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Extreme Dynamics of Nanoelectrospray Droplets in Complex Gas Flows to Enable New Modes of Direct-Write Nanomanufacturing

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Nanoelectrospray (NanoES) generates an aerosol of highly charged nano-to-micrometer size droplets from a conducting liquid dispersed from a tapered order-of-μm diameter capillary under the influence of an electric field. These droplets accelerate in the applied electric field, disperse due to the electrostatic inter-droplet interactions and charge-induced instabilities and fission, and engage in complex hydrodynamic interactions with the surrounding gas. The main forces acting on the droplets are the viscous drag and inertia. Depending on the hydrodynamic environment (i.e., stagnant or flowing gas), drag could either promote or impede droplet motions and/or result in the change of droplet trajectories. Reciprocally, the motion of droplets could induce motion of a surrounding gas via interfacial momentum transfer. The induced gas jetting has a complex structure with high kinetic energy, tightly confined (within 10s of micrometers) core and active suction of the surrounding gas from behind of the capillary emitter producing NanoES. We used the Schlieren flow visualization, ion current measurements, mass spectrometry, and multiphysics simulations to uncover the complex behavior and derive the governing laws for multiphase femto-to-nanoliter charged droplet-gas interactions. This fundamental understanding of gas-assisted NanoES enables the development of new important applications. Of particular interest is the use of NanoES for delivery of energized precursor molecules to achieve the new modes of atom-by-atom fabrication of topologically complex nanostructures from a variety of materials using the Focused Electron Beam Induced Processing (FEBIP). Energized micro/nano-jets of electro-kinetically energized precursors in liquid phase provide unique capabilities for localized delivery of precursor molecules to the substrate, thus establishing locally controlled deposition/etching site for FEBIP. Understanding of fascinating and interacting chemistry and physics on the most fundamental level will be discussed as a route to develop new FEBIP modes and applications to emerging 2D electronic and quantum devices.

References:

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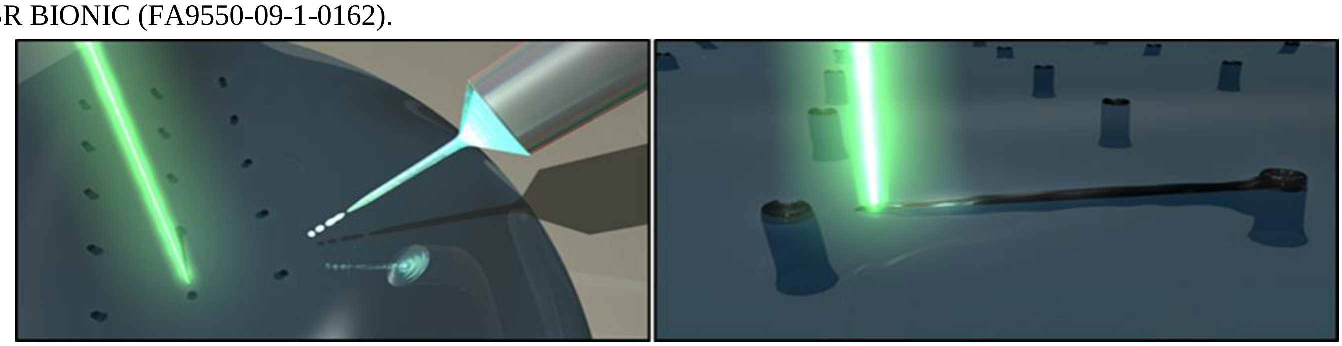

Illustration: Writing of 3D Nanostructures with FEBIP with Electrified Nanojetting: Fisher et al., *Nano Letters*, 15 (**2015**)