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Field Effects on Particle Assembly in Composite Needle Systems

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Electrostatic field distributions can have a profound effect on the deposition of particles within nanoscale material/geometric systems. Control of the assembly process of nanoscale systems by electrostatic mechanisms may allow the efficient creation of tailored nanoscale electronic devices, however thermal and hydrodynamic forces may dominate the assembly process and inhibit such control. The degree of electrostatic control of the nanoparticle assembly process can be greatly increased using geometric field amplification concepts and mechanisms, such as using high aspect ratio metal needles as the base substrate. These needles have the added benefit of being easily prepared for transmission electron microscopy.

Our group has used electrophoretic and dielectrophoretic electrostatic mechanisms to deposit diamond nanoparticles on metal needles. The structural evolution of these nanodiamond particles, radii ~ 2-10 nm, and particle clusters affects material and electronic properties of the composite needle system, such as field enhanced emission of electrons from the composite needle structure. The interplay between structural morphology and particle assembly was examined through a combination of TEM and numerical analysis.

Molybdenum-nanodiamond composite needles with typical radii ~50 nm were nondestructively prepared for examination as in FIG. 1. Assembly of nanoparticles across the Mo needles takes two distinct forms: distinct embedded particles across the needle apex as in FIG. 2 and clusters of nanoparticles lying along the needle shank as in FIG. 3. TEM micrographs of these needles were analyzed to extract morphological data used in the numerical analysis. Electrostatic fields were calculated for these realistic tip shapes as in FIG. 4 using finite element analysis of Poisson's equation, $\nabla \cdot \left(\varepsilon_r \nabla V\left(\bar{r}\right)\right) = 0$.

Electrostatic modeling of needle-particle geometric and material field effects showed effects that might effect particle transport, agglomeration and de-agglomeration within the system. Geometric effects due to needle morphology are observed in the calculated field distribution across the sample surface which is highly nonlinear as in FIG. 5 and peaked along regions of largest morphological curvature, which is the region where assembly of nanoparticles on the needle surface appears to occur. Electrostatic simulations of material effects due to the material dielectric constant of dielectric particles and fluids showed strong field dependencies on the material system.

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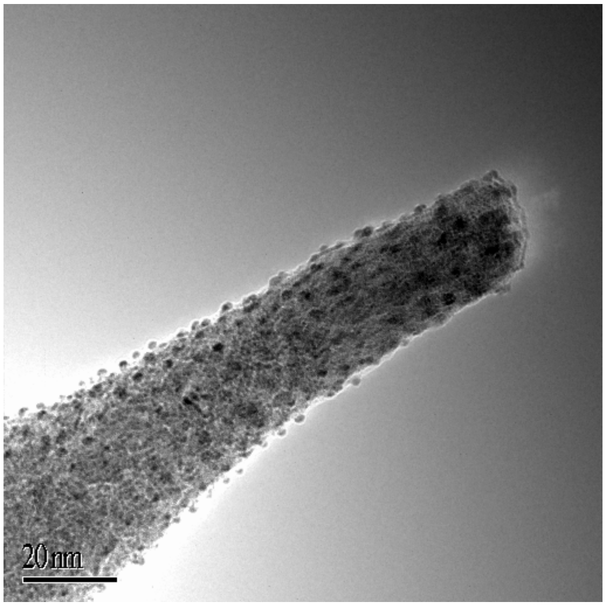

FIG. 1 Molybdenum Needle with nanodiamond particles.

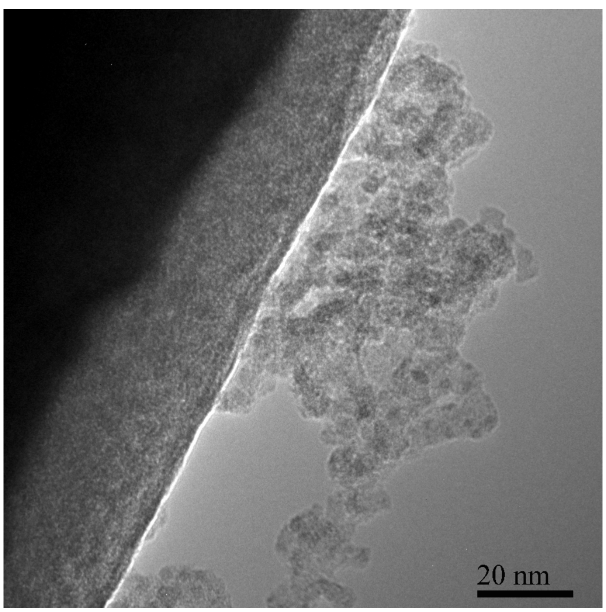

FIG. 3 Nanoparticle clusters lying on the needle shank.

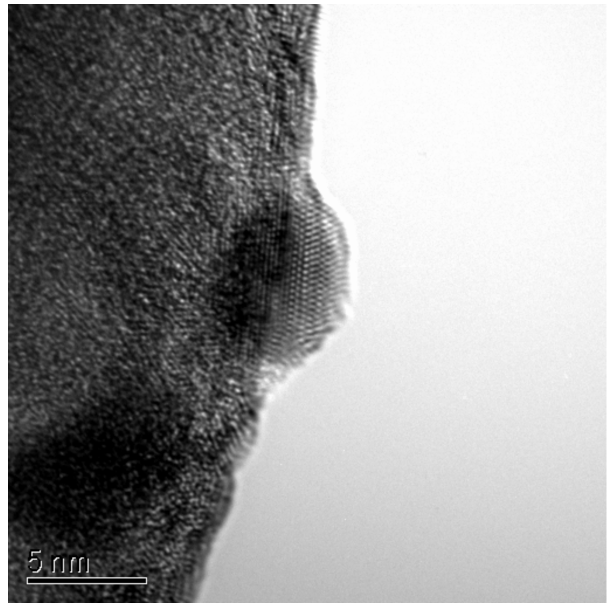

FIG. 2 Nanoparticle embedded in metal needle.

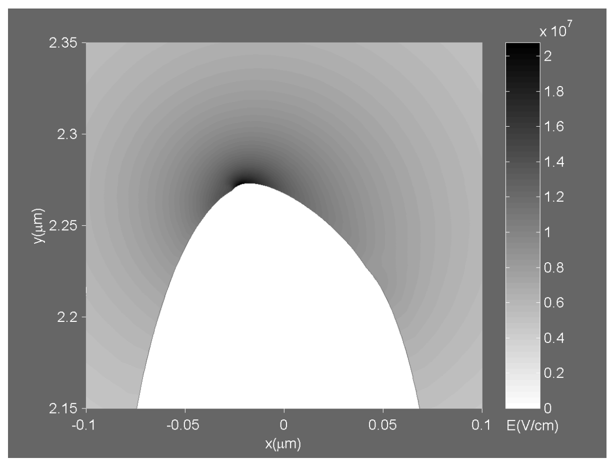

FIG. 4 Electric field distribution of a realistic needle profile extracted from micrographs.

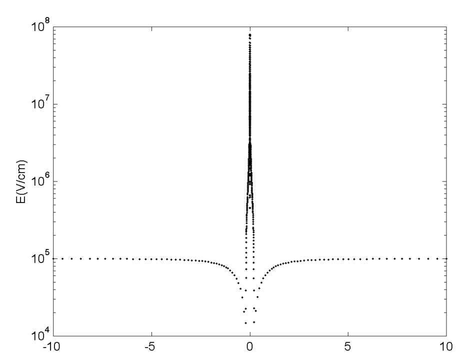

FIG. 5 Nonlinear field distribution across the needle surface

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