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Focused Ion Beams of Xe^+, Ar^+, O^+, and N^+: Sputter Rate Trends, Chemical Interactions, and Emerging Applications

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Focused Ion Beam (FIB) instruments utilizing liquid metal gallium ion sources have been important workhorse instruments in research and industry for many years. The appearance of Helium/Neon ion microscopes improved imaging and milling resolution at low beam currents [1]. Later, plasma-based FIB instruments utilizing xenon ion sources extended capability into higher current regimes [2,3], significantly expanding the types of samples that can be processed by FIB milling. Most recently, plasma FIB systems with switchable primary gas sources have allowed users to select various primary ions (typically Xe^+, Ar^+, O^+, and N^+). With the advent of these new ion source possibilities, new operational considerations and applications are emerging.

In this work we examine the important and sometimes surprising chemical effects of the primary ion. Inert species such as Xe^+ and Ar^+ have sputter rates that are reasonably well-predicted by Monte Carlo simulation methods (SRIM, for example), but the behaviors of O^+ and N^+ can vary dramatically from what would be expected based on the ion mass [4]. This is due to the ability of these ions to form strong chemical interactions with the substrate atoms. This ability can be exploited to direct-write patterns resulting in local areas with different mechanical, chemical, or electrical properties from the surrounding substrate. Comparisons between the behaviors of these new plasma FIB species are made to gallium, revealing that gallium sputter rates are also subject to interesting chemical effects, which have largely gone unnoticed in the past due to a lack of alternative technologies to compare against.

Polymers are particularly challenging materials for focused ion beams, due to their electrically insulating properties and susceptibility to beam damage. However, oxygen ion beams appear to be particularly suitable for use on a range of carbonaceous substrates including polymers, resin, biological tissue, graphite, and diamond. We find that milling with O^+ results in higher sputter rates, smoother surface texture, and less beam-induced damage compared to other primary ions.

References:

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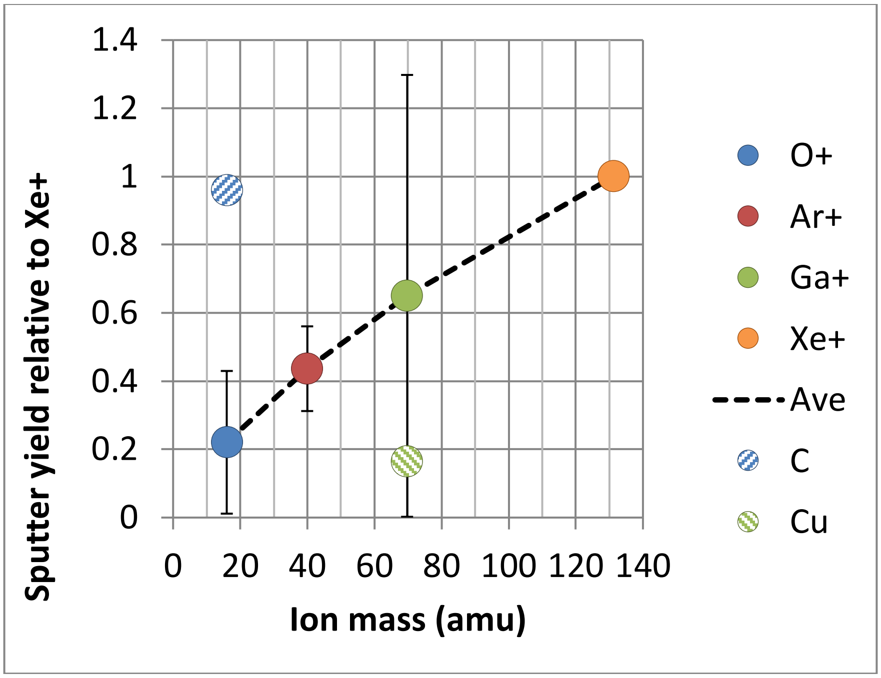

Figure 1. Average sputter rate trends for various primary ion beams. In general, sputter rates increase as the ion mass increases, but some outliers exist, pointing to important chemical interactions between ion and substrate, such as O^+ with C and Ga^+ with Cu.

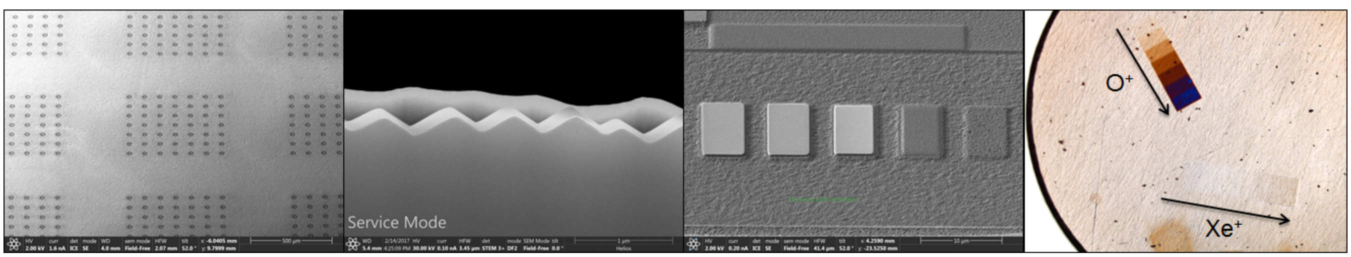

Figure 2. Examples of alternate primary ion applications. A) array of Si_3N_4 dots direct-written onto silicon. B) Nanotexture resulting from non-normal incidence milling of O^+ onto Si. C) Chemically resistant SiO_2 pads written onto Si using O^+, with a subsequent chemical etch step using XeF_2. D) controlled implantation of oxygen produces oxide films with variable thickness.

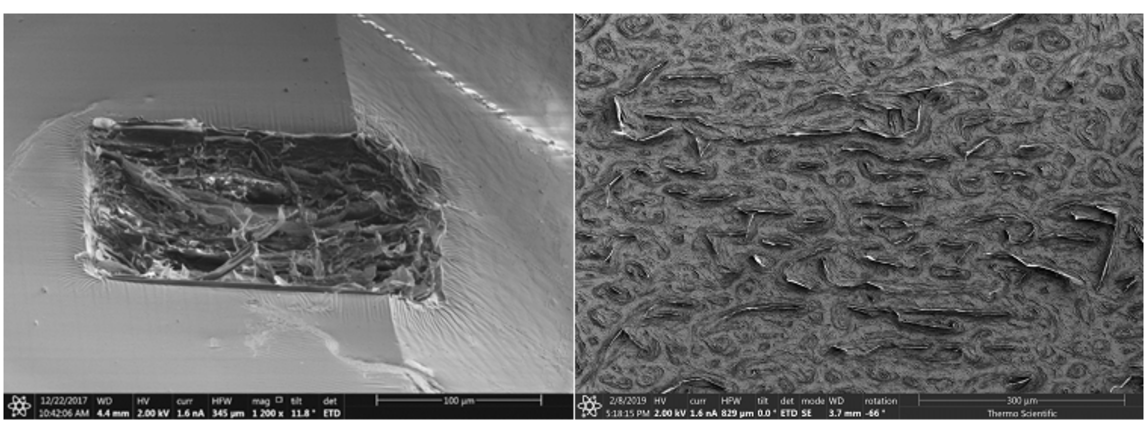

Figure 3. Examples of ion beam induced damage on EPON resin (left) and polyimide film (right).