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Improved DICM with an IR camera for Imaging of Strain and Temperature in Cross Section of TO packages

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Abstract*—Digital image correlation method (DICM) is effective for failure mechanism investigation of power semiconductor packages by obtaining the mechanical strain in the package. In DICM, the displacement and strain are calculated by the images of a random pattern on the surface of the object captured by a camera. We have developed a new DICM system to obtain the mechanical strain and the temperature distributions simultaneously using an infrared camera (IR-DICM). In previous IR-DICMs, the strain observation was limited to high temperatures under constant condition, so that stress location and phase in the power cycle cannot be identified for failure mechanism investigation. In this paper, We successfully demonstrated the IR-DICM on TO-3P package power cycling test and obtained strain and temperature distributions throughout the power cycle using new sample preparation and special image processing algorithm.

***Keywords*—, Digital Image Correlation, Infrared camera, Strain distribution imaging, Temperature distribution imaging**

I. INTRODUCTION

The decrease in the mechanical strength of package materials and joints in power semiconductors by temperature swing is the serious problem causing device failure[1]. The situation will be exacerbated according to the increasing in power density of the device[2]. To prevent the decrease in mechanical strength, structural design and material selection to release mechanical stress are required, and the thermomechanical behavior of the device must be evaluated experimentally.

We have developed a technique for simultaneous measurement of strain and temperature using an infrared camera(IR-DICM) (Fig. 1) [3][4][5]. The proposed system realizes simultaneous measurement of strain and temperature using an infrared camera by applying the image correlation method to the infrared images, enabling simplification of the system and approach to minute areas. By applying this system to power semiconductors, we can visualize the mechanical stress generated locally inside the device and extract the relationship with the failure phenomenon. In previous IR-DICMs, the strain observation was limited to high temperatures under constant condition, so that stress location and phase in the power cycle cannot be identified for failure mechanism investigation.

In this paper, new sample preparation and special image processing algorithm have been implemented into the IR-DICM to expand the temperature range under transient conditions. We successfully demonstrated the IR-DICM on TO-3P package power cycling test and obtained strain and temperature distributions throughout the power cycle with a single IR camera.

II. DIGITAL IMAGE CORRELATION METHOD(DICM)

The digital image correlation method measure the strain distribution on the surface of the object and is being studied as an effective method for analyzing the thermomechanical behavior of electronic devices[6][7]. Since failure phenomena such as cracks and voids occur inside the device due to local stress in power semiconductors, mechanical stress analysis is effective for failure mechanism investigation[8].

In the digital image correlation method, a random pattern is applied to the surface to be measured. An image to be measured is acquired using a camera. The random pattern between the reference image before the load is applied and the target image after the load is applied are compared. Calculation areas called subsets is used as a method for measuring displacement. The random pattern area is divided

