Understanding and Controlling the Beam Energy Spread of Ionic Liquid Ion Sources for Focused Ion Beam Applications

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Ionic liquid ion sources (ILISs) have attracted a great deal of attention as through their use of ionic liquids (ILs) with high conductivity and low vapor pressure at room temperatures, they can emit beams with unique properties via a strong electric field formed around an emitter protrusion. The energetic beam ions (generally at 2-3 keV) have been utilized in electrospray thrusters with IL propellants previously.[1] The beam can be composed of monomer molecular ions (A+, B-), dimers ([AB]A+, [AB]B-), or larger molecules ($[AB]_n$A+, $[AB]_n$B-). The collision of this complex beam of particles with a target initiates momentum transfer with target. The milling of target material and emission of secondary species from the target have become of interest especially for focused ion beam (FIB) applications[2] (e.g., lithography) and secondary ion mass spectrometry (SIMS)[3] providing an alternative to traditional liquid metal ion sources.

A beam source capable of working with a variety of different IL compositions in each polarity provides flexibility in surface processing, however; an IL ion beam consisting of monomers and polymers can go through multiple fragmentation processes due to Coulombic and thermal forces as reported in the literature.[4] Understanding the effects of fragmentation on the ion beam energy distribution and utilizing this fragmented beam of ions for FIB applications presents a two-step goal for our study. Firstly, we will analyze the beam energy with a retarding potential analyzer (RPA) with two different ionic liquids: 1-ethyl-3-methylimidazolium tetrafluoroborate (EMI-BF_4) and 1-ethyl-3-methylimidazolium tris(pentafluoroethyl)trifluorophosphate (EMI-FAP). Larger variation in beam energy (ΔE) is an undesired aspect for localized surface modifications. Secondly, we will place a gold target at a distance to study the etching rate with ion beam for a certain time (Figure 1). This study will be accompanied with a time-of-flight (ToF) mass spectrometer to investigate the departing particles (sputtered ions and fragments) from the surface by placing the target at a 45-degree angle (Figure 2). We aim to demonstrate the potential of ILISs for FIB applications while addressing the inherent challenges of the implementation and investigating the effects of electric field via simulations and experiments.

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[1] C. Ma and C. Ryan, Journal of Applied Physics 129, 083302 (2021).

[2] T. Xu, et al., Journal of Vacuum Science & Technology B 36, 052601 (2018).

[3] Y. Fujiwara and N. Saito, Journal of Vacuum Science & Technology A 39, 063218 (2021).

[4] N. Nuwal et al., Journal of Applied Physics 130, 184903 (2021).

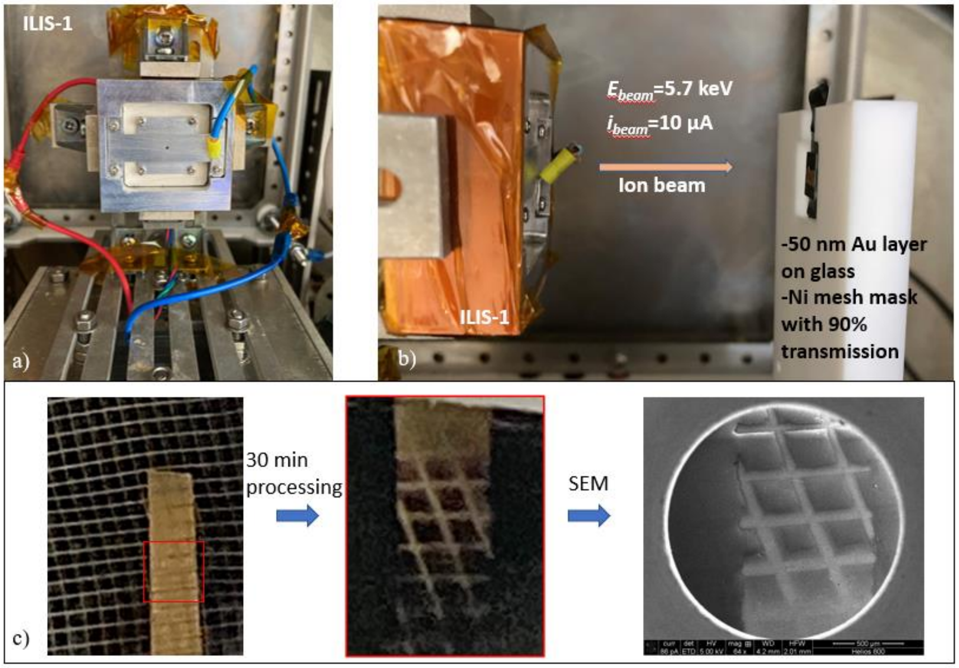

Figure 1: a) Ionic liquid ion source (ILIS) testbed for focused ion beam (FIB) applications. b) Gold coated glass sample attached to a grounded sample holder. c) Pictures showing before and after gold sample treated for 30 min with EMI-BF$_4$ anions.

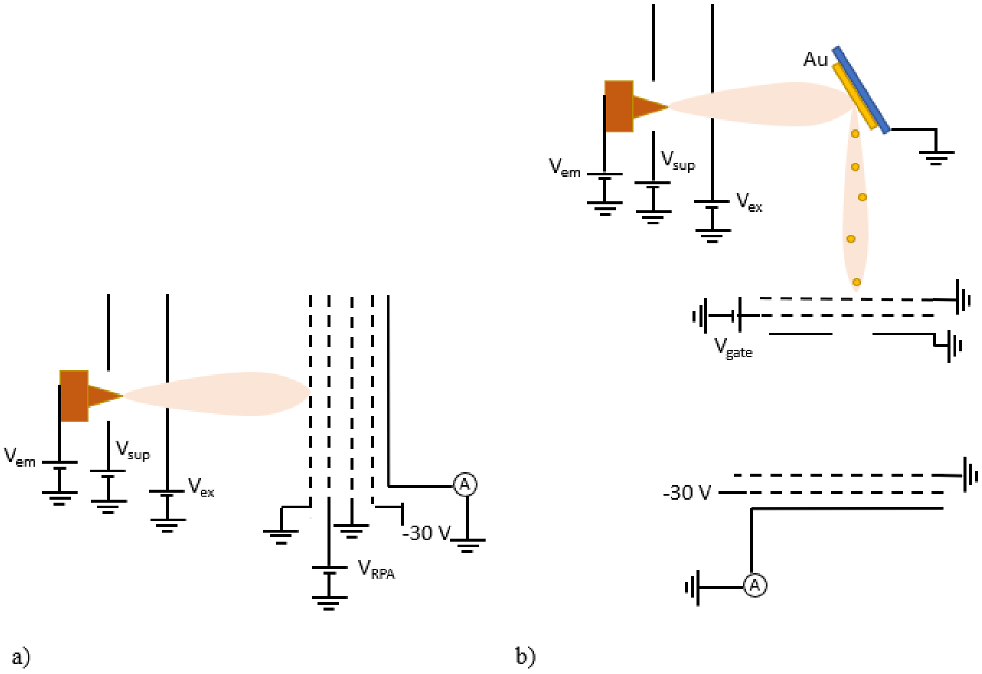

Figure 2: a) Schematic of the experimental setup with a retarding potential analyzer (RPA). b) Schematic of the experimental setup with a gold target and time-of-flight system.