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AiLoV ET ADVANCED OPTICS LAB @ TOR VERGATA FOR ET

Advanced Coating Studies for the Einstein Telescope:

Optical, Mechanical, and Topo-Morphological Characterization at AiLoV_ET Laboratory in Roma Tor Vergata

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The sensitivity of next-generation gravitational wave interferometers, such as the Einstein Telescope, is fundamentally limited by thermal noise originating from the mirror coatings, especially in the mid-frequency detection band (10–100 Hz). Minimizing this noise is essential to extend the observatory's reach into the universe.
High-reflectivity Bragg mirrors, composed of alternating thin dielectric layers, are crucial for achieving the necessary optical performance. However, these multilayer coatings also introduce Brownian noise due to internal friction at the atomic scale, known as coating thermal noise. In addition to mechanical losses, the optical properties of coatings — including absorption and scattering — are critical factors in managing the high optical powers circulating in the interferometer.
Reducing both mechanical and optical losses requires the development of novel coating materials. Current research focuses on understanding how impurities, atomic structure, and stoichiometry affect these properties, as even slight variations can significantly impact performance at both cryogenic and room temperatures.
A new facility at the University of Roma Tor Vergata is equipped with advanced characterization tools to investigate innovative materials, such as nitrides and complex oxide mixtures, aiming to develop coatings with superior mechanical and optical performance.

The AiLoV_ET Laboratory

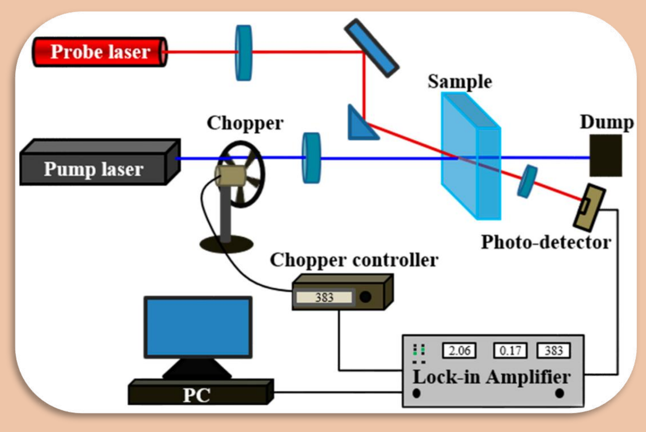
To address these challenges, the AiLoV_ET laboratory has been established in Rome Tor Vergata, dedicated to advanced studies on optical coatings for the Einstein Telescope.


External view of the newly established AiLov_ET laboratories.

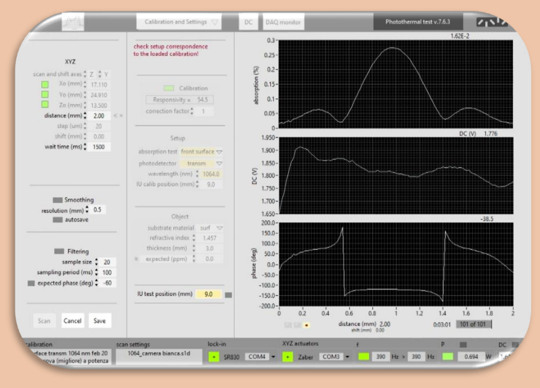

Interior view of the ISO7 cleanroom

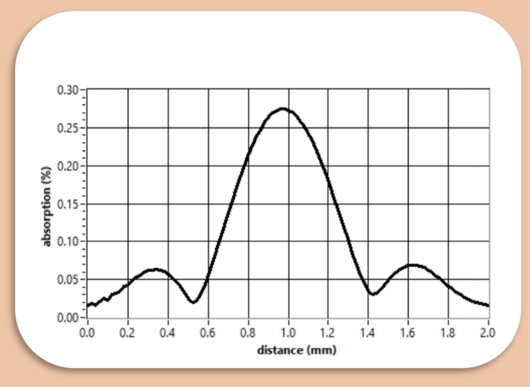
The laboratory includes a state-of-the-art clean room for high-sensitivity optical and mechanical characterization. One of the central instruments is a Photothermal Common-Path Interferometer (PCI), capable of measuring optical absorption at 1064 nm and 1550 nm with extreme precision.


PCI system used for highly sensitive absorption measurements.



Schematic of the PCI setup used in our laboratory. A modulated pump beam induces localized heating in the sample, generating a thermal lens. The resulting phase shift is measured via interference in a common optical path, allowing high-sensitivity absorption measurements.

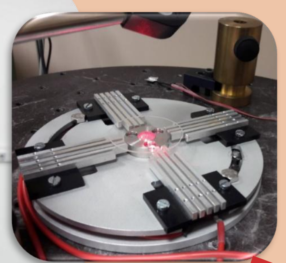

LabVIEW-based graphical user interface (GUI) developed for real-time control and data acquisition in PCI measurements.



