# Aerosol Printing of High Resolution Films for LTCC-Multilayer Components

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***Abstract***

*For the electronic packaging of sensor stable and cost-efficient fine-line printing technologies on LTCC and high frequency laminates are needed. Especially common technologies like screen printing and thin film techniques are unsuitable for fine structures or too expensive. In addition there is no direct write technology for 3D-LTCC-designs as well as for high reliability Co-firing structures. Closing this gap the aerosol printing technology is used to print high resolution conductors on planar and non-planar substrates.*

*Aerosol printing is a direct write non-contact printing technology of functional layers. After a pneumatic atomization the ink is transformed into 1 to 5 µm droplets. The resulting, continuous aerosol stream is focused by a sheath gas in the printing head. Thus the long standoff distance between substrate and deposition tip of max. 5 mm allows the 3D-printing on non-planar substrates. With optimized inks and printing parameters line widths of 10 µm are achievable. This paper will present applications for aerosol printed functional layers on LTCC. These are, for example, aerosol printed films embedded in co-fired LTCC, fine line structures for high frequency applications and the evaluation of printed 3D-structures like LTCC-stairways. Furthermore the 90 degree contacting of unconventional sensor designs will be presented.*

**Key words:** LTCC, Aerosol Printing, 3D structures, Microsystems

## 1 Introduction

Screen printing has been the dominant technology for the deposition of functional films required in ceramic thick-film or LTCC components. Latest developments for an improvement of the fine-line ability were aligned on new screen meshes, emulsions or adopted pastes. Minimum structure sizes e.g. for high-frequency applications presently reached 25µm [1]. Required optimizations of fine-line screen printing are related to improved film thickness homogeneity, better printing reproducibility and enlarged printable areas [1].

Aerosol printing belongs to digital printing technologies. That means the required pattern can be printed directly from the pattern generator of the circuit design software [9]. As an additional deposition technology for ceramic thick-film or multilayer technology it closes the gap between screen printing and photolithography.

This novel direct writing method for ultra fine pattern is used in photovoltaic applications [2], [3] and polymer electronics (touch screen, fully printed TFTs) [4], [5], [6]. The deposition of high-permittivity materials on PCB substrates [7] and the contacting of stacked dies are further applications for aerosol printing [8].

In the aerosol process the ink droplets are generated and brought into a gas flow using a spraying (pneumatic) or an ultrasonic ‘atomizer’ unit. Furthermore, the droplet flow is compacted (virtual impactor) and led to the deposition head where it is finally focused (Figure 1).

Because of the large standoff distance of the deposition head to the substrate, 3D surfaces can be printed. The minimum diameter of the focused droplet flow is smaller than 10 µm.

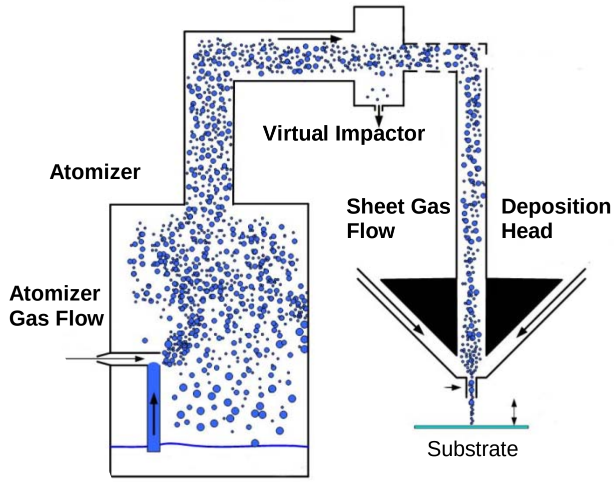


**Figure 1:** Principle components of an aerosol printer (Optomec Aerosol Jet) [10].

Potential applications for aerosol printing within hybrid electronic packaging include Ag metallization lines for LTCC rapid prototyping, ultra fine line printing, e.g. high-frequency applications, sensors and 3D printing, e.g. chip contacting (Figure 7), microsystems and sensors.

