

Wafer level chip size package integration of an aero-acoustic MEMS microphone into a thin and flexible substrate

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Abstract

This publication describes a novel combination of a chip-scale-package-approach for micro-electro-mechanical systems with flush surface chip embedding in thermal Polyurethane. The concept enables the fabrication of thin and flexible substrates in which sensor chips with fragile membranes are integrated. The presented sensor array can be used for applications like sound source localization in streams of passenger airplanes whilst test-flights.

Key words

MEMS chip-scale-package, flush with surface Polyurethane chip embedding, flexible microphone array

I. Introduction

All passenger airplanes today use so called turbofan engines for propulsion. In these engines, a combustion turbine rotates a large fan, that accelerates air and generates the forward speed of the plane. At the outlet nozzle of the engine two jets are formed, the primary jet from the engine, which is hot and comparably slow and the secondary jet from the fan, which is cold and supersonic fast. Mixing these jets with each other and the ambient air behind the nozzle, develops shock cell patterns at the interfaces between the jets, due to the different velocities and temperatures. This creates very loud noise emissions with different directivities and frequency ranges, so called Broad-Band-Shock-Associated-Noise (BBSAN). At cruise condition, the BBSAN is the major noise source next to aero-acoustic generated noise [1].

The creation and behavior of BBSAN has not been fully understood yet, also due to a lack of sufficiently high-resolution measurement systems. To enable the reduction of noise emission by airplanes globally, the manufacturers require miniaturized microphone systems, that are suitable to be mounted on the fuselage of test flight planes [2]. This miniaturization of the microphone package can be achieved by chip-scale-packaging (CSP) technologies, such as Through-Silicon-Vias (TSV) in custom application designed Micro-Electro-Mechanical-System (MEMS) microphones [3]. The novel approach of combining CSP-MEMS-

technology with the lamination of thermal-Polyurethane (TPU)-substrates, allows to embed the chip flush to the substrates surface without any topography larger 7 μm on the surface. This low-profile surface does not interfere with the high Mach-number flow to which the sensors are exposed to in flight-tests.

The technology presented in this paper, enables very thin ($< 500 \mu\text{m}$) and small in diameter ($< 10 \text{ mm}$) sensor devices, which allow array measurements with a high resolution. This measurement data is a necessary basis for understanding the noise creation, so the aircraft manufacturers can take countermeasures in future airplane generations, that are mandatory to meet the internationally increasing noise limitations of airports. Goal of the packaging approach is to fabricate a flexible and very thin substrate, in which several MEMS microphone sensor dies are integrated. The MEMS sensors have been fabricated and proven functional in a wind tunnel facility [4]. Arrays with large numbers of sensors can detect the amplitude and location of the noise sources. The location of the source is then calculated by the phase shift of one noise phenomenon at one frequency, when the sensor positions in the array are known [5]. The manufactured array is ready to be mounted on the fuselage of airplanes to enable high resolution noise measurements, which are converted into noise-maps with the use of beamforming postprocessing.

The chip-scale-package of the MEMS device is fabricated by a standard backside via last process, which is modified to

a depth of 300 μm . On the backside of the chip Copper redistribution lines (RDL) and reflow SnAgCu-soldering compatible SnAu-Pads are plated, combined with a polyimide-solder-stop-ring.

In this paper the demonstrator chips with a 5 μm thin square membrane with edge length of 1900 μm are embedded. The chips have a copper backside RDL metallization, a polyimide solder-stop-ring and SnAg-solder-pads. All functionalities are built with the same layout as the functional MEMS microphones, the technology was developed for. This allows a direct technology transfer to build the packages with the working MEMS devices.

This setup is chosen to be able to test the reflow soldering process and see the influence on the very thin membrane after the embedding process. The basic structure of the demonstrator chip is shown in Fig. 1, a picture of the bottom view of one chip is shown in Fig. 2.

