Development of a TiAu TES microcalorimter array as a backup sensor for the Athena/X-IFU instrument

K. Nagayoshi[1]*, M.L. Ridder[1], M.P. Bruijn[1], L. Gottardi[1], E. Taralli[1], P. Khosropanah[1], S. Visser[1] and J.R. Gao[1, 2]

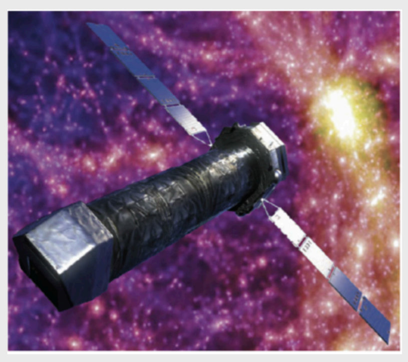
[1]*SRON Netherlands Institute for Space Research*
[2]*Kavli Institute of Nanoscience, Delft University of Technology*

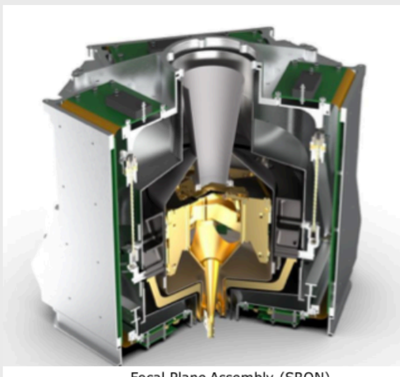
* K.Nagayoshi@sron.nl

Outline

Athena is a future X-ray observatory led by ESA, to be launched in early 2030s. The X-ray Integral Field Unit (X-IFU) instrument on board Athena provides spatially-resolved high resolution spectroscopy of 2.5 eV with a large array of Transition Edge Sensor (TES) microcalorimeters. The main sensor is a MoAu bi-layer TES array provided by NASA-Goddard. Pixels are read out with a frequency-division multiplexing (FDM) readout system developed by SRON, using VTT SQUIDs. Extensive research collaborations between NASA-Goddard and SRON on TES design optimizations under FDM readout have been made resulting in TES design rules such as: low resistivity, moderately high ohmic resistance by changing the TES aspect ratio and no metal strips on the bi-layer. We have been developing a TiAu bi-layer based TES array as a backup sensor for the Athena/X-IFU. We have improved our detector fabrication procedure along the design principles. The bi-layer thickness is Ti 35/Au 200 nm which leads to ohmic resistances that vary from 25 to 150 mΩ depending on the aspect ratios. An X-ray absorber is made of 2.3 μm thick electroplated Au, that is thermally connected to the TES via small stems on the sides of the TES. We fine-tuned Tc to 90 mK and as a preliminary result, the best energy resolution of 2.0 eV has been achieved with a 120x20 μm² TES pixel, showing that our TiAu TES array has a potential to be a real backup sensor for the X-IFU. In this paper, we will present our successful fabrication results.

Athena/X-IFU Instrument

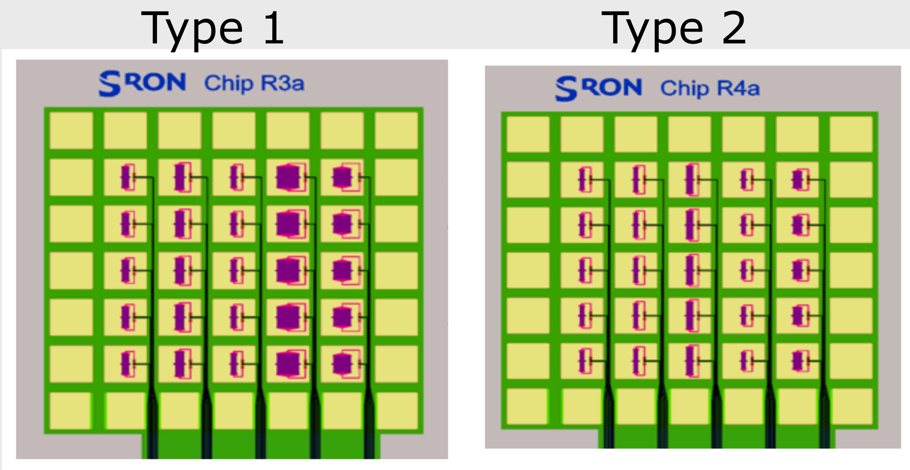



Focal Plane Assembly (SRON)