## 2 Aerosol Printed Inner Layer Ag Conductors Co-Fired in LTCC

For an improvement of the throughput times for the manufacturing of LTCC prototypes delay times for screen manufacturing must be reduced significantly. Using a direct writing technology like aerosol printing, is one possible way to reduce the manufacturing times for prototypes or small series.

The goal of the experiments was to determine a material combination (LTCC/ Ag-ink) and a suitable processing method (printing, lamination and firing) for aerosol printed Ag conductor lines. For the investigations an adapted screen printing paste, a micro ink and a nano ink were printed on DP 951 LTCC tapes.

Table 1 lists the three types of investigated commercial inks and their particle size distribution.

**Table 1:** Particle size distribution: D(50) and D(90) and viscosity (η) of aerosol printable silver inks.

| | Unit | Ag nano ink | Ag micro ink | adapted Ag paste |
|---|---|---|---|---|
| **D(50)** | µm | 0.06 | 0.55 | 1.51 |
| **D(90)** | µm | 0.11 | 2.08 | 4.05 |
| **η*** | Pa·s | 0.1 | 1.9 | 35.2 |

* T=20 °C, shear rate 10 $s^{-1}$

By a four-point resistivity measurement and the analysis of the cross-sectional area of the inner layer conductors, the specific resistivity was calculated. Figure 2 shows the measured values.

Using the Ag nano ink, a resistivity near the bulk silver can be reached. The specific resistivity of the aerosol micro ink is comparable to screen printed inner layer conductor pastes.

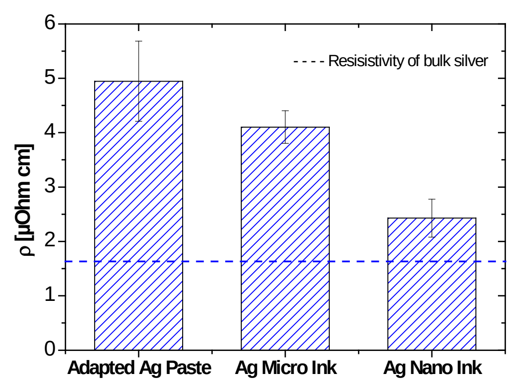


**Figure 2:** Specific resistance of the co-fired fine line Ag inner layer conductors (embedded in DP 951).

The microstructure of the samples was analyzed using SEM/EDX**.** Figure 3 shows the cross-section of an innerlayer conductor line printed on DP 951 using the silver nano ink. The lines have a width of about 30 µm and a thickness of 15µm. The high aspect ratio of 0.5 was reached by multiple pass printing (10 times). The cross section of the nano silver shows just a few pores in the line and in the ceramics in comparison to the aerosol micro ink. EDX analysis detected no silver diffusion in the LTCC interfacial area.

By varying the printing parameters line widths between 15-50 µm and line thicknesses between 8-20 µm were achievable for the micro and nano ink by 10 multiple passes.

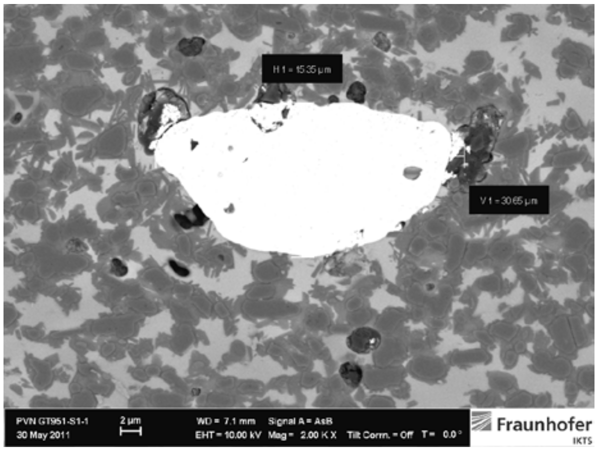


**Figure 3:** Microstructure of a co-fired aerosol printed conductor line (silver nano ink 10 times printed and embedded in LTCC DP 951).

