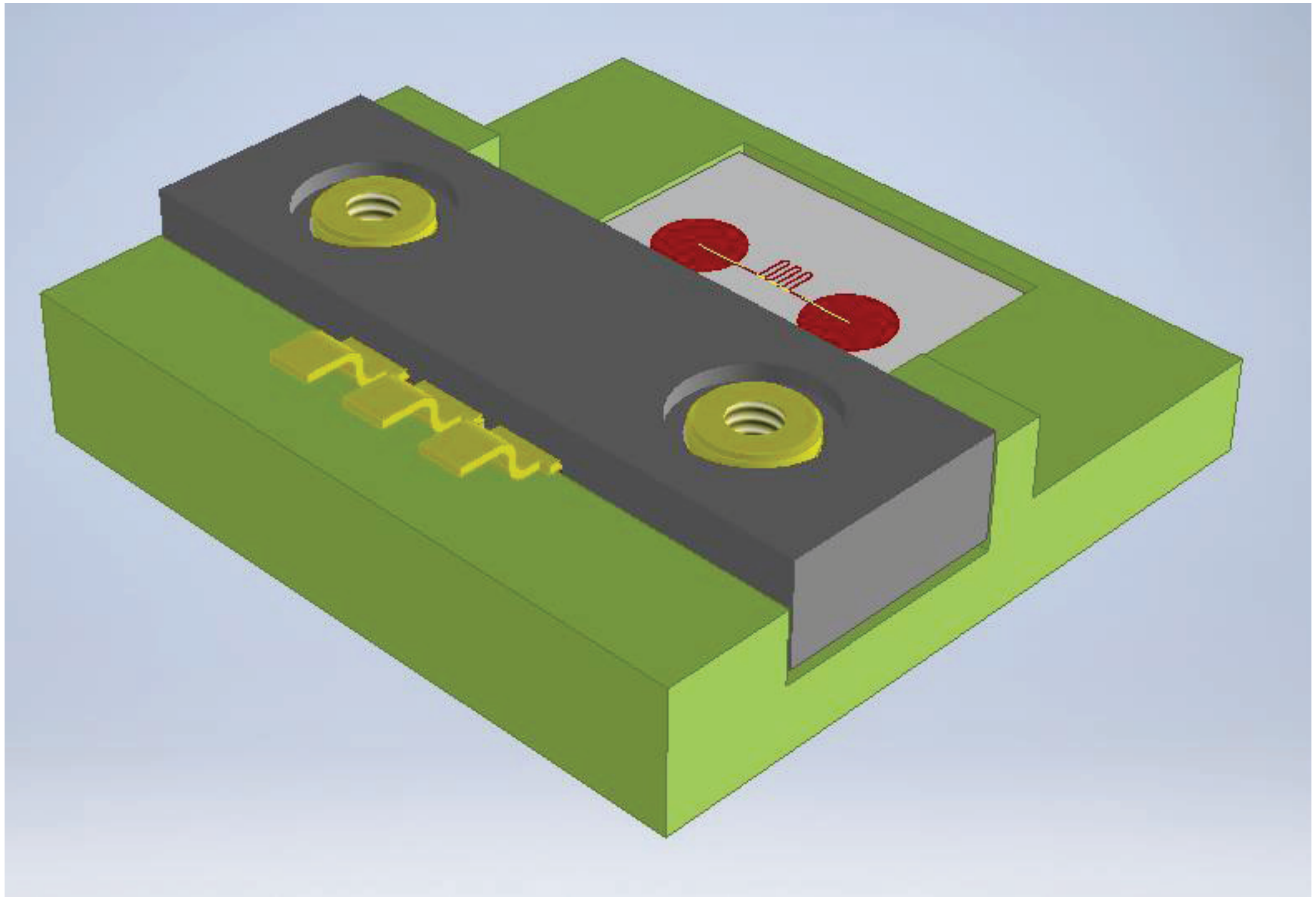
Pre-machined wafer





Stand-alone TES chips





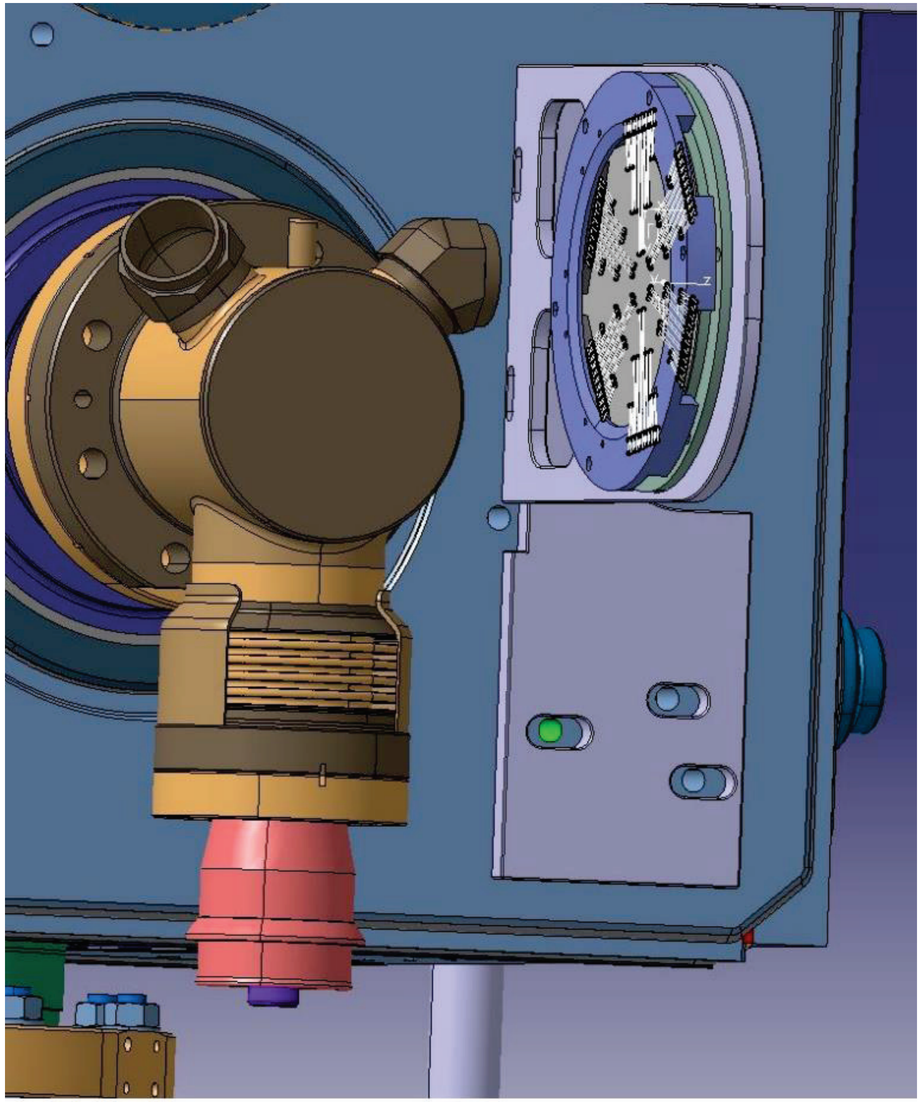
Towards the validation of TES as thermal mapping system

TES CRAB Cavities HOM - quench test

Very recently dressed CRAB cavity with HOMS tested at SM18

It was an opportunity to start commissioning TES as a quench localisation system at SM18

