Infrared image correlation for thermal stress analysis of power devices

著者	Watanabe Akihiko, Masuda Yoshiki, Omura Ichiro
journal or publication title	Microelectronics Reliability
volume	100-101
page range	113414-1-113414-4
year	2019-09-23
URL	http://hdl.handle.net/10228/00008478

doi: https://doi.org/10.1016/j.microrel.2019.113414

Infrared image correlation for thermal stress analysis of power devices

Akihiko Watanabe[a,*], Yoshiki Masuda[b] and Ichiro Omura[b]

[a] *Department of Electrical Engineering and Electronics, Kyushu Institute of Technology, Kitakyushu, Japan*
[b] *Department of Biological Functions Engineering, Kyushu Institute of Technology, Kitakyushu, Japan*

Abstract

Thermal stress analysis is indispensable to improve the reliability of power devices. We propose a technique to observe a temperature distribution and a thermal strain simultaneously for thermal stress analysis of power devices. A temperature distribution is measured by an infrared (IR) camera and a thermal strain is measured by a digital image correlation (DIC) with IR images under a power cycling test. To apply DIC to IR images, we propose techniques to make a random pattern on the surface which can be recognized by IR camera even if a surface temperature is changed. This technique realises an observation with completely same field of view even in a localized area on power devices. This method provides an experimental means to verify simulation results of thermal stress analysis.

1. Introduction

A power device is constructed by a combination of several materials with different coefficient of thermal expansion. A temperature swing during the device operation generates thermal stress between their interfaces and it results in causes of failure, for example a heal clack of bonding wire or delamination of soldering [1-6]. Moreover, miniaturization of power devices and new devices using new materials increase the operating temperature. Therefore, development of new packaging technology with high reliability is in progress. To find out a mechanical weak point where thermal stress concentrates is necessary for enhancing reliability of power device. Although numerical simulations are often used for such analysis, its accuracy has to be validated by experimental measurements. However, it is difficult to experimentally evaluate thermal stress. Since temperature changes and deformation of constitutional material of power devices is strongly related to thermal stress generation, simultaneous measurement of temperature and deformation is one of the solutions for the problem. To feedback a finding related to thermal stress to a design and material selection is an effective method for a development of high reliable packaging of power device (see Fig. 1).

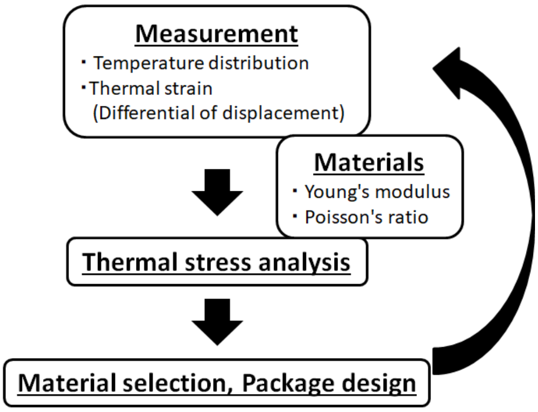

Fig. 1. Improvement packaging of power device by thermal stress analysis.

An infrared (IR) camera is often used for measurement of temperature distribution [1,6-9] and a digital image correlation (DIC) is also used to measure thermal strain [9-13]. To apply these techniques to simultaneous measurement, an infrared camera and an optical camera are required. However, due to the camera arrangement, it is difficult to observe the target area within the same field of view.

In this paper, we propose a technique to observe distribution of temperature and thermal strain of power devices by using single infrared camera. This technique makes it possible to observe the same field of view even in a localized area.

