# Low Profile Packaging for MEMS Aero-acoustic Sensors

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## Abstract:

This paper describes a semi-automated conductive ink process used for packaging MEMS devices. The method is applied to packaging of MEMS sensors for wind tunnel testing. The primary advantage of the method is a reduction in surface topology between the package and the integrated MEMS sensors. In this paper we explore the relationship between trace dimensions, resistivity, and deposition parameters such as feed rate, tip-substrate separation and tip diameter. Using this procedure it is possible to generate interconnects between a PC board and MEMS sensor chip with a topology of less than 25 micrometers.

## Introduction:

The ability to produce low-profile connections easily and effectively allows for a simple integration of MEMS devices into low topology packages. In this work, we explore the possibility of using an automated micropositioning stage and computer-controlled pressure driven syringe to draw interconnects between a PC board and a MEMS chip using conductive silver filled ink. By optimizing the flow characteristics of the conductive ink through the syringe and the velocity of the micro-positioning stages, the height of the silver traces can be reduced to fewer than 25 micrometers in order to achieve low profile, low resistance, and versatile connections for a wide variety of applications.

The previous packaging approach employed by our group, which is similar to other methods commonly used for surface mounting MEMS sensor chips, used gold wire bonds with potting epoxy fill. With careful application of this procedure, including computer numerically controlled milling of the epoxy cavities; a minimum surface topology of approximately 100 micrometers was achieved. For flow measurement applications under turbulent boundary layers with Reynold's numbers on the order of $10^6$ and flow speeds on the order of 200 m/s, a surface roughness of less than 25 micrometers is desired. This is a lower surface topology than could be achieved with the wirebonding method. In addition, for large arrays of MEMS microphones, yield issues were dominated by wire bond integrity problems. These two issues were the primary motivation for developing the low profile conductive ink process [4].

However, the process is generally useful and can be applied to the packaging of various types of sensor systems that require low profile interconnects. Since the material properties of the silver conductive ink are suitable from a low profile (10µm-15µm silver particles), low volumetric resistivity, and material compatibility standpoint, it serves as a good candidate for making interconnections easily and effectively. There are multiple applications where precise placement of silver conductive ink can be useful. Some applications include the production of active and passive components such as transistors, resistors, capacitors, diodes, and even complete circuits such as RFID tags, keypads, sensors, and electrodes, as well as backplanes of organic light-emitting diodes (OLEDs) and other electroluminescent displays[6].

There are a wide variety of packaging techniques for MEMS acoustic sensors, including flip chip packaging, wirebonding, photodefined interconnections, and through- silicon-vias (TSVs) [5]. During flip-chip packaging, the surface of the chip has an array of solder interconnects that are joined to a substrate when the chip is flipped over. One of the great advantages of the area array package is an increase in the number of available input/output leads over peripheral designs [1].

Wedge and ball or capillary bonding tools are also commonly used to connect packages to MEMS sensors using pads on the top side of the chip and wire bond interconnects [2]. Through- silicon-via is the enabling technology for either 3D integration of multiple dies into a single stack. TSVs can reduce wire length, increase performance and alleviate congestion [5].

