Microfabrication of transition-edge sensor arrays of microcalorimeters with ^{163}Ho for direct neutrino mass measurements with HOLMES

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The HOLMES experiment will provide an important step forward in direct neutrino mass measurements with a calorimetric approach as an alternative to spectrometry. In such approach the beta source is embedded in the detector and the energy emitted in the decay is entirely measured by the detector, except for the fraction taken away by the neutrino. HOLMES plans to deploy a large array of transition-edge sensor (TES) microcalorimeters with implanted ^{163}Ho nuclei. The detectors will be Mo/Cu TES on a solid Si_3N_4 membrane and a gold absorber. While good progress has been made in optimizing single pixel design and fabrication to achieve the target resolution, a major challenge is the fabrication of arrays of such microcalorimeters with the required amount of ^{163}Ho nuclei embedded in the gold absorber. Fabrication needs to be compatible with ion implantation, while preserving detectors performance. Specifically, the gold absorbers will need to be fabricated in more than one step, before and after ion implantation, in order to fully embed the isotope. We outline here the multi-step microfabrication process implemented to produce the final detector arrays for HOLMES, its challenges and our progress.

Detector array design

Driving requirements:

- need to deposit gold during ^{163}Ho implantation, in order to avoid dose saturation, while controlling precisely over time the deposited Au:^{163}Ho
- optimize ^{163}Ho implantation efficiency

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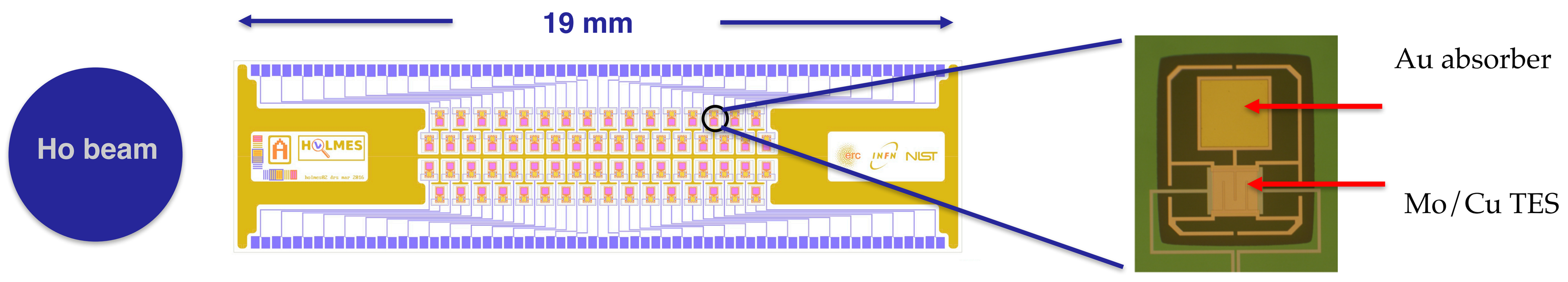
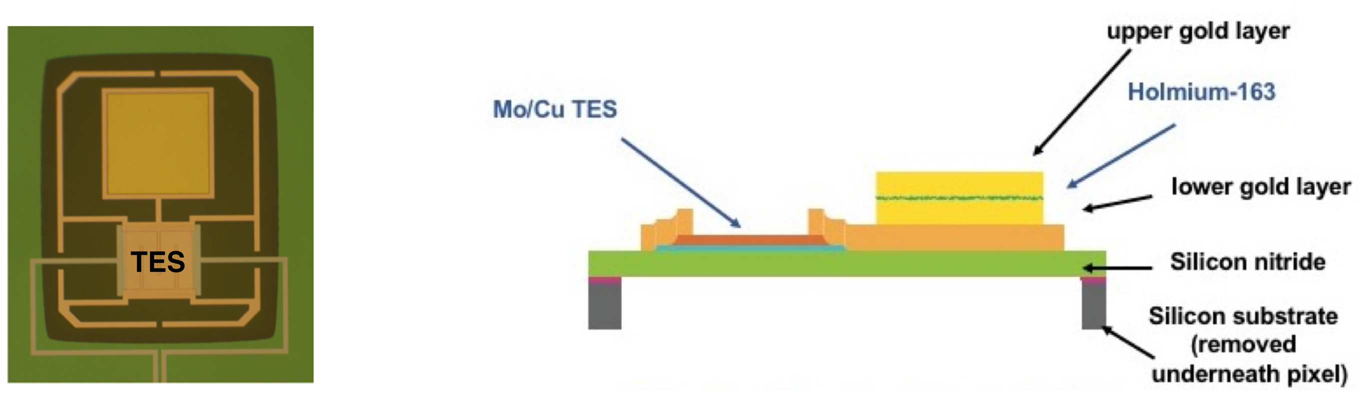
- ➢ designed a new 16x4 detectors array layout, 5x19 mm in size
- ➢ implant single chip array by small horizontal scanning of a focused 4-5 mm ^{163}Ho beam