Test were done with OST's simultaneously, but no quench was detected at any HOMS



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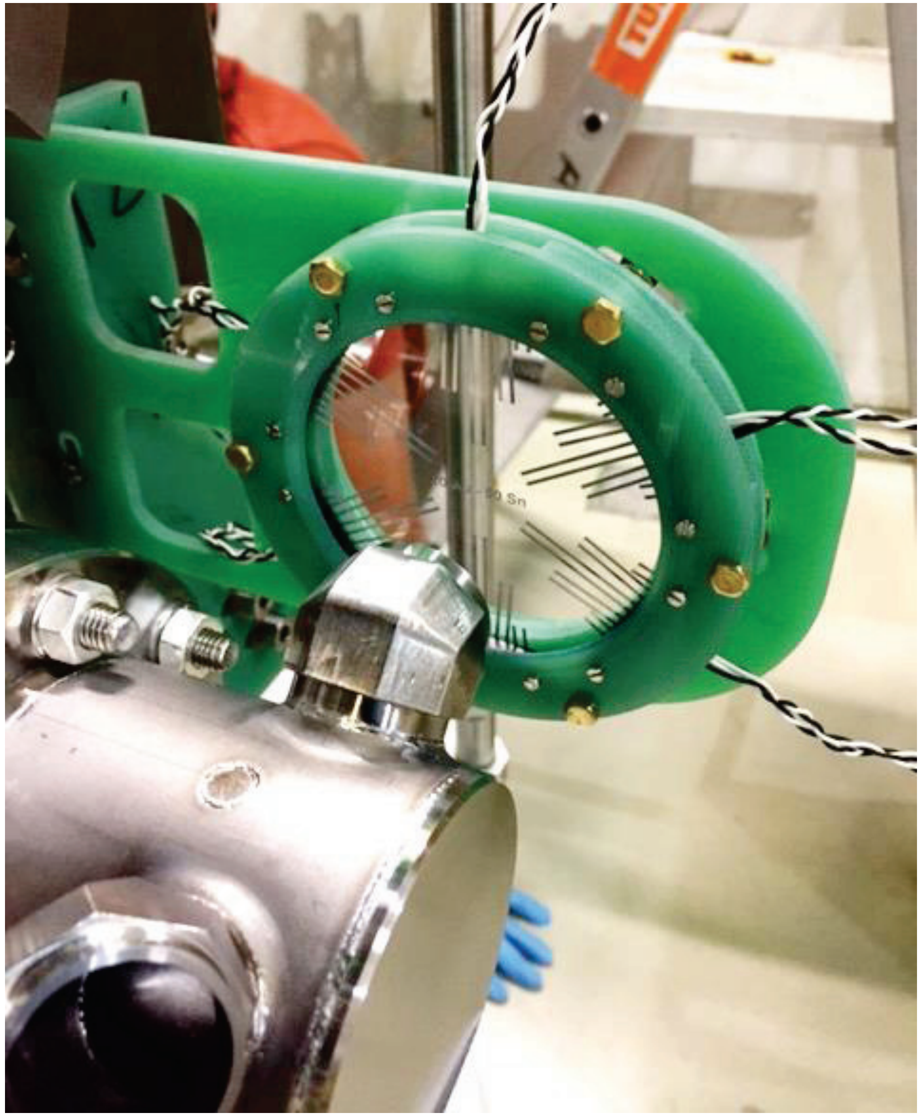
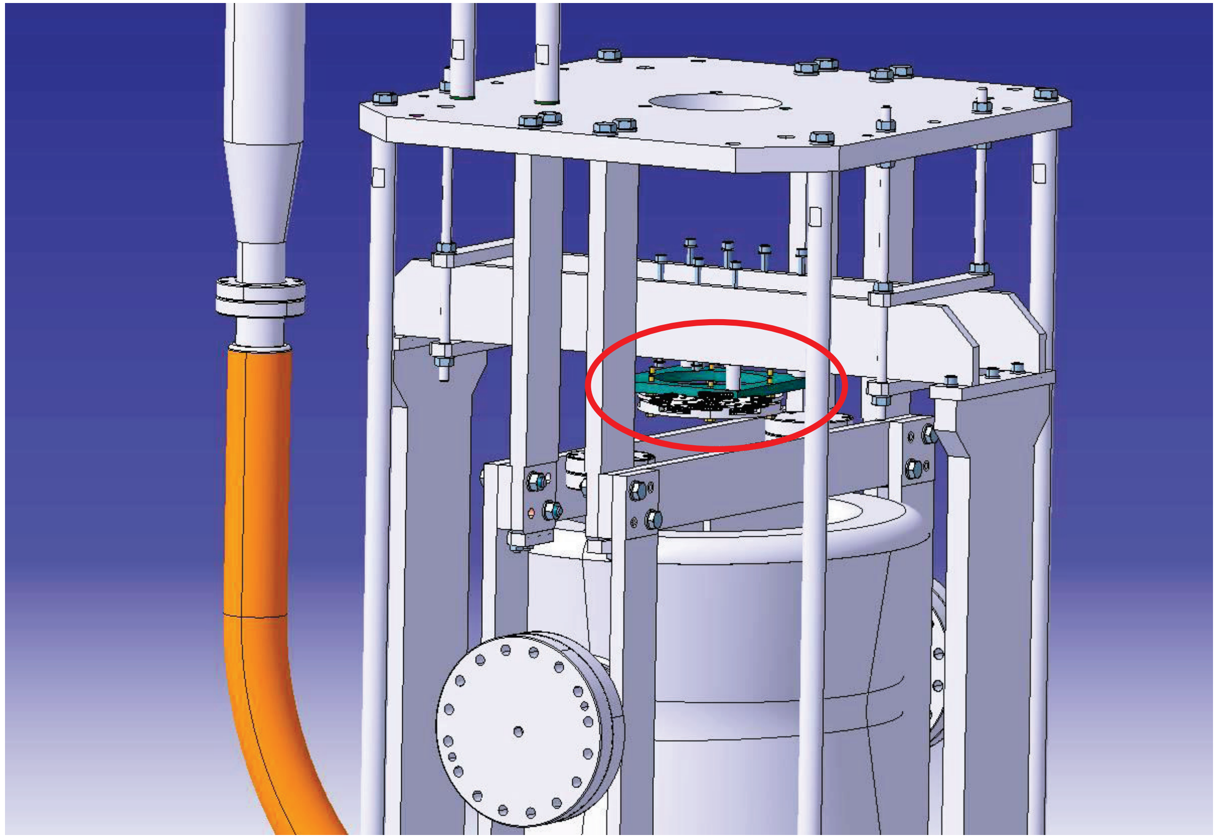


