A HIGH SENSITIVITY DIC TECHNIQUE FOR CHIP-LEVEL PACKAGING MATERIALS

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Summary We present an experimental investigation on a high-sensitivity digital image correlation (DIC) based strain measurement technique. The technique is developed for applications of characterizing small thermal deformation of microelectronics packaging materials at the silicon chip level. By using a reference glass-ceramic material of very low thermal expansion, a high-speed digital camera, and some improvements in the experimental set-up and post digital image processing, the DIC technique is shown to be able to reliably measure the coefficients of in-plane linear thermal expansion of thin silicon wafers and Invar-like materials over an area of 28×21 mm^2.

INTRODUCTION

Thermal stress due to the mismatch of coefficients of thermal expansion (CTEs) in microelectronics materials is a major factor affecting the reliability of microelectronics components. Due to its relatively simple optical set-up, the non-contact, digital image correlation technique has been successfully applied to measure the thermal deformation of metallic solder joints and board-level plastic packages for microprocessor product developments [1]. For chip-level packaging materials with much lower coefficients of thermal expansion (about 2-3 ppm/°C), techniques such as electronic speckle pattern interferometry (ESPI) [2] may have to be used. The measurement accuracy of CTEs by digital image correlation is claimed to be about 1-2 ppm/°C [3,4]. Recent works on the bias and variability in displacement measurements by digital image correlation indicate that measurement errors by DIC may be further reduced [5,6]. In this paper, we investigate various ways to extend the measurement accuracy of CTEs by digital image correlation to 0.1 ppm/°C between 40°C and 160°C.

EXPERIMENTAL DETAILS

The schematic of our experimental set-up for the in-plane CTE measurements is shown in Fig.1. It consisted of a miniature heating oven, a high-speed digital image capturing system (a Phantom Miro4 camera from Vision Research and a telecentric zoom lens from Edmund Optics), and an LED white light source. The upper part of the oven is covered by an optical quality quartz glass plate to allow direct imaging of the test sample placed in the oven. In a typical experiment, a flat thin silicon sample (28mm×24mm×0.66mm) with its surface decorated with fine paint speckles was placed on a horizontal support inside the oven. The optical axis of the camera was first aligned perpendicularly to the sample surface. The focus of the camera, the zoom lens, and the LED light level were adjusted to have a high quality clear image of the sample surface with a field of view of 28×21 mm^2. The oven heated the specimen gradually from ambient temperature to 200°C and then its power was turned off. The temperature of the specimen and the support was measured by two J-type thermocouples. A set of 8-bit grayscale digital images of 800×600 pixels were acquired by the high-speed camera at a frame rate of 1000 fps for each temperature decrement of about 20°C during the slow cooling of the test sample inside the oven from 200°C to 40°C. The acquired images at each temperature were first averaged to reduce the image noise level [7]. The averaged frames were then analyzed by linear digital image correlation with bias correction [5,6] to measure the thermal strain between two points at about 400-500 pixels apart on the images.

RESULTS

To reduce the distortion effect of hot air turbulence from the heated oven on acquired images, a pneumatic device was added on the one side of the oven (see Fig.1). The pneumatic device consisted of a compressed air source, an adjustable gas pressure valve, and a plastic gas pipe. The end of the pipe was plugged, and a row of small pinholes were drilled at a distance of 5 mm apart along the pipe. The pipe with small pinholes was positioned slightly above the glass window on the side and blew a steady stream of air parallel to the quartz glass window surface. Fig.2 shows the measured strains from the correlation among 1000 images at the same temperature without and with the air flow from the pipe. Clearly, the image stability degraded with increasing temperatures and the distribution is far from a normal one when there was no air flow. On the other hand, the air flow was effective in stabilizing the images acquired at elevated temperatures and the strain error is $0.5\pm5.26\times10^{-6}$ at 130°C. The expected variability in the CTE measurements over the span of 130-40=90°C is thus less than 0.1 ppm/°C. The accuracy of in-plane strain measurements by digital image correlation will be affected if there is some out-of-plane motion between the oven and the camera [8]. The use of a telecentric lens only reduces but cannot completely eliminate its effect for small thermal strain measurements. Fig.3 shows the measured strain of an optical flat made of Zerodur glass-ceramic with CTE of 0.0±0.1 ppm/°C (Edmund Optics) between 40°C to 140°C. The strain is significantly higher than that due to its own thermal expansion, indicating the thermally-induced out-of-plane motion between the optical flat in the oven and the camera. Consequently, any CTE measurements by DIC would require the placement of a reference material with a known CTE with the test sample during the thermal loading and imaging so the out-of-plane motion effect can be corrected. Fig.3 shows the results of

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the measured CTE of an Invar-like reference alloy sample (about 10mm×10mm×0.5mm) and its average CTE was estimated to be 1.24 ppm/°C, similar to the reported value in the literature.

