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Electron beam generated plasma as a low T_e approach to atomic-precision processing[1]

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The advantages of plasma-based materials processing techniques are numerous. The capability to rapidly and uniformly modify large ($>10^3$ cm^2) areas with high precision is one reason plasmas are widely used in the materials and surface engineering communities. However, with the ever evolving demand for new materials and single nanometer-scale device dimensions across a variety of applications, some of the limitations of conventional plasma sources are becoming apparent. The lack of process control and excessive ion energies in the development of atomic layer processing strategies are examples. The Naval Research Laboratory (NRL) has developed a processing system based on an electron beam-generated plasma. Unlike conventional discharges produced by electric fields (DC, RF, microwave, etc.), ionization is driven by a high-energy (1-3 keV) electron beam, an approach that can overcome many of the problems associated with conventional plasma processing systems. Electron beam-generated plasmas are generally characterized by high charged particle densities (10^{10}- 10^{12} cm^{-3}), low electron temperatures (0.3 - 1.0 eV), and in reactive gas backgrounds, a relatively low radical production rate compared to discharges. These characteristics allow the ability to precisely control the flux of charged and reactive neutrals as well as ion energy at adjacent surfaces. This provides the potential for controllably etching, depositing, and/or engineering the surface chemistry with monolayer precision. An overview of NRL's research efforts in developing this technology will be presented, with a focus on source development and operation, plasma characterizations, and how the system can be advantageously applied to the processing of select systems. Examples include monolayer materials, such as graphene and MoS_2, where erosion and damage is a major concern and the etching of semiconductor materials, such as Si, SiN and SiO_2, where the focus is on etch rates and selectivity at low ion energy.

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