Inkjet Printing and Microwave Sintering of Conductive Tracks on Polymer Substrates

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Introduction

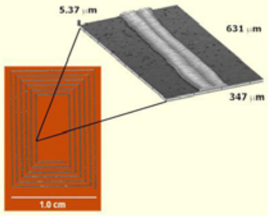

Figure 1. An inkjet printed antenna structure on polyimide, which can find its application in the cheap and fast production of Radio Frequency Identification (RFID) tags.

Inkjet printing has become an interesting tool since it allows precise and controlled deposition of various materials onto substrates, such as paper, ceramic, glass, and polymer foils. Typical inks are solutions of polymers or colloidal suspensions which contain particles or pigments with a certain size distribution.

An exciting application is the production of conductive tracks by inkjet printing, which can be printed directly from solution[1] or suspension.[2] A subsequent sintering step is necessary to render the tracks conductive. A typical ink is a suspension of noble metal nanoparticles, for example silver. The nanoparticles in the ink have a metal core and a polymeric shell, which stabilizes the particles to avoid agglomeration in the liquid phase. After printing the polymeric shell has to be removed which is done in the sintering step.

The conventional sintering method involves heating the sample at 220 °C for 60 minutes, which removes the dispersing agents. This allows the metal cores of the nanoparticles to touch and sinter together. As a result of the sintering mechanism, a continuous percolation network is formed that provides continuous channels for the conduction electrons to flow throughout the material without obstacles, therefore forming a low resistance pathway.

Inkjet printing has become a low-cost technique to produce electronic and other structures due to the variety of inks and substrates that can be used. Here we present our recently obtained results on inkjet printing of silver tracks onto polymer substrates and a new method to sinter these tracks using microwave radiation.[3]

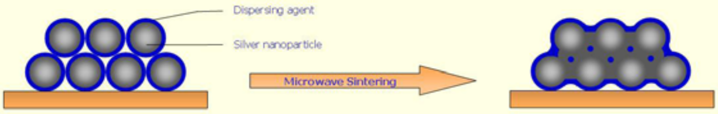

Figure 2. A mechanism for the low temperature sintering of conductive nanoparticles.

Inkjet Printing

A suspension of silver nanoparticles in tetradecane (Nanopaste™, Harima Chemical Ltd.) was inkjet printed using Microdrop's Autodrop system, which is equipped with a MD-K-140 dispenser system. The substrates used were polyimide (Kapton®), polycarbonate (Makrofol®) and polyethylene terephthalate (PET). Figure 4 shows typical prints.

Figure 3: Stroboscopic control image of a drop formation through a dispenser nozzle. Every image has been taken with an interval of 100 µs.

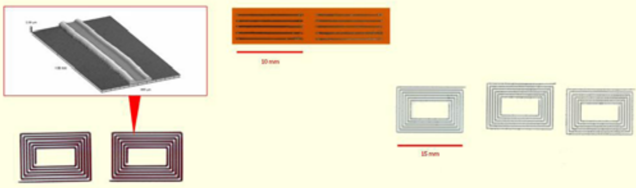

Figure 4. Photographs of inkjet printed silver tracks on polycarbonate, polyimide and PET, respectively from left to right.

For the microwave sintering experiments an array of parallel lines with a typical length of 1 cm and an interline spacing of 1 mm was printed onto polyimide by depositing droplets using a spacing of 50 µm. In order to minimize the 'bleeding' of a printed line the substrate was heated to 150 °C during printing. The elevated temperature increases the evaporation rate of the solvent tetradecane (T_b = 253 °C) which subsequently limits the expansion of the printed line.

Microwave Sintering

Printed lines on polyimide foil were sintered for 3 minutes by microwave radiation using a monomodal microwave oven (Emrys Liberator, Biotage Monomodal Microwave System) operating at 2.45 GHz and a power of 300 W. The resistance per unit distance of the sintered lines was 4 to 6 $\Omega.cm^{-1}$ and the resistivity of the material as calculated from the resistance and the cross-sectional area of a line is 30 x 10^{-8} Ω.m, which is 5% of the value of bulk silver (1.59 x 10^{-8} Ω.m).

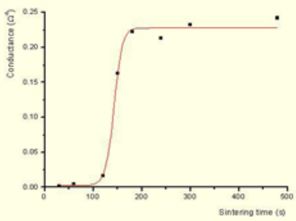

Figure 5. Conductance as a function of time for the microwave sintering of silver tracks.

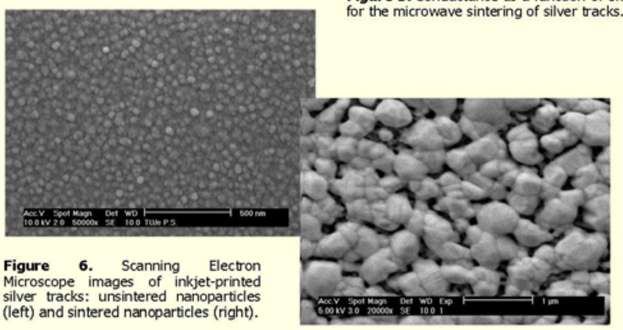

Figure 6. Scanning Electron Microscope images of inkjet-printed silver tracks: unsintered nanoparticles (left) and sintered nanoparticles (right).

Conclusions

We have successfully prepared conductive silver tracks by inkjet printing silver nanoparticles onto a polymer foil and by using microwave radiation to sinter these lines. We were able to use the microwave as a selective heating device, since conductive (silver) particles absorb microwaves to a better extent than polymer foil. Furthermore, the microwave was used to shorten the sintering time from 60 minutes down to 3 minutes. The resistance per unit distance of the sintered lines was 30 x 10^{-8} Ω.m.

References

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[3] J. Perelaer, B.-J. de Gans, U.S. Schubert, *Adv. Mater.* **2006**, *18*, in press.

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