Chapter 18
Observation of Thermal Strain on Electronic Packages Using Digital Image Correlation

Yasutaka Tominaga, Shuichi Arikawa, Satoru Yoneyama, Yasuhisa Fujimoto, and Yohei Omoto

Abstract In this study, the thermal expansion of bi-metal specimen is measured by digital image correlation (DIC). A measurement system is developed for the evaluation of complex thermal strain distribution on electronic packages. A heating chamber is designed for applying the thermal load and DIC provides the full-field thermal deformation distribution of the bi-metal specimen due to temperature changes. The in-plane strain distribution measured by DIC is influenced by the out-of-plane displacement. By measuring the thermal expansion of the materials having known thermal expansion coefficient at same time, the effect of the out-of-plane displacement on the in-plane strain measurement is corrected. Experimental Results show that the thermal strain of the bi-metal specimen can be obtained by the measurement system including the out-of-plane displacement correction.

Keywords Digital image correlation • Thermal strain • Bi-metal • Electronic packages • Out-of-plane dispalacement

18.1 Introduction

In recent years, with the needs for miniaturization, weight saving and the improvement of the performance of electronic devices, electronic packages have been miniaturized and highly integrated. Damages such as debonding wires and solder occur by thermal stress caused by the difference of thermal expansions of elements in the packages. Therefore, the improvement of the structural reliability of the packages is required. Thermal strain and stress have been evaluated by the measurement using strain gauges and finite element analysis. However, with the miniaturization and the complication of structures, it is difficult to evaluate the actual thermal deformations. Therefore, in order to ensure the structural reliability of the electronic packages, the development of a quantitative evaluation technique of thermal stress and strain should be used. Considering electronic packages are heterogeneous materials, a full-field and noncontact measurement method is required for the thermal strain measurement. Holography and electronic speckle pattern interferometry (ESPI) are known as such method. However, there are problems that the measurement environment is limited and the process is complex for these methods. On the other hand, digital image correlation (DIC) has low environmental vulnerability and simple measurement process [1–3]. Therefore, it is considered that DIC is effective to measure the thermal deformation.

In this study, the observation method of the thermal strain on electronic packages with DIC is investigated. A heating chamber is designed for applying the thermal load and DIC provides the full-field thermal deformation. A bi-metal specimen is used to measure the inhomogeneous strain distribution. By measuring the thermal expansion of the materials having known thermal expansion coefficient at same time, the effect of out-of-plane displacement which influences in-plane strain distribution measured by DIC is corrected. Thermal strain of the bi-metal specimen can be obtained by the measurement system including the out-of-plane displacement correction.

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18.2 Structure of Heat Chamber

The heat chamber is developed to produce thermal strain on the electronic packages. The structure is shown in Fig. 18.1. The outside frames are made of aluminum alloys. Insulating materials are set inside of the frame. The dimensions of the heating room are the size of 60 × 60 × 10 mm. A heater is inserted under the heat spreader made of copper in the heating room. The temperature is controlled by feedback system including thermocouple attached on the heat spreader and the controller. The controllable temperature range of the chamber is from room temperature to more than 300° which is above the melting point of solder. The sample is set on the heat spreader with thermal transfer grease. A tempered glass plate is used for the upper window of the chamber to take images of the sample surface. The thermal strain is measured by DIC using the images which are captured by CCD camera through the window.

18.3 Basic Principle of DIC

In two-dimensional digital image correlation, displacements are directly detected from digital images of the surface of an object. The plane surface of an object is observed usually by a CCD camera with an imaging lens. The images on the surface of the object, one before and another after deformation, are recorded, digitized and stored in a computer as digital images. These images are compared to detect displacements by searching a matched point from one image to another. Because it is almost impossible to find the matched point using a single pixel, an area with multiple pixel points (such as 20 × 20 pixels) is used to perform the matching process. This area, usually referred as subset, has a unique light intensity (gray level) distribution inside the subset itself. The light intensity distribution basically remains unchanged during deformation. Figure 18.2 shows the part of the digital images before and after deformation. The displacement of the subset on the image before deformation is found in the image after deformation by searching the area of same light intensity distribution with the subset.

