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Understanding stability in functional nanoparticle inks

The past decade has seen an explosion of interest in 3-D printing. While many applications of 3-D printing use curable polymers to construct macroscopic scale objects (think printing of toys, jewelry, and architectural models), one of the most exciting emerging applications is printing functional nanoparticles to construct devices, like batteries, fuel cells and sensors, with micron scale structure. In such an application, the device would be built up layer by layer through dropwise deposition of nanoparticles. This printing of functional nanoparticles is an exciting application because realizing this goal may enable device performance improvements as well as cheap, scalable manufacturing.

The critical challenge in realizing the goal of printing microstructured functional devices is formulating the ink. The ink must be a dispersion of nanoparticles in a vehicle of liquid solvent and additives. But how do we prevent the nanoparticles from clumping together and settling out of the liquid like cereal in milk? A common approach to preventing the aggregation of nanoparticles is to attach different chemical species to the surfaces of the particles. The attached species can carry electrical charge and thus repel particles from one another. Alternatively, the attached chemical species can be long chain molecules that repel particles from one another due to the unfavorability of molecular entanglement. In either case, the ink formulation chemist must choose which molecule to use and, in particular, what types of chemical structures readily attach to the nanoparticle surface. While it is possible to try a large number of particles and simply observe which ones prevent the nanoparticles from settling, such a “guess and test” approach can be time consuming.

One way to gain insight into the types of molecules that could stabilize functional nanoparticles inks is to use infrared radiation to probe the way in which different molecules interact with nanoparticle surfaces. In “Diffuse Reflectance Infrared Spectroscopic Identification of Dispersant/Particle Bonding Mechanisms in Functional Inks,” published in the Journal of Visualized Experiments, we illustrate a simple experimental protocol for probing nanoparticle attachment to the types of nickel oxide particles that may be used in the printing of solid oxide fuel cell anodes. In our illustration of the method, we begin with a dispersion of nickel oxide particles with a fatty acid dispersant in an alcohol solvent. We show how to use centrifugation to separate the functionalized particles from the rest of the ink. We then dry the functionalized particles and show how to prepare them for analysis with infrared radiation. From these measurements, we show that it is most likely that fatty acid dispersants chemically bond to nickel oxide particles through a chelating or bridging configuration of the carboxylic acid functionality. The presence of a bidentate chemical bond indicates that fatty acid dispersants or molecules with similar carboxylic acid functionalities would be good candidates for creating stable nickel oxide dispersions.

While the infrared spectroscopy protocol we illustrate in the Journal of Visualized Experiments is not unprecedented, it is something more typically practiced in the field of colloid and surface science and not broadly known or applied in the field of inkjet ink manufacturing. However, if inkjet device printing is going to truly take off as a manufacturing technology, then we must start applying these fundamental surface and colloid science techniques so that we can rationally develop the necessary functional nanoparticle inks.

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