Development of Mo/Au Transition Edge Sensors for cryogenic X-ray detectors

L.Fàbrega[a], A.Camón[b], C.Pobes[b], P.Strichovanec[b], J.Moral[a], N.Casañ-Pastor[a], R.Jáudenes[a], J.Sesé[c]

[a]ICMAB-CSIC, Bellaterra (Spain) [b]ICMA, CSIC-Universidad de Zaragoza, Zaragoza (Spain) [c]INA and LMA, Universidad de Zaragoza, Zaragoza (Spain)

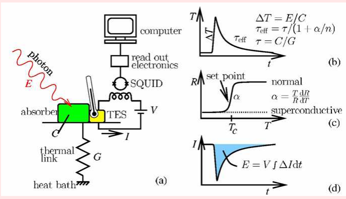
Abstract

The so-called Transition Edge Sensors (TES) , whose basic element is a superconducting film operating at cryogenic temperatures (~100mK), constitute high performance detectors for a very wide radiation range. Thus, they are considered essential for extremely sensitive astronomic instruments, either on ground or in space, such as EDELWEISS, CRESST, BICEP2, SCUBA2, ACTPol, SAFARI and ATHENA's X-IFU, as well as for other applications in science and industry. TES X-ray detectors with extremely high spectral resolution have been fabricated by NASA and SRON, using respectively Mo/Au or Ti/Au bilayers as the sensing element and Bi or Au as absorber.

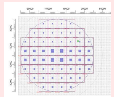
We report here our progress in the fabrication of TES X-ray detectors based on Mo/Au bilayers, within the framework of the initiative to develop a european backup for the X-IFU detector. Mo/Au TES are fabricated on SiN membranes in Ultra High Vacuum conditions through a two-step deposition process, using sputtering and electron-beam deposition, followed by dry etching photolithography. Superconducting Nb wiring is used. Electrodeposited Bi is being developed as absorber. An advanced specific characterization setup has been implemented, involving complex impedance and I-V curve measurements using superconducting electronics in a dilution refrigerator (base temperature <30mK). The first results of characterization are presented.

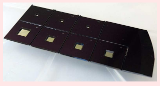
What's a TES? Why is it so interesting?

- ❑ A TES is basically a **superconducting thermometer**. It is able to detect very small changes of temperature (produced by a single photon) because of its very steep change of resistance through the transition. This steepness, together with the low operation temperature and the narrow bandgap of superconductors, makes TESs **extremely sensitive devices**.
- ❑ The radiation detectors incorporate to the TES some device or material, capable of absorbing photons and converting them into heat. For X-rays, a high Z, low C material is used as **absorber**.
- ❑ The **resolution** of the device depends on superconducting, electrical and thermal parameters of the TES and the absorber.

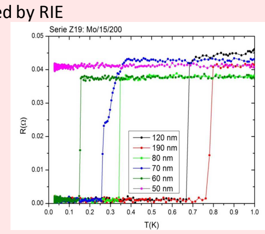


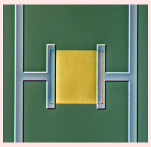
Fabrication

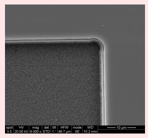




- **TES** fabricated on **low stress Si_3N_4 membranes** (1μm thick) opened by RIE
- Mo/Au bilayers deposited in **UHV** at room temperature (deposition homogeneity area >2'')
- **Trilayer design**: **Confocal RF sputtering** of Mo + in situ DC sputtering of 15nm Au + ex situ Au deposition by **ebeam**
- Sensor fabricated by **dry etching**
- **Nb pads** 150nm thick, with T_c=8.8K, I_c(4.2K)>20mA

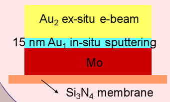


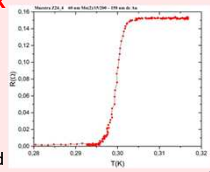




Optical and SEM micrographs of a Mo/Au TES

ΔT_c~ 2-10mK



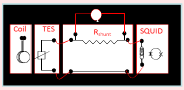


- **Bi films** prepared by **electrochemical deposition** at room temperature.
  - Deposited on Au(10nm)/Cr(2nm)/glass for functional test pourposes
  - Several solutions and electrochemical processes have been optimized

