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Effect of Thin Film Interconnect Inelasticity on MEMS Pressure Sensor Hysteresis

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Summary: Thermal hysteresis dominates precision errors in absolute low pressure piezoresistive Silicon-based MEMS pressure sensors. A population of 10 experimental unpackaged “floating” bare devices were subjected to pressure and temperature cycles resulting in a mean hysteresis error of initially 0.062 % of full scale (FS) that reduced to 0.036 %FS after the third cycle. Within the limited 5 to 65 °C thermal cycles used in this study, this hysteresis is not predicted by the elastic recovery regime and is attributed to low temperature creep phenomena caused by stresses, that develop as a result of the coefficient of thermal expansion (CTE) mismatch between the Al-1 %Si bond pads and the Si substrate.

Keywords: Thermal hysteresis, piezoresistive pressure sensor, Al-1 %Si metalization pads.

1. Introduction

Al-1 %Si thin film metalizations are a classical packaging element for silicon MEMS devices that make use of wire bonds as electrical interconnects. The bond pads are typically sputtered onto MEMS wafers, sintered at 450 °C then cooled to room temperature [1]. The $20.7 \times 10^{-6} \text{ K}^{-1}$ CTE mismatch between the Al-1 %Si bonds pads and Si substrate result in the thin film being in tension at room temperature, with stresses that may be beyond the elastic regime. When subsequently thermally cycled from 25 to 450 °C, 1 μm thick Al-Si films start at 25 °C in the elastic return region before recrystallization at temperatures varying from 75 to 175 °C depending on the load history [2]. Several studies have analyzed hysteresis effects in piezoresistive pressure MEMS devices e.g. [3-5], where the cyclic temperature range is from -55 to +125 °C and the devices are structurally bonded to transistor outline (TO) headers. Having extra packaging elements, one cannot segregate thin film effects from other packaging effects. In this study the piezoresistive chips were therefore tested in an unmounted “floating” bare package, ensuring any effect observed is likely to be due principally to the thin film. This, to the authors’ knowledge, has not been previously accomplished. In this study, even for a significantly reduced thermal range compared with these earlier studies, hysteresis errors limit the performance of the MEMS device.

2. Packaging Method

This study used an experimental MEMS absolute pressure device as shown in Fig. 1 and having dimensions of $1.65 \times 1.65 \times 1.37 \text{ mm}^3$. To obtain floating devices, the MEMS chip was temporarily bonded to a stainless-steel TO enclosure using photoresist to retain

the die in place during wire bonding. Acetone was then used to remove the photoresist, leaving the device free. Visual inspection of 10 devices was carried out to make sure they were clean and only supported by the wire bonds in a floating configuration. After an initial 5 to 65 °C conditioning cycle, the devices were then tested over 3 cycles of 50 to 200 kPa absolute pressure and from 5 to 65 °C as shown in Fig. 2.

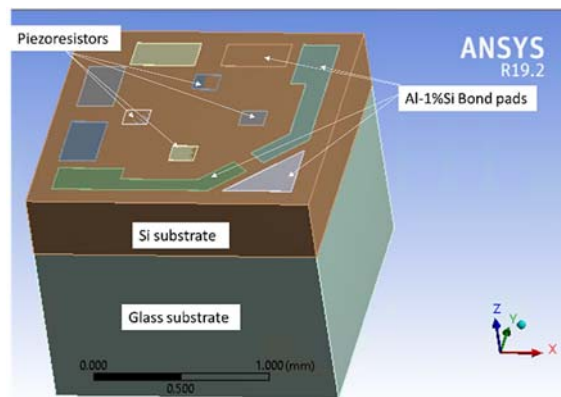


Fig. 1. Isometric view of pressure MEMS device with Al-1 %Si bond pads.

3. Figs. and Tables

An ANSYS® R19.2 FEA analysis was carried out that estimated the Von Mises (VM) stress in the metalization to be 280 MPa at 25 °C after cooling from 450 °C with a 100 kPa applied pressure as a boundary condition. This value was obtained using a bilinear hardening model for Al taken from the Granta material property library. The VM stress value exceeded the 150 MPa 0.2 %-offset yield limit for a thin film predicted by Gardner and Flinn [1] and would therefore be expected to result in significant plastic

strain. During the limited thermal cycle range carried out here, the metalization would therefore be expected

to remain in the elastic return regime, thus yielding a linear behaviour.

