Investigating radiation damage in materials using ion beams

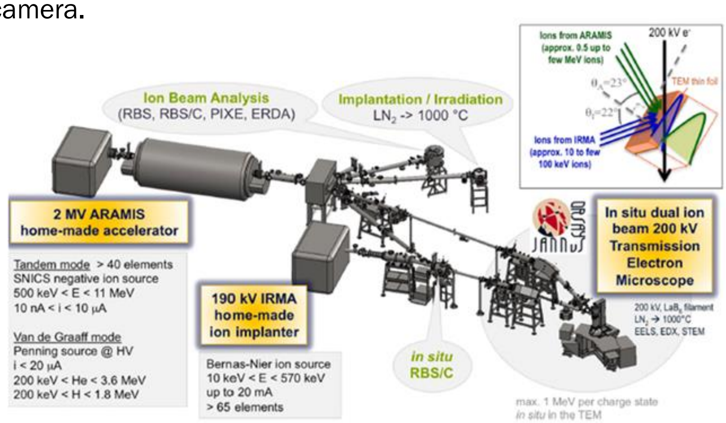
Considering the evolution of microstructures and material properties under extreme radiation conditions, the JANNuS facility has been developed at University Paris-Saclay that allow multi-scale modelling of radiation effects in materials with in situ observations of microstructure modifications. The versatility of conditions in terms of particle energy, dose rate, fluence, etc., is a key asset of ion beams allowing fully instrumented analytical studies. Coupling of two or more beams, use of heated/cooled sample holders, and implementation of in situ characterization and microscopy pave the way to real time observation of microstructural and property evolution in various extreme radiation conditions more closely mimicking the nuclear environments. Many promising applications in electronics, space, geology are considered.

Description of the technology

JANNuS platform for 'Joint Accelerators for Nanosciences and Nuclear Simulation' in Orsay comprises one ion implanter and one accelerator. This platform offers the opportunity to perform fully instrumented irradiation experiments on advanced materials which may be supplemented by in situ characterization techniques such as Transmission Electron Microscopy or Ion Beam Analysis (IBA). Particle beams make it possible to irradiate small samples in a perfectly controlled manner, and thus to observe and quantify the evolution of their microstructure (segregation, precipitation, formation of dislocation loops, cavities, bubbles, etc.) and service properties.

The JANNuS-Orsay in situ dual ion beam TEM facility at CSNSM, CNRS/IN2P3 and Université Paris-Saclay, is composed of a 2 MV Tandem-Van de Graaff homemade ion accelerator (called ARAMIS), a 190 kV ion implanter (called IRMA), and a 200 kV Transmission Electron Microscope (TEM). JANNuS-Orsay is operating according to three modes: i) TEM+IRMA ion implanter, ii) TEM+ARAMIS ion accelerator and iii) TEM in dual ion beam mode (TEM+IRMA+ARAMIS). The temperature range from 77 to 1300 K, allow in situ observation and analysis of the material microstructure modifications induced by single or dual ion implantation/irradiation. More than 40 elements from H to Yb can be produced from their ion sources, and both beams are rastered during ion implantation/irradiation, so that ion irradiation of the observed zone is homogeneous. Inside the TEM, the typical range of beam energies available depends on elements and is within 10–500 keV for the IRMA 190 kV ion implanter and 0.5–6 MeV for the 2 MV ARAMIS ion accelerator. The measurements of the flux and fluence are given with an accuracy of 10%. The typical flux range measured in the microscope, depending on elements and energies, is between approximately 1×109 cm−2.s−1 and 5×1011 cm−2.s−1. The two ion beam lines have a 45° angle between them, and 22° with respect to the surface normal direction, as shown in the inset in Fig. 1. The TEM is a 200 kV FEI Tecnai G2 20 Twin equipped with a LaB6 filament, with a spatial resolution of 0.25 nm. Images and videos are recorded using a 2k×2k CCD high-resolution camera, with 30 frames per second recording, or a high speed and wide area-imaging camera.

Overview of the JANNuS-Orsay facility, showing the coupling between the Transmission Electron Microscope and the two ion accelerators. The inset shows the geometry of the in situ TEM experiment with two ion beams.



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Innovation and advantages of the offer

The value proposition of the facility is that it allows multi-scale modelling of radiation effects in materials with in situ observations of microstructure modifications. It is then possible to perform fully instrumented irradiation experiments on advanced materials, to irradiate small samples in a perfectly controlled manner.

- Real time observation and in situ quantification of microstructure evolution and service properties
- Big versatility of conditions in terms of particle energy, dose rate, fluence,
- mimic of the nuclear environments
- curtail the global cost

Non-fusion Applications

The multi-scale modeling of radiation effects in materials with in situ observations of microstructure modifications could find a lot of promising applications where radiation are met: for example, Fission material transformation, space environments, Electronic/microelectronic and geology.

EUROfusion Heritage

Ion accelerators have been used by material scientists for decades to investigate radiation damage formation in nuclear materials and thus to emulate neutron-induced changes. Several classes of materials are of interest for the nuclear industry ranging from metals and alloys, to oxides or glasses and carbides. The laboratory has been involved in multiple EUROfusion related activities, especially with the work packages MAT IREMEV (Irradiation Effects Modelling and Experimental Validation)

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