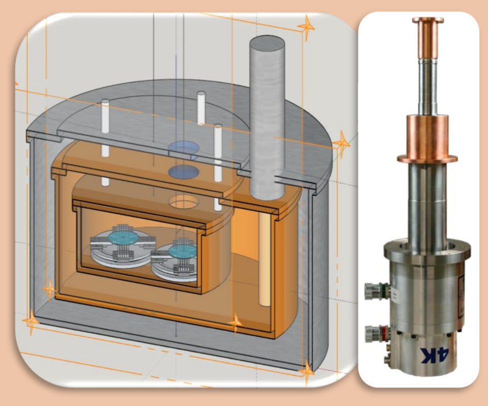
Representative PCI output showing the linear photothermal response from a dielectric coating surface under modulated laser excitation.

For mechanical loss studies, the lab will house two GeNS system (room T and low T), allowing accurate loss angle measurements in materials with ultralow internal friction. The facility also features a sample preparation station, equipped with polishing tools and an ultrasonic cleaning bath to ensure high-quality coating substrates.


Vacuum chamber housing the GeNS system for mechanical loss measurements.


Internal view of the vacuum chamber. The sample is placed on a hemispherical support and excited via adjacent electrodes for mechanical loss measurements.

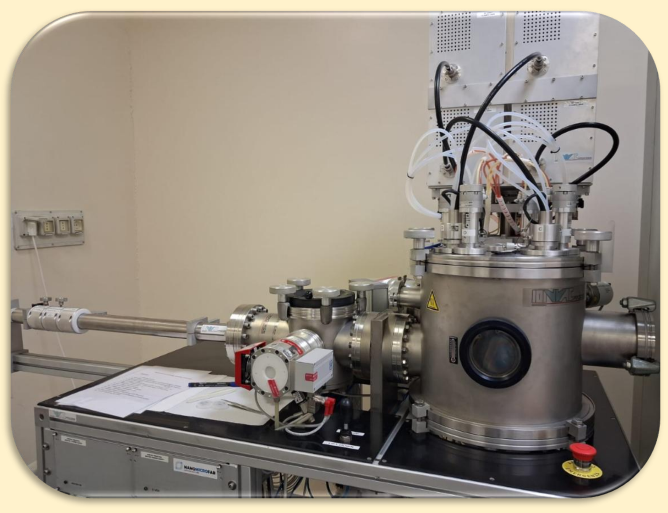

Sample cleaning and handling station inside the cleanroom equipped with pure gases.


Design of the Cryo-GeNS chamber under production equipped with a low vibration GM cryocooler for characterization at low temperatures


Furnace for treatment both in air and in controlled atmosphere with inert gases; located in the adjacent lab, it is part of the equipment used for coatings.

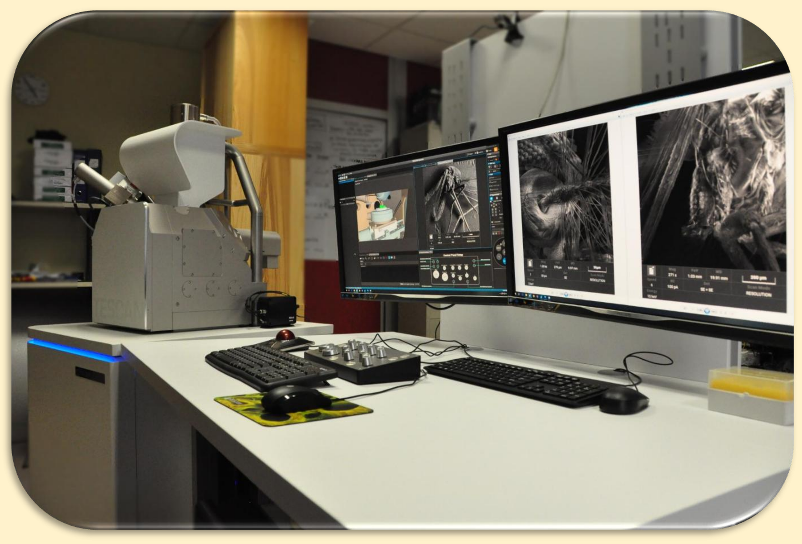
Morphological and Compositional Analysis of Si_3N_4 Coatings