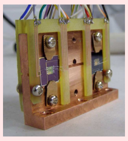
Advanced characterization

Dilution refrigerator Kelvinox MX40 (Oxford Instruments):

- Sample in vacuum
- Base temperature 27 mK
- dT/dt = 10^{-2} mK/s
- Field screening
- Low H superconducting coil

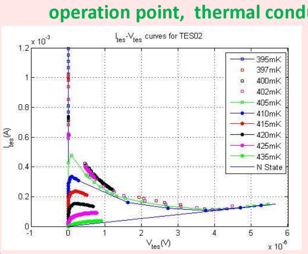


SQUIDs from PTB (series C6)
R_{SHUNT} = 2 mΩ



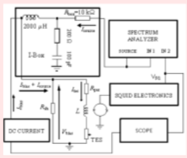
I-V curves:

operation point, thermal conductance

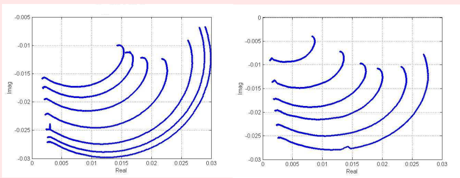


✓Mo/Au TESs:
- α ~150
- R_n ~30-40mΩ

Complex impedance: complete dark characterization of the TES



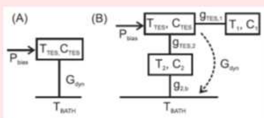
- From Z(ω) all the TES parameters are obtained, through the use of a suitable thermal model. Operation point can be refined.
- Once the parameters are known, the different contributions to noise can be calculated.
- Calculated and measured noise are compared, and main contributions identified. This allows optimization of TES parameters (size, thickness, Rn, α, geometry, connection to absorber: P, C, G…), for each specific application.



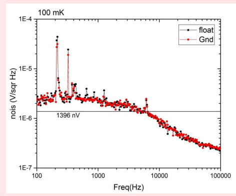
Complex impedance of a TES with Tc=157mK; recorded at 138mK and 140mK, between 1kHz and 100kHz

ΔE_{FWHM}=2.36 $[0.5n]^{1/4}$ $\sqrt{4kT^2C/\alpha}$

τ≈ C/α T/P

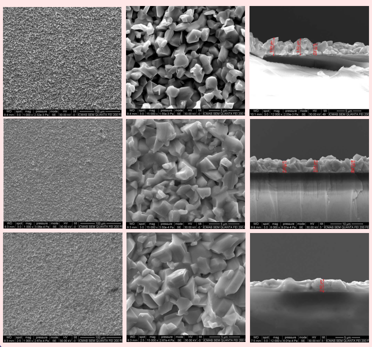


The two most simple thermal models



System noise recorded at 100mK

Electrodeposited Bi as X-ray absorber

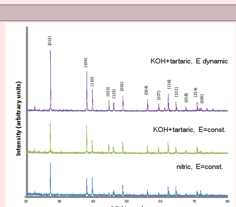


- **Very crystalline** films (Cu Kα1 and Kα2 visible)
- Thickness and microstructure control achieved at the micron scale
  - Better compacity with dynamic deposition
  - Better thickness uniformity with E=const deposition

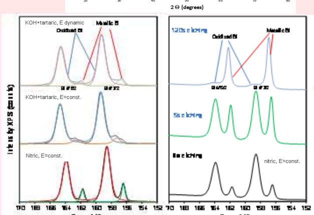
Morphology controls functional properties (ρ, K, QE, stability)

- **Pure, metallic** Bi
- Surface (~2nm) oxidized

SEM images of three films, from top to bottom:
- *Nitric solution, E=const, 3.7 μm*
- *KOH+tartaric solution, E=const, 3.6 μm*
- *KOH+tartaric solution, dynamic deposition, 2μm*



X-ray diffraction patterns



XPS spectra for Bi 4f

Conclusions

- ❑ TES with tunable Tc and Rn are fabricated in a reproducible way. Very good homogeneity.
- ❑ Setup for complete dark characterization ready
- ❑ Bi absorber under optimization

Work in progress

- ❑ Optimization of Mo/Au sensors (size, design)
  - Thermal models
  - Study of weak link effect
  - Comparison to Ti/Au
- ❑ Assembly of TES and absorber
- ❑ Setup for spectral resolution

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