Metal films for printed electronics

Ink-substrate interactions and sintering

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Abstract

A new manufacturing paradigm may lower the cost and environmental impact of existing products, as well as enable completely new products. Large scale, roll-to-roll manufacturing of flexible electronics and other functionality has great potential. However, a commercial breakthrough depends on a lower consumption of materials and energy compared with competing alternatives, and that sufficiently high performance and reliability of the products can be maintained. The substrate constitutes a large part of the product, and therefore its cost and environmental sustainability are important. Electrically conducting thin films are required in many functional devices and applications. In demanding applications, metal films offer the highest conductivity.

In this thesis, paper substrates of various type and construction were characterized, and the characteristics were related to the performance of inkjet-printed metal patterns. Fast absorption of the ink carrier was beneficial for well-defined pattern geometry, as well as high conductivity. Surface roughness with topography variations of sufficiently large amplitude and frequency, was detrimental to the pattern definition and conductivity. Porosity was another important factor, where the characteristic pore size was much more important than the total pore volume. Apparent surface energy was important for non-absorbing substrates, but of limited importance for coatings with a high absorption rate. Applying thin polymer–based coatings on flexible non-porous films to provide a mechanism for ink solvent removal, improved the pattern definition significantly. Inkjet-printing of a ZnO-dispersion on uncoated paper provided a thin spot-coating, allowing conductivity of silver nanoparticle films. Conductive nanoparticle films could not form directly on the uncoated paper.

The resulting performance of printed metal patterns was highly dependent on a well adapted sintering methodology. Several sintering methods were examined in this thesis, including conventional oven sintering, electrical sintering, microwave sintering, chemical sintering and intense pulsed light sintering. Specially designed coated papers with modified chemical and physical properties, were utilized for chemical low-temperature sintering of silver nanoparticle inks. For intense pulsed light sintering and material conversion of patterns, custom equipment was designed and built. Using the equipment, inkjet-printed copper oxide patterns were processed into highly conducting copper patterns. Custom-designed papers with mesoporous coatings and porous precoatings improved the reliablility and performance of the reduction and sintering process.

The thesis aims to clarify how ink-substrate interactions and sintering methodology affect the performance and reliability of inkjet-printed nanoparticle patterns on flexible substrates. This improves the selection, adaptation, design and manufacturing of suitable substrates for inkjet-printed high conductivity patterns, such as circuit boards or RFID antennas.

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