Figure 4 shows the cross section of the adapted paste in DP 951. For 10 printing times conductor widths of 25-50 µm and line thicknesses between 3.5-5 µm were achieved. Less selective overspray is visible next to the conductor line. A major fraction of particles of the paste were filtered in the pneumatic atomizer and could not be deposited. All printing results of the tested inks are listed in Table 2.

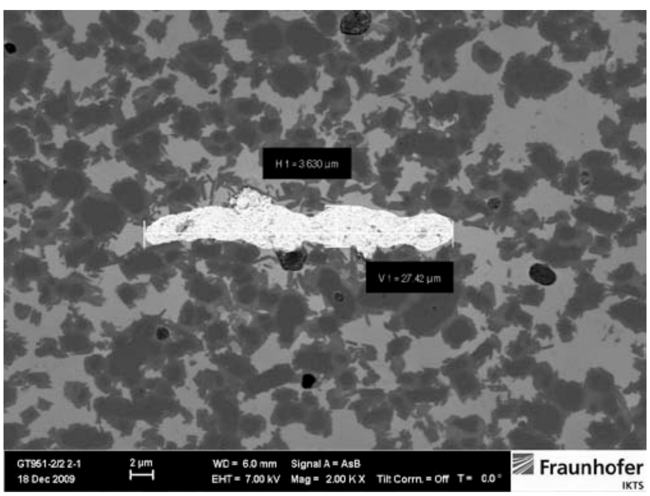


**Figure 4:** Microstructure of a co-fired aerosol printed conductor line (adapted silver paste embedded in LTCC DP 951).

In summary the nano ink shows the best results regarding resistivity, porosity of the conductor cross section and fine line printing ability in the inner layer conductor tests. An aspect ratio of 0.5 is printable in LTCC. The micro ink offers the best deposition rate with 5 µm per print repeat. A less overspray was detected for optimized printing parameters for both inks.

The screen printing paste is just an alternative for both inks. Less than a half of the printable silver cross section area of the micro ink could be deposited for the same conductor width.

**Table 2:** Printing results (optimized printing process).

| | **Unit** | **Ag nano ink** | **Ag micro ink** | **adapted Ag paste** |
|---|---|---|---|---|
| **Print quality*** | - | +++ | +++ | + |
| **Over spraying*** | - | no | no | some |
| **Max. Deposition rate (dried)** | µm/print | 4 | 5 | 1.5 |
| **Minimal line width** | µm | 15 | 20 | 25 |
| **Firing tempera-ture** | °C | 875 | 875 | 875 |
| **Spec. resistivity** | µOhm·cm | 2.43 | 4.10 | 4.95 |

* +++ = very good, + =suited

## 2.1. Application example for Ag Inner Layer Conductors Co-Fired in LTCC

An application example for a co-fired functional layer is a high frequency test structure printed with the Ag micro ink on Heraeus CT708 tape as shown in detail in figure 5. In this layout fine-line conductors are mixed with laminar shapes which have to be filled by aerosol printing. To get high quality filled shapes, the single lines of the line-raster were printed with a width of 30 µm to avoid overspraying effects at the edges. By four printing passes the thickness in unfired state is ca. 10 -20 µm.