## Procedure:

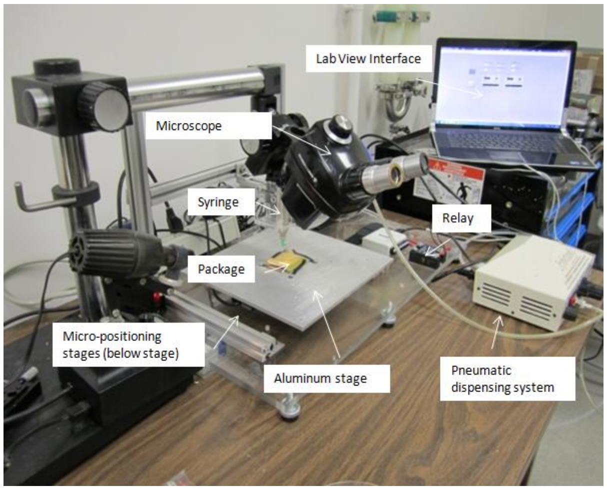

Figure 1: The setup for packaging with conductive ink

The conductive ink process consists of a low profile, low volumetric resistivity silver conductive ink [125-13, Creative Materials, Ayer, MA] which is pneumatically dispensed from a syringe between the pads of the printed circuit board package and its integrated sensor. The package and sensor are mounted to an aluminum fixture on top of computer controlled micro-positioning stages for accurate and precise placement of the silver traces as shown in Figure 1. The syringe press fits into a fixture hanging above the stage which can be adjusted up and down with a manual micro positioning stage. The syringe is attached to a pneumatic dispensing system which is controlled by a National Instruments data acquisition board and relay. This setup allows for the syringe pump to be controlled by a 5V digital output from the National Instrument device interfaced with the lab view software on the computer.

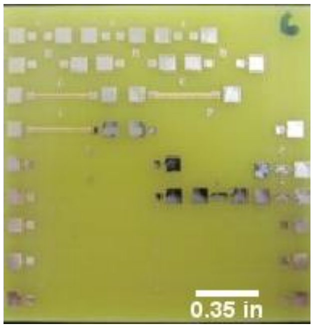

Figure 2: Test Board

Multiple parameters were explored in order to optimize a process by which conductive ink is deposited to package a MEMS acoustic sensor. A test matrix was produced, starting from the baseline parameters, in order to characterize the parameters by which the conductive ink was deposited. A test board was manufactured with varying lengths in between pads as shown in Figure 2. Since the pads on the test board themselves have added resistance, a connection on the board was made with both pads fused together in order to subtract their resistance from the resistance of the silver ink when

| Parameters | Baseline |
|---|---|
| Stage Velocity | 0.75 mm/s |
| Tip Inner Diameter | 0.005'' |
| Syringe Pressure | 60 psi |
| Tip Distance from PCB | 0.5mm |
| Interconnect Length | 0.35'' |

Table 1: Baseline Parameters

tested. The test matrix consisted of thirteen tests varying the stage velocity, syringe tip diameter, syringe pressure, tip distance from the package, and interconnect length form the baseline case shown in Table 1. Each parameter was varied individually above and below the baseline parameters with a total of two lines drawn for each test scenario. After all the tests were complete, the conductive ink was cured at 150°C on a hotplate in air for five minutes and then raised to 180°C for one minute to complete the cure. Next, the resistance was measured on each of the traces using a digital multi-meter and hand probes. The surface profile of the ink was measured using a stylus profilometer. Three measurements were taken along the conductive ink trace in order to check for variation in surface topology and line width. The resistance and surface topology of the conductive ink packaging scheme were then compared to previous wire bonded hybrid packaging schemes. After these tests were complete, a test sensor chip was packaged in a custom designed PCB in order to demonstrate the conductive ink system.

**Results:**

After plotting each of our test results versus resistance, line height, and line width it was determined that for the lowest profile traces, the optimal parameters to package an acoustic sensor, with our design, is with a tip diameter of 0.002 in, 0.25mm from the package, at 60psi, with a 0.5mm/s stage velocity, and at the smallest length possible in order to reduce resistance. The resistance measurement plot as a function of line length as shown in Figure 4 shows the resistance measurements with a best fit linear trend. The plot of tip diameter versus resistance shown in Figure 3 was particularly interesting because it showed how the cure temperature is very sensitive to the size of the cross sectional area of the trace. Since the trace width and height for the smallest tip diameter was so small, the amount of time needed to cure the ink was much less than the largest tip diameter.

