Ion Beam Formation and Modification of Metal Nanoparticles

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Metal particles of nanometric dimensions exhibit finite-size effects that perturb their structural and vibrational properties relative to bulk material leading to novel technological applications. For this presentation, we report on ion beam formation and modification of metal nanoparticles in silica characterized with a combination of conventional and synchrotron-based analytical techniques. As metal nanoparticles decrease in size, a capillary-pressure-induced decrease in bondlength is measureable, from which the surface tension is calculable using a liquid drop model. We show the surface tension in metal nanoparticles typically exceeds that of bulk material. With a correlated anharmonic Einstein model and thermodynamic perturbation theory, Einstein temperatures can be determined. Compared to bulk material, the mean vibrational frequency of the smallest nanoparticles is reduced due to a greater influence of loosely-bonded, under-coordinated surface atoms relative to the effect of capillary pressure generated by surface curvature.

Ion irradiation in the nuclear stopping regime induces a crystalline-to-amorphous phase transformation in metal nanoparticles not achievable in bulk material with the inter-atomic distance distribution consistent with molecular dynamics simulations. Though bulk elemental metals are insensitive to ion irradiation, we suggest nanoparticles are amorphisable due to their greater inherent disorder and the stabilizing influence of the surrounding amorphous matrix. As such, the atomic-scale structure of selected amorphous elemental metals is measureable for the first time

Ion irradiation in the electronic stopping regime yields an intriguing shape transformation where metal nanoparticles progressively change from spherical to rod-like, the latter aligned with the incident ion direction. We show the transformation necessitates a molten ion track plus metal melt and flow and is governed by the thermodynamics of both the metal and matrix.

In summary, ion implantation and ion irradiation are well suited to metal nanoparticle formation and modification, respectively, and further enhance the technological applicability of these metal/matrix combinations in, for example, plasmonic devices and resonant optical antennas.