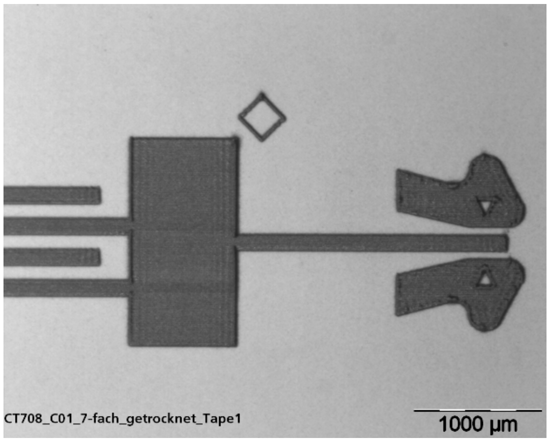


**Figure 5:** High frequency test pattern on LTCC for co-firing tests

## 3. 3D - Aerosol Printing of Post-Fired Ag Conductors

In addition to fine-line printing on planar substrates the unique 3D-printing ability of the Aerosol Jet printer should be discussed. The 3D-ability of aerosol printing results from the combination of the long standoff distance of the aerosol printing nozzle and the large focus length of the droplet flow. The nozzle can be adjusted up to 4-5 mm above the substrates.

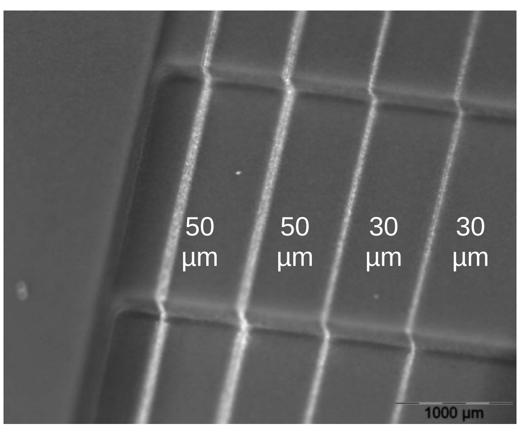


**Figure 6:** 3D printing on LTCC stairways (step height 220 µm, DP 951) with aerosol printed Ag micro ink.

Figure 6 shows 30 to 50 µm wide conductive lines printed over 280 µm high LTCC stairways with silver micro ink. To print over a 90 ° step the nozzle or the substrate as well as the substrate table have to be shifted (up to 20 °) to reach similar deposition angles.

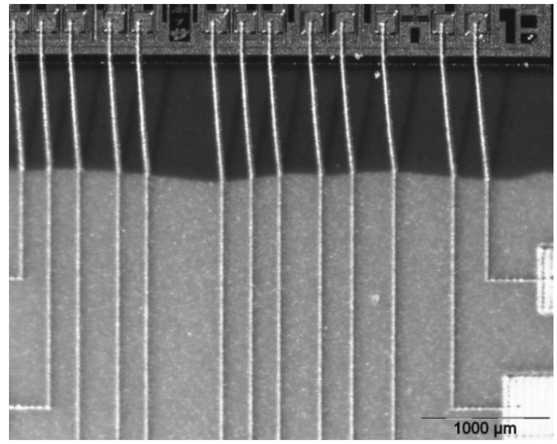


**Figure 7:** Aerosol printed 3D chip contact

Another 3D-application could be the printing over an adhesive ramp which is dispensed at the edge of a 90 ° step. The advantage of this technology is that the nozzle or substrate has not to be shifted. Like in figure 7 the conductor lines are continuously contacting a 350 µm high chip. For this application, the sintering temperature is restricted to be up to 200 °C because of the temperature sensitive chip. The required sintering temperature is determined in the required temperature range as figure 8 shows. For this reason, the Ag nano ink was used.

