Characterization Tests of Thermal Filters for the ATHENA mission X-IFU Low Temperature Detector

Marco Barbera[1,2], Ugo Lo Cicero[2,1], Luisa Sciortino[1], Giancarlo Parodi[3], Fabio D'Anca[4,1], Paolo Giglio[5,4], Salvatore Ferruggia Bonura[1,2], Flavio Nuzzo[1], Antonio Jimenez Escobar[2], Angela Ciaravella[2], Alfonso Collura[2], Salvatore Varisco[2], Valerie Samain[6]

1. Dipartimento di Fisica e Chimica - Università degli Studi di Palermo (UNIPA), Palermo, Italy; 2. Osservatorio Astronomico di Palermo "G. S. Vaiana" - INAF, Palermo, Italy; 3. BCV progetti s.r.l., Milano, Italy; 4. Istituto di BioFisica U.O.S. di Palermo - CNR, Palermo, Italy; 5. Dipartimento dell'Innovazione Industriale e Digitale - UNIPA, Palermo, Italy; 6. Centre Spatial de Liège - Université de Liège, Angleur, Belgium

1. INTRODUCTION

The X-Ray Integral Field Unit (X-IFU) **[1]** is one of the two detectors of the Advanced Telescope for High-ENergy Astrophysics (ATHENA) space mission **[2]**. ATHENA has been selected by ESA in 2014 (launch scheduled in 2028) to address the "Hot and Energetic Universe" science theme **[3]**. The X-IFU will provide spatially resolved high-resolution X-ray spectroscopy from 0.2 to 12 keV, with 5" pixels over a field of view of 5' equivalent diameter and a spectral resolution of 2.5 eV up to 7 keV.

The X-IFU consists of a large array of Transition Edge Sensors (TES) micro-calorimeters with 3840 individual pixels operating at ~ 50 mK inside a sophisticated cryostat. A set of thin filters will be mounted on the windows opened on the cryostat and focal plane assembly thermal/EMI/mechanical shields, in order to allow the focused X-rays to reach the detector and at the same time to attenuate the IR radiative load avoiding energy resolution degradation due to photon shot noise. The thermal filters (TF) will also have to attenuate Radio Frequency EMI onto the detector and the read-out electronics, and to protect the detector from contamination.

We presently consider to use five filters operating at different temperatures, each one consisting of a 45 nm thick polyimide foil coated with 30 nm of aluminum **[4,5]**. In order to provide mechanical support to the thin membranes, to provide RF attenuation in the 1-10 GHz frequency range, and to allow filter de-contamination bake-out, we are currently investigating the use of a metal mesh on each filter. At this stage stainless steel (SS) AISI 304 meshes have been procured and tested.
In order to allow for a uniform illumination of the detector array by the Modulated X-Ray sources, the filter diameters range from 56 to 100 mm, and the distances from the focal plane range from 130 to 240 mm as shown in Table 1 and Figure 1. Table 2 describes the main characteristics of the currently investigated meshes. Both mesh types with hexagonal pattern are made of SS AISI 304 coated with 5 µm of gold to absorb Fe fluorescence lines generated by particles interacting with the SS.

In this paper, we describe the filter samples developed/procured so far, present preliminary results from the ongoing characterization tests, and discuss areas of trade-offs to fully meet the scientific requirements .

TABLE 1. Main characteristics of the presently investigated set of TF.

	T_{SHIELD} [K]	Z* [mm]	I.D. [mm]	Mesh Type	Polyimide [nm]	Al [nm]
TF1	0.050	130	56	1	45	30
TF2	2	150	64	2	45	30
TF3	30	180	76	2	45	30
TF4	100	210	88	2	45	30
TF5	300	240	100	2	45	30

* Z = distance from the focal plane.

TABLE 2. Characteristics of the investigated supporting meshes.

Mesh Type 1: wires cross section = 30 µm x 60 µm (width x thickness); pitch = 2 mm; blocking factor = 4 %
Mesh Type 2: wires cross section = 65 µm x 130 µm (width x thickness); pitch = 5 mm, blocking factor = 3 %

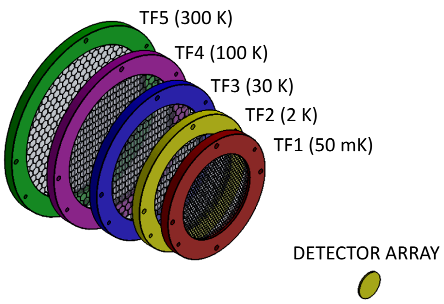

FIGURE 1. Schematic drawing of the investigated set of TF.