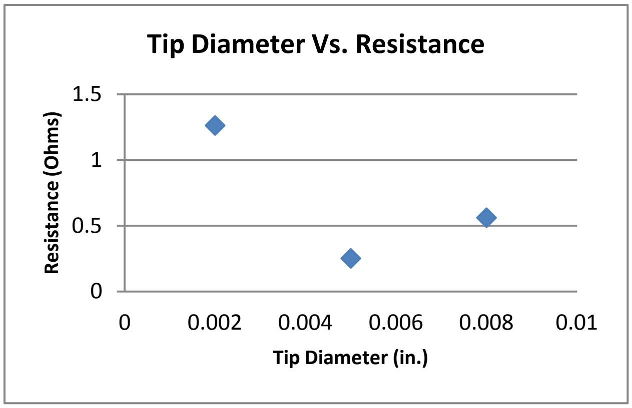

Figure 3: Tip Diameter Vs. Resistance

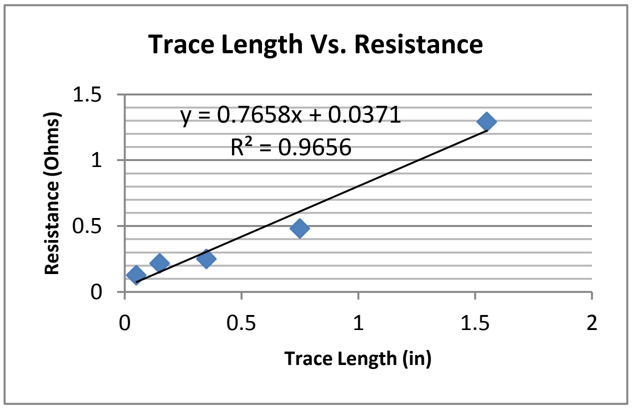

Figure 4: Trace Length Vs. Resistance

The distance the syringe tip was from the package had a larger effect on how wide and how tall the traces were than originally expected, shown in figure 5. For the baseline case at distances of 0.25 mm and 0.5 mm away from the package, the trace height was roughly the same, but when the tip was moved to 0.75 mm away from the package, the trace nearly doubled in height.

However, if the tip is away from the package by more than 0.75 mm, then the ink will not touch the package at all. A manually adjustable micro positioning stage needed to be added to the design in order to accurately adjust this setting.

As expected, the height of the traces decreased as the velocity increased as shown in figure 6 and the change in height of the traces was much greater from 0.25mm/s to 0.75mm/s than from 0.75mm/s to 1.25mm/s. Depending on the size of the trace being drawn, the velocity needed to be calibrated accordingly; otherwise if the tip size is too small and the velocity of the stage is traveling too fast, then the traces will not be completely continuous. This is the reason for choosing such small values for the velocity of the stages.

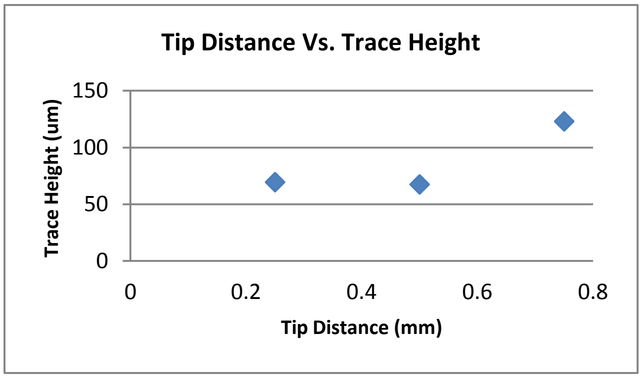

Figure 5: Tip distance Vs. trace height

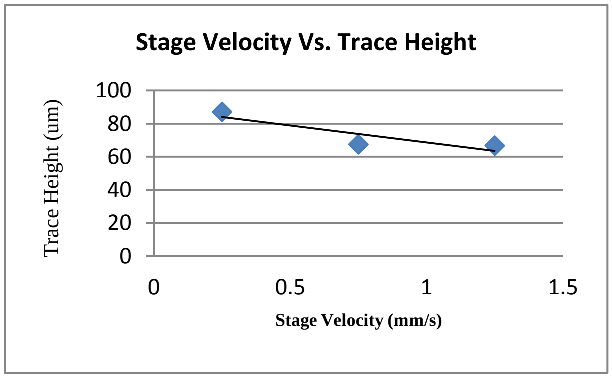

Figure 6: Stage velocity Vs. trace height

The graphs shown in figure 7 and 8 show the direct relationships between increasing the tip diameter and increasing the syringe pressure as a function of trace height. The tip diameter is one limiting factor with the conductive ink design. A tip diameter smaller than 0.002 in. is difficult to manufacture, and also expensive.

