Inkjettable Electronic Materials for Flat Panel Display and Passive Component Manufacture

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Abstract

Inkjet printing represents a manufacturing process that can replace more expensive patterning techniques reducing the cost of display and component manufacture. Cabot Corporation has developed a family of inkjet printable electronic materials with performance properties acceptable for mainstream adoption into manufacturing processes. For inkjet printable metallic conductors, performance characteristics such as adhesion, jetting performance, process compatibility, resistivity, cure temperature and time, makes these materials suitable for a wide range of applications, including flat-panel displays and printed circuit boards.

Introduction

While large-area flat-panel displays and PCBs are produced today by more conventional photolithographic, screen-printing and wet-etch technologies, digital inkjet printing as a manufacturing process has a strong value proposition, most notably cost reduction. Inkjet deposition systems have been envisioned to drastically reduce the cost of large TVs like PDPs and AMLCDs[1] as well as PCB's[2] and other low cost electronics[3] by significantly reducing capital cost, fab floor space and materials usage and increasing production yields. While inkjet printing for displays has been envisioned, and research and development breakthroughs have been reported in this general area,[1] what has barred the progress of inkjet as a display manufacturing process to date has been a lack of suitable materials, i.e. materials with the proper electrical and mechanical performance and high print reliability. Cabot-Printable Electronics and Displays (PEDs), a business of Cabot Corporation, a $1.9B ultra-fine particulates and specialty chemical company, has developed digitally printable metallic conductors specifically for display and electronic component manufacture. These novel materials are designed to adhere to display glasses, lower cost polymer substrates, have low resistivity, high print reliability and are designed to be compatible with other in-line processes and materials sets. Cabot PEDs has technical competencies including fine particle manufacture, surface modification and dispersion, ink formulation, printing and processing know-how. All of these competencies are leveraged to overcome the obstacles stopping the commercialization of inkjetting as a major display manufacturing process. Cabot PEDs has many years experience in the development of a host of inkjet printable inks designed for high-speed printing on low, mid, and high-temperature substrates including metallic silver and nickel, low TCR resistors and high-K dielectrics. Cabot's metallic conductive inkjet inks enable direct high-resolution inkjet printing of pure metal electrodes and interconnects with resistivities at the micro-ohm-cm-level (bulk resistivity) on a variety of traditional substrates with excellent adhesion and 100% reliable jetting with leading industrial piezoelectric drop-on-demand inkjet printheads.

Results

Key results related to inkjet printable metallic conductors for displays and electronic components lie in three main areas: 1) resistivity versus cure time 2) resistivity versus cure time (TAC time) and 3) inkjet print reliability. These three parameters are the most critical in the introduction of industrial inkjet printing of metallic conductors into a production environment for these types of devices. For this reason, these are areas that Cabot PEDs has developed significant new technology, which will be presented in this paper.

Resistivity versus Cure Temperature

Display and electronic component manufacture require metallic-based conductors as electrodes and interconnects. Resistivity requirements are typically in the microOhm-cm range. The challenge is to achieve such low resistivity without sacrificing other key attributes like cure temperature, cure time, adhesion, and jet reliability. Cabot PEDs has achieved significant process improvements in this area by developing modified nanoparticle-based inkjet inks. Because metal nanoclusters have reduced melting and sintering temperatures as compared to their micron-sized counterparts, these inks can be processed at temperatures as low as 100ºC. This enables printing of highly conductive metal features on low temperature substrates such as polymers and reinforced epoxies (PET, PI, PEN, FR4), silicon, and glass, making it compatible for use in displays, and high density packages and PCBs. The data in Figure 1 illustrates the low temperature performance of Cabot silver ink for inkjet printing.

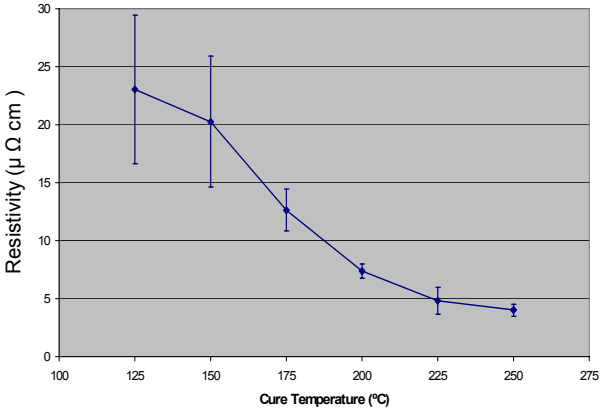

Figure 1. Low temperature resistivity (vs. cure temperature) performance data of Cabot's inkjet silver conductor.

