Development of a low energy neutral particle printer for atomically precise patterning of desorption resists

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Atomically precise control of lateral dimensions far beyond the limit of conventional lithography is necessary for nanoelectronic circuit manufacturing. Today, this can only be achieved by direct-write patterning of *desorption resists* with a scanning tunneling microscope (STM). The approach has been particularly successful in *hydrogen depassivation lithography*, where the STM *selectively* removes hydrogen atoms from a passivated silicon surface, creating a pattern of chemically active sites that guides template-growth of chemical vapor deposited metals, insulators, semiconductors, and dopants.[1] Scalability of STM lithography is very limited, however, as the single-tip removal rate is only about 50 atoms /second. The scaling of *desorption lithography* to nanoelectronic systems of IC complexity requires bridging the *roadblock* of ultra-low STM throughput. Our goal is to develop a high-throughput, parallel exposure technique for atomically-precise patterning of desorption resists. Our approach is based on neutral atom proximity lithography where a beam of neutral atoms illuminates a stencil mask and transmitted beamlets transfer the mask pattern to resist on a substrate. An example with promising energetics is the formation of semiconducting graphene strips by selectively removing fluorine atoms from a fluorinated graphene sheet with a low energy (~60 eV) Xe beam. Atomistic simulations[2] show a sharp threshold in this energy range below which no carbon atoms will be removed from the graphene backbone. Still, the maximum energy transferred to the heavier F-atoms is more than 15 times larger than the bond dissociation energies of F on graphene (0.25-2.5 eV).[3] Below about 200 eV, no secondary electrons will be produced that could blur the image. As shown in Fig. 1a, there is significant diffraction for a 4 nm wide mask opening, even for a 100 nm proximity gap. Fig. 1 b,c,d shows the results of a Monte-Carlo simulation based on ref. 1 and assuming that the cross-section for removing fluorine atoms is 5×10^{-16} cm^2. Equivalently, the diameter of the fluorine atom would appear to be 1.25 Å, approximately equal to the interatomic distance in graphene. Note the remarkably low image noise for Xe densities a few times larger than the C-atom density.

Our paper will report virtual source size, brightness, and energy spread of a xenon atom source operating the voltage range 50-100 eV. The experimental apparatus is based on a 30 keV helium ion source, fig. 2, with source size and brightness of 82 ± 10 μm [2σ] and 1,068 A/cm^2-sr. [4]

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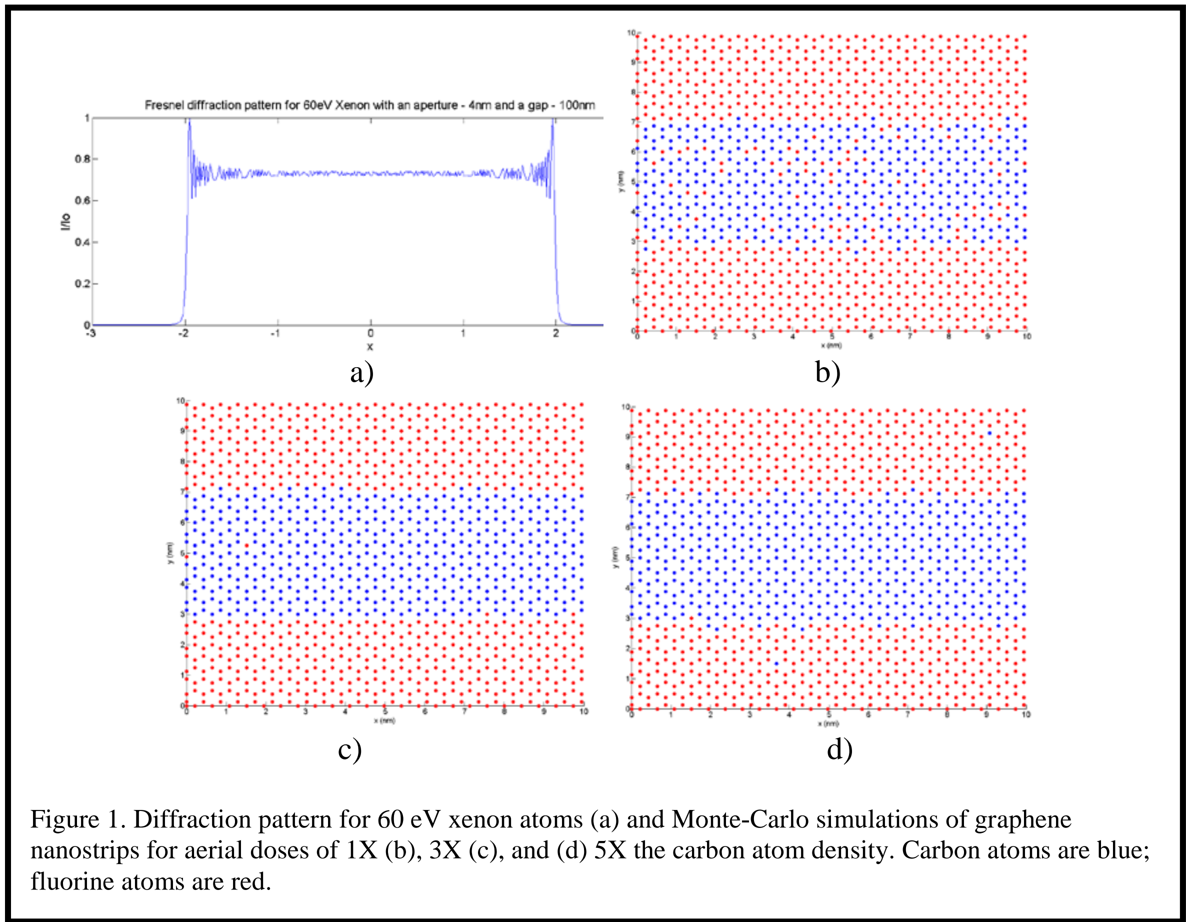