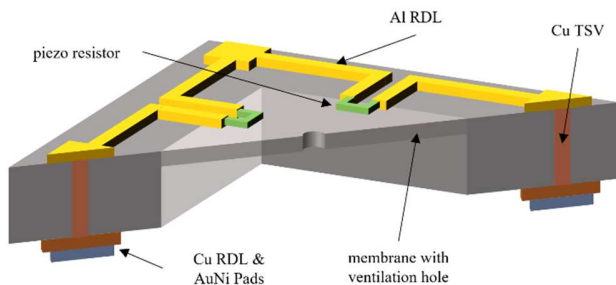


Figure 1: Cross section imaging of the demonstrator chip

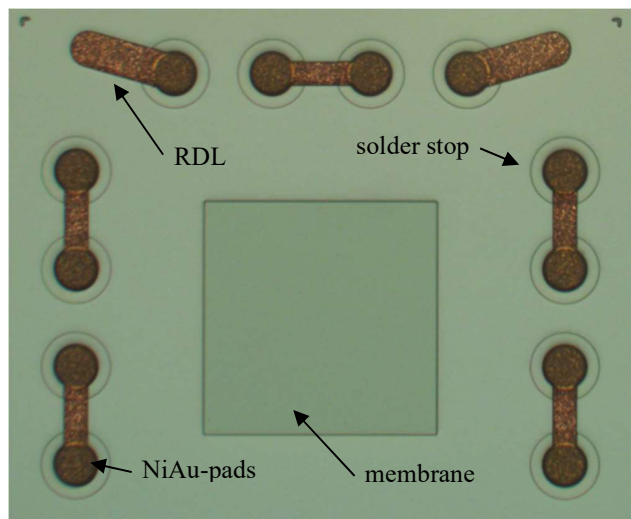


Figure 2: Bottom view of the demonstrator chip

II. Package Concept

The fabrication flow of the package is shown in Fig. 3. The substrate fabrication starts on a 50 μm thick polyimide foil

with 12,5 μm thick copper leads on both sides (1) and the holes for the vias are opened with a laser drill (2). Then the side walls of the holes are coated by a copper plating

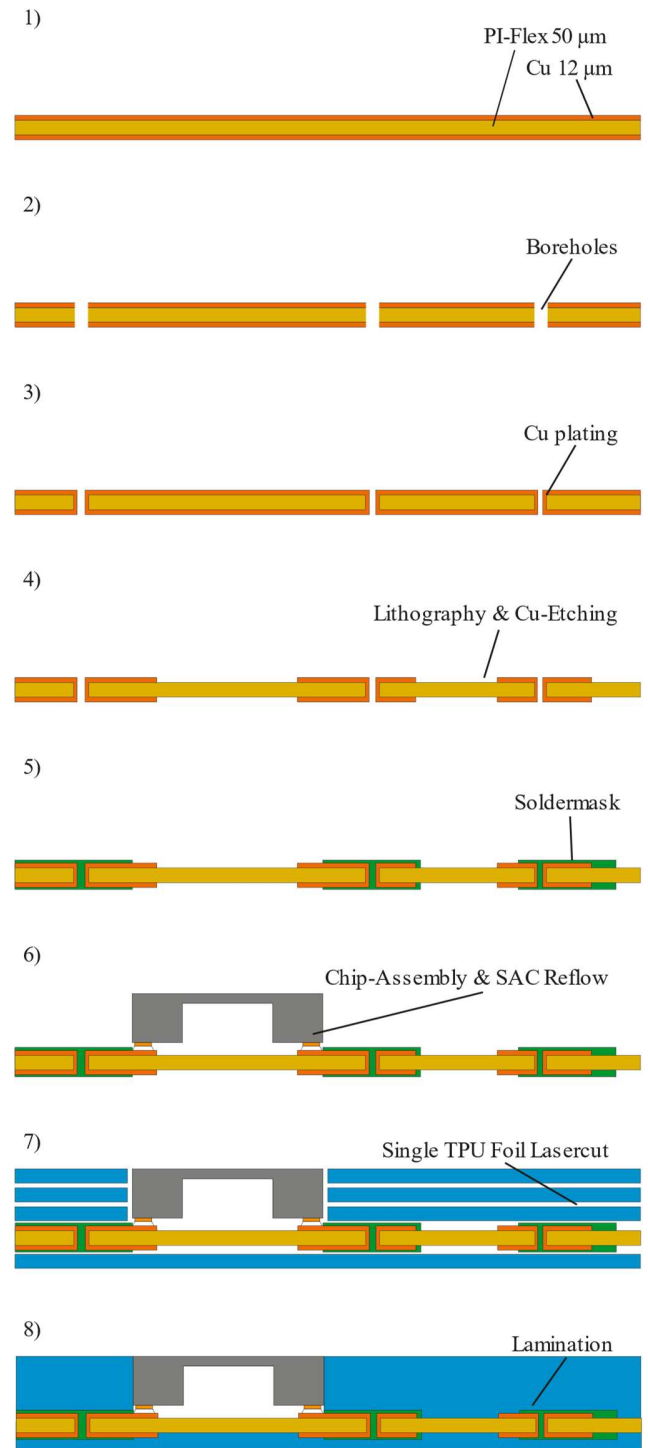


Figure 3: Process steps from the initial substrate to the placing of the pre-structured TPU-foil

