4ch Surface Engineering of Micro and Nanoparticles

Kenneth K. S. Lau

The ability to properly design the surface chemistry and properties of micro and nanoparticles is important in enabling technologies in a wide range of applications that includes drug delivery, sensory devices, optics, composite materials, and environmental mediation. There currently exists a variety of methodologies to engineer a particle surface to yield the requisite functions, such as using colloidal chemistries, layer-by-layer assembly, and chemical vapor deposition. Functional polymer materials have been laid down to encapsulate particles through these techniques, polymers being particularly amenable towards imparting functionality, stability and compatibility. However, many of these methods require a solvent phase, which often renders processing difficult, requiring delicate control of solvent conditions to minimize particle agglomeration, especially when particle sizes become smaller than 100 μm. Vapor deposition processes are attractive since the liquid phase is essentially bypassed. However, common vapor deposition methods find it hard to produce clean, well-defined polymer functionalities necessary for precise surface engineering. A new method, termed initiated chemical vapor deposition (iCVD), is proposed to not only tackle the issues of solvent use and particle agglomeration during surface functionalization and encapsulation, but also to offer a powerful way to intelligently design surfaces with well-defined polymeric materials that extends beyond just enabling particle technologies.

The iCVD process can be viewed as conventional polymerization sans a liquid phase. Initiator and monomer molecules are activated in the vapor phase, adsorb on a particle surface, and react to form a conformal polymer coating. The design aspect of polymerization chemistries is retained and even extended since polymerization of monomers normally incompatible in solution can be achieved without solvent restrictions. The ability to encapsulate finer particles is now possible and more facile, without the strong liquid surface tension forces which lead to severe particle agglomeration during solvent removal by evaporation. A variety of substrates, from the macroscopic to the nanoscopic scale that includes planar silicon, silica microspheres, polymer nanospheres and carbon nanotubes, have been successfully encapsulated. A diverse range of polymer functionalities have been demonstrated, including poly(tetrafluoroethylene), poly(glycidyl methacrylate), poly(methacrylic acid), and copolymers like poly(methacrylic acid-co-ethyl acrylate) and crosslinked polymers like poly(methacrylic acid-co-ethylene glycol dimethacrylate). Spectroscopic analysis, such as FTIR, NMR and XPS, confirms that these polymers are identical to those made by conventional solution means. Microscopy, such as SEM and TEM, reveals that individual particles are conformally encapsulated, with coating thicknesses that can range from nanometer-thin to micrometer-thick dimensions. Kinetic studies and vapor-to-surface adsorption measurements point to well-defined chemical reaction pathways that follow conventional polymerization behavior. This not only enables precise control over the coating material structure and properties, it makes iCVD particularly attractive as a design tool since reaction probability and rate can be a priori assessed in the development of new surface materials,

In particular, in the area of biomedicine, iCVD is expected to bring novel approaches to the surface engineering of micro and nanoparticles for drug delivery, biodiagnostics and bioassaying. Smart materials for controlled release of finer drug particles would enhance drug therapy by offering more benign routes for prolonged drug release and reducing the frequency of drug intake. Methacrylic acid copolymers are demonstrated to be pH-sensitive release layers that allow the enteric release of potent drugs across the GI tract. Surface encapsulation of drug nanoparticles with stealth polymers that include poly(ethylene oxide) and poly(hydroxylethyl methacrylate) can provide precise delivery to target sites. Further, the ability to bind ligands and immobilize bioactive molecules onto particle surfaces would enable more effective drug targeting, and enable the devising of more sensitive diagnostic and assay tools. This can be done by binding with a reactive polymer, such as poly(glycidyl methacrylate) or poly(acrylamide), or through unique multifunctional polymers with two, three or even more monomeric functionalities, each functionality providing a specific purpose and property. On a broader note, iCVD's surface engineering concepts for micro and nanoparticles are anticipated to be useful in developing new materials and devices across a spectrum of applications that includes sensing, optics, and environmental mediation.