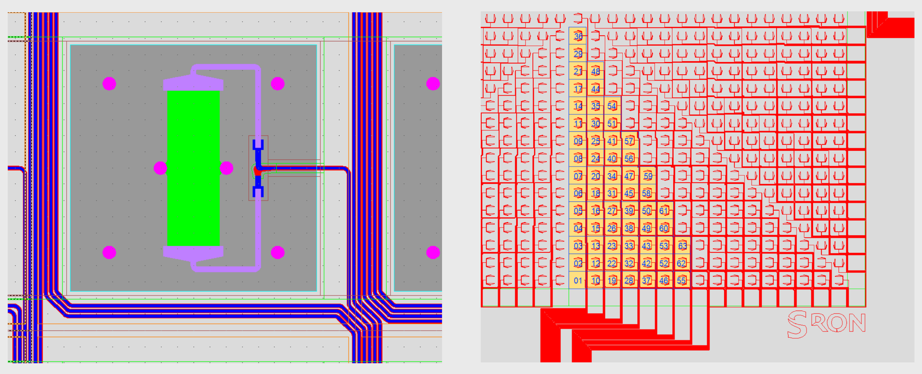
- **Athena** (Barcons+, 2017)
  - X-ray observatory led by ESA, to be launched in early 2030s.
  - provides high resolution (**2.5 eV at 6 keV**) spectral data on hot gases located in various astronomical objects, which are crucial to study how the universe has grown as it is observed today.
- **X-IFU (X-ray Integral Field Unit)** (Pajot+, 2018)
  - Main sensor: an array of ~4000 TES microcalorimeters based on a MoAu superconducting bi-layer (NASA/GSFC) (Smith+, 2016).
  - Read out: FDM readout technique (SRON) (Gottardi+, 2016).
  - SRON is also developing a TES microcalorimeter array based on a TiAu bi-layer as a backup sensor.

TES Design

- **FDM readout system favors a device with moderately high Rn and a bare TES**
  - AC bias (1-5 MHz) related issues such as ac losses and a week-link effect has been identified with TES devices of which Rn ~10 mΩ. Normal metal bar structures on a TES also degrade the performance in terms of stability (see see the poster **97** for more details) (Sakai+, 2018, Gottardi+, 2018).
- **5x5 array**
  - Bi-layer Ti 35/Au 200 nm (25 mΩ/□)
  - Explore an optimal TES geometry.
    - Type 1: 100x30, 120x30, 100x25, 100x100 and 80x80 μm².
    - Type 2: 100x20, 120x20, 140x30, 80x20 and 80x40 μm².

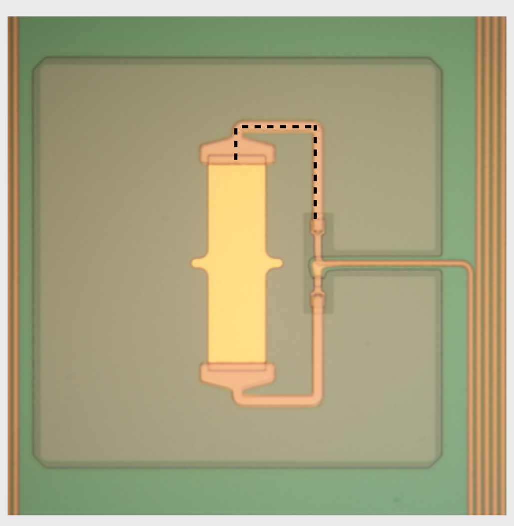


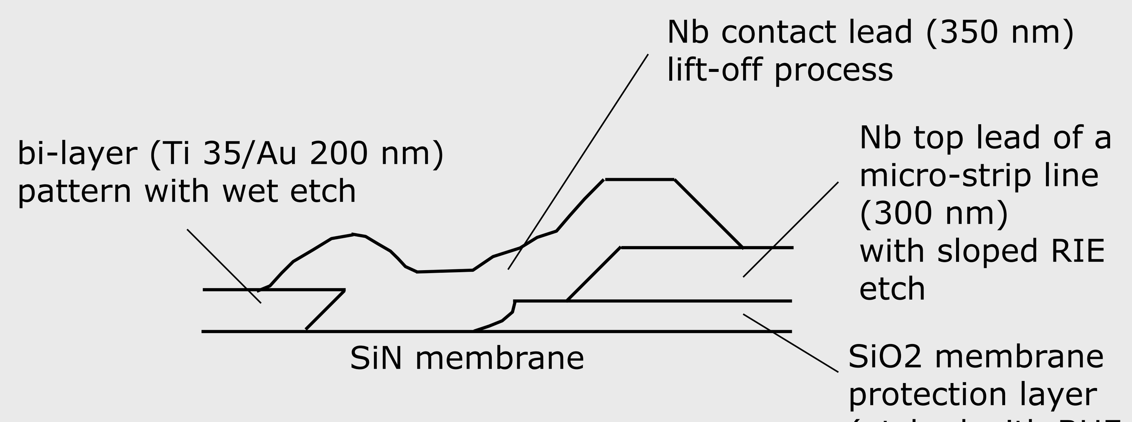
- **32x32 array (kilo-pixel array)**
  - wired with fine-pitch strip-lines compatible with a 4000 pixel array.
  - 256 TES pixels are accessible (64 pixels from each side).
  - Uniform arrays of a TES 100x30, 120x40 and 140x30 μm² are available.
  - Uniformity check + electrical and thermal cross talk studies.