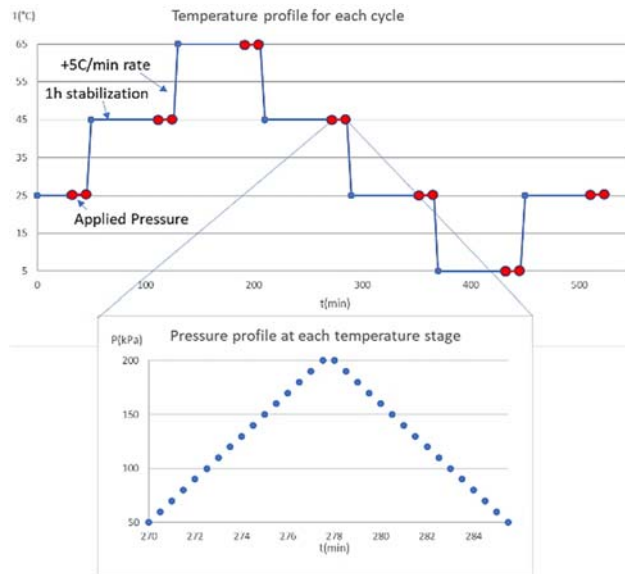


Fig. 2. Temperature and pressure profile for the first cycle. Each temperature has a stabilization period of 1 h at the end of which the pressures are applied.

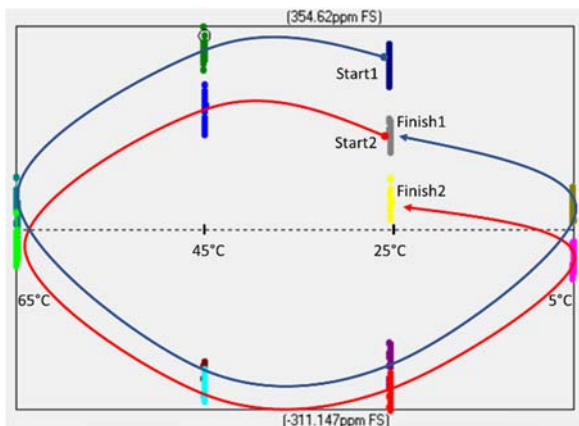


Fig. 3. Hysteresis error plot for an individual sensor over two temperature cycles.

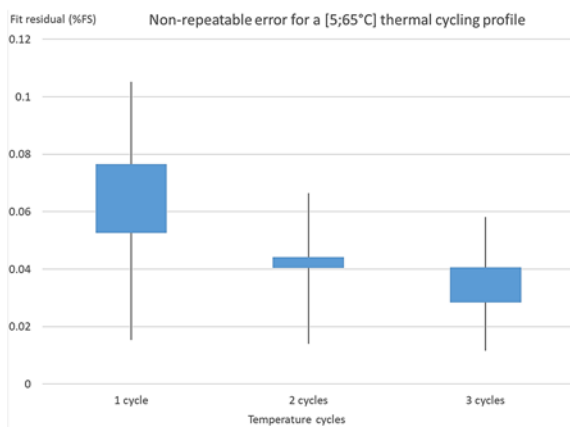


Fig. 4. Hysteresis drop over a 5 to 65 °C temperature cycle range for a population of 10 units. The average values decrease from 0.062 %FS to 0.036 %FS.

The sensor's Wheatstone bridge voltage output and diode voltage (a measure of temperature) were fitted with a third order polynomial function to calculate the "fitted pressure", which would be the pressure returned by a commercial pressure sensor. Hysteresis errors were then calculated as the error between the actual applied pressures and fitted pressures, which can be seen in Fig. 3. This shows a hysteresis error plot for an individual sensor over the first two temperature cycles, where each data group represents a 50 to 200 to 50 kPa pressure cycle. Data groups vertically aligned are for pressure cycles obtained at the same temperature, while the vertical axis is the residual error which ranges from -0.031 to +0.035 % of full scale (FS) pressure. It can be seen that the error is mainly dominated by thermal hysteresis. Fig. 4 shows a box plot of hysteresis values after each thermal cycle. The average hysteresis for the first cycle error was 0.062 % full scale (FS) peak-to-peak, which reduced to 0.036 %FS at the third cycle. Although only three cycles are used here, the results indicate that the thermal hysteresis is improved by cycling the units.

4. Conclusions

Within the limited 5 to 65 °C temperature range, the reduction in thermal hysteresis with the number of cycles cannot be explained by the thermal expansion mismatch directly, as the stresses are predicted to be in the elastic recovery region. Therefore, stress relaxation and creep phenomena at low temperature are believed to be the source of the observed hysteresis and its stabilization over the cycles. Further low temperature creep properties of the Al-1 %Si are therefore needed for use within a more detailed FEA model to validate this creep-induced hysteresis hypothesis.

Acknowledgements

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