Transition Edge Sensors for quench localization in SRF cavity testing

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Presentation of our team

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

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- 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

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

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

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

Image sources:
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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SC-region

NC-region

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Transition Edge

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Evaporated Leads Sensor Stripes Quartzglass Plate

Soldered Junctions for Supply Lines

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

Transition Edge Sensors

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

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

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

<table>
<thead>
<tr>
<th>Process description</th>
<th>Cross-section after process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substrate: Borofloat 33</strong></td>
<td></td>
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<tr>
<td>Coating – positive resist</td>
<td></td>
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<tr>
<td>Machine: ACS 200</td>
<td></td>
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<tr>
<td>LASER Writing</td>
<td></td>
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<tr>
<td>Machine: VPG 200</td>
<td></td>
</tr>
<tr>
<td>Developing</td>
<td></td>
</tr>
<tr>
<td>Machine: ACS 200</td>
<td></td>
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<tr>
<td>Metal Evaporation</td>
<td></td>
</tr>
<tr>
<td>Metals: Au-Sn</td>
<td></td>
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<tr>
<td>Lift-off</td>
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</tbody>
</table>
Prototype wafer design

Strips
- 30 µm wide
- Variable length (1 to 7 mm)
- Meandering design
- Sensing area ≈ 1 mm²

Leads
- Oriented for cabling
- Big enough for cabling
- Same material as sensor (low J \( \rightarrow \) SC always)
- Pads for Indium cold weld or pressed contact
Fabrication results

After laser writing and development

1mm

After metallization and lift-off

1mm

Sensor cabling

Instrumented wafer
4 wire measurement configuration
Indium soldering
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

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Different distances
Sensors biased at constant current

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

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Heat flux: $1.40 \pm 0.07 \, W/m^2$
Distance $\sim 50 \, mm$

$T = 1.6 \, K$
$I = 0.9 \, mA$

270 $\mu V$ 2nd S. signal

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Further studies on TES thin film

<table>
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<th>Variation of composition and its impact of TES quality</th>
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<tbody>
<tr>
<td>Other material combinations</td>
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<tr>
<td>Reproducibility</td>
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<td>Effect of adhesion-improving pre-layer on the TES performance</td>
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</table>
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
Stand-alone TES chips

Pre-machined wafer
Stand-alone TES chips
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Towards the validation of TES as thermal mapping system
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
TES CRAB Cavities HOM - quench test

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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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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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SEM, SESI, ESB, EDX, FIB, etc.

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