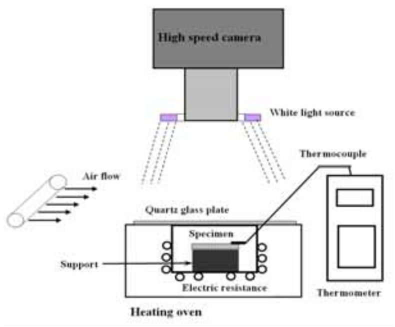

Fig. 1 Schematic of the expeirmental setup.

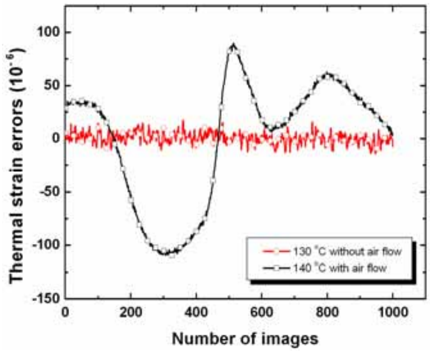

Fig.2 Effect of air flow above the glass window on image stability.

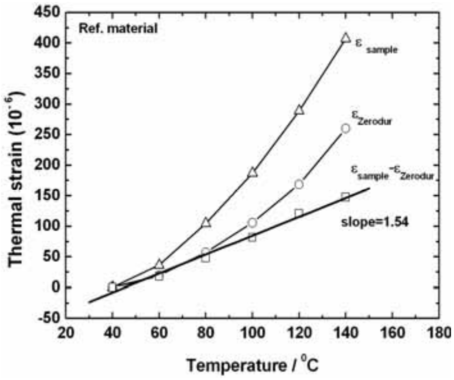

Fig. 3 Thermal strains on Zerodur and a reference material.

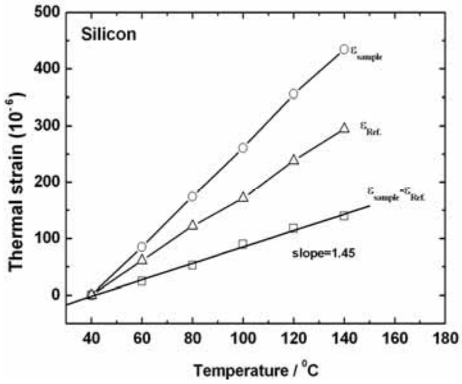

Fig.4 Thermal strains on silicon wafer with the reference material.

Finally, the test on the thin silicon wafer was carried out with the placement of the thin reference material (whose average CTE is shown as the slope in Fig.3) on its top. The thermal strain measurement results are shown in Fig.4 for both the reference material and the silicon wafer sample. The slope of 1.45 ppm/°C given in Fig.4 is the difference between the average CTE of the silicon and the average CTE of the reference material. Consequently, the average in-plane CTE of the silicon wafer sample was estimated to be 2.99 ppm/°C, again very similar to the reported value in the literature. Recent theoretical and numerical results [5] have shown that both bias and variability in displacement measurements by linear digital image correlation can be reduced to 0.002 pixels or less by using bias reduction and by using a sufficiently large subset size. The estimated strain measurement error over a gage length of 500 pixels is 4×10^{-6}, about the same as the measured variability of images at elevated temperatures given here.

CONCLUSIONS

We conducted CTE measurements on a thin poly-silicon plate by a high-sensitivity digital image correlation technique. The result was found to 2.99±0.1 ppm/°C. The accuracy of the measurement using the described experimental set-up and procedure was estimated to be 0.1 ppm/C or better, which is compatible with that claimed by [2] for ESPI technique.

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