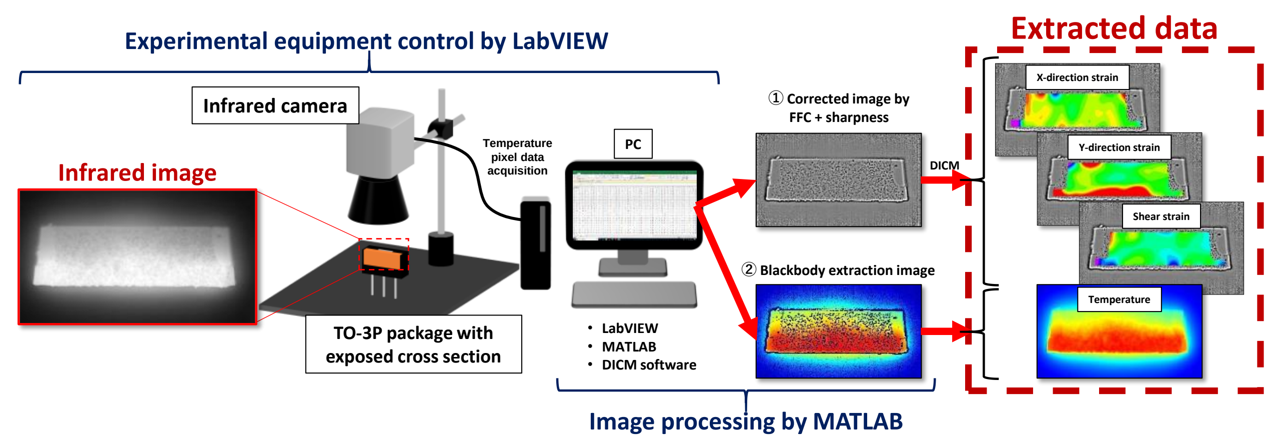

Fig. 1. DICM system to obtain the mechanical strain and the temperature simultaneously using an infrared camera.

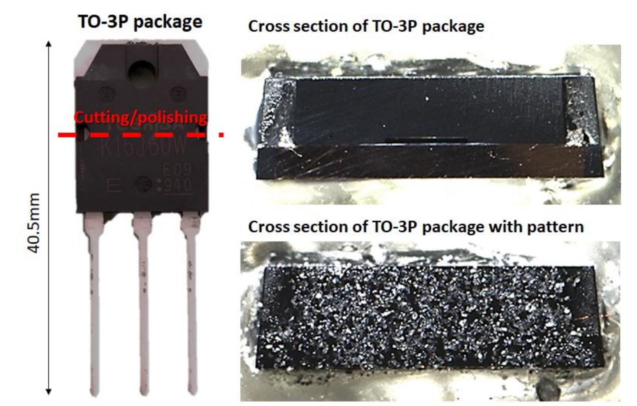

Fig.2. Random pattern on samples for IR-DICM

into multiple subset. A region showing a good match with the brightness pattern of the subset in the reference image is searched in the target image. By performing this calculation throughout the divided subsets, the displacement/strain distribution of the entire measurement area is obtained.

III. SIMULTANEOUS MEASUREMENT OF STARIN AND TEMPERATURE USING A SINGLE INFRARED CAMERA

A. *Sample preparation*

Cross section of TO-3P packages that exposed by cutting machine and polishing machine is used to measure strain and temperature of inside the package (Fig. 2).

In the conventional image correlation method using a visible light camera, reflected light difference by color is used for random pattern. For example, the surface to be measured is filled with black paint and a white paint random pattern is applied.

In the proposed method IR-DICM using an IR camera, radiant light difference by emissivity and the delay in temperature change must be used for visualizing random pattern[9][10]. We have developed a random pattern formation with alumina powder particles on the blackbody coating. Random pattern can be recognized by infrared cameras due to the difference in emissivity and the delay in temperature change between blackbody coating and alumina powder particles (Fig. 2).

B. *Strain extraction from IR image*

In the image correlation method, the strain is calculated by comparing and analyzing the random pattern between the reference image before the load is applied and the target image after the load is applied. When materials with different thermal conductivity are combined such as the cross section of a TO-3P package, pattern recognition becomes difficult due to the difference in infrared intensity.

We introduced image processing to the IR-DICM so that random patterns among the reference image and another image to indicate a high correlation when temperature of the object to be measured changes. We used flat-field correction and sharpening processing to adjust the brightness distribution and sharpen the pattern. In the image processing program of system we developed, the optimum images for DICM are acquired by changing the parameters of the flat-field correction.

In flat-field correction, a smoothing image that determined the degree of brightness adjustment is acquired using a smoothing filter called Gaussian filter. To acquire the optimum image for DICM, the standard deviation of the Gaussian filter is changed within a certain range. Corrected reference image is acquired by flat-field correction and sharpening processing in initial setting. The correlation coefficients are acquired by the corrected reference image and the target image with the changed standard deviation. By extracting the image with the highest correlation coefficient, the optimum standard deviation is selected and the image used for the image correlation method is created.