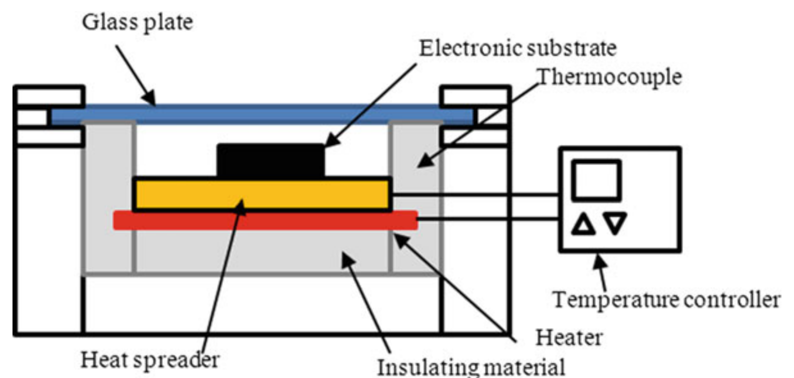

Fig. 18.1 The configuration of heat chamber

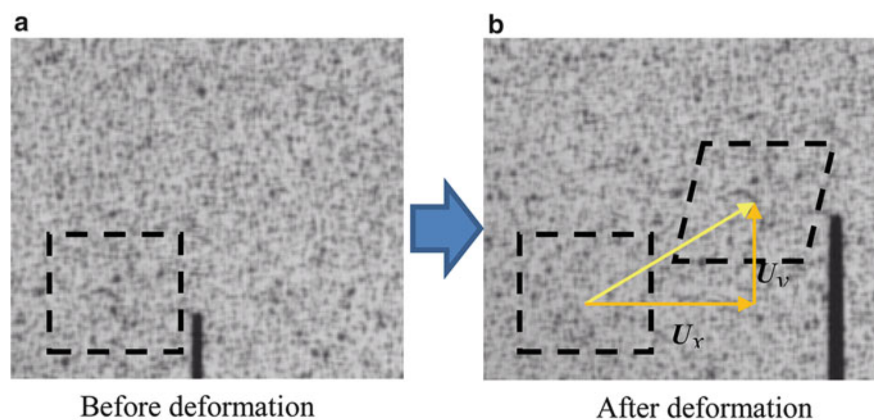

Fig. 18.2 Movement of random pattern (**a**) before deformation (**b**) after deformation

Once the location of this subset in the deformed image is found, the displacement of this subset is determined. Strain distribution is then obtained by differentiating the displacement distribution. In order to perform this process, the surface of the object must have a feature that allows matching the subset. If no feature is observed on the surface of the object, an artificial random pattern must be applied.

18.4 Correction of Apparent Strain Caused by Out-of-Plane Displacement

18.4.1 Correction Method

The heat chamber and the sample have out-of-plane displacement with heating. This phenomenon influence in-plane strain distributions because of the change of the distance between the camera and the sample surface. The out-of-plane displacement before and after deformation is shown in Fig. 18.3. The solid lines in Fig. 18.3 mean a condition before deformation and broken lines mean a condition after deformation. Because the image captured after deformation includes influence of the out-of-plane displacement and the in-plane deformation, the strain measured using DIC represents not actual but apparent strain. Therefore, the additional strain caused by the out-of-plane displacement should be removed. We propose a method for the correction of the additional strain as follows. The apparent strain of a specimen is obtained using DIC. On the other hand, the strain of a reference specimen whose coefficient of thermal expansion (CTE) is known is measured simultaneously. The additional strain caused by the out-of-plane displacement is obtained by subtracting the strain calculated by CTE of the reference specimen from the strain measured by DIC. Then, the actual thermal strain distribution of the sample can be obtained.