---

[*] Corresponding author. nave@elcs.kyutech.ac.jp
Tel: +81 (93) 884 3298 ; Fax: +81 (93) 884 3298

Table 1
Camera and software specification of system

Camera		pixel number	Frame rate	Lens
IR camera	Optris OPTPI640O33T900	640×480	32Hz	O33: FOV 33^o x 25^o
Optical camera	POINT GREY GRAS-20S4M-C	1624×1224	30Hz	XENOPLAN 1.9/35-0901
Software				
IR image acquisition	Optris PIX-Connect			
2D digital image correlation	Correlated solutions Vic-2D 2009			

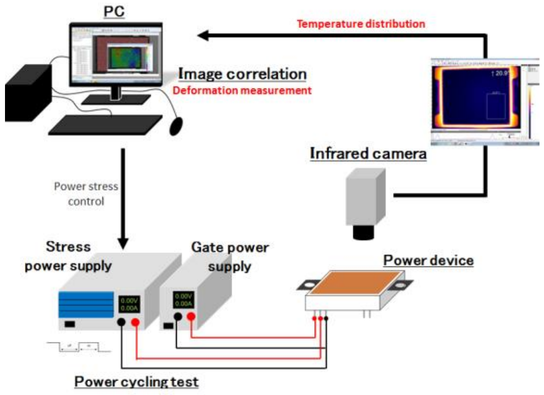

Fig. 2. System setup for infrared image correlation of power device under power cycling test.

2. Infrared image correlation

2.1. System setup

Fig. 2 shows a schematic of our system for simultaneous measurement of temperature and deformation by single IR camera. In this study, the system applied to measure a thermal strain distribution of a power device during a power cycling test. The system was constructed by an IR camera, DC power supplies for a power cycling test and a control PC. An obtained IR image is stored in the PC and a deformation of the package is analysed by DIC. The result of DIC by IR images was confirmed by comparing with DIC with optical images. The cameras and software are listed in Table 1.

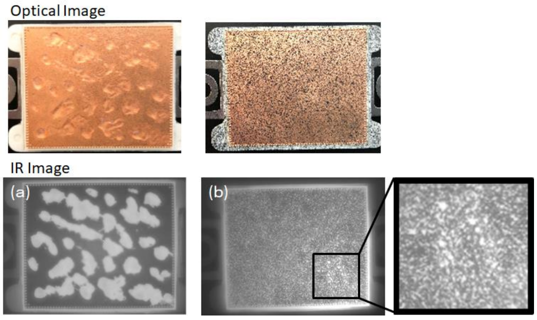

Fig. 3. Random pattern recognition by IR camera. The pattern is made by silicone paste (a) and black paint (b).

2.2. 2D Digital image correlation

We applied 2-dimentional DIC to IR images. The DIC is a method to measure a deformation and strain of an object by using a random pattern on the surface [10]. To obtain a strain by DIC, small area called “subset” constructed by pixels is defined and the deformation is calculated from displacement of the subset. Considering displacement in x direction, when two points P : x and X : $x + dx$ move to P’ : $x + u(x,y,z)$ and X’ : $x + dx + u(x + dx,y,z)$ respectively, a strain in x direction ε_x is obtained as follows:

$$\varepsilon_x = \partial u(x,y,z) / \partial x \qquad (1)$$

The important technique to apply this method to IR images is to make a random pattern on the surface which can be detect by IR camera. In the case an optical camera, an easy way to make the random pattern is to paint a black and white pattern. However, in the case of an IR camera, if amount of infrared radiation from the surface is the same, that is, if the temperature is uniform, a visible colour pattern is not recognized in an IR image.

3. Results and discussion

3.1. Surface pattern recognition for DIC

In order to visualize the random pattern in the IR image, we made the pattern based on two different principles, one is based on a difference of thermal conductivity and the other utilizes a difference of IR emissivity. Fig. 3(a) shows the result when the pattern was made with silicone paste. During the power cycling test, a time delay in temperature change occurs at the pasted region because of a low thermal conductivity of the silicone paste. This patterning method is efficient when a temperature change occurs in short time. On the other hand, when the temperature change occurs slowly, the pattern is hard to recognize because the temperature of pasted region and other region is almost same. Fig. 3(b) shows the result when the pattern was made by a black paint with emissivity 0.94. In this case, the pattern is recognized as deference of emissivity between painted region and others. The temperature measured in the painted region is in the actual one as the emissivity of this region is almost equal 1. In addition, the pattern can be recognized even if the surface temperature is uniform.