Revising TES Wiring Process

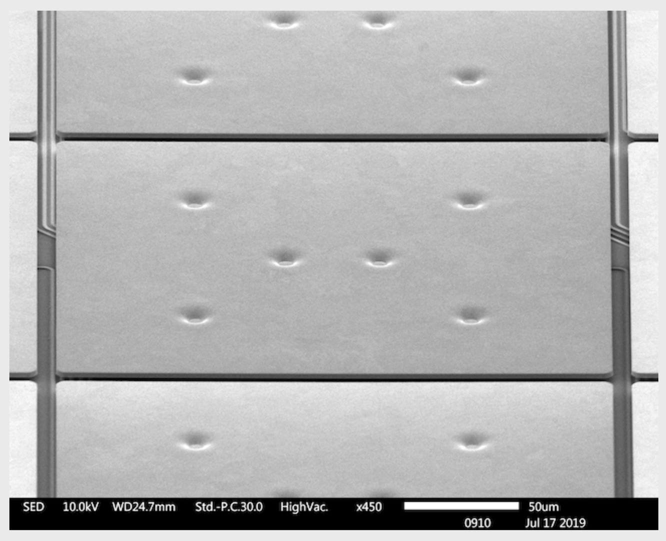
- **Nb residue under the edges of a TES**
  - Significant undercut created by Au wet etch, due to increase of the TES thickness.
  - Nb gets into the undercut cannot be etched away during a RIE etch process for strip-lines, causing a Nb short issue between the electrodes.
- **No Nb residue related to the RIE etch process with a Nb lift-off process**
  - TES bi-layer is deposited after the strip-line process.
  - TES is connected to the strip-line with Nb contact leads fabricated with lift-off.
  - During the strip-line process, a membrane area is protected by a SiO_2 layer. TES can sit on the clean membrane which is important to control Tc reproducibly.



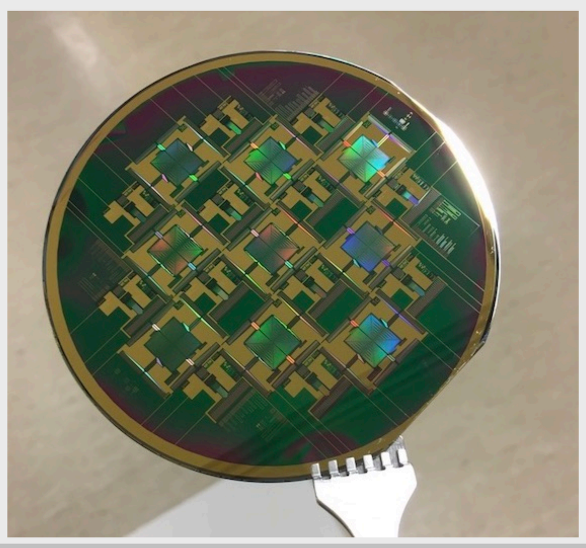


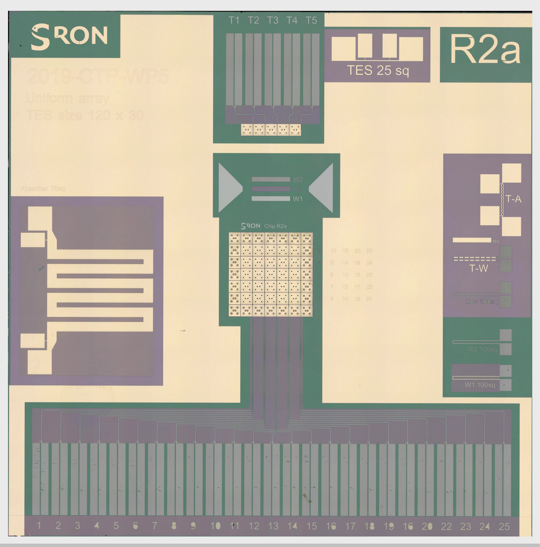
Cross sectional view along with the dashed-line

