

Ion Implantation into Semiconductors using Ionic Liquid Ion Sources

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Ionic liquids are salts comprised purely of ions that exist in the liquid phase at temperatures below 100°C. An Ionic Liquid Ion Source (ILIS) utilises field evaporation to produce a beam of ions from this novel type of liquid. ILIS consist of a sharp emitter needle and an extractor. A potential difference is applied between the emitter and the extractor, deforming the liquid into a sharp meniscus from which ions are evaporated. ILIS can provide positively or negatively charged beams for material processing and focused ion beam (FIB) applications¹. ILIS has been shown to reactively etch silicon², producing competitive sputtering yields compared to liquid metal ion sources (LMIS).

This work will present atom probe tomography (APT) data showing ion implantation into semiconductor substrates caused by irradiation with ILIS beams. APT is a characterisation technique which produces three-dimensional atomic composition maps at sub-nanometer spatial resolutions. FIB is used to shape a sample into an APT specimen needle with a 50-100 nm apex diameter, and field evaporation assisted by a laser is then used to strip atoms from the specimen and perform the tomographic reconstruction. APT has been used to characterise ion implantation from other FIB ion sources, such as Xe into Si³.

APT data will be presented for irradiations of Si substrates using filtered and unfiltered beams from 1-ethyl-3-methylimidazolium tris(pentafluoroethyl)trifluorophosphate (EMI-FAP) and 1-ethyl-3-methylimidazolium tetrafluoroborate (EMI-BF₄) in both positive and negative polarities at beam energies of up to 15 keV using a custom-made ILIS setup, shown in Figure 1. Samples have been prepared using a TFS Helios Ga FIB and a TFS Hydra plasma FIB. An APT reconstruction of a Si substrate irradiated with a filtered beam of EMI⁺ ions at 4.2 keV is shown in Figure 2, displaying the implantation of carbon at depths of up to 10 nm. This work will be complemented with secondary ion mass spectrometry (SIMS) data to show changes in chemical composition on the substrate.

¹ Zorzos, A.; Lozano, P. The use of ionic liquid ion sources in focused ion beam applications. *J. Vac. Sci. Technol. B* 2008, 26, 2097–2102.

² Perez-Martinez, C.; Guilet, S.; Gogneau, N.; Jegou, P.; Gierak J.; Lozano, P. Development of ion sources from ionic liquids for microfabrication. *J. Vac. Sci. Technol. B* 2010, 28, L25-L27.

³ Estivill, R.; Audoit, G.; Barnes, J.; Grenier, A.; Blavette, D. Preparation and Analysis of Atom Probe Tips by Xenon Focused Ion Beam Milling. *Microscopy and Microanalysis* 2016, 22 (3), 576-582.

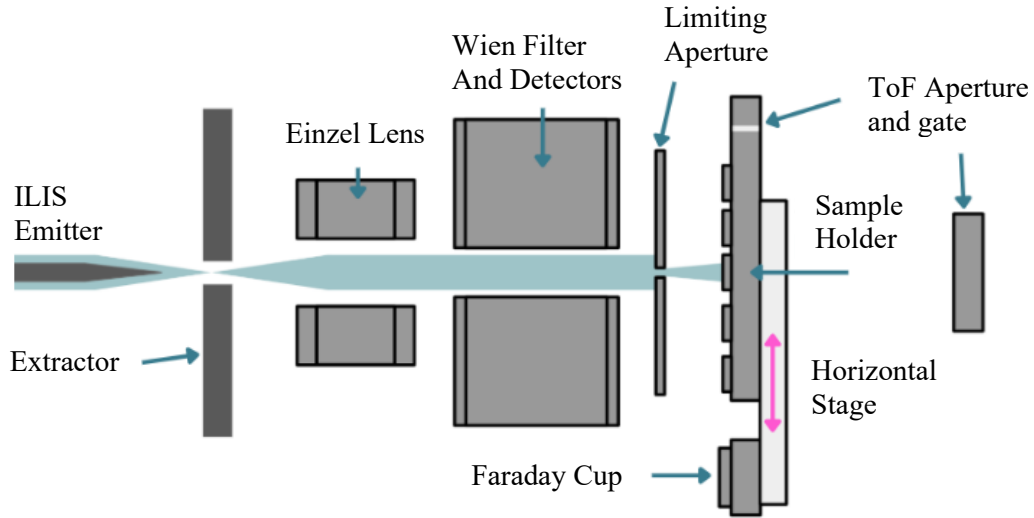


Figure 1: A simplified schematic diagram of the custom ILIS irradiation setup, consisting of an emitter, extractor, Einzel lens, Wien filter and deflectors, a limiting aperture, sample holder, Faraday cup and the ToF gate. Note that there is a ToF detector much further along the ion beam's path

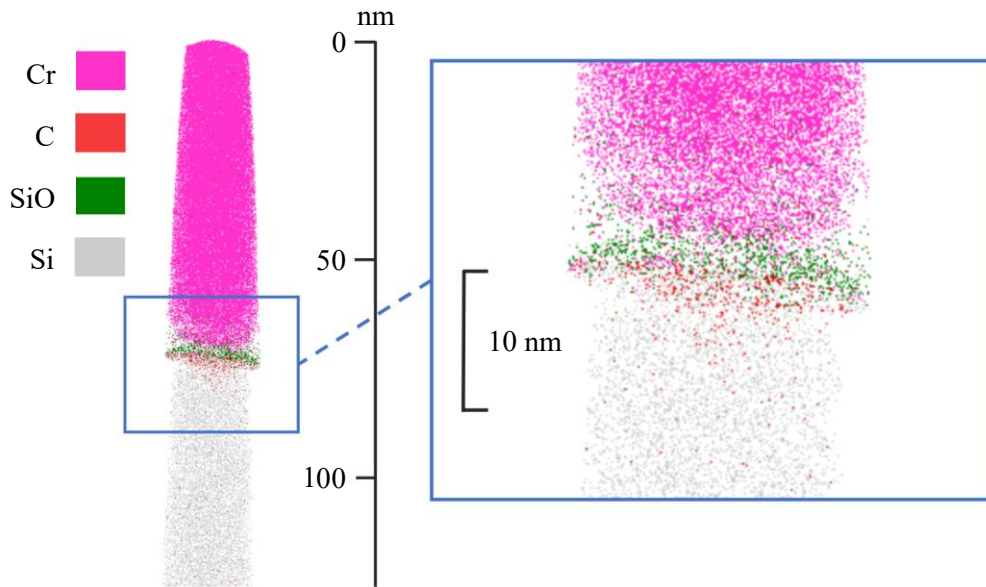


Figure 2: An atom probe tomography reconstruction of a specimen prepared from Si sample irradiated with a pure EMI+ beam. The grey points represent Si atoms, green points represent SiO, red points represent C, and pink points represent Cr, which was added as a sacrificial coating layer. The magnified image on the left shows some C atoms implanted within the first 10 nm of the Si. Data was taken using a Cameca LEAP 5000 XR Atom Probe.