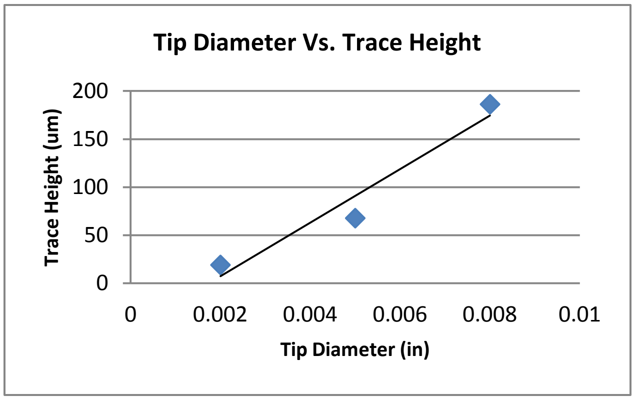

Figure 7: Tip Diameter Vs. Trace Height

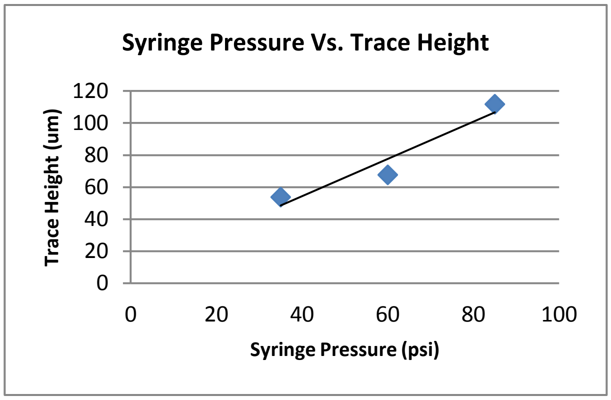

Figure 8: Syringe pressure Vs. trace height

The profilometer measurements of the individual traces showed a greater percent thickness variation the smaller the traces were drawn. As shown in Figure 12, the trace width varies from 212µm to 151 µm along the trace drawn with inner tip diameter of 0.002 in. For the inner tip diameter of 0.005 in, the thickness only varied from 550µm to 521µm shown in figure 11.