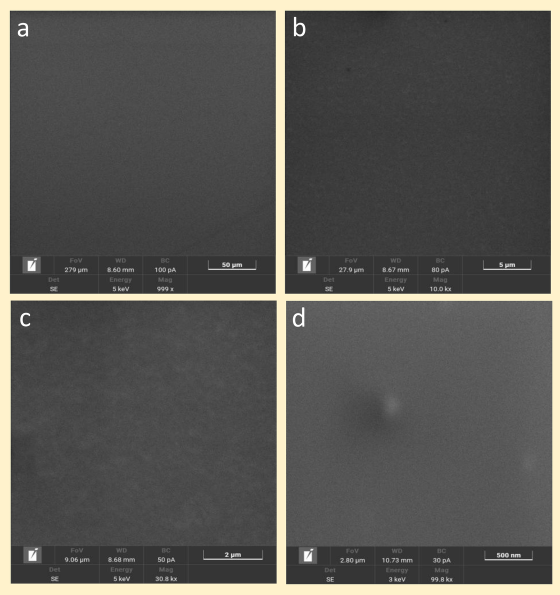
Si_3N_4 thin films were deposited on Si substrates via radio-frequency (RF) sputtering, achieving uniform layers up to 60 nm in thickness.


RF sputtering system used for the deposition of dielectric thin films under controlled plasma conditions.


View through the viewport showing the inside of the RF sputtering vacuum chamber.

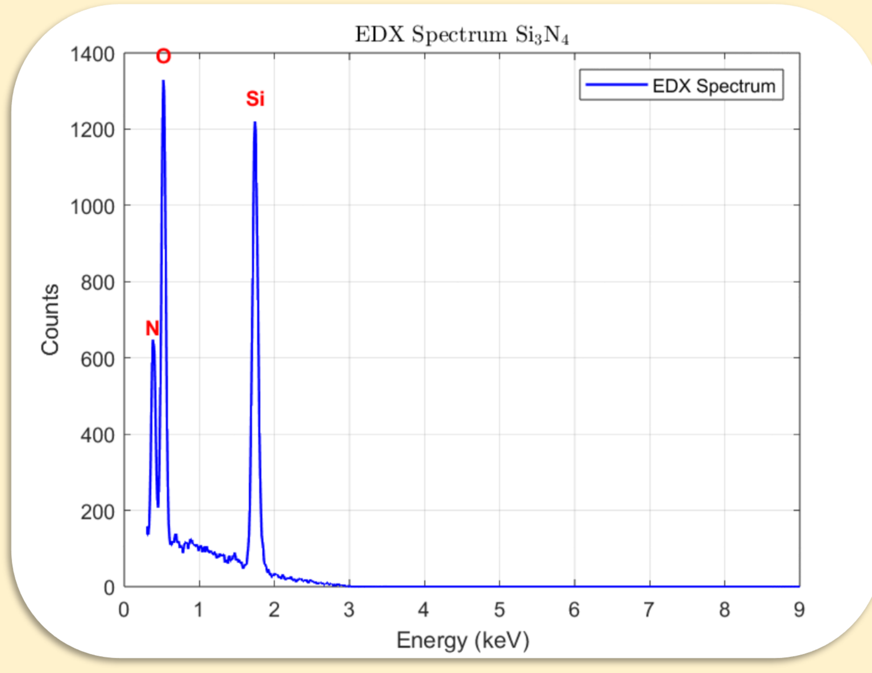
Scanning Electron Microscopy (SEM) imaging revealed high surface uniformity and compact morphology, with no evidence of structural irregularities except for the occasional presence of surface bubbles in the sub-micrometer range, probably due to localized gas trapping during deposition.


Scanning Electron Microscope (SEM) used for morphological and compositional analysis, equipped with an integrated EDX detector.



(a–c) SEM images at increasing magnifications showing the smooth and uniform surface morphology of the sample. (d) High-magnification SEM image highlighting a surface bubble with dimensions on the order of a few hundred nanometers

Energy Dispersive X-ray Spectroscopy (EDX) confirmed the compositional purity of the films, with no detectable contamination or extraneous elements. Spectra were collected at several locations across the sample surface and showed consistent results. Only one representative spectrum is shown. These findings indicate that the deposition process produces high-quality coatings



EDX spectrum of the deposited material showing no detectable impurities, except for oxygen, probably introduced during air exposure

Other facilities available: Annealing, CO2 laser Polishing, Spectrophotometer with integrating sphere, Ellipsometer, AFM, XPS, XRD.

Future development

Planned upgrades to the AiLoV_ET laboratory include the implementation of a cryogenic system for mechanical loss measurements at low temperatures, in alignment with the operating conditions of the Einstein Telescope. A Quadrature Phase Differential Interferometer (QPDI) will also be integrated to enable direct measurements of thermal noise on cantilevers, providing a complementary and sensitive approach to characterize coating losses. Moreover, efforts are underway to increase the thickness of sputtered coatings—both nitrides and oxides—with the target of reaching at least 200 nm, a critical threshold for reliable mechanical characterization. Strategies under consideration include optimizing the current RF sputtering process or adopting alternative deposition techniques capable of producing thicker, high-purity films with controlled stress and surface morphology.