Nanoscience and Nanotechnology: Why, When and How

Stan Veprek

Department of Chemistry, Technical University Munich, Lichtenbergstr. 4,
D-85747 Garching, e-mail: stan.veprek@lrz.tum.de

Why: Many properties of solids significantly change when the particle size decreases below 100 nm, and in particularly below 10 nm. I shall discuss the localization of surface plasmons, electronic quantum eigenstates and phonons as function of particle size and particle separation, and their effect on the properties of the nano-sized and nano–structured materials. It will be shown that not only the particle size, but also the particle separation plays an important role, because when the particle separation decreases below 1 nm, the electronic eigenstates begin to overlap and the confinement gets lost. Also the mechanical properties are significantly influenced by the particle size and their connectivity, and also by the scale of the experimental testing of conventional materials ("small is strong"). Nature has developed many nano-structured systems with hierarchic architecture, which provide unique mechanical and surface properties to plants and living species. For time limitations, I'll be able to bring only few examples from which we can learn a lot.

When a field suddenly becomes fashionable, it is essential to distinguish 'science facts' from 'science fiction'. I shall briefly mention some example where the 'nano does not work', and when one should better adhere to the conventional physics at the macro-scale.

How: The preparation of nano-sized and nano-structured materials requires special techniques which sometimes raises the question of the 'costs vs. gain'. The high dispersion (ratio of the number of the atoms at the surfaces to the atoms in the bulk) makes it difficult to keep nano-structured materials sufficiently pure, particularly free of oxygen impurities. For example, at an oxygen impurity concentration of 2-3 at.%, oxygen containing clusters in silicon decrease the diffusivity and the kinetically controlled crystallization, thus stabilizing amorphous silicon even at high temperatures of ≥ 600 °C. In nc-TiN/Si_3N_4 and related superhard nanocomposites, oxygen impurities of ≥ 1000 ppm (0.1 at. %) decrease the diffusion rate and segregation of the TiN and Si_3N_4 phases, thus apparently stabilize the $Ti_xSi_yN_z$ solid solution and hinder the formation of the stable and superhard nanostructure. The problem of impurities is not limited to oxygen only. For example it is known for more than 100 years that 100 ppm of bismuth in copper causes embrittlement of grain boundaries making copper very brittle metal. Yet, there is not any unambiguous, common agreement on the mechanism of that embrittlement. Obviously, there is a long way to go to understand all the important and relevant aspects of the nanoscience, and to learn how to utilize them in the technology, medicine and other fields.