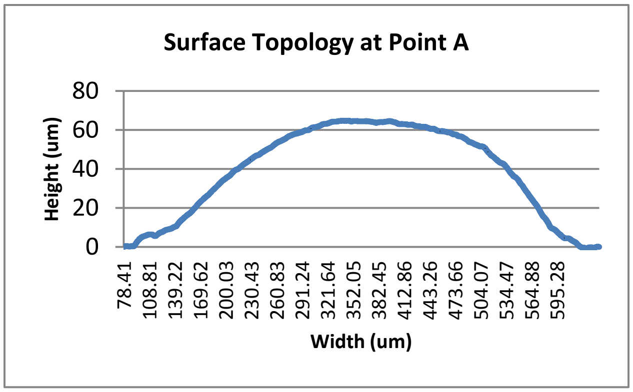

Figure 9: Stylus profilometer measurement at point A

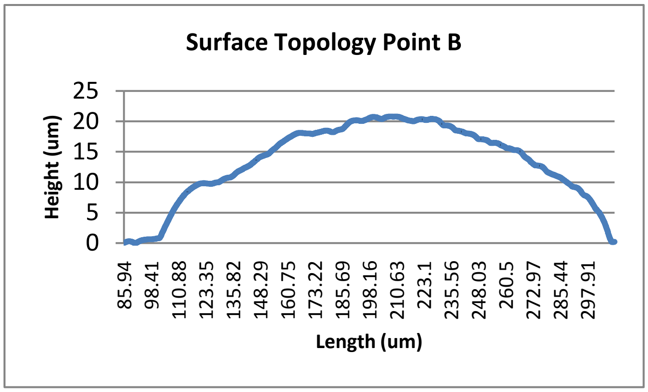

Figure 10: Stylus profilometer measurement at point B

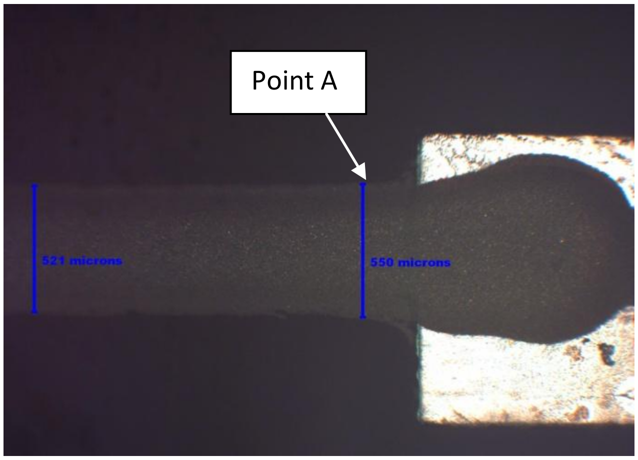

Figure 11: Microscope measurements one trace drawn with the 0.005 in tip.

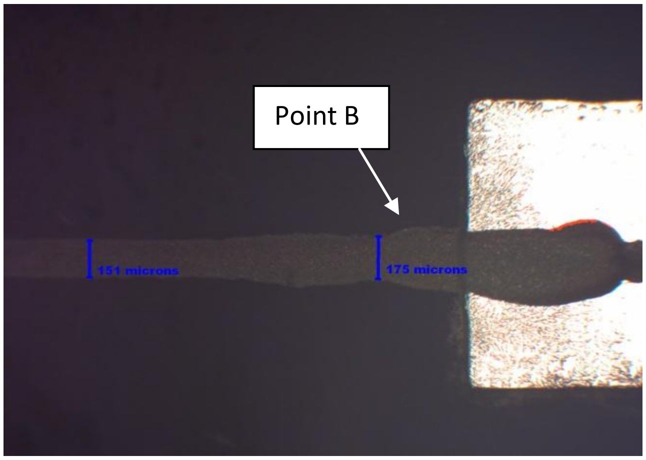

Figure 12: Microscope measurements one trace drawn with the 0.002 in tip.

The surface topologies of these traces were compared to that of the current packaging system of wire bonding to pads. The average height of the traces drawn with the smallest tip was 18.86 µm. The height of the wire bond is 102 µm tall as shown in Figure 13.

Figure 13 shows the entire package that connects to the MEMS structure. There are numerous other surface protrusions in addition to the wire bond, which can be minimized through the epoxy potting process.

The resistivity of the conductive ink was calculated using equation 1 to be $8.5 \cdot 10^{-5}\ \Omega \cdot \text{cm}$ where $\rho$ is resistivity, R is resistance of the trace, A is the cross sectional area, and $l$ is the length.

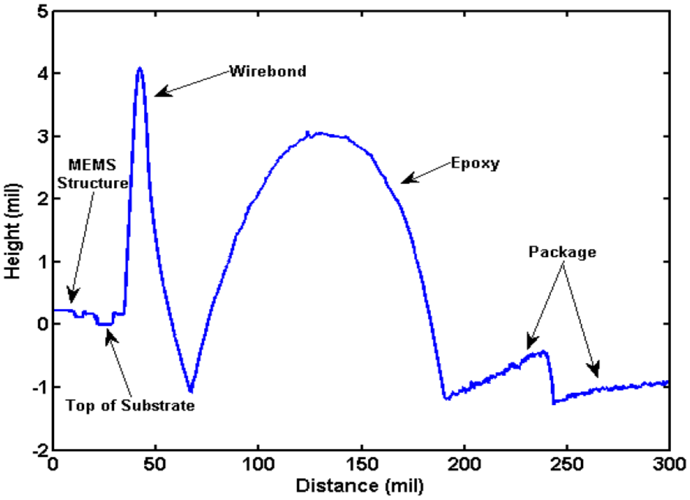

Figure 13: Current package design with gold wire bonds as connections.

$$\rho = \frac{RA}{l} \tag{1}$$

The cross sectional area of the conductive ink was calculated by taking the integral under the surface profile in Matlab. The resistivity of the material at the specific cure time used was roughly double that of what was reported in the data sheet, which was $4 \cdot 10^{-5}\ \Omega \cdot \text{cm}$. This difference in resistivity is attributed to a non optimal cure time. In comparison, the measured resistance of a gold wire bond was 9 Ω for a 1.5 mm long, and 25 micrometer diameter wire, including contact resistance.