3.2. Demonstration of temperature and strain analysis by infrared camera

An IGBT module incorporating 6 chips in the package was used for the demonstration. A random pattern was made by a black paint. A power cycling was applied to one IGBT chip to make a temperature gradient on the surface. IR image was captured at 50 °C, 60 °C, 70 °C and 80 °C. The temperature was measured by a thermistor embedded in the module. DIC was applied to the IR images and x- and y-direction strain distribution were obtained by comparing with the image acquired at 50 °C. The results are shown in Fig. 4. The random pattern was recognized in IR image even at 80 °C. The strain patterns indicate a degree of deformation caused by

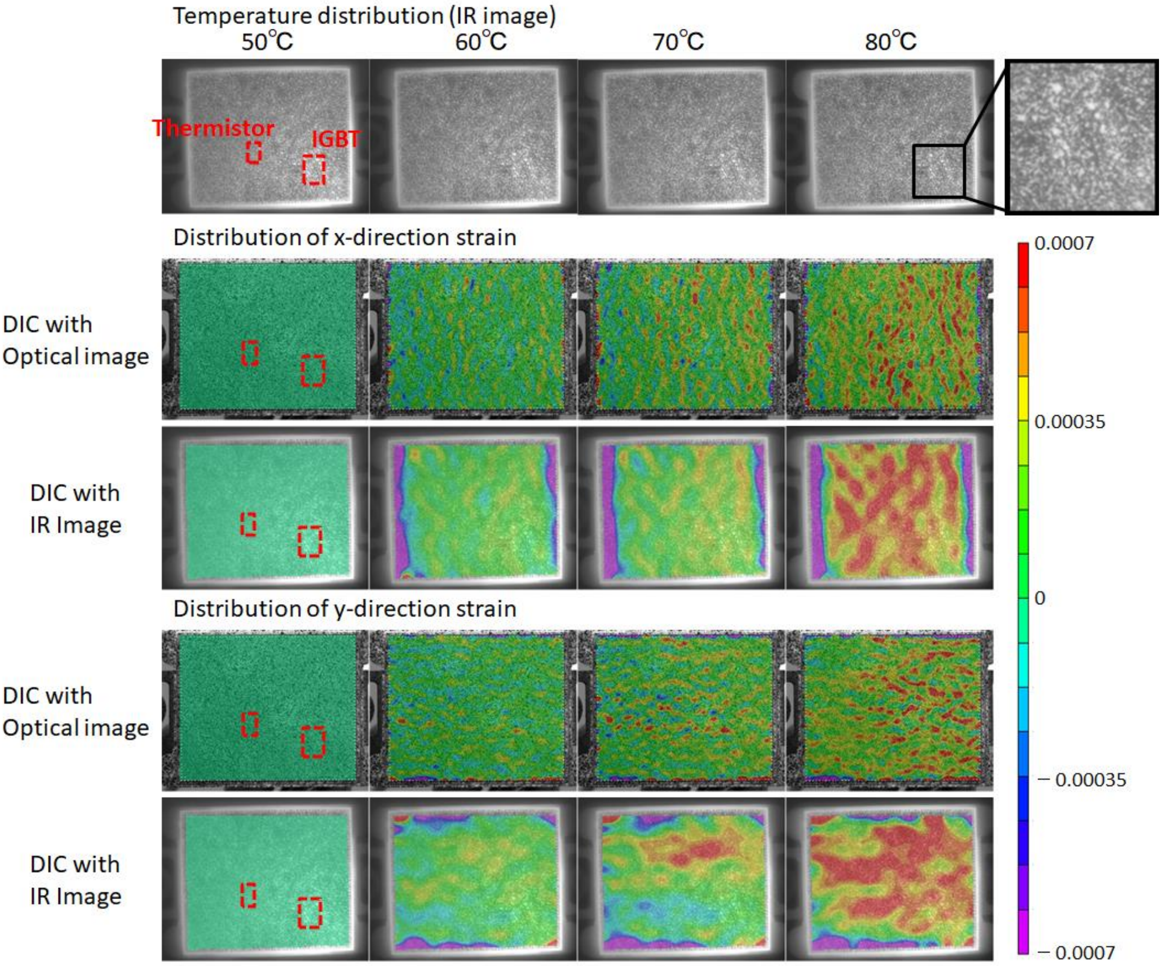

Fig. 4. Results of temperature and strain analysis by infrared camera.

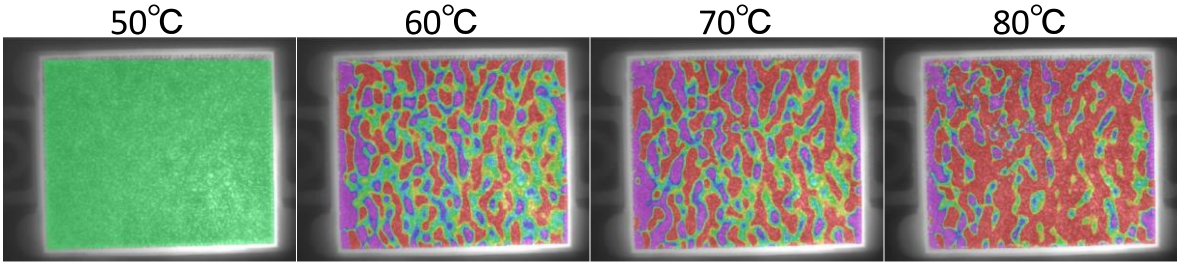

Fig. 5. Infrared image correlation obtained when the subset was set to same area size of the optical DIC result in Fig. 4. These images show the distribution of x-direction strain.

temperature change. The positive value means expansion and negative value means compression.

In the results with optical image, the strain near the chip side was lager both of x- and y-direction analysis. In the results with IR image, although similar distribution could be recognized but it was unclear. In the results, we could not find obvious relationship between the strain distribution and the IGBT chip position. In this experiment, the temperature gradient on the surface was small because the images were captured when the thermistor on the substrate indicated a target temperature. Therefore, the strain caused by thermal distribution on the substrate surface was not localized. To analyse a strain generated by a localized heat source, a series of IR images obtained during the temperature change is necessary.