The pattern area of the reference image is specified as the coordinate area when comparing the correlation coefficients. The same coordinate area in the reference image from the target image is specified as the evaluation area and gets the correlation coefficient. By performing the image correlation method using an infrared image corrected by image processing, it becomes possible to calculate the strain distribution (Fig. 3).

C. *Temperature extraction from IR image*

The temperature distribution is extracted from the same infrared data which is used to measure the strain distribution. The temperature distribution can be easily acquired by converting infrared data into an image, however, a random pattern remains in the acquired temperature distribution image, and data defects cannot be avoided. The image processing program for temperature measurement extracts only the temperature of the blackbody paint portion from the acquired infrared image and applies linear interpolation to the area where the blackbody paint is not applied. Since the temperature value of the blackbody paint part with an emissivity of 0.94 is used for interpolation, an accurate and smooth temperature distribution image can be obtained(Fig. 4).

The proposed IR-DICM image processing configuration is shown in Figure 5.

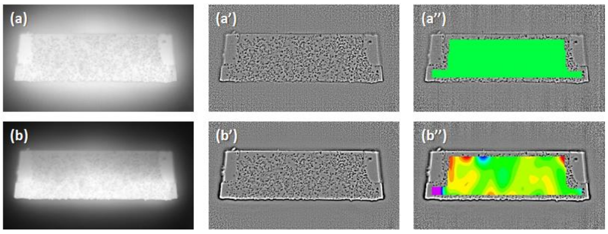

Fig.3. Image comparison in each process of image processing to extract the strain distribution

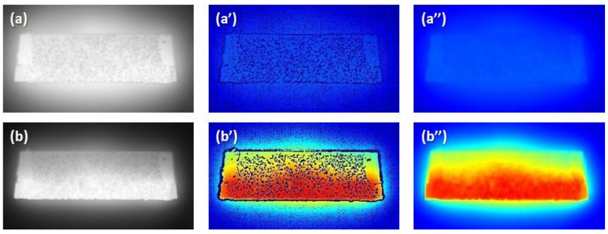

Fig.4. Image comparison in each process of image processing to extract the temperature distribution