Resistivity versus Cure Time

For the integration of inkjet printing into display or electronic component manufacture, high speed through-put is critical. To address this issue, Cabot has developed it's Inkjet Printable Silver Conductor materials to have a short post processing (TAC) time at various temperatures. Figure 2 shows data for the change in resistivity at cure time at different fixed temperatures. It is important to note that at cure temperatures of 250 C and above cure times can be as short as 1- 2 minutes.

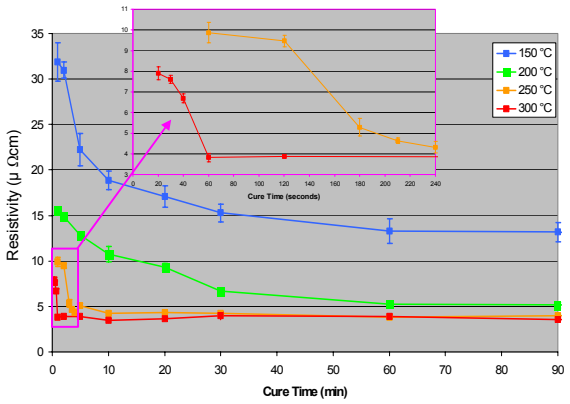

Figure 2. Resistivity (vs. cure time (TAC Time)) performance data of Cabot's inkjet silver conductor at various temperatures.

Inkjet Printing Reliability

Nanoparticle inks are stable dispersions of nanoparticles in a liquid vehicle. Cabot inks contains surface modified ultra-fine particles that are engineered for a particular electronic application, making it possible to reliably inkjet print the nanoparticles and form high-resolution electronic features on a variety of substrates. Cabot-PEDs metallic nanoparticle-based inkjet inks are designed such that they have minimal particle agglomeration. This achievement results in reliable jetting in multi-nozzle heads. Most importantly, 100% of nozzles operate routinely. This is critical for production yield in a manufacturing environment.

Table I: Typical Cabot Inkjet Printable Inkjet Ink Properties

Viscosity	14.4 cP at 22ºC
Surface tension	31 dynes/cm at 25ºC
Solid loading	20 wt%
Density	1.24 g/cc
Vehicle	Solvent based

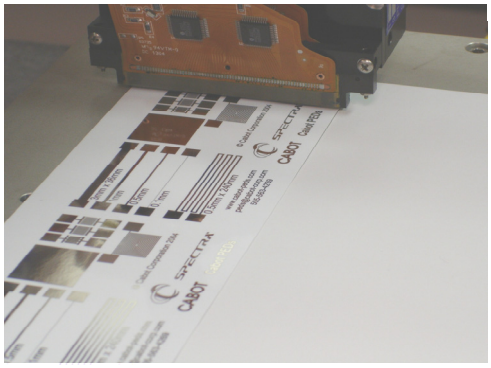

Figure 3. Inkjet printing of Cabot Inkjet Printable Silver Conductor on paper using Spectra-SE128 printhead.

This ink is compatible with Spectra SE-128 and similar heads and highly reliable printing has been demonstrated, as shown in Fig. 3.

Conclusion

The impact of these results lies in the fact that large-format flat-panel display, high density packages and printed circuit board manufacturers can now seriously consider integrating inkjet-printing systems into their production lines for interconnect deposition. These inkjet print systems can replace vacuum sputtering, photolithography and photo-definable screen-printing technologies, reducing the amount of clean-room floor space down by a factor of three just in electrode and interconnect fabrication alone as well as increase materials utilization, increase production time, especially for short runs (just-in-time manufactureing), decrease chemical waste streams and simply inventory control.

References

1. Ink-jet Technology for Fabrication Processes of Flat Panel Displays, Tatsuya Shimoda, SID Symposium Digest 34, 1178, 2003.
2. Application of Soldermaskand Etch Resist by Inkjet: End User Experiences. Giles Branthwaite, IMI 2nd Digital Electronic Materials Deposition Conference, October, 2003.
3. Markets for Plastic Electronics. Tom McLean, IMI 1st Digital Electronic Materials Deposition Conference, October, 2002.

Author Biography

Mark Kowalski received his B.S. Degree in Chemistry from the College of William and Mary in Virginia in 1983 and a Ph.D. degree in Organic Chemistry from the University of Utah in 1988. He has worked for DuPont as a Researcher in the Corian® Business (1988-1993) and Hewlett Packard in the Ink Jet Supplies Business as an Ink Chemist and Project Manager (1993-2000). He joined Cabot Corporation in 2000, where he has been a Technology Manager for the Ink Jet Colorants Division and is now in the some role in the Printed Electronics and Displays business.