As mentioned in the section 2.2, since the deformation is calculated from displacement of the subset, the resolution of the strain analysis by DIC depends on the setting of the subset. Comparing the DIC results with IR image and optical image in Fig. 4, a spatial resolution with IR image was low. In this case, the subset for DIC was set as same number of pixels. When a same region of the object is observed, since the pixel number of the IR camera is smaller than the optical camera, the area of subset in IR image is larger than that in optical image. Therefore, the number of subset for the DIC is decrease in the case of IR images. On the other hand, if the subset is set as same area size, the number of subset for DIC is same. However, the detection accuracy for displacement is decrease with IR camera because the number of pixel is small in the subset (see Fig. 5). Since a resolution of the strain analysis is 1/100 of pixels for our DIC system, the resolution of analysis can be improved by using a high resolution IR camera.

For other reason to degrade accuracy of DIC, the random pattern recognition by IR image cannot negligible. Indeed, in the case of high temperature observation over 150 ^{o}C, to detect the random pattern was sometimes difficult. Sudden changes of temperature result in halation at the edge of random pattern. We try to solve this problem by optimizing experimental condition and image processing.

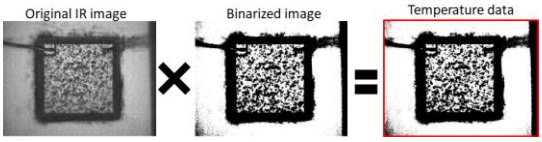

Fig. 6. Procedure to extract temperature data of patterned surface (an example).