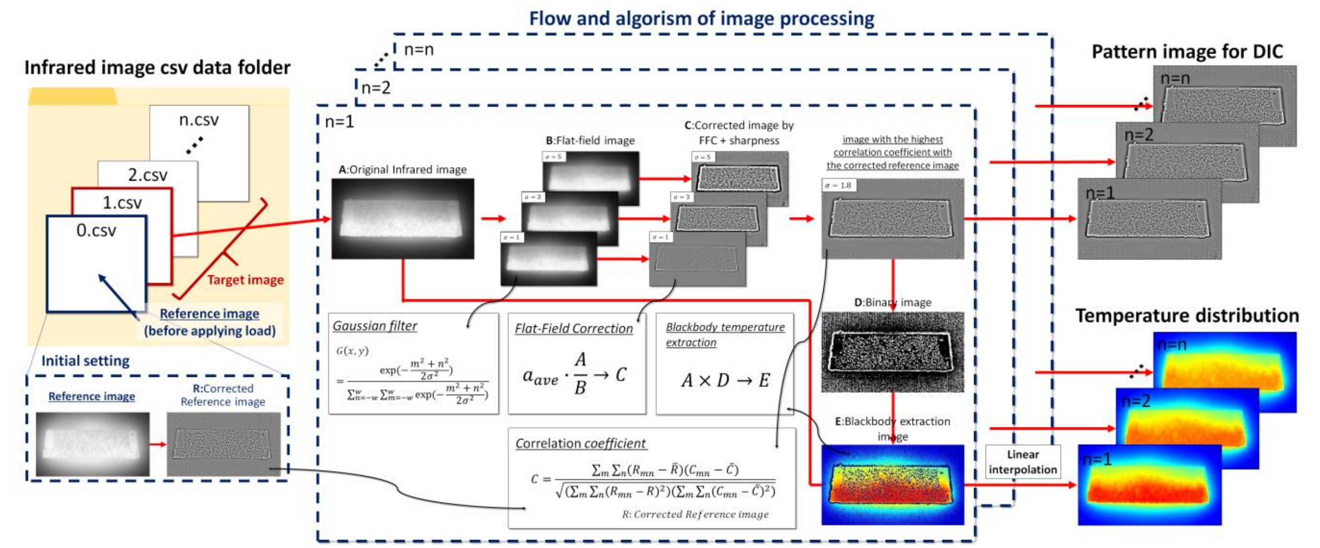

Fig. 5. IR-DICM image processing configuration to obtain strain and temperature image

IV. System Demonstration of Improved IR-DICM Under the Power Cycing Test

A. Power cycling test condition

To confirm the effectiveness of this system for devices under the power cycle test, we aimed to reach the ΔT of about 80 ℃ and the maximum temperature of around 120 ℃ . The power cycling test was conducted in which a current of 10 A was passed in the opposite direction of the MOSFET, and the on-time was 20 seconds and the off-time was 40 seconds. In the pattern construction method, the pattern is visualized by the difference in emissivity and the delay of the temperature change, so that it is difficult to recognize the pattern at room temperature. Since temperature change is required to visualize the pattern, the power cycling time was decided two times. The pattern can be recognized from the start of the second cycle by the temperature change in the first cycle.

B. Result of image processing

Figure 4 shows the output image of the image processing program. From Figure 4, it can be confirmed that the infrared image before correction has a bias in the brightness distribution due to the temperature change due to energization. When the image correlation method is applied to this image, the displacement / strain cannot be calculated because the bias of the brightness distribution hinders the detection of the pattern. The corrected image developed by the image processing has the brightness distribution adjusted and the pattern sharpened by the sharpening processing and the flat-field correction. By using this corrected infrared image, it is possible to run an image correlation method that was not possible with the original infrared image before correction. With regard to the temperature distribution, an accurate and smooth temperature distribution using the temperature value of the blackbody portion can be obtained by applying vertical linear interpolation with a random pattern as a missing value.

C. Measurement of strain and temperature in cross section of TO-3P package

Figure 5 shows the experimental results of this system using the TO-3P package. Strain and temperature were acquired at 4-second intervals in the second cycle. The strain distribution was acquired using image correlation software after applying the image processing for strain measurement developed. Three types of strain, x-direction strain, y-direction strain and shear strain were acquired by image correlation software. Positive values in the strain distribution represent tensile strains and negative values represent compressive strains. The temperature distribution was obtained by extracting the temperature data of only the blackbody paint part of the acquired infrared image and applying linear interpolation in the y direction.

Since this system collectively controls the experimental equipment with LabVIEW, it is possible to acquire parameters such as the output current, output voltage, and drain-source voltage of the power supply due to time changes during the power cycle test. In this experiment, in addition to the strain distribution and temperature distribution, the current value during the power cycle test, the drain-source voltage and the temperature acquired by the infrared camera were output. The temperature of the infrared camera shows the average value near the chip in the infrared image.

The chip temperature during the power cycle test has risen from about 40 ℃ before the start of the two cycles to a

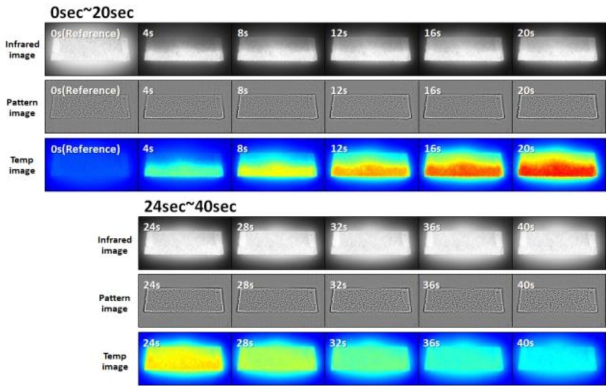

Fig. 6. Image processing results with time-series infrared image with acquired during power cycle test