18.4.2 Experimental Procedure for Correction

The thermal strains of two specimens which have different CTE are measured by DIC. The specimens are an austenitic stainless steel (JIS SUS304) having CTE of 17.3×10^{-3}/K and an oxygen-free copper (JIS C1020) having CTE of 17.7×10^{-3}/K. The dimension of the specimens is $10 \times 3 \times 0.5$ mm. The surfaces of the specimens are colored with white and black speckle pattern for DIC. The thermal loads are applied with the temperature differences of 50, 100, 150, 200°. The temperature is maintained for 30 min at each step. Then, the images of the samples are captured. Figure 18.4 shows the schematic view of the measurement system. The camera for DIC is Jai CV-M4 + CL. The resolution of the camera is 1380×1030 pixels and 8 bits. The subset size for DIC is set to 51×51 pixels. The strain distributions are calculated from the displacement distributions using local least-squares. The gauge length is set to 200 pixels for the strain calculation.

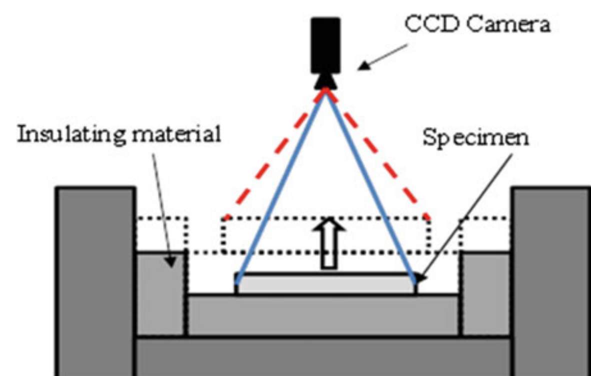

Fig. 18.3 Out-of-plane deformation and increasing strain

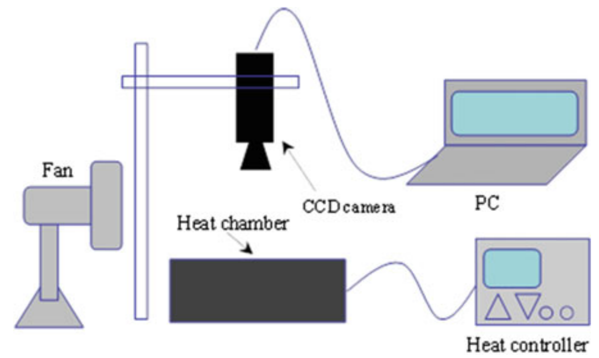

Fig. 18.4 The thermal strain measurement system

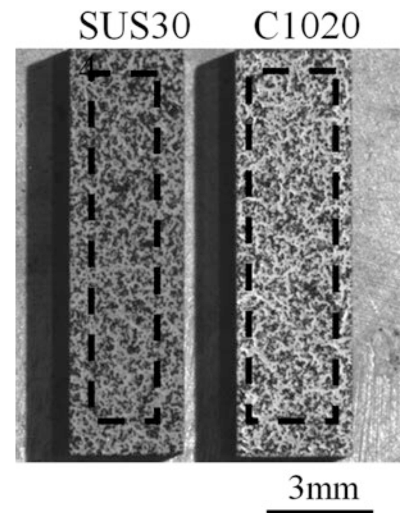

Fig. 18.5 Specimens for calibration

18.4.3 Results and Discussion

The image of two samples is shown in Fig. 18.5. The broken lines on the each sample represent the measurement region. The relation of the measured strains and the temperature is shown in Fig. 18.6. Solid markers show the measured strains which are averaged in the measurement region and open markers show the additional strains that are obtained by subtracting the strain obtained by the CTEs from the measured strains. The lines show the linear approximation of the additional strains. The lines show good agreement. In Table 18.1, the CTEs of materials and the gradients of the approximation lines are shown. The strain values of SUS304 and C1020 are very similar. It is preferred to select copper (C1020) for the correction because the electronic substrate is made of copper.

