Thin conductive layers from Cu nanopowders produced by arc discharge

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The production of electrically functional devices can be done more economically by means of printing technologies when compared to conventional high-vacuum PVD technology. In this field, the synthesis of copper nanoparticles has attracted much attention because of its huge potential for replacing expensive nano-silver inks utilized in conductive printing. The used copper nanoparticles are traditionally synthesized by wet chemistry routes, which are difficult to scale-up. In this work, an arc discharge process was optimized for the requirements of copper-based nanoinks, and a dispersion of gas-phase synthesized copper nanoparticle powder was formulated.This work is aimed at maximizing the electrical conductivity of thin layers produced from these dispersions as function of the process and film preparation conditions.

The arc discharge process (Stein et al., 2013) guarantees the availability of high-purity metallic nanoparticles with high-process throughput (guaranteed by the concept of parallelisation of simple single units), low product costs and high energy-efficiency, with minimal impact on the environment. A pilot plant applying 16 single discharge units was developed to allow sufficient supply of nanopowder. The most important powder property is the primary particle size, which can be varied by means of the carrier gas composition or the arc current. Nanopowders based on particles of two different primary particles sizes are investigated here, 86 and 50 nm.

The dispersion with 40 wt% of copper added was optimized in view of its stability as well as the electrical conductivity of the produced films. Ethanol is used as main dispersant for the 50 nm samples, whereas isobutanol and glycerol were added to the 86 nm dispersions. The nanodispersion is mill grinded (M400, Retsch, Haan, Germany) for 3 hrs to break soft agglomerates. The stabilized dispersion is then printed on a glass substrate by a spin coater (Spin 150, SPS, Putten, Netherlands), which allowed to vary the film thickness by means of the rotating speed. The inks were then dried at different temperatures to obtain a solid thin film. Film thicknesses between 500 and 5000 nm were obtained, which was measured by means of a profilometer (XP200, Ambios, Santa Barbara, US). The electrical resistance has been measured in a four-point probe station, the resistivity can then be calculated by multiplying with the measured film thickness.

For both particle sizes, a study was made of the sintering conditions such as sintering pressure and temperature. In Fig. 1, the effect of sintering can be seen. The electrical conductivity of the printed layer is also dependent on the layer thickness, as the thinner layers show better conductivity.

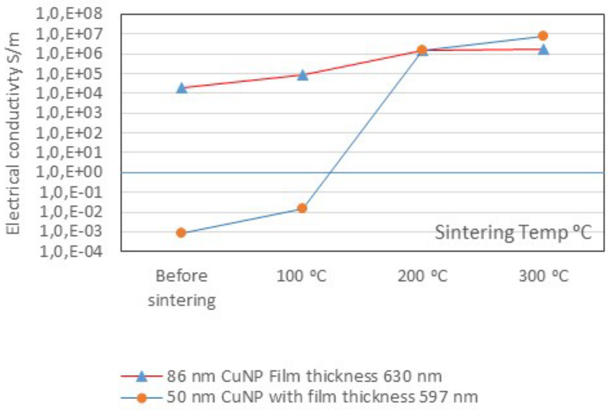

Figure 1. The effect of sintering of the electrical conductivity.

The results are compared to nanoinks produced via wet chemical routes in Table 1.

Table 1. Comparison of electrical conductivity of the thin Cu films from different preparation routes.

Cu primary particle size	Electrical conductivity (unsintered)	Electrical conductivity (sintered)
50 nm	$9 \cdot 10^{-4}$ S/m to $1.1 \cdot 10^{-1}$ S/m	$2.7 \cdot 10^{6}$ S/m to $7.7 \cdot 10^{6}$ S/m
86 nm	$6.7 \cdot 10^{4}$ S/m to $2.3 \cdot 10^{5}$ S/m	$8.4 \cdot 10^{4}$ S/m to $1.8 \cdot 10^{6}$ S/m
Liquid phase processes, literature data		$9.1 \cdot 10^{5}$ to $8.7 \cdot 10^{6}$ S/m
Bulk copper		$5.8 \cdot 10^{7}$ S/m

The printed copper films maintained their electrical conductivity after 14 months, with only a small decrease in conductivity.

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