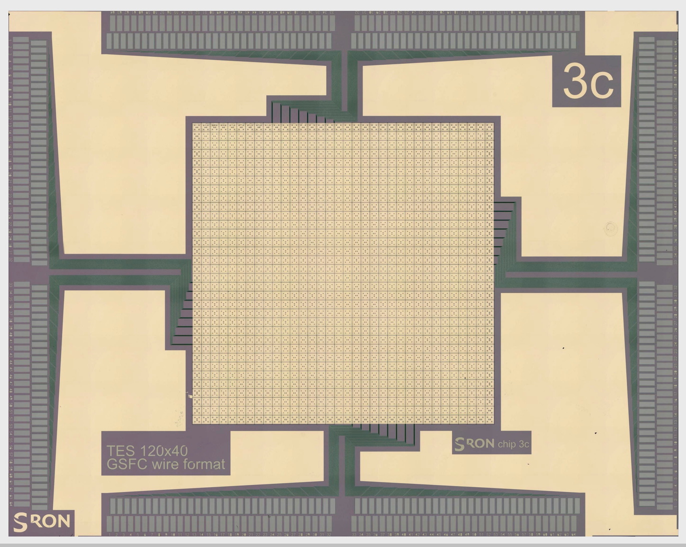
Detector Fabrication



- **X-ray absorber**
  - 2.3 μm thick electroplated Au film (RRR~30 typically).
  - 240x240 μm² pixel with a gap of 10 μm.
  - Heat capacity of 0.85 pJ/K@90 mK.
  - coupled with a TES via the two "stems" (3.5 μm height) located near the center of the pixel.
  - The other four stems stand on a SiN membrane (0.5 μm) produced with deep-RIE Si etch.
- **Frontside and backside metallization of a wafer**
  - Frontside thermalization layer: 0.5 μm thick electroplated Au.
  - Backside heat-sink layer: 1 μm thick EB-evaporated Cu coated with 10 nm Au. Si side walls inside a well formed with the DRIE process are also metallized by using a shadowing deposition technique.
- **Production of 5x5 and kilo-pixel arrays**
  - Many chips were successfully produced from a 4-inch wafer.
  - 2 pixels with an electrical short were detected out of 300 pixels located across the wafer (process yield ~99 %).

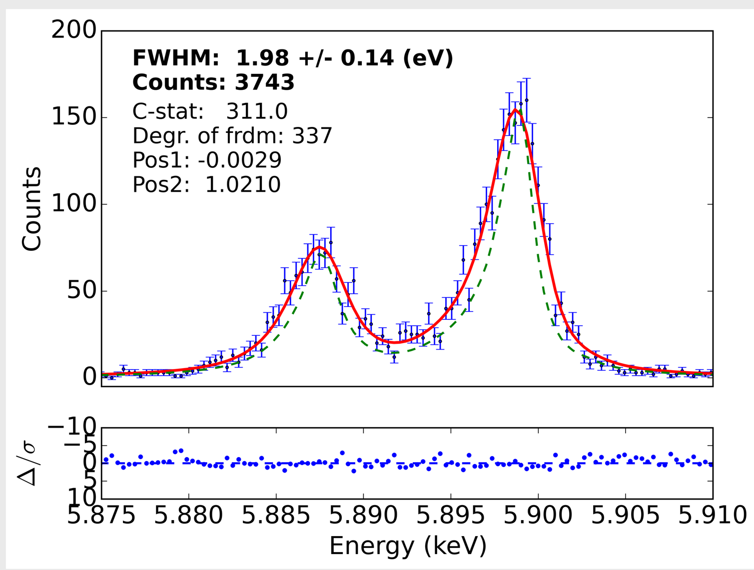






Microcalorimeter Performance and Future Work

2 eV@6 keV has been achieved with a 120x20 μm² TES (Rn 150 mΩ) at 2.2 MHz!!



- 5x5 arrays have been characterized extensively (a talk will be given by Emanuele Taralli and see the poster **97**).
- Tc of ~110 mK was observed initially, although 90 mK was expected.
- Nevertheless, many pixels with various TES geometries have shown encouraging results of 2.4-2.8 eV.
- $\Delta E \propto T_c^{1.5}$. We tweaked Tc in order to obtain 90 mK by "baking" the detector chip for 3 hours at 135 ℃ (determined from experience in the past. Heijden+, 2014).
- **Future works**
  - Measurement of a k-pixel array.
  - Au/Bi absorber to improve quantum efficiency (83 % with the 2.3 um Au absorber).
  - Ti TES contact leads instead of Nb, which can suppress Tc non-uniformity in the TES film (see the poster **351** for more details).

Acknowledgement

This work is partly funded by European Space Agency (ESA) and coordinated with other European efforts under ESA CTP contract ITT AO/1-7947/14/NL/BW and is partly by the European Union's Horizon 2020 Program under the AHEAD project with grant agreement number 654215.

The authors would like to thank F. Dirne, C. de Boer, M. Zuiddam and M. van der Krogt at Kavli nano lab TU Delft for their supports.