High Accuracy Die Mechanical Stress Measurement with the ATC04 Assembly Test Chip

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Piezoresistive stress sensing chips have been in use for over a decade for measuring package induced mechanical stresses. However, the accuracy and precision of previously reported die is open to question because of the intrinsic difficulties of making sufficiently precise resistance measurements and then compensating these measurements for temperature induced resistance variation. We have designed and manufactured a new CMOS piezoresistive stress sensing chip, ATC04, with an advanced cell design which enables stress measurement to much higher accuracy and precision than any other known die.

The ATC04 Assembly Test Chip is fabricated in a 2 μm twin-tub CMOS process and operates at 5 V. The chip is square, ≈ 0.25 in. on a side, and all required bondpads are replicated on each side of the die. Hence, the chip may be used in an array or matrix format to simulate a larger die, with all required connections being made on the perimeter of the array. The die contains an array of 25 stress sensor cells, ≈ 200 μm on a side, as shown in the figure on the next page. Each cell contains four n-type and four p-type resistors and a diode for temperature measurement. Two resistors of each type are oriented along the chip horizontal and vertical axes and two at $\pm 45^\circ$ with respect to the horizontal. Resistance and diode voltage measurements are made using a four terminal geometry to insure the highest accuracy and precision. The individual cells and cell components are accessed by sending a nine bit address word to the chip.

In addition to stress sensing capability, the chip also has four polysilicon resistance heaters for use in thermal resistance measurement and two ring oscillators which can be used to monitor the chip *state-of-health* during accelerated aging tests. One oscillator uses a conventional design and has a frequency ≈ 14 MHz while the other oscillator uses a modified design with two level metal links between adjacent stages to increase its susceptibility to corrosion induced damage. This oscillator has a design frequency ≈ 45 MHz.

Evaluation of the precision of resistance and temperature measurements using the resistors and diode in the ATC04 stress cell show that a nominal resistance of ≈ 10 k Ω can be measured to about ± 0.1 Ω , or one part in 10^5 . The diode voltage may be

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determined to about $\pm 10 \mu\text{V}$, corresponding to a temperature sensitivity $\approx \pm 5 \text{ mK}$. These precision numbers make the determination of the in-plane compressive stress difference, $\sigma_{xx}-\sigma_{yy}$, and the in-plane shearing stress, σ_{xy} , to a precision $\approx \pm 1 \text{ MPa}$ theoretically possible. In practice, the absolute accuracy of the stress measurement is limited by the uncertainties in the piezoresistive coupling constants; π_{11} , π_{12} , and π_{44} for the n and p-type resistor material.

In this talk, we illustrate the use of the chip in resolving small to moderate stresses. In some of our measurements, stress was induced by applying a force to the centerline of a ceramic package supported at both ends. In other experiments, glob-top epoxy coatings were applied after initial resistance measurements were made on bare die. Where possible, we compare the measured results with theoretical stress predictions. The data presented support the claimed $\approx \pm 1 \text{ MPa}$ precision in determining $\sigma_{xx}-\sigma_{yy}$ and σ_{xy} . Data obtained from uniaxial stress calibration measurements at Auburn University are also presented and used to determine best estimates for the π coefficients. From these data we also derive estimates of the precision with which the individual stress tensor elements, σ_{xx} , σ_{yy} , and σ_{zz} may be determined.

ATC04

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