A high brightness source of energetic helium atoms for neutral particle lithography

Venu Sushir, Navjot S. Randhawa, Hong-Jie Guo, Barry Craver, Apeksha Awale, Pratik Motwani, and John C. Wolfe (wolfe@uh.edu)

Nanosystem Manufacturing Center, Texas Center for Superconductivity, and Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204

The helium ion microscope has enabled novel devices, including planar high temperature superconducting tunnel junctions[1] and graphene nanoribbons,[2] based on displacement damage to single crystal substrates. There are more subtle possibilities with untapped potential; Causer et al.,[3] for example, have shown chemical mixing in $FePt_3$ without disrupting the crystal lattice and molecular dynamic simulations[4] suggest the possibility of forming graphene nanoroads[5] by selectively desorbing F from fluorographene with low energy Xe ions. In this paper, we describe a source of energetic He atoms for use in a proximity printing tool with the throughput and depth-of-field required for system-level studies of these intriguing technologies. Neutral particles are required since they are immune to charge build-up on the mask and substrate. [6] A very small virtual source and large angular current density are needed to supply the staggering doses (3-4 orders of magnitude larger than in lithography) required for nanoscale substrate modification.

Fig. 2 shows the new source. He^+ ions are extracted from a multi-cusp ion source, accelerated and focused by a 2-electrode lens, and neutralized in a high pressure, charge-transfer cell filled with thermal He gas. The main idea is to place the cell as close as possible to the final electrode. This reduces the cross-over (the virtual source) diameter by minimizing space-charge bending of ion trajectories within the cell. At 50 keV, the source size and brightness are 50 μm and 2,540 A/cm^2-sr, resp. In the present configuration (8M beamline and 5 μm proximity gap), penumbral blur=0.031 nm (2σ), current density=0.156 μA/cm^2; beam diameter=50 mm, and the PMMA exposure time is 12 s. Reducing the beamline to 1 M reduces exposure time to 0.2s, while penumbral blur (0.24 nm) remains small enough to provide nanometer resolution. We will discuss the low voltage characteristics of the source for each of the noble gasses at the conference.

---

[1] Shane A. Cybart, et al. , "Nano Josephson superconducting tunnel junctions in $YBa_2Cu_3O_{7-\delta}$ directly patterned with a focused helium ion beam," Nature Nanotechnology **10**, p. 598 (2015).

[2] Ahmad N. Abbas, et al. "Patterning, characterization, and chemical cSensing applications of graphene nanoribbon arrays down to 5 nm using helium ion beam lithography," ACSNano **8**, pp. 1538–1546 (2014).

[3] Grace L. Causer, et al. "The microstructural evolution of chemical disorder and ferromagnetism in He^+ irradiated $FePt_3$ films," Applied Surface Science **459**, Pages 672-677 (2018).

[4] O. Lehtinen, et al., "Effects of ion bombardment on a 2-dimensional target: Atomistic simulations of graphene irradiation," Phys. Rev. B **81**, 153401 (2010).

[5] Withers et al., "Nanopatterning of Fluorinated Graphene by Electron Beam," Nano Lett. 11, 3912–3916 (2011).

[6] B. Craver, H. Nounu, J. Wasson, and J.C. Wolfe, "Neutral particle proximity lithography: Non-contact nanoscale printing without charge-related artifacts,"J. Vac. Sci. Technol. B **26**, pp. 1866-1870 (2008).

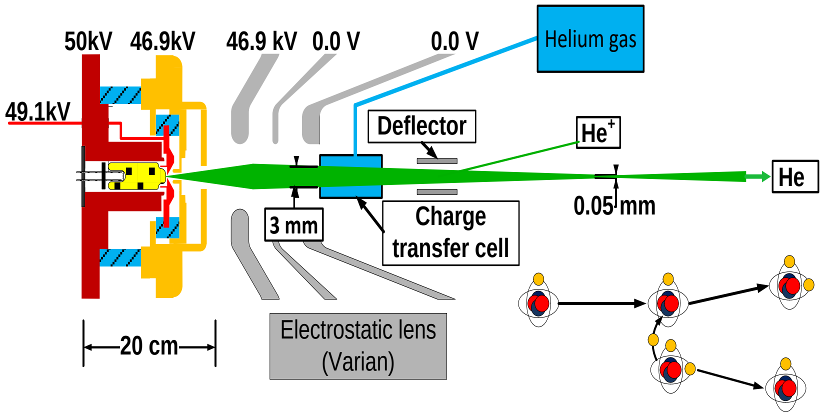

Figure 1: Schematic of the 50 keV helium atom source. Ions are extracted from a multi-cusp ion source, accelerated by a 2-electrode lens, and neutralized in a charge transfer cell filled with thermal He gas. The neutralization process, lower right, involves charge transfer scattering, where an electron is transferred to a positive energetic ion by an atom in the helium ambient.