First test of graphenic carbon vacuum windows with heavy ions

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Currently, one of the main concerns in experiments involving high-luminosity hadron beams is the limitations imposed by the materials directly interacting with the beam. Beam windows are essential components in every accelerator and many experimental systems, and they experience enhanced radiation damage, high operation temperatures, and high thermal and transient stresses, adding to pressure differences between the beam vacuum and atmosphere. Graphenic carbon membranes are an excellent replacement for conventionally used window materials such as steel, beryllium, aluminum, or Inconel alloys because of their low atomic number and excellent thermomechanical properties. The excellent mechanical properties and molecular impermeability of suspended graphenic carbon membranes[1,2] make them an ideal vacuum window material with an extremely low window thickness that meets the mechanical stability requirements.

Due to the ultrahigh electron transmissivity in a wide electron energy range, high electrical conductivity, and high chemical stability of suspended graphenic carbon membranes, their use as a vacuum window material is currently being explored, and they are being implemented in fields such as electron microscopy and X-ray photoelectron spectroscopy. In a recent development, a novel x-ray transmission window based on polycrystalline graphene or graphenic carbon (GC) has been developed[1,2] as a replacement for the beryllium transmission windows in X-ray detectors. A maximum burst pressure of about 0.5–0.6 MPa at a window thickness of 1 μm and a diameter of 7.5 mm has been reported in Ref. 2).

The work outlined here aims intended to explore the outstanding mechanical properties demonstrated by the above-mentioned GC X-ray window within the context of hadron beams. As the first step, different aspects of irradiation-induced damage in the material were investigated in detail using 200 particle nA, 5 MeV/nucleon ^{20}Ne ion beam from the AVF accelerator at RIKEN. GC samples were placed at the E7B target position and irradiated. The total dose of each irradiation procedure was quantified by measuring the beam current with an accuracy of 5%. A collimator slit of a 3 mm width was used to limit the beam size on the samples. A Faraday cup downstream of the collimator was used to quantify the fluence.

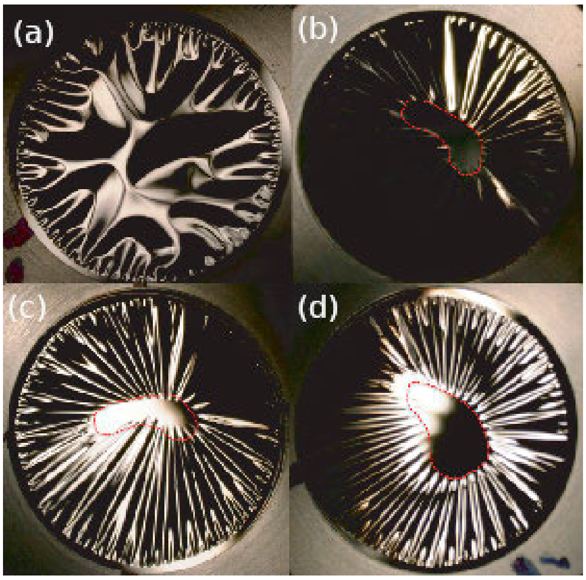

Fig. 1. (a) Non-irradiated sample. Foil irradiated at 200 particle nA for (b) 1 h 51 min at a total fluence of 9.7×10^{16} particles/cm^2, (c) 3 h 30 min at a total fluence of 2.1×10^{17} particles/cm^2, and (d) 10 h at a total fluence of 2.1×10^{17} particles/cm^2. Although the beam was collimated using a 3 mm collimator slit, the obtained beam spot was "comma" shaped with a non-uniform intensity distribution. This is reflected in the shape of the beam-induced compaction (marked with red dotted curves).

Five graphenic carbon samples of thickness 1 μm and diameter 7.5 mm were irradiated for different time intervals (fluences ranging from 9.7×10^{16} particles/cm^2 to 9.7×10^{17} particles/cm^2) to study the evolution of irradiation-induced structural change.

The foil could mechanically withstand a 200 particle nA DC beam up to 10 h. A detailed investigation of the effects of irradiation-induced damage in the material is ongoing at the University of Münster and at GSI using Raman spectroscopy, scanning and transmission electron microscopy, and nanoindentation.

The next step will be to evaluate the performance under pressure during the irradiation under a differential helium pressure of 0.2 MPa across the membranes while monitoring the evolution of helium leakage. This will check the feasibility of the GC vacuum window as a candidate for hadronic ion beams.

References

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2) S. Huebner *et al.*, IEEE Trans. Nucl. Sci. **62.2**, 588 (2015).

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