# Structural, Mechanical and Physical Properties Characterization facility for High Performance Materials

*National Centre for Scientific Research "Demokritos" gained extensive know-how and capabilities on multi-purpose characterization of high-performance materials for extreme environments supporting material optimization in the intended application and overall performance improvement. The facilities and know-how have been generated for the characterization and development of fusion structural, high heat flux and functional materials, allowing for dozens of material properties to be accurately determined. Thanks to these remarkable performances, preliminary applications for materials used in aerospace applications have already been found. Material characterization in conjunction with know-how for innovative material development and material testing capabilities are now available for further use in applications where materials are exposed to extreme environments, like Nuclear, Aerospace, Energy systems, Automotive, Marine and Defence sectors.*

## Description of the technology

Radiation damage studies in fusion energy relevant materials and the assessment of the impact of radiation on the physical properties of the materials is of great significance for the development of radiation resistance materials. On the other hand erosion, deposition, and materials migration in fusion plasma devices and fuel retention in plasma-facing components are issues of great importance for the safe operation of fusion devices.

To better understand these phenomena and make predictions regarding the lifetime of components, National Centre for Scientific Research "Demokritos" adopted a combination of material characterization technologies to extensively study properties of high-performance materials subject to extreme environment exposure. Technical features and properties that could be investigated, thanks to available capabilities and facilities include:

- Crystal structure, phase transitions, grain size, residual stresses, texture of bulk materials and coatings as a function of temperature using X-ray diffraction in the temperature range -150 to 1500 °C.
- Structural analysis of films and multilayers (thickness, density and roughness of each layer) using X-ray reflectivity in the temperature range -150 to 800 °C.
- Mechanical properties (hardness, creep, fracture, fatigue, stress-strain, elastic properties) using micro/nano-indentation, universal testing machine, impulse excitation apparatus).
- Materials surface morphology using scanning electron microscopy with high spatial resolution (0.6 nm).
- Transmission electron microscopy for nano-structure investigation.
- Elemental analysis using energy dispersive X-ray analysis and X-ray fluorescence spectroscopy (detection limit at ppm level for elements with Z>11).
- Optical properties of materials (FT-IR transmittance and reflectance, UV-Vis transmittance, diffuse reflectance, photoluminescence, Raman spectroscopy).
- Electrical properties of conductors and insulators as a function of temperature; Dielectric spectroscopy (-196 °C to 500 °C, 0.01 Hz-1 MHz), thermally stimulated currents (-196 °C to 227 °C, 1000 V max applied voltage).
- Magnetic properties of materials in bulk or thin film form as a function of temperature (10 K to 900 K).
- Elemental analysis and depth profiling of materials down to depths of about 10 μm using ion beam analytical techniques.
- Light and heavy ion implantation of materials to modify their properties.
- Open volume defect (from single vacancy to nano-voids) characterization in materials using positron annihilation lifetime spectroscopy.

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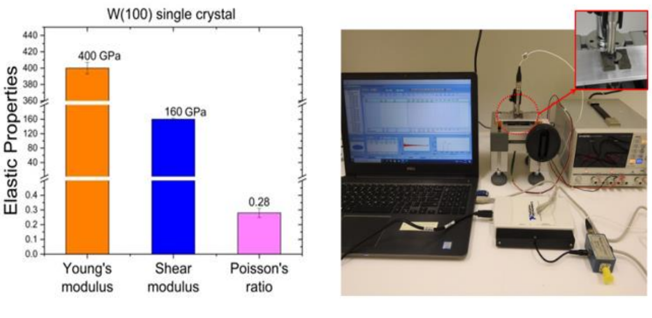
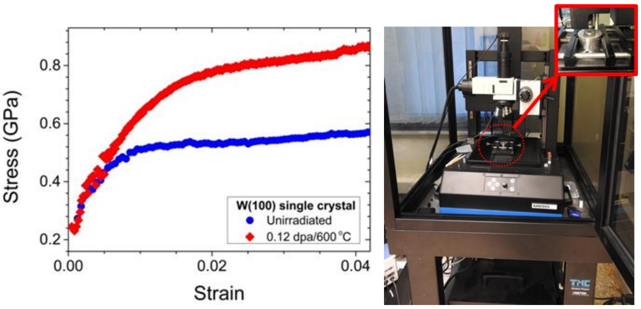
## Description of the technology

