Nanomedicine & Biotherapeutic Discovery

Extended Abstract

The route to nanomaterials manufacturing incorporating nanoparticle beam deposition

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Abstract

If we imagine a factory of the future in which nanoparticle beams are integrated into the production of advanced materials or devices, then a set of critical research challenges emerge for Cluster Beam Deposition (CBD). These include control of nanoparticle composition, size, quantity (scale-up), interaction with the support, response to the environment and performance validation. The prize is a set of applications ranging from water treatment and theranostics to catalysis and memristors. The cluster beam approach is green; it involves no solvents and no effluents; particles can be size-selected and challenging combinations of metals (nanoalloys) can readily be produced. Here we discuss four of these research challenges: Environment (temperature), scale-up, formulation engineering and Validation :(1) Environment: aberration-corrected Scanning Transmission Electron Microscopy (STEM) is used to investigate the behavior of deposited clusters at elevated temperatures, including structural transformations and (core and surface) melting. (2) Scale-up: Industrial catalysis R&D typically requires a gram of catalyst or 10 mg of clusters at 1% loading on a suitable catalyst support. The Matrix Assembly Cluster Source (MACS) is based on ion beam sputtering of a rare gas matrix into which metal atoms are pre-loaded. A scaleup of five orders of magnitude in cluster intensity has been achieved to date. (3) Formulation Engineering: We will discuss several means by which size-controlled clusters may be presented in a form matching the desired functional application, e.g., catalysis and theranostics. These examples of formulation engineering on the nanoscale include direct deposition of metal cluster beams onto powders. (4) Validation: Finally will illustrate the validation challenge to show that cluster-based functional materials are superior to more traditional advanced materials. We will focus on the hydrogenation (both gas and liquid phases) of organic molecules over or applications in the fine chemicals sector and on water splitting

It is hard to predict the future of science. For example, when C_{60} and its structure were identified from the mass spectra of gas phase carbon clusters, few could have predicted the era of carbon nanotechnology which the discovery introduced. The solubilization and functionalization of C_{60}, the identification and then synthesis of carbon nanotubes, and the generation and physics of graphene have made a scale of impact on the international R&D (and to some extent industrial) landscape which could not have been foreseen. Technology emerged from a search for molecules of astrochemical interest in the interstellar gas. This little sketch provides the authors with the confidence to present here a status report on progress toward another radical future—the synthesis of nanoparticles (typically metals) on an industrial scale without solvents and consequently effluents, without salts and their sometimes accompanying toxicity, with minimal prospects for unwanted nanoparticle escape into the environment, with a high degree of precision in the control of the size, shape and composition of the nanoparticles produced and with applications from catalysts and sensors to photonics, electronics and theranostics. In fact, our story begins in exactly the same place as the origin of the nanocarbon era—the generation and mass selection of free atomic clusters in a vacuum chamber. The steps along the path so far include deposition of such beams of clusters onto surfaces in vacuum, elucidation of the key elements of the cluster–surface interaction, and demonstrations of the potential applications of deposited clusters. The principal present challenges, formidable but solvable, are the necessary scale-up of cluster beam deposition from the nanogram to the gram scale and beyond, and the processing and integration of the nanoclusters into appropriate functional architectures, such as powders for heterogeneous catalysis, i.e., the formulation engineering problem. The research which is addressing these challenges is illustrated in this Account by examples of cluster production (on the traditional nanogram scale), emphasizing self-selection of size, controlled generation of nonspherical shapes, and nonspherical binary nanoparticles; by the scale-up of cluster beam production by orders of magnitude with the magnetron sputtering, gas condensation cluster source, and especially the Matrix Assembly Cluster Source (MACS); and by promising demonstrations of deposited clusters in gas sensing and in heterogeneous catalysis (this on the gram scale) in relevant environments (both liquid and vapor phases). The impact on manufacturing engineering of the new paradigm described here is undoubtedly radical; the prospects for economic success are, as usual, full of uncertainties. Let the readers form their own judgements.

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Biography

Richard E Palmer is a Senior Research Fellow in the College of Engineering, Swansea University and Professor at Nanjing University's School of Physics. His research is focused on nanomaterials, including scale-up and atomic structure/dynamics. He has received awards which include the IOP Boys Medal, an Honorary Doctorate from Hasselt University, the BVC Yarwood Medal and an EPSRC Senior Fellowship. He is a Fellow of the IOP, RSC and LSW. He has published ~400 papers and about 20 families of patent applications. He is Editor-in-Chief of Advances in Physics: X and Editor of the Elsevier Book Series 'Frontiers of Nanoscience'.

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