Electronic Materials for Flat Panel Display and Passive Component Manufacture

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Abstract

Direct printing processes such as inkjet or gravure represent a paradigm shift in flat panel display manufacturing. The reduced process complexity and associated reduction in materials consumption can significantly reduce the cost of large format flat panel TV's to a level where broad market penetration can be realized. Cabot Corporation is developing complementary sets of printable materials with electrical performance properties, adhesion, printing performance, and process compatibility, that will enable low cost direct deposition processes such as inkjet. Recent results on printing materials and performance will be discussed.

Introduction

While large-area flat-panel displays are produced today by conventional photolithographic and screen-printing technologies, direct deposition techniques such as flexographic printing or inkjet printing are being considered to reduce cost. These deposition processes have the opportunity to drastically reduce the cost of large televisions like PDPs and AMLCDs by significantly reducing capital cost, fab floor space, and materials usage. While inkjet printing for displays has been envisioned, and research and development breakthroughs have been reported in this general area [1,2], 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, optical, and mechanical performance and high print reliability. Materials compatibility with substrates, other materials and processes has also largely been neglected. Cabot Corporation, Printable Electronics and Displays (Cabot PEDs), a business of Cabot Corporation, a $1.9B particulates and specialty chemical company, has developed digitally printable materials sets (including: Silver, Nickel, Black Matrix, Resistors, Inductors, Dielectrics, and Transparent Conductors) that are compatible with each other, the advanced deposition tools, and the PDP and AMLCD manufacturing processes. These novel materials are designed to adhere to relevant display substrates, have competitive performance parameters, high print reliability and are designed to be compatible with other in-line processes and materials sets. Cabot PEDs has technical core competencies including fine particle manufacture, surface modification and dispersion, ink formulation, and printing and processing know-how. All of these competencies are leveraged to overcome the obstacles stopping the commercialization of ink-jetting as a major display manufacturing process.

Results

Key progress will be presented in the following three areas: 1) inkjet printing reliability and performance, 2) materials performance versus tact time, and 3) development of complementary materials sets for display manufacturing and process compatibility. These three parameters are the most critical in the introduction of printable materials into display fabrication lines. For this reason, these are areas that Cabot PEDs has developed significant new technology.

Inkjet Printing Reliability and Performance

Cabot PEDs performs nanoparticle synthesis and ink formulation producing stable dispersions of nanoparticles in liquid vehicles. Cabot inks contain 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 [3]. Cabot PEDs nanoparticle-based inkjet inks are mono-dispersed resulting in reliable jetting in industrial multi-nozzle heads. High reliable jetting has been demonstrated in a variety of Spectra piezo head (S-class, galaxy) Konica-Minolta, Xaar, and Epson heads. Various inorganic electronic components are printed and tested for resolution, edge definition, electrical performance and mechanical strength (adherence testing). All these are key parameters in meeting the tight performance and resolution tolerances and production yields.

As two examples of Cabot's materials deposition technology inkjet printed Nickel features are shown in Figure 1, and line profiles of inkjet printed and cured Cabot Silver ink are illustrated in Figure 2.

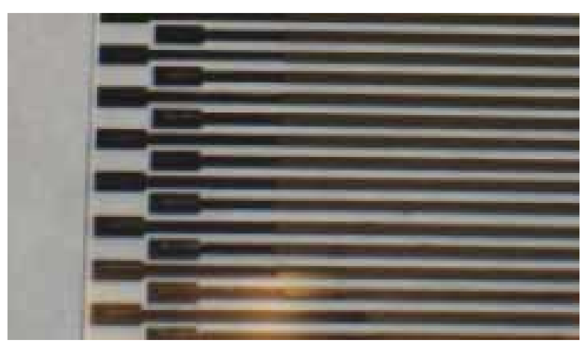

Figure 1: *Inkjet Printed Nickel Electrodes and Interconnects (down to 100 micron line width)*