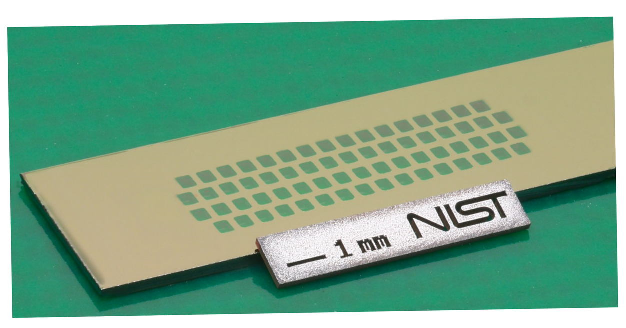
Detector array fabrication



Top : sketch of the current pixel design, including all processing steps. The detectors will be fabricated at NIST up to the bottom half of the gold absorber, then in Italy the absorbers will be completed with Au:^{163}Ho implantation/final gold deposition to fully encapsulate the isotope and, finally, the silicon nitride membranes will be released by deep etch of the silicon on the backside of the array.

- modified some detector fabrication processing steps at NIST to allow ^{163}Ho implantation and further fabrication steps on a single 5x19 mm chip, rather than a full 3" wafer:
- ➢ processed full wafers are diced into individual chips after absorbers photolithography
- ➢ evaporation of gold (first half of the absorbers) is performed on diced chips
- ➢ silicon oxide hard mask (for silicon deep etch) patterned before absorber steps

→ first successful mechanical tests of backside deep silicon etch on individual chips with silicon oxide hard mask performed at NIST (*right*)