process (3). The copper on the substrate gets structured by means of photolithography and wet etching to form the leads for the signal readout (4). To enhance the solder process, a solder resist mask and silver coating are applied (5). In step (6) the Sn-Ag-Cu-solder-paste is jetted on the substrate, on which the demonstrator chips get placed with a fine-placer, followed by a reflow solder process. To embed the chip in the substrate, three layers of thermal-polyurethane (TPU) with thicknesses of 250 μm , 100 μm and 50 μm get laminated to one layer-stack with a resulting thickness of 390 μm . This foil is then structured by laser-cutting, the laser cuts windows into the foils to leave space for the chips. The edge length of the chips is 5000 μm and the windows in the TPU have a size of 7000 μm . The void of 1000 μm between chip and TPU allows the assembly of the foils without damaging the chips. The void is later filled with liquid TPU, when the TPU is heated and pressed in the void. The structured TPU-foils then get stacked on the PI-substrate (7) and laminated under pressure and temperature. The TPU gets liquid and embeds the sensor chips. To keep the liquid TPU from flowing onto the chip surface, a tight sealing with a 500 μm thick PTFE-foil is achieved. To prevent the sensible membranes of the chip to break, openings in the PTFE-foil ensure that the pressure is applied only on the TPU and sensor bulk material, not the membranes in center of the chip. To keep the substrates aligned three centering pins in the steel pressing plate keep the substrates in place. As the coefficients of thermal expansion of Polyimide and Polyurethane differ, the laminated substrate tends to roll after the lamination process. To keep the substrate plane, one more TPU layer with a thickness of 50 μm is laminated on the bottom side of the substrate stack. In the last step the PTFE sheet is removed from the top side and the finished array remains (8). The result is a flexible substrate with flush-mount integrated chips with a membrane directly exposed to the sound waves in order to achieve high sensitivity, but low flow interaction and signal routing in the inside of the substrate. The very thin sensor system with large numbers of sensors addresses all the limitations stated above of current microphones used for noise measurements in flight testing.

III. Fabrication of Sensor-Array

To demonstrate the developed technology on a large scale a sensor array with 8 sensor positions and a size of 130 mm x 165 mm was fabricated with the process flow described above. The footprint of the demonstrator chip is shown in Fig. 4 and contains 16 pads from which 4 are connected to the leads for signal processing, while the 12 remaining are for mechanical stabilization. The picture shows the pads with solder paste jetted on, ready for the placing of the chips.

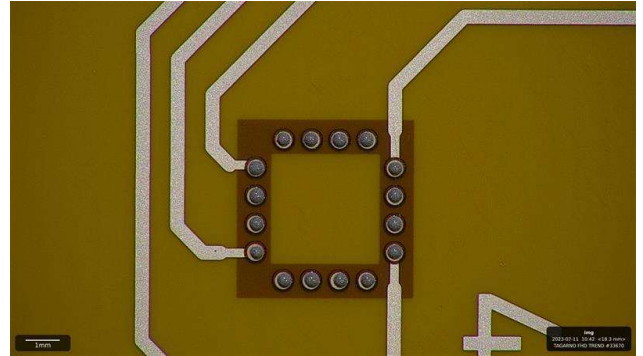


Figure 4: Substrate with jetted solder paste

Fig. 5 shows an overview of the substrate and the demonstrator chips before assembly. The darker areas under the pads and the frame of the substrate are remaining copper on the substrate bottom for mechanical stabilization whilst the lamination process.