18.5 Thermal Strain Measurement of Bi-metal Specimen

18.5.1 Experimental Procedure

In electronic packages, the complex thermal stress distribution occurs because the packages consist of the various CTE materials. In order to validate the method of thermal strain measurement, the thermal strain of a bi-metal specimen is measured in this study. Figure 18.7 shows the bi-metal specimen consists of SS400 having CTE of 11.7×10^{-3}/K and C1020 having CTE of 17.7×10^{-3}/K. The dimension of both SS400 and C1020 specimens is $5 \times 10 \times 3$ mm. Figure 18.8

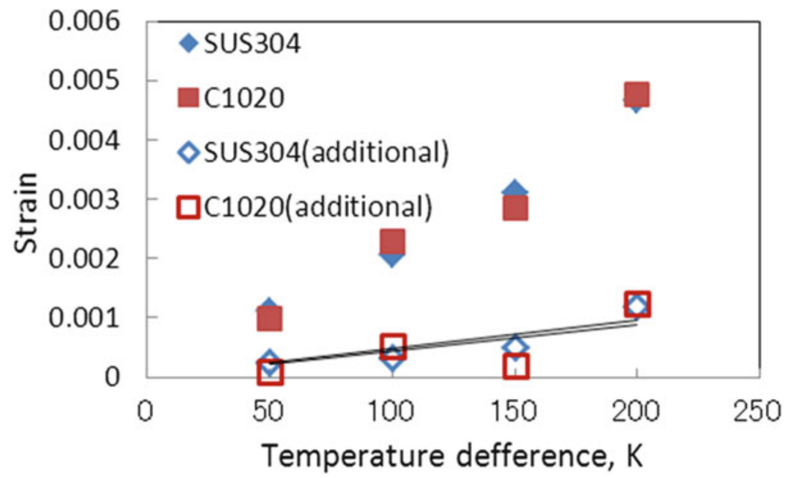

Fig. 18.6 Relationships of strain and temperature

Table 18.1 Rates of changing strain depending on temperature

	SUS304	C1020
CTE[$\times 10^{-6}$/K]	17.3	17.7
Out-of-plane displacement[$\times 10^{-6}$/K]	4.1	4.4

