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Fabrication and characterization of high-speed PZT sensors for the investigation of ultrasonic wire bonding process

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Abstract
In this investigation a single-element high bandwidth force sensor will be designed and characterized. The main manufacturing technology of the single force sensor is the sputtering process for the contacting on the piezoelectric element. After sputtering the back electrode, the electrical contact and the bond layer (aluminum) are deposited. The layer of the electrical contact is made of gold, which also offers as an etch stop for the reuse process.
We report in this investigation about the different influence factors of the high-resolution and high-speed force measurement process. Main points of the research work are the layer thicknesses of the front and back electrodes and the influence of the lead titanate zirconate (PZT) layer to the sensitivity of the charge output. To receive the highest sensitivity of the force sensor the method of Design of Experiments (DoE) will be used. A force measurement setup will be utilized for calibration and validation of the sensor. The behavior of the sensor will be compared to the simulation results.

Keywords: Sputtering process, PZT sensor, piezoelectric properties, ultrasonic wire bonding

1. Introduction

Ultrasonic (US) wire bonding technique has been widely applied in the microelectronic packaging industry for more than half a century. The process of US wire bonding can be divided into four phases: 1) Pre-deformation and activation of US vibration, 2) Friction, 3) US softening and 4) Interdiffusion [1,2,3].
During the US wire bonding process, specific phenomena occur at the interface between the wire and the metallization layer of the substrate, which are not completely understood yet, because the high frequency, the short process time, and the tiny dimensions present challenges for the investigation of these interface phenomena. The tangential force between the wire and the substrate is an essential factor in monitoring the bonding process and indicating the bonding quality [1]. It is also of particular importance for the basic understanding of the bonding mechanisms.
Against this background, the central task is the developing of a sensor based on a piezoceramic which overcomes these challenges. For this purpose, high-precision microproduction technology methods are used.

2. Sensor Manufacturing

To get started with the Design of Experiments, the piezo ceramic must be processed in several steps. A functional sensor is manufactured using the general process chain described below (Figure 1). The key technologies herein are mechanical micromachining, thermal evaporation, and sputtering.
In the first step, the surface roughness and the thickness of the PZT ceramic are tuned by chemical mechanical polishing. Substrate thicknesses of 500, 750 and 1000 µm were realized (basic PZT thickness 1200 µm).

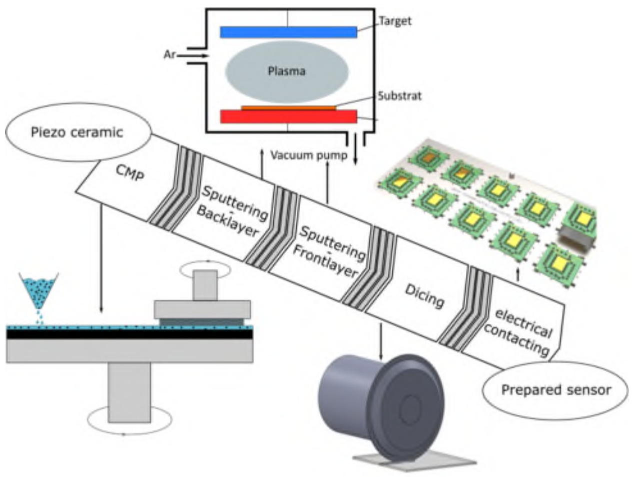

Figure 1. General process chain for sensor production

During the second step (sputtering), an adhesion layer of 50 nm of chromium is applied to the front and back layer. Subsequently, varying gold layer thicknesses are added on both sides on top of the adhesion layer (200, 700, and 1200 nm). The gold layer thicknesses on the front and back are identical. In the third step, a final aluminium layer, which serves as a bonding layer, is placed on the gold layer using thermal evaporation, with thicknesses of 300, 550 and 800 nm.
Lastly, exact sensor dimensions of 3x3 mm are generated in the dicing step. Following dicing, electrical contacting of the sensors is performed.

3. Experimental setup

This DoE involves a full factorial process chain. The PZT-layers, the front-, and the back-layers thicknesses are varied. Thus, 16 tests are carried out with the respective layer thickness combinations. The statistical model was validated using two averaging tests.
Before the electrical voltage was investigated, the roughness Ra and Rz were examined in order to show the influence of the applied layer thicknesses. Roughness was measured using roughness measuring system. The goal was to achieve a very low roughness for this effect to be negligible during the US bonding process studies.
Following the roughness measurements, the sensors were subjected to a defined force of 1 N cyclic loads. These loads are repeated 50 times to reduce measurement uncertainties. One influencing factor that can lead to measurement-noise is, for example, the contacting of the sensors on the printed circuit board and on the bond layer of the sensor. 50 repetitions have been chosen to compensate for measurement associated noise. Voltages are filtered using a measuring-amplifier, e.g. a 1 Hz filter for measurement noise during the experiment.