The strength of this technology offer is the possibility to combine all the characterization techniques and capabilities listed above for all class of materials (including metallic and non-metallic materials, in bulk or in film structures).

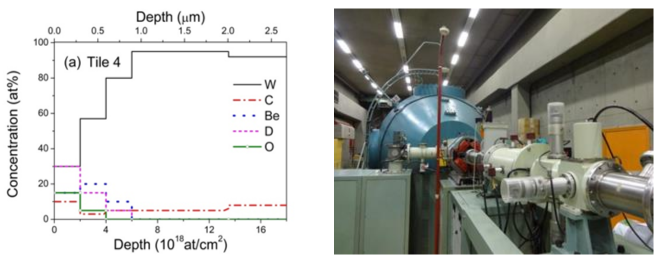
The core research team comprises eight Research Directors and Senior Researchers with over twenty years of experience in structural, mechanical, electrical, magnetic, optical and radiological properties of materials and in material fabrication in bulk and film form. Collaboration and contribution from other research teams at NCSR "Demokritos" are in place and can be utilized for addressing specific material issues. NCSR "Demokritos" employs over 200 researchers in material related areas and has extensive material related research facilities. In addition, there is a strong team in Informatics and Artificial Intelligence (AI) which contributes in the employment of AI in material applications.




Elastic properties of tungsten (W) single crystal (left) measured using impulse excitation apparatus (right).




Stress-strain of tungsten (W) single crystal before and after irradiation (left), measured using depth sensing indentation and a spherical indenter (right)




Depth profile of deposited elements in tungsten JET divertor after plasma exposure (left) employing nuclear reaction analysis with deuterium ions ($^2$H) at the TANDEM accelerator at NCSR "Demokritos" (right)

EUROfusion
TECHNOLOGY TRANSFER PROGRAMME

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## Innovation and advantages of the offer

The most relevant character of the materials characterization approach offered by NCSR "Demokritos" and its main strength is the possibility to combine different material characterization techniques and methodologies to deeply understand material behaviour and further customize performances in accordance with the foreseen application. The combination of several characterization techniques and the know-how on material allows to analyse and develop high-performance materials for different demanding applications. For example for aerospace applications the expertise and facilities have been used in collaboration with Aerospace Industry for the developemnt of a) innovative techniques for the joining of dissimilar materials offering increased shear strength and b) oxidization protective coatings with thermal shock resistance and high temperature operation.

## Non-fusion Applications

The possibility to combine different techniques and finely tune material properties, extensively developed and strengthen in the frame of fusion research to study materials exposed to extreme environmental conditions (e.g. high temperature, high heat fluxes, high radiation) is available to be applied for the characterization of materials subject to demanding environments. This highly accurate characterization procedure is relevant, for example, for Nuclear, Aerospace, Energy systems, Automotive, Marine and Defence sectors.

## EUROfusion Heritage

NCSR "Demokritos" in the framework of the Eurofusion research activities investigated

- Radiation damage effects on the mechanical and structural properties of tungsten (W) materials and iron-chromium (Fe-Cr) based alloys within the framework of the Work Packages MAT-IRRAD and MAT-IREMEV.
- Samples from different areas of the ITER-like wall of the JET tokamak in order to assess material migration and deposition from other places of the tokamak wall and fuel retention, as well as erosion of the sample surface within the framework of the Work Packages JET2 in FP8 and PWIE in FP9.
- Radiological properties of ITER materials in the Work Package JET3 in FP8 and PrIO in FP9.

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