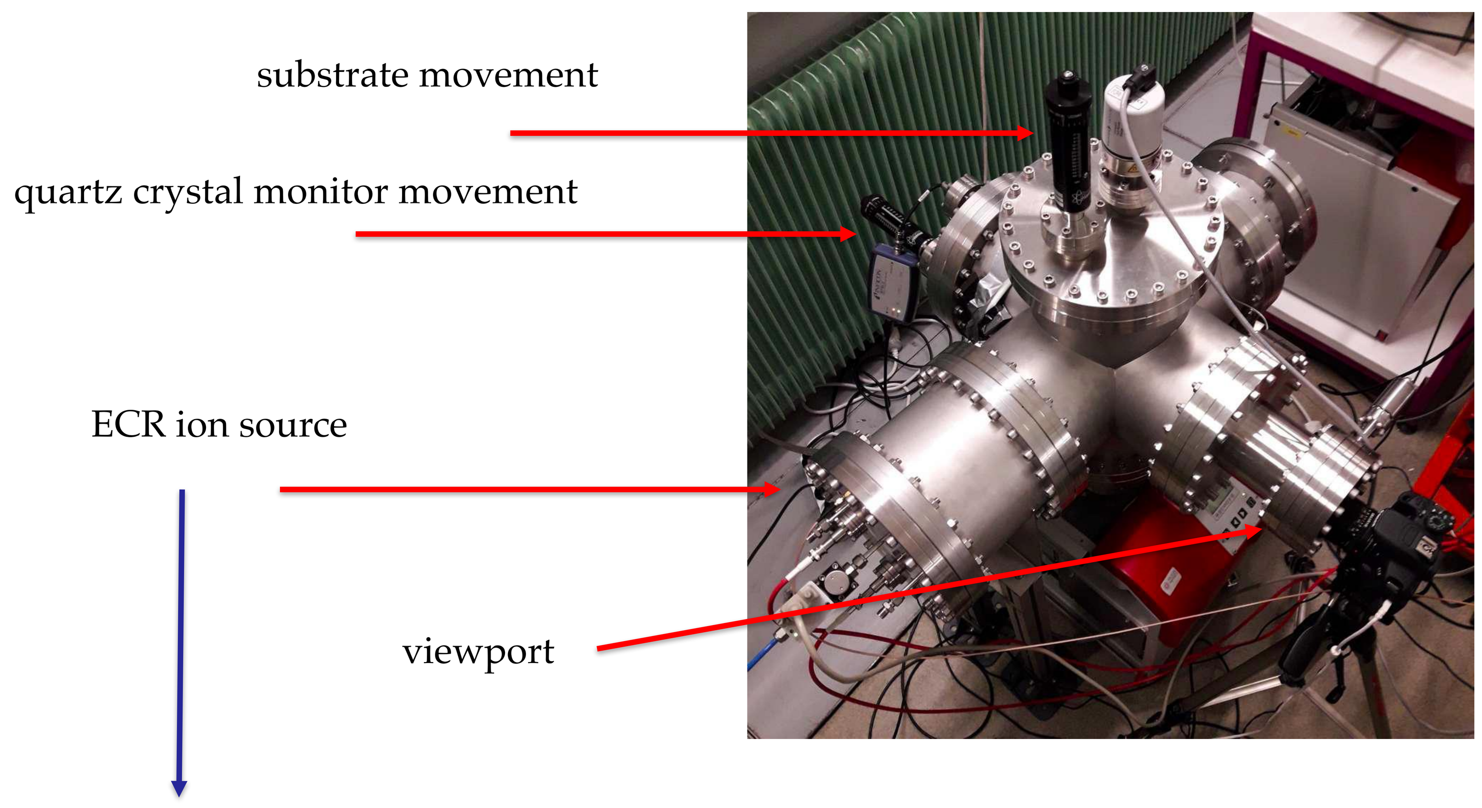


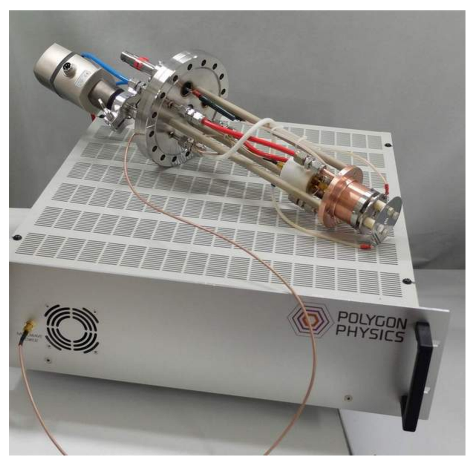
- Tests of backside deep silicon etch on test chips with thermal/PECVD silicon oxide hard masks to find optimum Si/SiO2 selectivity are being performed in Italy (in a private fabrication facility).

Target chamber with integrated gold deposition system

- HOLMES ^{163}Ho ion implanter will be completed by a target chamber, a UHV chamber where the substrate (i.e. the detector array) will be mounted for ^{163}Ho implantation.
- such a chamber needs to include a gold deposition system characterized by compactness, good uniformity of Au deposition over the implanted area and stability over hours of operation.