2. FILTER SAMPLES

For the **first vibration test campaign,** two filters have been manufactured consisting of a stretched polypropylene membrane (BASF Novolen 1302L) ~ 600 nm thick, coated with 40 nm of titanium, supported by mesh, and mounted on 2-parts type aluminum custom frames representative in size and design to TF5 and TF1 (**samples #1 and #2).** By using a thick polypropylene film (600 nm) instead of thin polyimide (45 nm) the membrane (filter+mesh) stiffness changes by few per thousands, and the areal density changes by few per cents, for this reasons **tests are fully representative of the stress level on the metallic mesh.** A **second vibration test campaign** will be performed in Q4 2017 on smaller size filter samples with 45 nm thick polyimide foil coated with 30 nm of aluminum supported by the same type of meshes (**samples #3 and #4**). Such tests will be **representative of the stress level on the thin polyimide/Al film.** Figure 2 shows pictures of the four investigated filter samples (Table 3).

TABLE 3. List of procured test filter samples.

• **Sample #1:** Polypropylene/Ti, I.D. = 100 mm (TF5), mesh type 2
• **Sample #2:** Polypropylene/Ti, I.D. = 56 mm (TF1), mesh type 1
• **Sample #3:** Polyimide/Al, I.D. = 30 mm (TF2÷TF5), mesh type 2
• **Sample #4:** Polyimide/Al, I.D. = 30 mm (TF1), mesh type 1

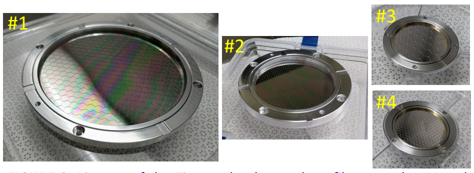

FIGURE 2. Pictures of the Ti coated polypropylene filter samples #1 and #2, and the Al coated thin polyimide filter samples #3 and #4.

3. VIBRATION TESTS

Performed/scheduled vibration tests in 2017 are not qualification tests but development tests to support the filter design. Tested prototypes partially represent the current design, which could still undergo significant changes (materials and geometries) before adoption.
Sine and random vibration tests have been carried out using the shaker model 4522 LX at the Centre Spatial de Liège (Belgium) thanks to the TNA program of the H2020 AHEAD project. The shaker is inside a class 100 environment. Both out of plane and in-plane tests have been carried out. The X-IFU **TF samples have been kept in vacuum during the vibration tests** in order to reproduce the launch conditions and to reduce potential damages from flying particles (Figure 3).

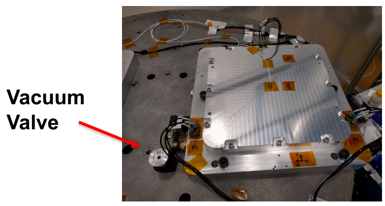

FIGURE 3. Vacuum chamber hosting the TF samples during the tests.

A **high resolution image** of the filter samples has been taken **in transmission and reflection** between nearly every two tests using a photographic scanner Epson Perfection V850 PRO.
The **Reference Vibration Test Levels** have been derived from **Req. # 14** in **APPENDIX A** of the **ESA ITT AO/1-8786** entitled "ATHENA: Large area high-performance optical filter for x-ray instrumentation" (Tables 4 and 5). **Increasing load levels** have been applied to each filter **approaching the reference level.** Lower levels had shorter duration, in order to reduce the risk of fatigue failure.

Table 4. Applied Sine Vibration Levels

S1 = (5-100 Hz, 6.25g (0-peak), Sweep rate = 4 Oct/min)
S2 = (5-100 Hz, 12.50g (0-peak), Sweep rate = 4 Oct/min)
S3 = (5-100 Hz, 18.75g (0-peak), Sweep rate = 4 Oct/min)
S4 – Sine Vibration Ref. Level = (25.0g (0-peak), Sweep rate = 2 Oct/min)

F1 (Hz)	F2 (Hz)	Level
5	25.0	9.9 mm (0-peak)
24.1	26.2	1.5 m/s (0-peak)
26.02	100	25.0g (0-peak)

S5 = (5-100 Hz, 30.00g (0-peak), Sweep rate = 2 Oct/min)
S6 = (5-100 Hz, 35.00g (0-peak), Sweep rate = 2 Oct/min)

Table 5. Applied Random Vibration Levels

R1 = R4 - 9dB (5.99g RMS, Duration = 30 s)
R2 = R4 - 6dB (8.47g RMS , Duration = 30 s)
R3 = R4 - 3dB (12.00g RMS , Duration = 30 s)
R4 - Random Vibration Ref. Level = (16.9g RMS, Duration = 150 s)

