Final Technical Report for DOE Grant DE-FG02-01ER45918, "Using Plasmon Peaks in Electron Energy-Loss Spectroscopy to Determine the Physical and Mechanical Properties of Nanoscale Materials", Contract Period 9/15/2001-3/14/2008.

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Abstract: In this program, we developed new theoretical and experimental insights into understanding the relationships among fundamental universality and scaling phenomena, the solid-state physical and mechanical properties of materials, and the volume plasmon energy as measured by electron energy-loss spectroscopy (EELS). Particular achievements in these areas are summarized as follows: (i) Using a previously proposed physical model based on the universal binding-energy relation (UBER), we established close phenomenological connections regarding the influence of the valence electrons in materials on the longitudinal plasma oscillations (plasmons) and various solid-state properties such as the optical constants (including absorption and dispersion), elastic constants, cohesive energy, etc. (ii) We found that carbon materials, e.g., diamond, graphite, diamond-like carbons, hydrogenated and amorphous carbon films, exhibit strong correlations in density vs. E_p (or maximum of the volume plasmon peak) and density vs. hardness, both from available experimental data and *ab initio* DFT calculations. This allowed us to derive a three-dimensional relationship between hardness and the plasmon energy, that can be used to determine experimentally both hardness and density of carbon materials based on measurements of the plasmon peak position. (iii) As major experimental accomplishments, we demonstrated the possibility of *in-situ* monitoring of changes in the physical properties of materials with conditions, e.g., temperature, and we also applied a new plasmon ratio-imaging technique to map multiple physical properties of materials, such as the elastic moduli, cohesive energy and bonding electron density, with a sub-nanometer lateral resolution. This presents new capability for understanding material behavior. (iv) Lastly, we demonstrated a new physical phenomenon - electron-beam trapping, or "electron tweezers" - of a solid metal nanoparticle inside a liquid metal. This phenomenon is analogous to that of optical trapping of solid microparticles in solution known as "optical tweezers", which is currently being used to manipulate molecules and inorganic materials in a variety of nanotechnology applications.

Keywords: Plasmons, electron energy loss spectroscopy, electron density, nanoscale material properties

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