To measure the surface temperature, we extract the temperature data in the painted region because the emissivity of this region is almost equal 1. An IR image was binarized to set the painted region as 1 and other region as 0. To multiply the original IR image and the binarized image, the temperature data only on the painted region can be extracted (see Fig. 6). If a true emissivity on a pixel is known, we can obtain temperature data in whole area by using the emissivity map instead of the binarize image.

6. Conclusion

We propose a technique to observe a temperature distribution and a thermal strain simultaneously for thermal stress analysis of power devices. An IR image correlation was realized by making a random pattern on the surface which can be recognized by IR camera even when a surface temperature is changed. In the case of high temperature observation over 150 ^{o}C, a halation at the edge of random pattern is degrade resolution of analysis. To analyse a strain generated by a localized heat source, it is necessary to obtain a series of IR images during temperature change by high-speed IR camera. Since the accuracy of deformation analysis is improved by using a high-resolution IR camera, this system can be applied to an analysis in more localized area on power devices.

References

[1] Lutz J, Schlangenotto H, Scheuermann U, Doncker RD. Semiconductor Power Devices, Springer, 2011.

[2] Herold C, Franke J, Bhojani R, Schleicher A, Lutz J. Requirements in power cycling for precise lifetime estimation. Microelectronics Reliability, 58 (2016) 82–89.

[3] Kociniewski T, Moussodji J, Khatir Z. Temperature mapping by μ-Raman spectroscopy over cross-section area of power diode in forward biased conditions. Microelectronics Reliability, 55 (2015) 547–551.

[4] Broeck C, Conrad M, De Doncker RW. A thermal modeling methodology for power semiconductor modules. Microelectronics Reliability, 55 (2015) 1938–1944.

[5] Choi UM, Blaabjerg F, Iannuzzo F, Jørgensen S. Junction temperature estimation method for a 600 V, 30A IGBT module during converter operation. Microelectronics Reliability, 55 (2015) 2022–2026.

[6] Riccio M, Maresca L, Irace A, Breglio G, Iwahashi Y. Impact of gate drive voltage on avalanche robustness of trench IGBTs. Microelectronics Reliability, 54 (2014) 1828–1832.

[7] Kölzer J, Oesterschulze E, Deboy G. Thermal imaging and measurement techniques for electronic materials and devices. Microelectronic Engineering. 31(1–4) (1996) 251–70.

[8] Wang X, Witz J, Bartali AE, Jiang C. Infrared thermography coupled with digital image correlation in studying plastic deformation on the mesoscale level. Microelectronics Reliability, 86 (2016) 264-274.

[9] Maynadier A, Poncelet M, Lavernhe-Taillard K, Roux S. InfraRed Image Correlation: a new method for characterizing thermal and displacement fields. Proc. of 11th International Conference on Quantitative Infrared Thermography, (2012). e-book proceedings http://dx.doi.org/10.21611/qirt.2012.166

[10] Sutton MA, Orteu J, Schreier HW. Image correlation for shape, motion and deformation measurements. Springer, Berlin, 2009.

[11] Silva ML, Ravichandran G. Combined thermoelastic stress analysis and digital image correlation with a single infrared camera. The Journal of Strain Analysis for Engineering Design. 46(8) (2011) 783–793.

[12] Niu Y, Wang J, Shao S, Wang H, Lee H, Park SB. A comprehensive solution for electronic packages' reliability assessment with digital image correlation (DIC) method. Microelectronics Reliability, 87 (2018) 81-88.

[13] Ikeda T, Kanno T, Shishido N, Miyazaki N, Tanaka H, Hatao T. Non-linear analyses of strain in flip chip packages improved by the measurement using the digital image correlation method. Microelectronics Reliability, 53 (2013) 145-153.