ELECTRON BEAM SINTERING OF COPPER INKS FOR APPLICATIONS IN RAPID PROTOTYPING AND PRINTED ELECTRONICS

Fraunhofer

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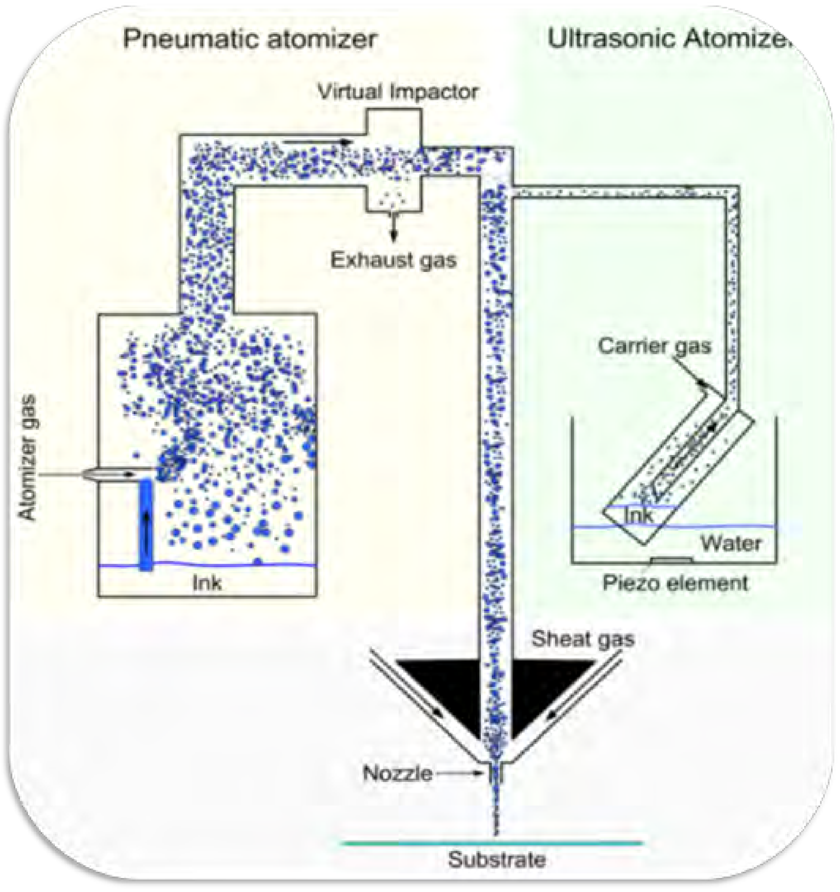
ABSTRACT

This work presents a novel technology for creating conductive paths on temperature sensitive substrates. In our approach we use cheaper copper based inks instead of silver. These novel inks consist of particles in the micrometer range and provide two significant benefits: First, the content of oxidized copper on the surfaces is drastically reduced in comparison to nanoscale particles. Second, the printing speed can be increased due to the bigger volume of the particles. The main disadvantage of these micrometer sized copper particles is the increased temperature of about 700-900 °C required for the subsequent sintering process. For this reason, the most interesting polymer substrates are excluded using conventional technologies. To resolve this restriction, we developed a process that confines the heating just to the desired structures, namely the aerosol jet printed copper lines. Therefore, undesired heating of the entire substrate is avoided. This is possible by using electron beams, in comparison to a conventional scanning electron microscope (SEM) a focused electron beam is scanned over the substrate with the printed electronic structures. Due to the unique absorption characteristics of this particle beam, the energy is locally brought into the treated material and only a certain volume next to the surface is heated up. So the whole volume of the printed line can be heated up to the sintering temperature within some microseconds while the underlying and the adjacent substrate is still not affected.

AEROSOL JET PRINTING

- Aerosol jet printing is a promising new technology to produce low-cost electronics into almost any substrate. In this direct writing method the ink is atomized (pneumatic or ultrasonic atomizer) and transferred to a nozzle. Advantageously, the printing process is contactless.
- In the printed head the aerosol is surrounded by a gas flow which avoids its contact to the nozzle tip. Since the aerosol stream is focused by the laminar gas stream, the width of the deposited line is only a fraction of the width of the nozzle tip. Also the distance between tip and surface can vary 2–3 mm without a significant change in line width, making it suitable for uneven surfaces.
- Typically, silver inks with nanoscale particles are used to reduce the required temperatures for sintering the deposited material and to achieve a sufficiently high conductivity. Curing temperatures of silver inks are about 200 °C and allow the use of polymer substrates. However, high material costs are the main disadvantage of the silver inks.
- In this approach cheaper copper based inks were used instead of silver.