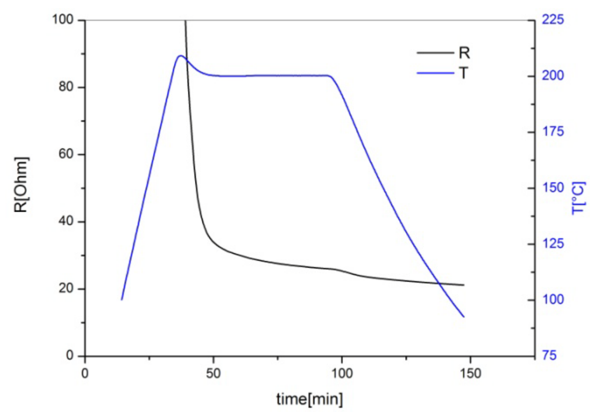


**Figure 8:** Sintering curve of the applied Ag nano ink (test structure embedded in LTCC DP 951).

## 3.1 Contacting of g-accelerometer by Aerosol Printing

For a novel, high-g-shock silicon accelerometer design (© Fraunhofer EMI) a true 90 ° 3D contacting should be demonstrated by aerosol printing. As a result of the sensors unconventional geometry of the spring-mass system, that the sensing direction is aligned in the wafer plane, the contact pads of the g-accelerometer are perpendicular to the substrate. The aerosol printing technology offers the ability to contact these accelerometer-chips in an efficient and space-saving way to the next substrate level.

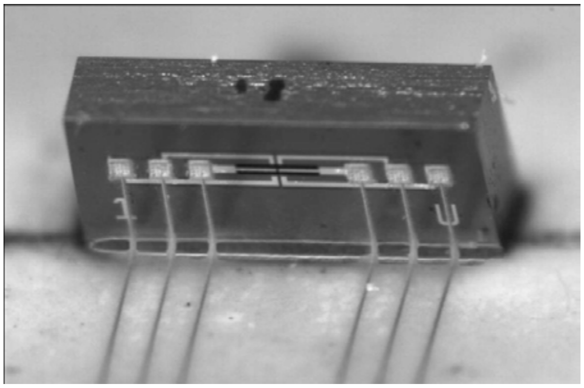

**Figure 9:** Contacted g-accelerometer (© Fraunhofer EMI) by aerosol printing.

Figure 9 shows a g-accelerometer contacted by aerosol printed 40 µm Ag conductor-lines. An important element is the adhesive for fixing the chip and works as a substrate-chip passage for the conductor lines, too. It should offer a low temperature coefficient (< 50 ppm $K^{-1}$) and should be temperature resistive up to 250 °C. First temperature-shock-tests with 82 cycles from -55 °C to 80 °C at the bare contacted sensors showed a slight drift in resistance value of the contacts.

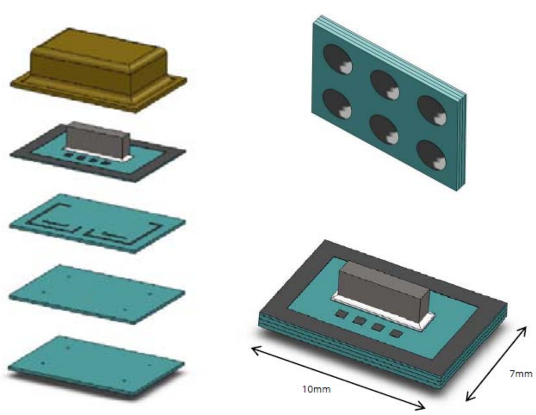


**Figure 10:** Packaging concept of aerosol contacted g-accelerometer in LTCC

For the current accelerometer-design a ball grid area packaging concept in LTCC in combination with aerosol and screen printing conductors was designed to get a robust sensor system with an overall dimension of 7 x 10 mm² (see figure 10).

## 4 Conclusions

The paper discusses the applicability of aerosol printing as an additional technology for the deposition of functional films required in ceramic thick-film or multilayer components.

It could be shown that aerosol printing is very well suited for LTCC co-firing and post-firing applications. Application examples for aerosol printed Ag lines include LTCC rapid prototyping, 3D printing and contacting of unconventional sensors and packages with the help of low temperature sintering Ag inks.

With this application portfolio, aerosol printing technology closes the gap between screen printing and photolithography regarding the printing resolution. Furthermore the packaging of sensors and specialized chips could become more flexible and space saving.

Current projects are focused on the development of aerosol printable inks (non-silver metallization, suited glasses and resistors), the optimization of the process repeatability as well as the application of aerosol printing for the fabrication of electronic packages, sensors and microsystems.

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