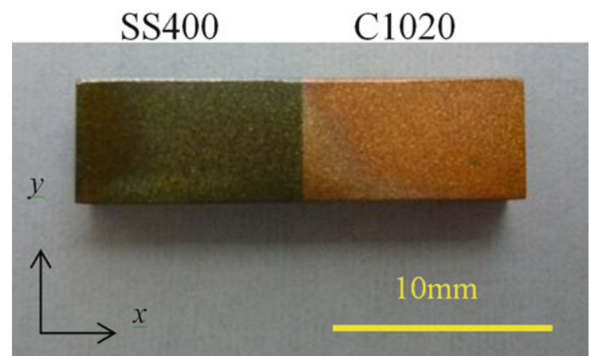

Fig. 18.7 Brazed specimen

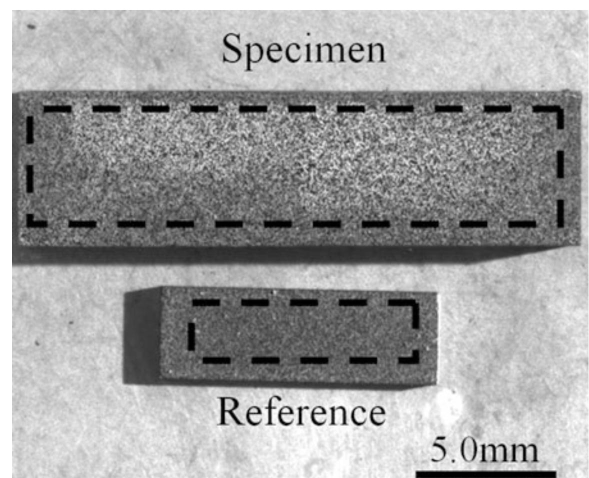

Fig. 18.8 Random patterned specimen

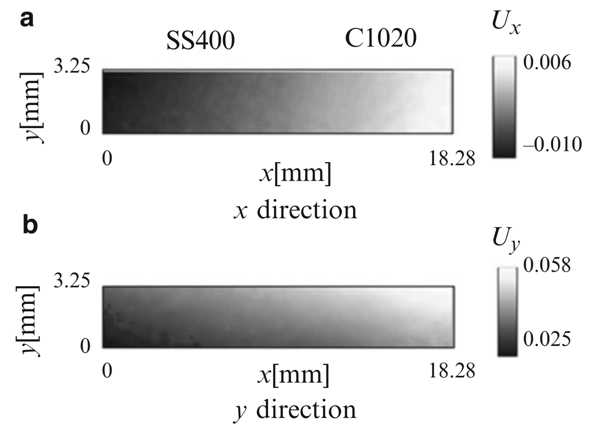

Fig. 18.9 Displacement maps measured by DIC

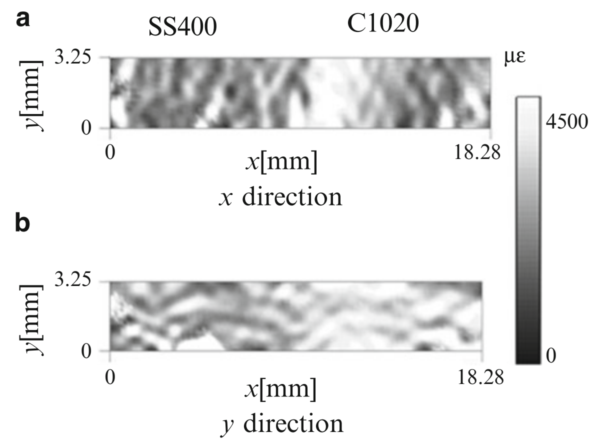

Fig. 18.10 Strain maps measured by DIC

shows the bi-metal specimen and the reference specimen colored in black and white random pattern. The thermal strains of the specimens are measured using the proposed measurement system. The thermal loads are applied with the temperature differences of 50, 100, 150, and 200°. The additional strain caused by the out-of-plane displacement is simultaneously measured and eliminated from the measurement results.

18.5.2 Results and Discussion

Figure 18.9 shows the x and y directional displacement maps of the bi-metal heated from 30° to 230°. The left side of the specimen is SS400 and the right side is C1020. The subset size is set to 31 × 31 pixels and the correlation area does not include the edges of specimen. In the maps of the displacement distribution, it is observed that the thermal expansion occurs. The strain distributions are obtained from the displacement distributions using local least-squares. Figure 18.10 shows the x and y directional normal strain maps. The gauge length of the strain calculation is 60 pixels. The gauge length equals to about 1 mm in this condition. The additional strain caused by the out-of-plane displacement is already corrected. The interface of C1020 and SS400 located at the center of the maps. In the strain maps, the strain values change suddenly around the interface. It suggests that the phenomenon is caused by binding with each other and the CTE difference. In the map of the x directional normal strain, the strains of C1020 and SS400 increase as closing to the interface. On the other hand, in the map of the y directional strain, the strain of C1020 decreases by the binding and the strain of SS400 increases by the tension of C1020 as closing to the interface. In the point away from interface, the strain should close to the value calculated by CTE because the force of the bond decreases. In fact, the thermal strain of C1020 by CTE is calculated as 3.54×10^{-3} and the average value of the measured strain near the edge is 3.55×10^{-3}. These results indicate that the behavior of the thermal strain on bi-metal can be measured.

18.6 Conclusions

The strain distributions of the bi-metal specimen are measured using digital image correlation for the establishment of the measurement system of the thermal strains of the electronic packages. By measuring the strains of the reference specimen simultaneously with the strain of the sample, the effect of the out-of-plane displacement is corrected. Results of the strain measurement of the bi-metal specimen show that the thermal strain of electronic packages can be measured by the proposed method.

References

1. Yoneyama S (2010) Displacement and strain measurement using digital image correlation. J NDI 59(7):306–310
2. Sutton MA (1991) Full-field representation of discretely sampled surface deformation for displacement and strain analysis. J Exp Mech 31(2):168–177
3. Bing P et al (2009) Measurement of coefficient of thermal expansion of films using digital image correlation method. J Polym Test 28(1):75–83