Working principle of the aerosol jet printing

These copper inks were developed by the Fraunhofer Institute for Ceramic Technologies and Systems IKTS.

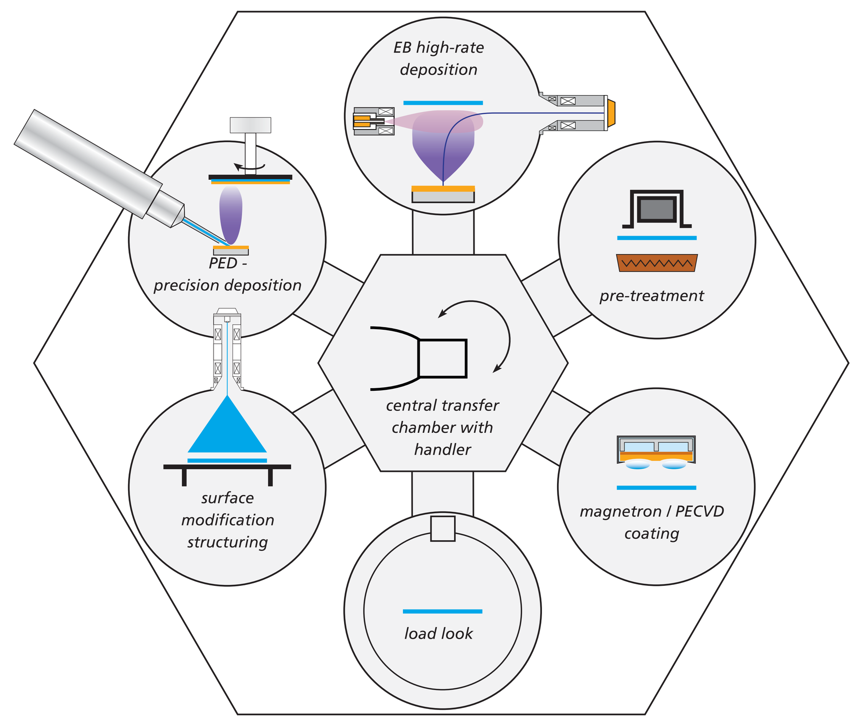
- Copper ink structures were created by aerosol jet printing on the polymer containing composite materials FR4 or RO3003.
- The main disadvantage of these micrometer sized copper particles is the increased temperature about 700-900 °C required for the subsequent sintering process.

ELECTRON BEAM PROCESS

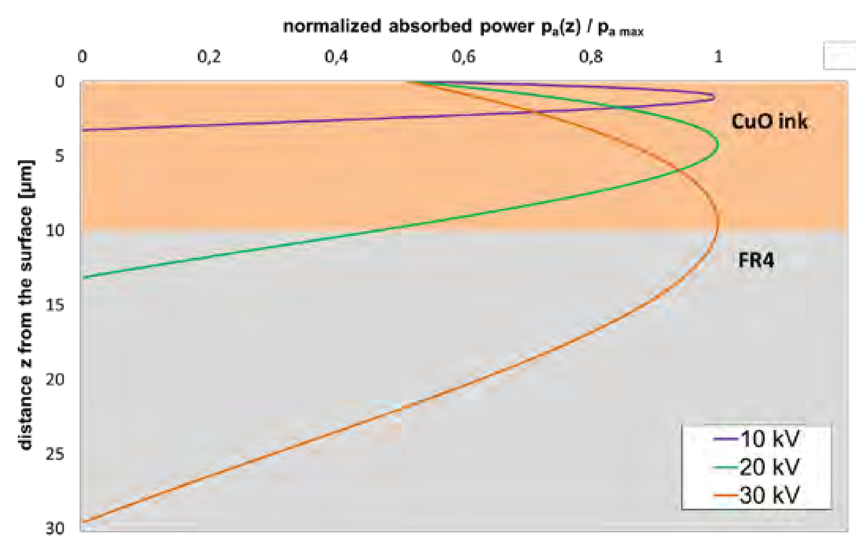
- To sinter micrometer copper particles on polymer substrates a localized sintering process was developed using a focused electron beams.
- Results were obtained with the Electron Beam Cluster Tool "ERICA" (including pre-treatment and structuring). Parameters were:

accelerating voltage	beam current	deflection angle	dwell time per point
≤ 60 kV	≤ 33 mA	≤ ± 35°	≥ 4 µs

- The electron beam is a particle beam with a characteristic and adjustable absorption profile. In contrast to near-surface energy absorption of laser light, the absorption depth of the electron beam is continuously adjustable by means of adjusting the accelerating voltage. So the voltage can adjust the thickness of the copper lines.
- The electron beam can transport energy to the work piece at high power density continuously and at high utilization efficiency (efficiency of beam generation 80-95 %). Inertia-free beam deflection enables very fast processing and the secondary effects can be used for process monitoring and controlling.