Bare cavity quench test with TES

Test the TES as a quench localisation system on a bare cavity

Current bare CRAB PoP cavity test is an opportunity

Alternative: Induce quench at known location on a cavity (heater or intentional surface defect) or simply test with a known bad-performing cavity



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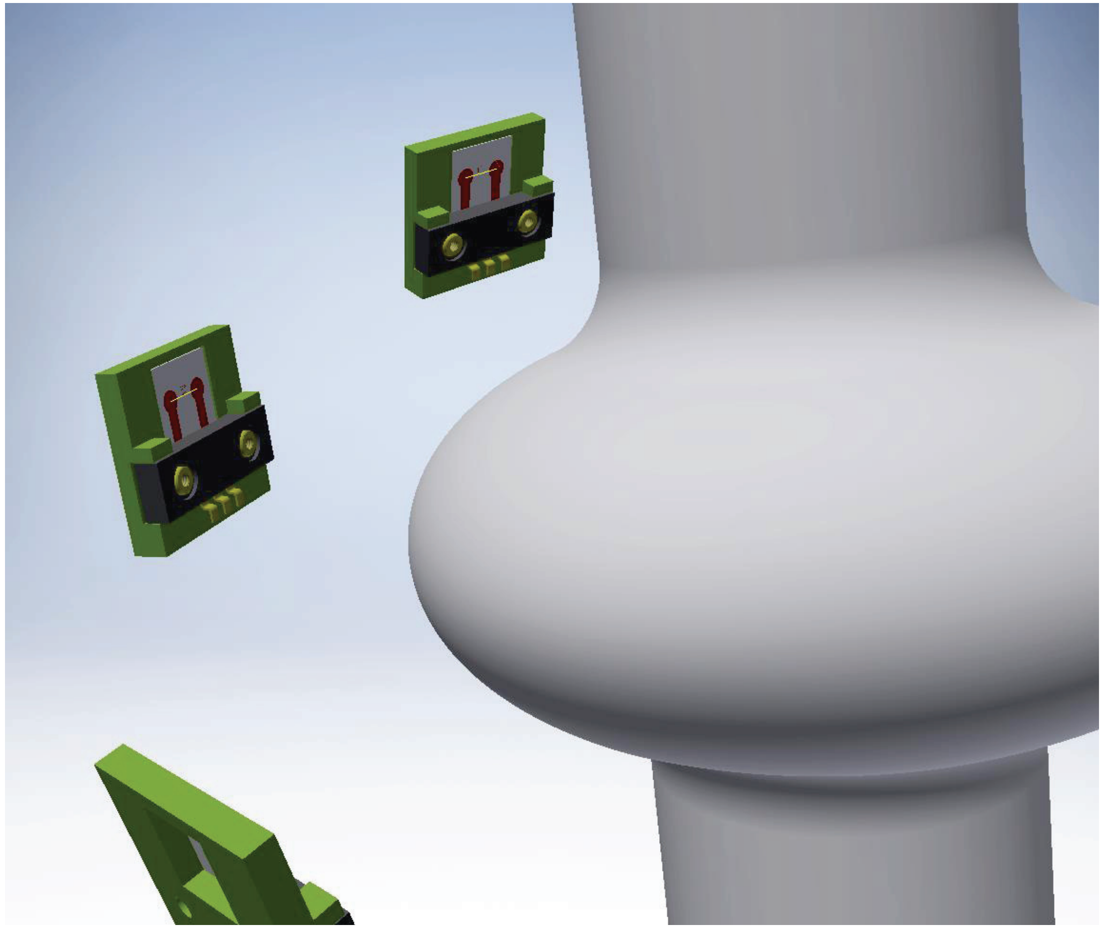

