Functional Metal Oxides for Additive Manufacturing

N. Hendricks, S. Lani, R. Pugin

Additive Manufacturing (AM) has numerous advantages over traditional manufacturing techniques such as reduced material waste, on demand fabrication times, and ease of customization, but there is a lack of new and advanced materials to further extend AM's capabilities. To address AM's material capabilities, CSEM is developing and expanding nanoparticle based materials which are capable of being processed with current AM techniques, such as Aerosol Jet Printing (AJP) and Stereolithography (SLA). Specifically, the use of functional metal oxide nanoparticles are of interest due to the broad range of applications such as sensors, photovoltaics, photonics, flexible electronics, and catalysts as well as the availability of such materials.

Additive Manufacturing (AM) is becoming more and more common today as a tool for researchers and companies that require rapid optimization and enhanced flexibility, specifically in the fast-paced research and start-up environments. At CSEM, there are several AM techniques readily available which includes Aerosol Jet Printing (AJP) and Stereolithography (SLA). To increase the value of AJP and SLA, inks and resins are being investigated that integrate the functional properties of metal oxide nanoparticles directly into 2D and 3D printed patterns, which will exploit the full potential of the functional metal oxide material.

Current materials for AJP, which are readily available, are based on conductors and organic dielectrics where the functionality is limited to electrical properties. Recently, the AJP community has been making efforts to print solvents for etching as well as other polymeric materials such as Teflon (poly(tetrafluoroethylene)) and Kapton (polyimide). For SLA, the common materials used are based on organic materials capable of undergoing photopolymerization with ultraviolet (UV) light to create photo-hardened polymers. As SLA has matured over the last three decades, the materials being utilized in SLA are expanding to include ceramics, various types of polymers, composites, and biomaterials.

By utilizing pre-synthesized, commercially available nanoparticle powders and highly concentrated nanoparticle solutions as starting materials, inks have been formulated specifically for use with the AJP system. Through optimized formulation, crack-free microstructures constructed from nanoparticle inks have been successfully patterned; as an example, stannic oxide patterns are shown in Figure 1. Other materials that have been printed crack-free with the AJP technique include titanium dioxide, aluminum dioxide, copper oxide, and iron oxide.

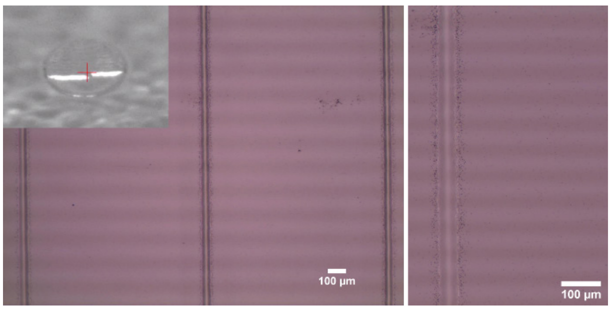

Figure 1: Crack-free microstructures from stannic oxide NPs.

Silicon dioxide nanoparticles have also been printed with AJP into photonic crystal structures with unique optical properties in the visible spectrum. Figure 2 is an example of silicon dioxide nanoparticles patterned into a monolayer structure. Such silicon dioxide nanoparticle inks have also been deposited on graphite electrodes for use as a sensing scaffold for detecting analytes in liquid solutions.

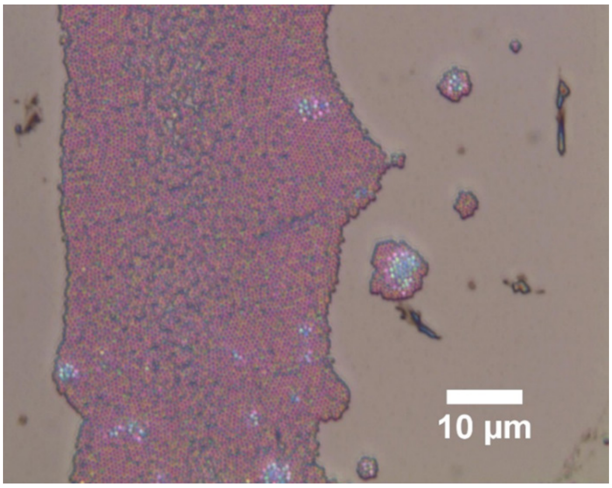

Figure 2: Photonic crystal structure from silicon dioxide NPs.

With SLA, the effort has been to create composite materials from pre-synthesized nanoparticles and commercially available resins. Through specific resin formulation and dispersion techniques, composites with functionality, such as piezoelectric or magnetic properties, have been realized. One such example of functional composite resins for SLA, shown in Figure 3, is with barium titanate nanoparticles and a commercially available resin. The concentration of the barium titanate nanoparticles in the composite can be tuned to adjust the piezoelectric response while also maintaining a high quality dispersion.

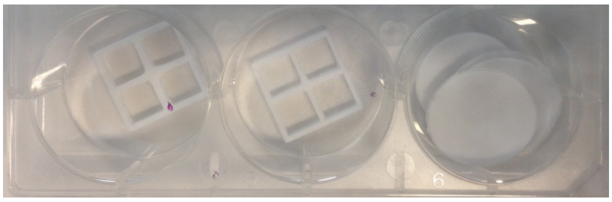

Figure 3: SLA printed structures from a barium titanate NP based composite resin.

In summary, strategies are in place to quickly print functional metal oxide nanoparticles, as inks for AJP or as resins for SLA, for a large range of applications. This provides a material platform for common AM techniques here at CSEM that is unique and flexible.