Materials Science and Technology
Components

Robotic Direct Write Materials

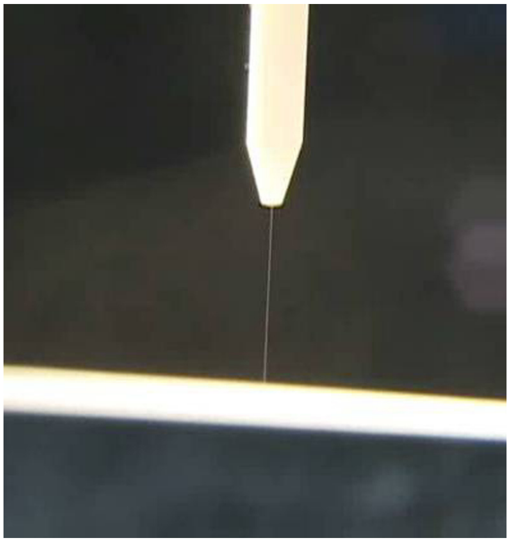

Figure 1: Ink jet of silver nanoparticles printed onto a circuit board. The print jet is only 30µm across.

Figure 2: 3D complex shape direct-printed onto a curved substrate. Conductors in this shape become highly sensitive antennas.

Augmenting COTS devices by post processing

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Today's requirements for new weapons and surety components require an ever-increasing accuracy of fabrication and amount of integration to allow for compact devices with more sophisticated capabilities. At the same time, cost and budget drivers provide an incentive for the use of commercial "off-the-shelf" devices (COTS) to be used. It is rare, however, that these COTS devices provide the full range of capability that is desired, or come in the form factor appropriate for a specific application. Thus, what is often needed is a low cost and versatile back-end capability to modify the functionality of COTS-type parts with a wide range of materials to enable further integration. It is this technology gap that Sandia's Direct Write capability aims to fill.

Direct Write technology utilizes a robotically-controlled printing tip (Fig. 1) to accurately deposit controlled amounts of nanoparticle-based slurries onto a substrate. Depending on the composition of the slurry, the deposited material is subsequently annealed to develop a densified microstructure with appropriate electronic, dielectric, catalytic, or optical properties. By choosing the starting nanoparticle size and composition, a wide variety of materials can be printed, from catalysts to quantum dots to electronic conductors with electrical properties close to that of the bulk. Additionally, control of the rheology of the slurries allows some of these materials to be cast either conformally on a 3D surface or across an unsupported span, allowing the fabrication of 3D lattices with complex geometries that cannot be fabricated using conventional machining techniques (Fig. 2).

The heart of Sandia's capability in direct write lies in combining both mechanical engineering (robotic printing from computer aided design, or CAD, files) and fundamental materials science (development of printable inks for

Figure 3: A COTS radio frequency ID tag embedded in 100 µm wide silver antenna lines directly written on a flexible substrate. Mating a tuned antenna to this COTS chip enhanced the range of activation of the chip significantly.

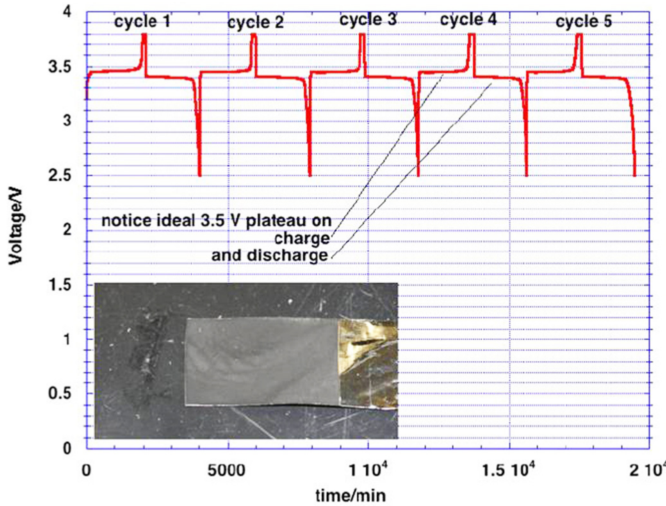

Figure 4: Performance of $LiFePO_4$-printed thin film cathodes in a test battery configuration, showing good charge/discharge characteristics, despite being very thin and flexible. Each charge cycle (increasing voltage with time) moves lithium out of the iron phosphate, and each discharge cycle (decreasing voltage with time) moves lithium back into the iron phosphate. A flat discharge profile (unchanging voltage vs. time) is indicative of good battery performance.

functional devices). By controlling the rheology of the slurries, materials precursors containing nanoparticles can be made as fluid as water or as thick as clay, allowing a wide range of shapes to be created. In contrast, traditional inkjet printing can print only a narrow range of viscosity in a planar array. Once a direct write slurry chemistry is defined, the robotic system uses a 2D or 3D CAD file to accurately control the deposition of the material. As an example, an ink composed of silver nanoparticles using a xylene-based solution can be printed conformally onto a surface with dimensions below 100µm to define a printed antenna or other conductive trace (Fig. 3). The resultant silver lines or patterns are annealed at 120ºC to produce a dense, conductive line suitable for connecting electronic circuits on a flexible substrate, or for making radio frequency antennas printed on curved surfaces. Alternatively, a paste composed of lithium iron phosphate, a cathode material for lithium ion batteries, can be cast into a highly porous structure, allowing for a high surface area of the cathode and subsequent increased rate capability of the battery (Fig. 4).

A fundamental understanding of nanoparticle sintering mechanisms is also critical, because this affects the final microstructure and properties of the printed material. Energy can be applied to printed slurries in various ways, either by traditional thermal annealing of the sample, by laser annealing, or even use of intense flashes of high energy photons to rapidly sinter the material. The effects of precursor particle morphologies, means of introducing energy for sintering, and understanding the interplay between processing and properties are areas of current research. As new nanomaterials are synthesized, they become the basis for a novel printed device capability; current examples of such nanomaterials are germanium nanoparticles and carbon nanotubes for printing semiconductor inks, biocompatible "bone scaffolding" ceramics, and polymer precursors for new coatings and subcomponent hermetic seals. From these applications, new fundamental science surrounding the densification of these materials is generated, leading to further understanding of nanoparticles and the effects of nanostructure and microstructure on functional properties

Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2008-5080P

National Nuclear Security Administration
08/2008