4. Results and discussion

The results from the roughness and voltage measurements are analyzed and evaluated using JMP®. The analysis software calculates the coefficient of determination (r^2), which provides information on the quality of the linear regression over the tests carried out. This allows statements to be made about the variance of the results. The program also outputs the p-value. If the p-value is smaller than the pre-selected significance level of 0.05, then the result is considered to be statistically significant.The influence of the different layer thicknesses on the result is shown.
The output voltages resulting from the test series are shown in Figure 2. Measured values range between 1.13 mV and 2.83 mV. Based on the coefficient of determination ($r^2 = 0.843$), it can be deduced that these results show reasonably small variance. The most important influence on the output voltages is therefore the aluminium layer in combination with the PZT layer (Prob ≤|t| = 0.0104) and the front layer in combination with the PZT layer (Prob ≤|t| = 0.0051).
The evaluation of the roughness values Ra shows that the roughness values are between 0.27 µm - 0.58 µm (Figure 3). The coefficient of determination ($r^2 = 0.895$) indicates a low variance of the results. The thickness of the PZT layer in combination with the aluminium layer (Prob ≤|t| = 0.0275) has the greatest influence on roughness Ra, followed by the combination of the back layer with the aluminium layer (Prob ≤|t| = 0.0193).

The simulation results are slightly below the test results. This can be attributed to external influences during the execution of the test. They are still in the same order of magnitude.

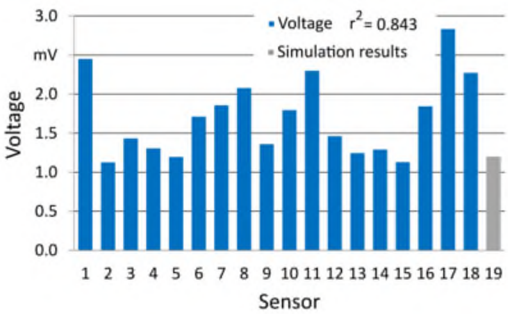

Figure 2. Voltage in relation to the different sensor layer compositions

The results of the surface investigation (Figure 3) show that the same layer variations have the highest influence on the roughness Rz, just as in the analysis of roughness Ra (back layer in combination with aluminium layer; Prob ≤|t| = 0.0436). However, the coefficient of determination is lower with $r^2 = 0.721$, which suggests a greater variance in results. This can also be seen in the variation in roughness of 1.6 µm - 3.61 µm.

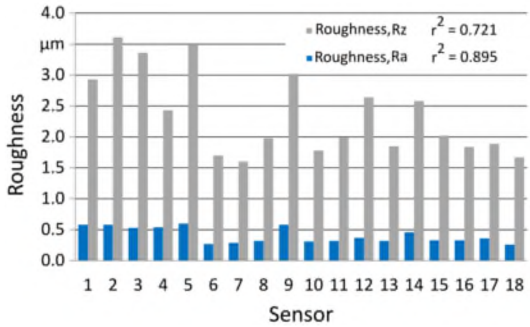

Figure 3. Roughness values Ra and Rz in relation to the different sensor layer compositions

After the correlations of the different layers were shown, a sensor was produced to show the US bonding process. With a force of 9 N and a process time of 50 ms, a power of 24 W was applied to the system. The result of the US bonding process can be seen in Figure 4. During the bonding process, the resulting voltage is 1.62 mV.

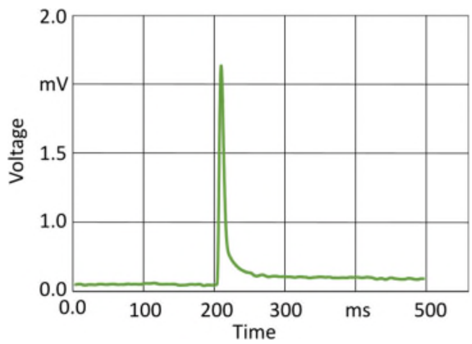

Figure 4. Sensor signal during US wire bonding

5. Conclusion

The herein described DoE shows the influences of different layer thickness combinations. These results allow it to make predictions about the dependency of the influencing variables on the target values. The PZT layer has the greatest influence on all 3 target variables (voltage, roughness Ra and Rz), the front, back and aluminium layer have only a minor influence on the values. After completion of the DoE, the sensor function was demonstrated using a US wire bonding process. Based on these results, further experiments can be carried out in order to gain additional knowledge regarding the US wire bonding mechanism.

References

[1] Long, Y.; Twiefel, J. and Wallaschek, J.: A review on the mechanism of ultrasonic wedge-wedge bonding, *Journal of Materials Processing Technology, Vol. 245* pp. 241-258, 2017

[2] Geißler, U.: Verbindungsbildung und Gefügeentwicklung beim Ultraschall-Wedge-Wedge-Bonden von AlSi1-Draht, *Dissertation*, TU Berlin, 2008

[3] Unger, A.; Sextro, W.; Althoff, S.; Eichwald, P.; Meyer, T.; Eacock, F.; Brökelmann, M.; Hunstig, M.; Bolowski, D.; Guth, K.: Experimental and Numerical Simulation Study of Pre-deformed Heavy Copper Wire Wedge Bonds, International Symposium on Microelectronics, pp. 289-294, 2014