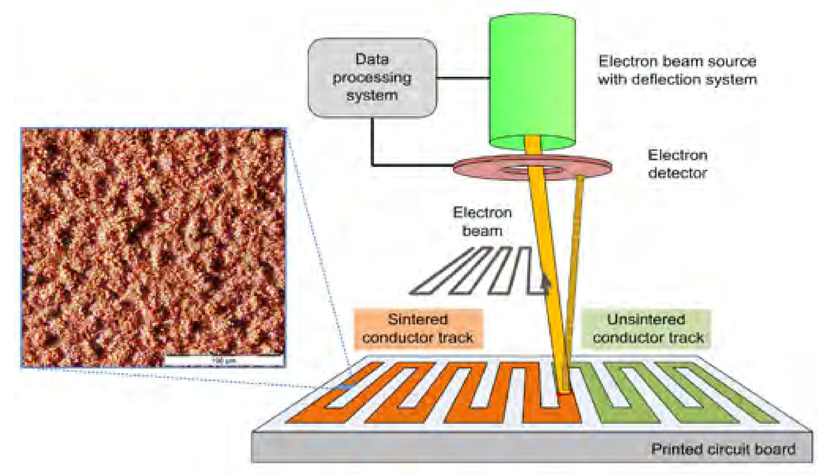
Schematic representation of the Electron Beam Cluster Tool "ERICA"



Simulated power absorption profile of the electron beam for different accelerating voltages and typical dimensions of the copper inks layer system.

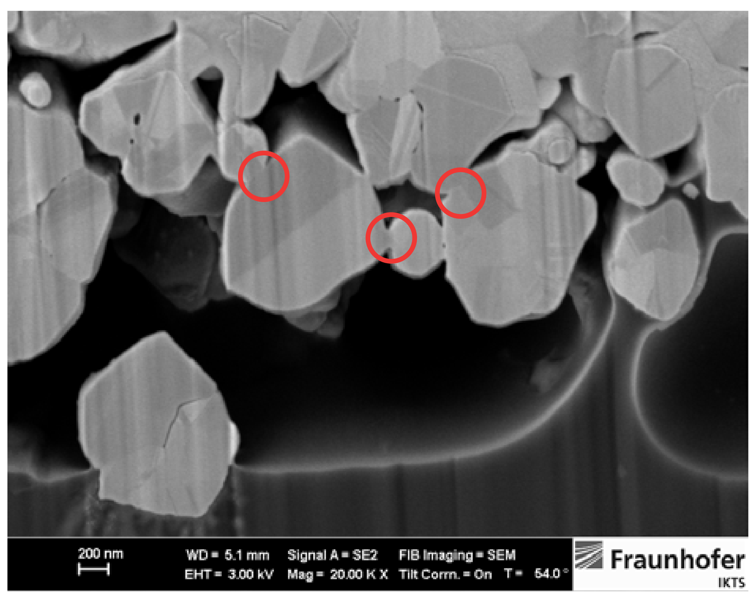
EXPERIMENTAL DETAILS AND RESULTS

- The electron beam parameters were adjusted with respect to the different thicknesses of the copper ink in such way that the maximum power absorption is brought to the center of the printed structure. For this reason, only the copper ink is exclusively heated and thus sintered, wherein the substrate is not heated by the electron beam. The power of the electron beam is set via the current strength.
- The power of the electron beam that is absorbed is set via the electron beam current strength and has a direct effect on the generated temperature in the structure. So it is necessary a minimum electron beam current for expulsion of the solvent and the subsequent sintering of the copper particles.
- If the chosen power of the electron beam is too high, the thermal impact is no longer limited to the printed structure so the thermal sensitive substrate might be damaged due to thermal conduction.