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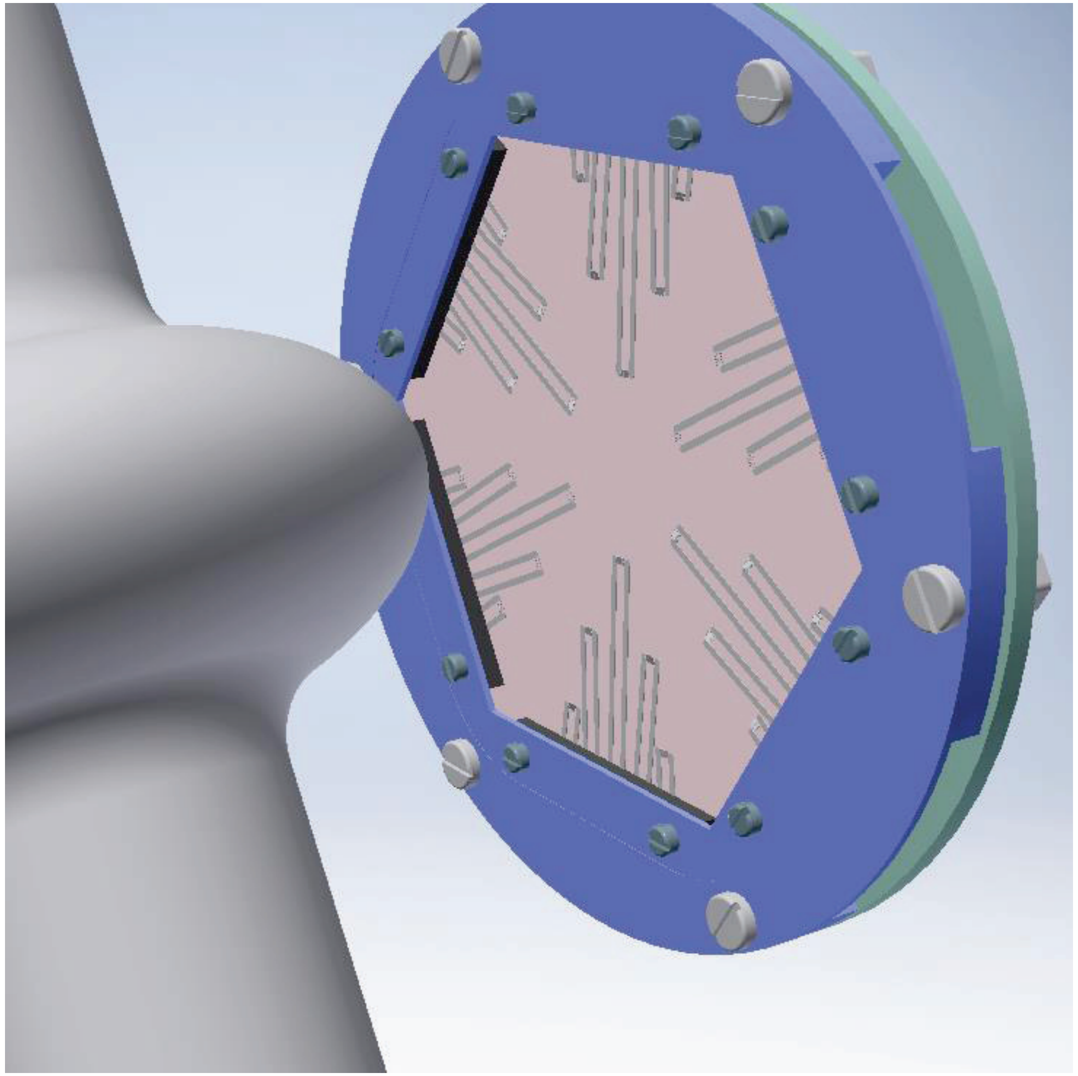

To summarize…

Conclusions on TES advances

TES as second sound detectors have been produced from Au-Sn thin films

The sensors were tested and satisfyingly detect second sound waves

Effects of composition, process flow parameters and adhesive layers have been/are being studied

A robust camera-like device has been designed, fabricated and incorporated to SM18 test facility

Next tests will allow to validate TES as a thermal mapping instrument and to compare their performance with that of OSTs

TES wafers as quench localization instruments are much more economic than a similar array of Cernox thermometers (when the technique is mastered and in relatively big production lots)

Acknowledgments

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G. Rosaz, Th. Schneider, M. van Stenis	Thin films consulting	Thin films tests
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A. Lunt, J. Busom Descarrega, F. Leaux	Microscopic analysis	SEM, SESI, ESB, EDX, FIB, etc.
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