After characterizing the conductive ink process, an acoustic sensor was packaged into a printed circuit board in order to reduce all surface topology to below 25 um. After packaging an acoustic sensor using the conductive ink process, the traces were all able to be precisely placed on each of the pads as shown in figure 15. The package will need to be tested in the wind tunnel to see the effects of the reduction in surface planarity.

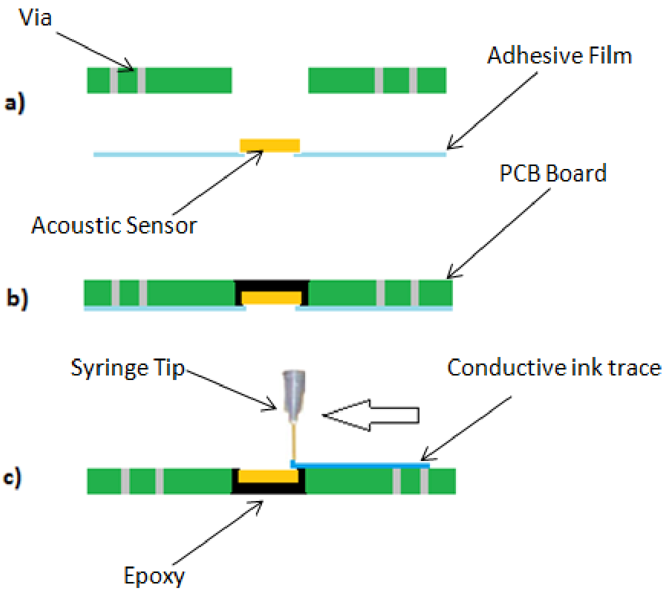

Figure 14: Process of packaging a sensor using conductive ink

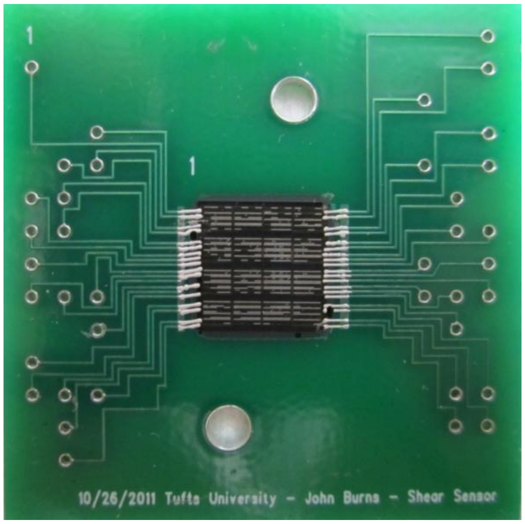

Figure 15: Packaged acoustic sensor with conductive ink.

The process by which the sensor is packaged follows the process outlined in Figure 14.

a) The sensor is placed on an acrylic adhesive film with a square cutout just large enough to adhere to the edges of the acoustic sensor. Next, the sensor is placed right side up against the adhesive film making sure the edges are covered but not touching the active device. Then the package is placed over the sensor making sure it adheres well to the film.

b) The epoxy is dispensed behind the sensor to hold it in place. The epoxy cures at 90 °C for 60 minutes and then 160 °C for a final 60 minutes. Then the film is removed from the package.

c) The conductive ink syringe tip is loaded into the syringe, and a trace is drawn with the optimal parameters for your intended application. Once the connections are made, the conductive is cured at 150 $^{o}$C for 5-10 minutes and then raised to 180 $^{o}$C for 1 minute.

## Conclusion:

These conductive ink methods for packaging acoustic sensors prove to be very useful, especially from a yield, low resistance, low cost, and surface planarity standpoint. There are many different applications where controlled placement of conductive ink proves to be useful as previously described, and only one specific application was explored in this paper. The limiting factor for even smaller line traces using conductive ink is the diameter of the tip that is used to dispense the ink. For interconnects with an order of magnitude smaller than 25 um, other packaging methods should be explored similar to MEMS processes for photo-defining traces.

## References:

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