F1 (Hz)	F2 (Hz)	PSD
20	100	3.0 dB/oct
100	300	0.5 g^2/Hz
400	2000	-5.0 dB/oct

Max Acceleration = 50.8 g
Max velocity = 0.514 m/s
Max displacement = 1.86 mm

R5 = R4 + 3dB (23.9g RMS, Duration = 150 s)

Both the two X-IFU "dummy" filter samples #1 and #2 have survived **lateral vibration levels according to ESA AO8786 ITT specifications** and **axial vibration levels increased by +10g 0-peak sine load and +3dB random** with respect to ESA A08786 ITT specifications. **Film defects present before vibration tests** (e.g. ripples on the filter) **did not change significantly** also after the highest loads levels (Figure 4 left). About **20 native pinholes** (typical size 50 µm) are found on each filter before the vibration tests. **Pinholes do not seem to have changed after vibrations** (Figure 4 right).

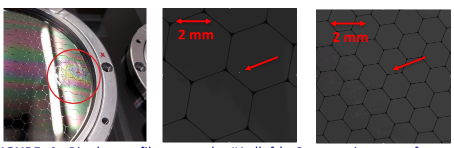

FIGURE 4. Ripple on filter sample #1 (left). Scanner images of small portions of the filter #1 (middle) and #2 (right) showing small pinholes.

Two scratches slightly larger than typical pinholes are found on filter sample #1 **after the last and most severe vibration test**. A few tens of **dust particles are present on the filter since the beginning** (size ranging between 10 and 300 µm). **Most of the particles move around the filter during the vibration tests.**

4. THERMO-VACUUM TESTS

A **first campaign of T-V tests** has been performed using the cryostat of the LIFE facility at INAF-OAPA (Palermo). The sample holder has been designed to accommodate both filter samples #3 and #4 simultaneously (Figure 5). Tests have been performed in a VHV environment (~ $1.2 \cdot 10^{-9}$ mbar).

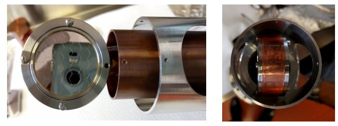

FIGURE 5. Filter samples #3 (left) and #4 mounted together (right) on the cold head of our cryostat for thermo-vacuum tests.

10 cycles have been completed between June 1-9, 2017 according to the following recipe:

- 300 K → 12 K → 300 K @ 3 K/min
- 20 min. hold time at 12 K and 300 K

Images were acquired with the high resolution photographic scanner before and after the first cycle and at the end of 10 cycles. **No evident visible damage or alteration of both filters has been observed.**

5. SUMMARY AND PERSPECTIVES

Vibration and thermo-vacuum tests have been performed on large size filter samples partially representative of the current investigated design. The SS meshes designed on the base of a detailed structural analysis and procured by LUXEL corp. have performed very well under vibration loads significantly higher than required. Future vibration tests will allow us to verify the performance of the thin polyimide/Al foils supported by such meshes. We plan also to perform in the near future static pressure load tests on a few filter samples to measure deformation as a function of applied pressure, necessary to constraint the structural modeling, and to measure the maximum stress that the meshes and the membranes can withstand before plastic deformation and failure.

Thermo-vacuum tests performed on small size partially representative filter samples have also confirmed the reliability of the current investigated TF design under thermal stresses. A new dedicated cryostat is under construction to perform T-V tests on larger size filter samples.

The current investigated X-IFU TF design differs from the baseline design:

1. thinner total layer of polyimide (225 nm vs. 280 nm);
2. thinner total layer of aluminum (150 nm vs. 210 nm);
3. use of metal meshes in place of polyimide meshes.

While the first two points allow the investigated design to be more performing with respect to the baseline at low energies; the use of metal meshes, driven by the need to provide mechanical robustness, RF attenuation, and good thermal conductance, significantly reduces the high energy transmission to a level lower than the scientific requirements.

New structural analysis based on results from mechanical tests will be performed to try and optimize the design of the meshes in order to increase the overall transmission. In addition, modeling and measurements will be performed to verify the RF attenuation of thin Al layers and thus try to release a bit the attenuation requirements on the meshes. Different materials (both meshes and foils) as well as geometries will also be investigated before the TF design needs to be consolidated to start the approach to TRL 5 required before the adoption of ATHENA by ESA expected at the beginning of 2020.

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Contact: Marco Barbera
marco.barbera@unipa.it

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