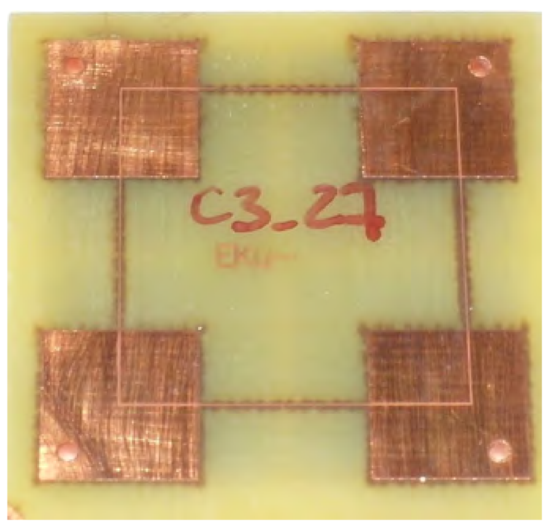


Schematic of the electron beam sintering process. Inset: Example of an electron beam sintered copper path on FR4

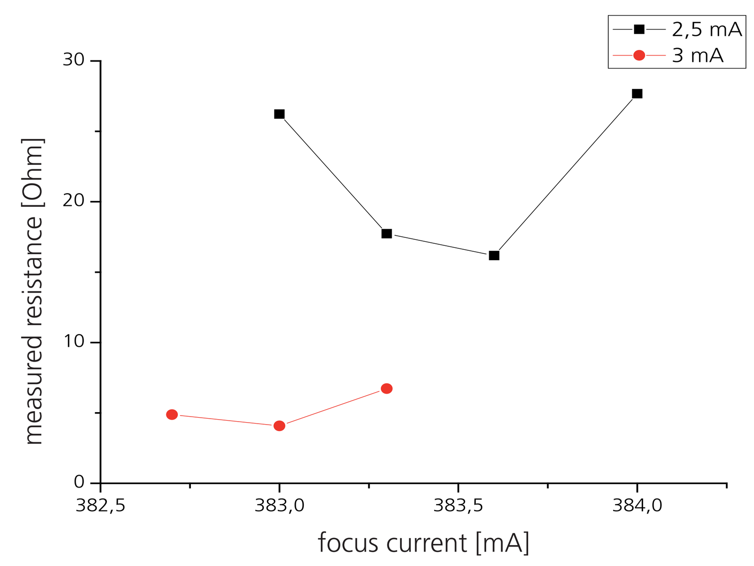
- Unnecessary treatment of blank areas of the polymer substrate is prevented by an automated beam deflection system. The beam is solely moving over the printed structures.
- Scanning electron microscopy images show the formation of sinter bridges between the particles after the treatment.
- The best result of the resistance of 0,74 Ω (structure height: < 5 µm, width: < 0,8 mm, length: > 7,5 mm) has been achieved with the electron beam parameters acceleration voltage of 20 kV and current of 3,5 mA.



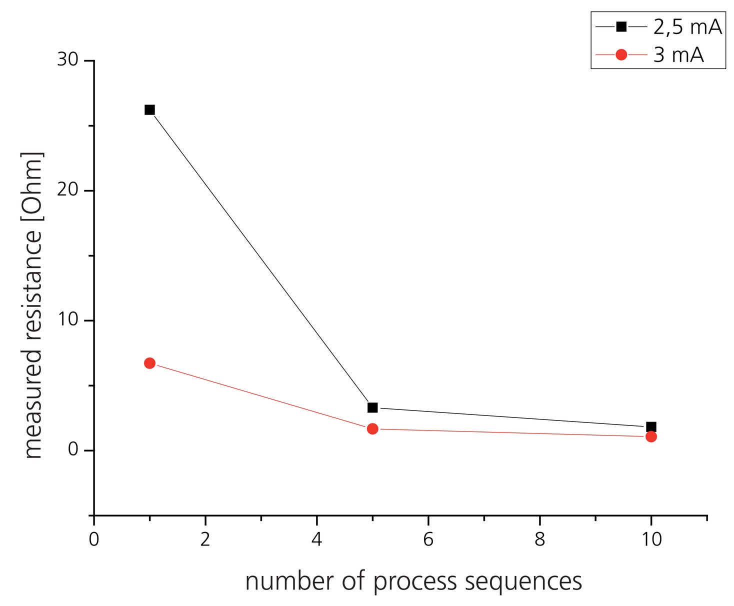
Scanning electron microscopy of an electron beam sintered copper ink



Sintered copper conductive path on FR4



Measured resistance in dependence of focus current



Measured resistance in dependence of the number of process sequences

CONCLUSION AND OUTLOOK

Future applications of the newly developed process are expected especially in the field of printed electronics (that means for example in mass production of RFID-antennas) as well as for rapid prototyping and small batch production of printed circuit boards. In particular the enhanced flexibility of a combined aerosol jet printing and tailored sintering method is a big advantage of the process.
In addition, the electron beam can be used wherever a specific amount of energy has to be brought to a certain depth range inside a layer. This property can be use for example for annealing, diffusion, local melting and evaporating as well as for sterilization.

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