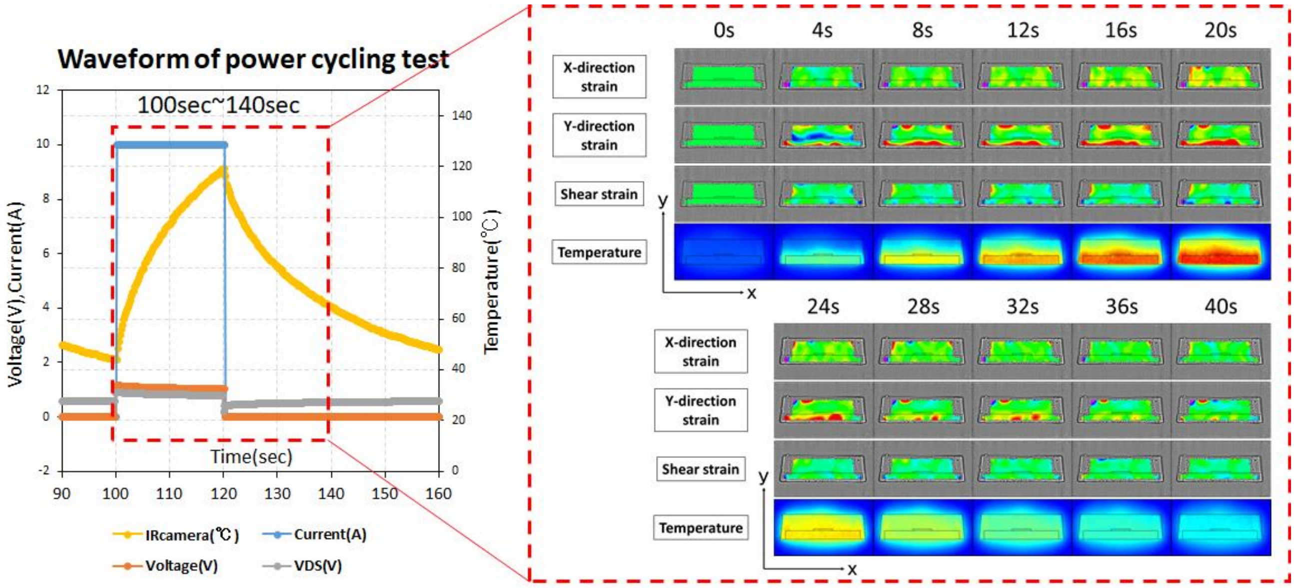

Fig. 7. Demonstration of IR-DICM on cross section observation of TO-3P package under power cycling test

maximum of about 120 ℃. The temperature distribution at this time indicates that the base plate has the highest temperature, and it can be confirmed that the heat generated by the chip is dissipated from the base plate. Regarding the strain distribution, the X-direction strain and the shear strain distribution are scattered, whereas the y-direction strain has a large strain bias in the upper and lower parts of the device. This result represents the strain caused by mechanical stress due to the difference in the coefficient of thermal expansion between the base plate and the encapsulant. Moreover, It represents the behavior of thermal expansion that occurs when the TO-3P package is energized and the temperature rises. In research on packaging technology for discrete semiconductors, it is known that differences in the material properties of base plates, silicon chips and resins cause variations in chip characteristics, passivation cracks and peeling. The bias of strain and temperature inside the device confirmed in the demonstration is thought to give mechanical stress inside the device and to cause a failure.

V. CONCLUSION

We successfully demonstrated the IR-DICM on TO-3P package power cycling test and obtained strain and temperature distributions to identify stress location and phase in the power cycle. The strain and temperature distributions in cross section of TO-3P package were obtained throughout the power cycle. According to experiment result, the strain and temperature distributions that located to baseplate of package was thought to give a mechanical stress to solder layer between chip and baseplate.

This method can contribute to evaluation of device failure mechanism in power semiconductors.

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