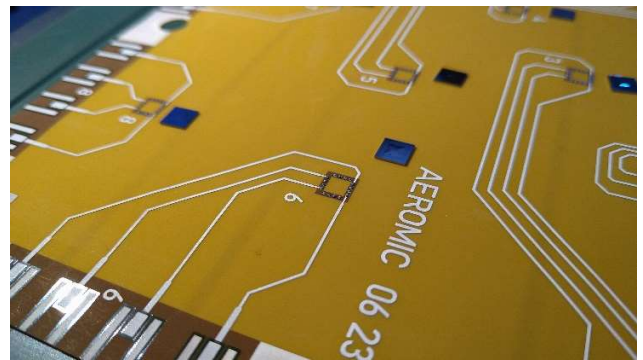


Figure 5: Substrate with demonstrator chips before assembly

After assembly of the chips and the reflow soldering, the structured TPU foil is assembled and aligned with the centering pins (shown in Fig. 7). The lamination process with a temperature of 180 $^{\circ}\text{C}$ is carried out under pressure between two stainless steel plates, covered with PTFE foils. The finished array is shown in Fig. 7.

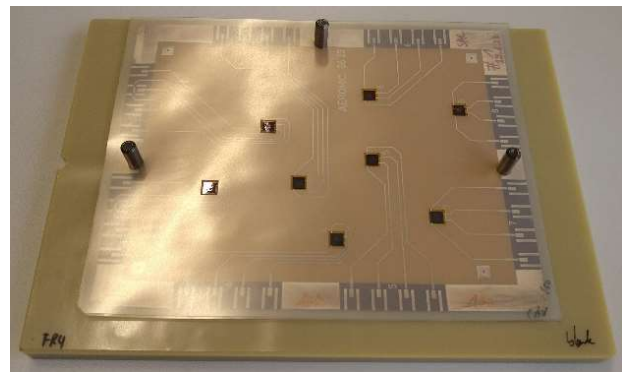


Figure 6: Substrate with assembled TPU foil and set centering pins



Figure 7: Finished array with 8 embedded sensors

V. Results and Conclusion

The result of the technology demonstration shows good results of the fabrication and the embedding of the demonstrator chips in the substrate. The x-ray inspection shown in the Fig. 8 & 9 show a good result of the solder joints. The shown voids in the solder will be prevented by adjustments of solder volume and reflow temperature. The voids next to the chips get completely filled with TPU during the lamination process after the size of the gap was varied in 200 μm steps. More experiments need to be conducted on the PTFE material and thickness. Different products were used and they either tend to stick to the PI substrate or change their geometry too much under temperature influence. Concluding the development of the packaging concept for the fabrication of MEMS microphone arrays is a success and will enable the required measurement systems as soon as the MEMS chips with whole functionality are finalized.

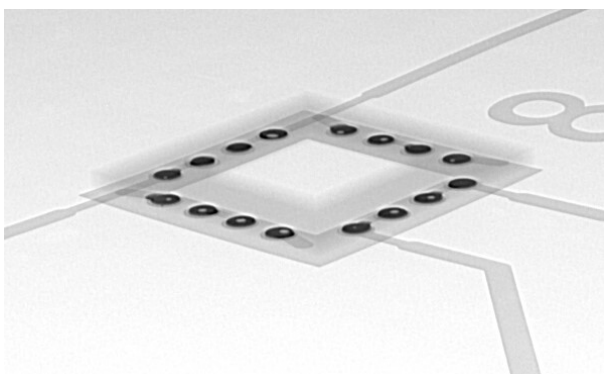


Figure 8: X-Ray picture of one embedded demonstrator chip

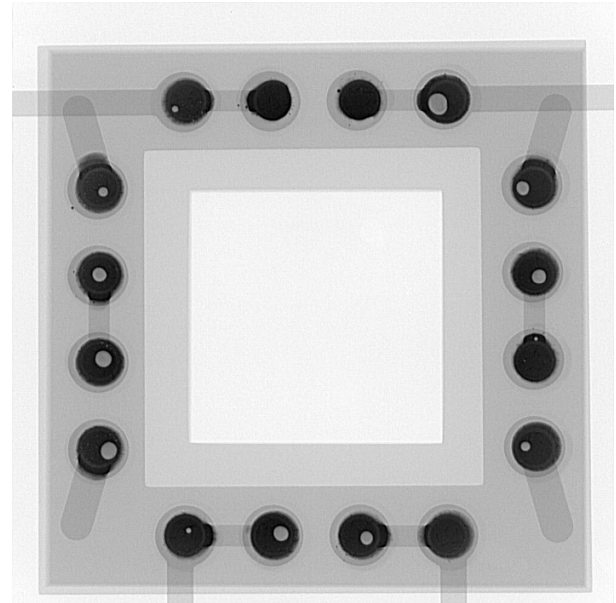


Figure 9: X-Ray inspection of the solder joint

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