Particle-Free Conductive Inks for Better Printed Electronics

The burgeoning printed electronics industry has the potential to revolutionize consumer electronics, with standard industrial printing equipment operating at ambient conditions producing high-performance electronic devices at a significantly lower cost.

At the heart of printed electronics are conductive traces that connect various electronic components. Such traces are typically manufactured by sputter (vapor-phase) deposition of metals under vacuum; relatively thick traces are generally printed from paste-based inks. The inks used in these traditional processes are dispersions of micro- or nano-scale metallic or carbon particles mixed with polymeric binders and dispersants. These dispersions present several limitations. The particle-laden traces must be processed at high temperatures that preclude the use of many flexible substrates. The additives used in the inks (*e.g.*, organic binders and dispersants) lower the connectivity of the metallic particles, thereby lowering the conductivity of the trace; since these additives remain in the final film, they also increase the sensitivity of the traces to humidity and thereby reduce the reliability of the printed circuit. And, conductive pastes work well for screen-printing and other analog processes, but they are not well-suited to digital and modern manufacturing technologies, such as 3D printing and inkjet printing.

Inkjet printing requires the deposition of low-viscosity inks with a relatively low solids content, so the inks must be much more conductive per unit mass of ink deposited. Many of the innovations in the past have not overcome the limitations of conventional conductive inks.

With funding from the National Science Foundation, Electroninks, a start-up company with a manufacturing facility in Austin, TX, and a development lab in Boston, MA, has developed novel reactive metal inks that are true molecular solutions rather than dispersions. Printed films made of these inks exhibit conductive properties nearly identical to those of bulk metals even when processed at low temperatures (<100°C). The new inks contain no binders or solid particles. Low temperatures are key to printing on flexible and stretchable substrates and fabric, and they enable higher throughput. The company is developing a range of metallic inks, including ones based on silver, noble metals, and alloys.

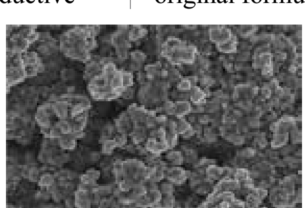
The Electroninks process is a chemical analog of electrical plating of copper on traditional circuit boards. The inks, which consist of inorganic constituents and a metal-reducing agent, both dissolved in a solvent, are deposited via inkjet printing. The traces are then plated, leaving behind a metal film as the solvent evaporates. One of the early versions of the company's reactive inks contained silver salt that was dissolved in ammonium hydroxide and then mixed with a weak acid. The ink, which contained about 22 wt% silver, was translucent and stable. Electroninks has modified the original formulation with additives to make the ink printable via inkjet and slot-die printing and to impart precise wetting and evaporative properties.

"The silver-based inks that we have been evaluating from Electroninks have some very unique properties that are not available from the other silver-based inks that we have tried," says Victor Zaderej, lead technologist of solid-state lighting at Molex, a provider of electronic components. "Not only can the inks be deposited using inkjet printing technology but they are more conductive than the nanoparticle inks that we have been using. And, the inks will be significantly less expensive to produce than the nanoparticle materials that require significantly more and more-expensive manufacturing processes."

The advantages of the particle-free conductive inks are that they cost less than existing nanoparticle-based inks and they can be printed at low temperatures, and the conductive films made with these inks have long shelf lives. In conjunction with modern additive printing techniques, such inks offer customers an opportunity to move away from multistep lithography. They also enable new applications that are incompatible with traditional ink formulations.

For electronic textiles and wearable electronics, for example, the new inks can infiltrate natural fibers to make them intrinsically conductive without resorting to specialty fibers, textiles, or wires. The high-performance display, organic light-emitting diode, and wearable electronics industries are rapidly adopting Electronink's conductive inks.

"We are working with world-class integrators from the U.S. and Asia in the consumer electronics value chain," says Brett Walker, CEO of Electoninks. The company is already producing its first reactive silver ink, and is developing an analogous copper ink. CEP



◀ Micrograph images show the film microstructure for Electronink's particle-free silver precursor ink solution (left) and a typical particle-based silver nanoparticle ink dispersion (right).

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