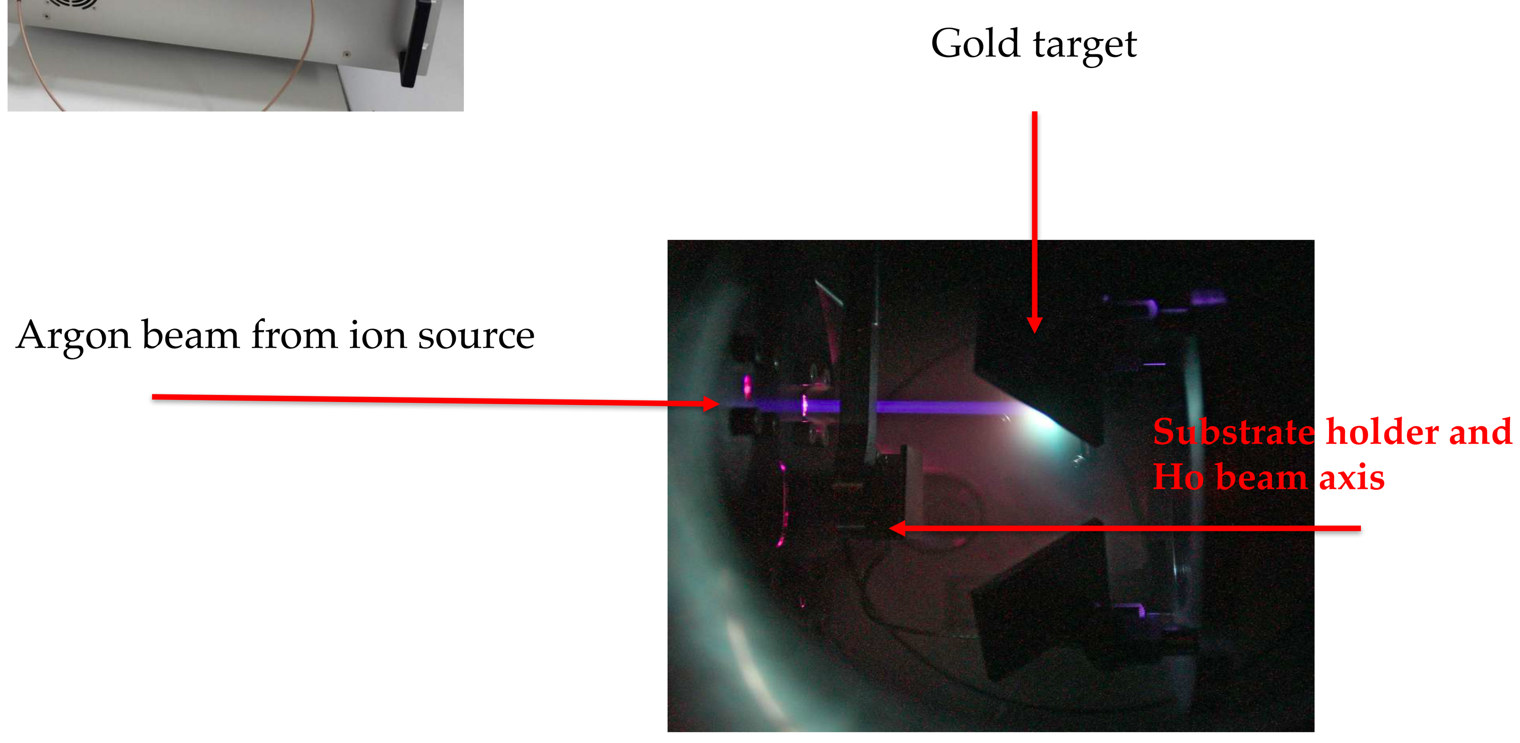
- ➢ defined project of target chamber meeting HOLMES requirements with company Polygon Physics, able to provide a ultra compact/ultra low power electron cyclotron resonance (ECR) ion source[a] for focused gold deposition – system can be upgraded to include four sources, to increase gold deposition rate and/or uniformity over a larger area.
- ➢ construction and first tests at company's site completed - just delivered to Milano





Left: ECR ion source with control electronics

Bottom: picture of ion source's argon beam hitting the gold target during deposition



- Chamber is being setup in Milano
- Need to fully characterize gold deposition system to meet HOLMES detector fabrication and ^{163}Ho implantation requirements

[a] P. Sortais et al., *Review of Scientific Instruments* **81** (2010)

Upcoming goals

- complete silicon deep etch tests on test chips
- start fabrication tests on 4x16 detector arrays (at first without implanted ^{163}Ho), with detector absorbers completed using the gold deposition system in the target chamber

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