Figure 1. Diffraction pattern for 60 eV xenon atoms (a) and Monte-Carlo simulations of graphene nanostrips for aerial doses of 1X (b), 3X (c), and (d) 5X the carbon atom density. Carbon atoms are blue; fluorine atoms are red.

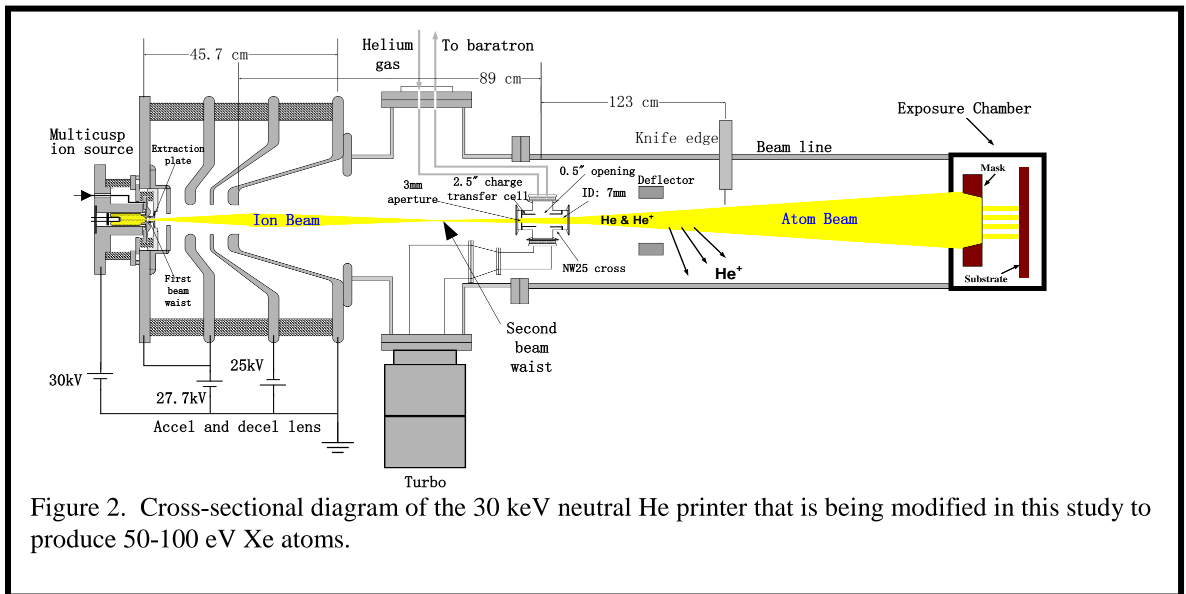

Figure 2. Cross-sectional diagram of the 30 keV neutral He printer that is being modified in this study to produce 50-100 eV Xe atoms.