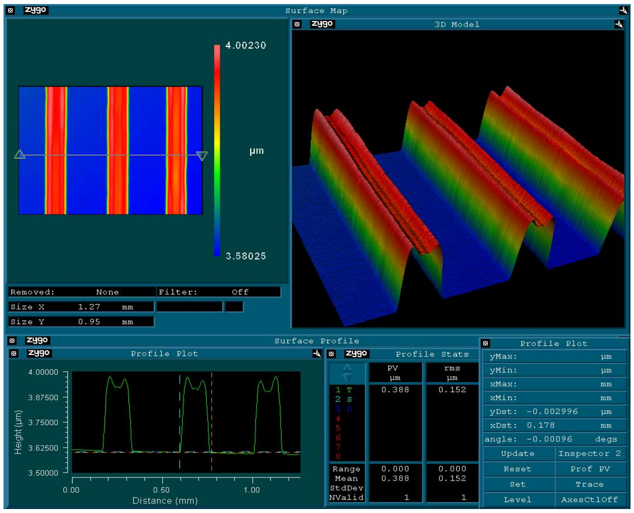

Figure 2: Zygo 3-D Imaging of Inkjet Printed Silver Display Data Lines

Materials Performance Versus Tact Time

Flat panel displays require robust materials such as highly conductive interconnects, electronically compatible electrode materials, and optical materials such as transparent conductors and black matrix materials that are both optically functional and chemically and mechanically robust. For electrodes and interconnects, resistivity requirements are typically in the micro-Ohm-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 rapidly and at much lower temperatures than their micon-sized counterparts. This enables printing of highly conductive metal features on display substrates such as polymer, silicon, and glass, with short tact times. The data in Figure 3 illustrates the ability to rapidly cure Silver ink, reaching single digit micro-ohm-cm level resistivity in less than one minute.

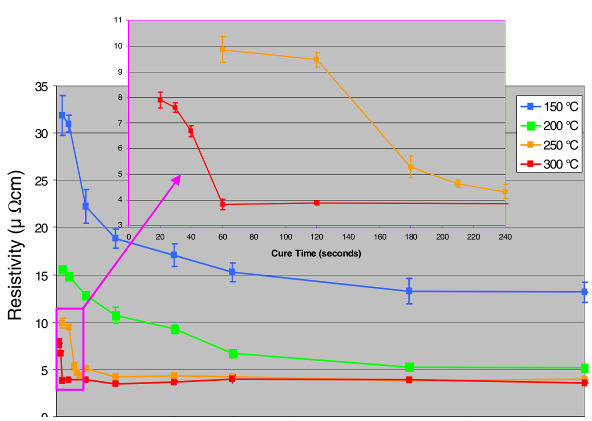

Figure 3: Bulk Resistivity of Silver Printed on Display Glass as a Function of Cure Time in Air

This advantage in short tact times can be exploited through the concept of roll-to roll printing as an electronics manufacturing tool. Cabot Printable Electronics and Displays is working with DGI to develop a silver ink that can be inkjet printed on a roll-to-roll inkjet printer designed for flexible-based circuit and display applications. A concept drawing is shown below.

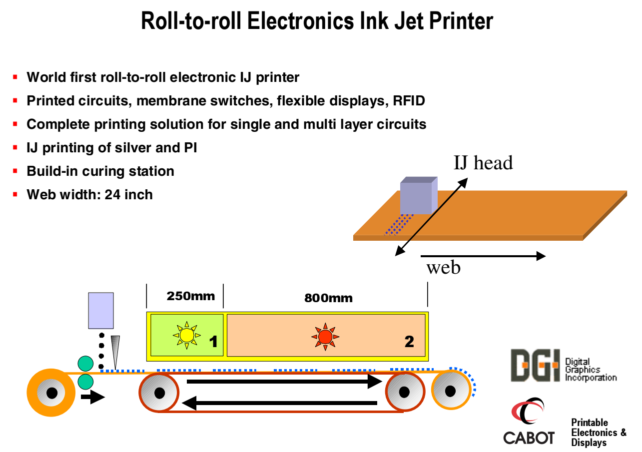

Figure 4: Schematic Concept Drawings of the DGI Roll-to-Roll Electronic Inkjet Printer

Development of Complementary Materials Sets for Display Manufacturing

The development of complementary and compatible materials sets is critical for the adoption of these new materials into production processes. For example, a silver -black matrix - ITO materials set is required in PDP manufacturing to optimize both electronic and optical functionality. Another example is complementary metals such as Silver and Nickel. Both metals can be printed in a two-step process to achieve both good electrical conductivity and optimized surface and interface properties such as matched work function and chemical barrier for material and process compatibility. Cabot PEDs is developing such material sets as can be seen in the SEM micrograph in Figure 5, where Silver and Nickel are inkjet printed in a multi-layer stack.

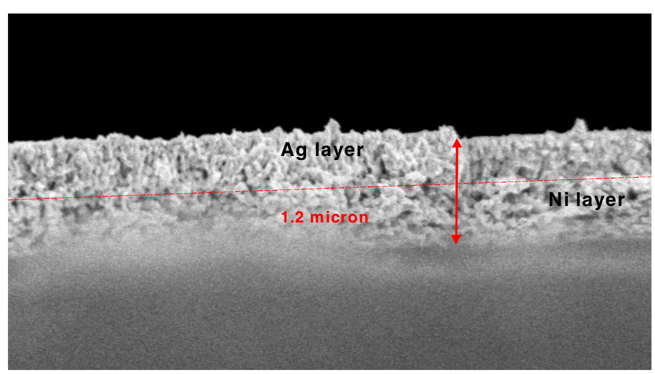

Figure 5: Cross-Sectional SEM of Ni-Ag Stack Printed by Spectra SE-128 Inkjet Head

Cabot PEDS, through various partnerships, is also developing conductor insulator material sets that will ultimately enable multi-layer printing for 3-D integration. But shorter term such material sets allow one to develop all-inkjet solutions for applications such as flexible segment displays. Preliminary experiments with a polyimide ink that can compliment Cabot Silver Ink for such applications have shown great promise. Wetting of polyimide ink on cured Cabot Silver and wetting of the silver ink on cured polyimide ink appeared to be similar to the wetting behavior of the same ink on DuPont™ Kapton®. Figure 6 shows the wetting behavior of Cabot 50 wt% prototype ink on DuPont™ Kapton® (left portion of image) and on inkjet printed and cured Chisso polyimide PIN-6100-001 ink (right portion of image). These data confirm that the resolution can be well controlled when printing on both standard substrates and inkjet printed dielectric materials such as polyimide. This is a critical step forward on the road to all-inkjet printed multi-layer devices.

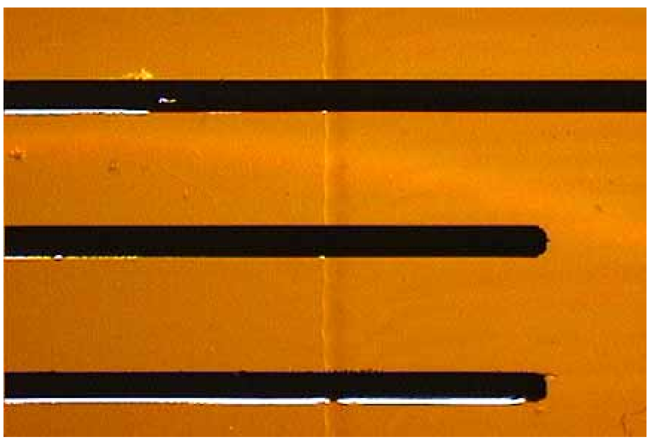

Figure 6: *Wet out of Cabot 50 wt% Prototype Silver Ink on DuPont™ Kapton® (left portion of image) and on Inkjet Printed and Cured Chisso PI PIN-6100-001 Ink Sample (right portion of image)*

Testing of line resolution with the polyimide ink indicated that resolutions of 100 µm or less are achievable and have been demonstrated. Further, dielectric strength testing indicated that a value of 0.1MV/cm has been achieved.

Cabot PEDs would like to extend its gratitude to Chisso Corporation for providing polyimide sample materials and for their continued involvement in developing ink jet printable electronic materials.

Impact

The impact of these results lies in the fact that large-format flat-panel display manufacturers can now seriously consider integrating inkjet-printing systems into their production lines for electrode and 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 and decrease chemical waste streams.

References

[1] Tatsuya Shimoda, Ink-jet Technology for Fabrication Processes of Flat Panel Displays, SID Symposium Digest 34, 1178 (2003).

[2] K. Vanheusden et. al, Advanced materials systems for ultra-low temperature, digital, direct write technologies, in "Direct write technologies for rapid prototyping applications", pp 123-172, Academic Press, New York, (2002).

[3] K. Vanheusden , Digital printing of metallic conductors for flat panel and flexible displays, USDC Flexible displays and Microelectronics Conference, (2005).

Author Biography

Klaus Kunze received his doctoral degree in inorganic chemistry from the University of the Saarland, Germany, in 1988. This was followed by postdoctoral research at the University of Utah and later at the University of New Mexico. Between postdoctoral studies he also developed organometallic compounds for biocidal applications at Schering, Germany, and held a faculty position at the University of Namibia. Klaus spent the last 11 years at Superior MicroPowders developing micro- and nanopowders, ink and paste formulations for advanced materials applications using spray pyrolysis, aerosol assisted CVD and direct write printing techniques, and later at Kovio in the area of printed electronics. He is now Project Leader for New Materials Development in Cabot's Printable Electronics and Displays division.