MEASUREMENT OF ELASTIC THERMAL STRESS IN COB PACKAGING STRUCTURES

Fanxiu Chen¹  Xiaoyuan He¹,²  Zhenbin Xu¹  Ming Li²  Jing Song²
1. Department of Engineering Mechanics, Southeast University, Si Pai Lou 2#, Nanjing JS 210096 China
2. Key Laboratory of MEMS of Ministry of Education, Si Pai Lou 2#, Nanjing JS 210096 China

ABSTRACT

Digital speckle correlation method (DSCM) is used to measure the thermomechanical coupling effect in COB packaging structures. CCD camera is applied to capture the speckle patterns of CMOS chip at different temperature fields. Analyzing the speckle patterns, the in-plane deformation of the CMOS chip is obtained. Based on the trigonometrical theory, out-plane displacement can be obtained by measuring of in-plane displacement, and then the elastic thermal stress of the chip is evaluated when the application of the temperature field is repeated. Experiment results are compared with both the results of FEM simulations and the theoretical model. There results are agreed well and it can be proved that DSCM can successfully be applied to analyze the thermomechanical coupling effect. The theoretical model was also verified by result of FEM simulations and experiment testing. Experiment results provide an availability consult to the design of MEMS apparatus.

Introduction

Packaging techniques is widely used in micro electro mechanical systems (MEMS). However, it produces a set of failure modes due to the mechanical nature of MEMS. Although challenges of MEMS packaging have been known for sometime, little published research have been achieved to compile data and work towards meeting these challenges. Experiment data for sensors, which exploit piezoresistivity, shows that packaging affects output of the device [1]. Therefore, it is important to investigate the stresses arising from the packaging process.

Packaging quality has a great effect to the finished product ratio and reliability of product and the research of packaging have become one of key technologies of reliability design. In order to improve characteristics, decrease price and enhance reliability of electron product, the packaging space of chip should be smaller, i.e. high-density packaging. The power of the chip is increasing constantly and the volume is decreasing continuously, thus the thermal design becomes an important problem that we should resolve as soon as possible. Multi-chip module (MCM) is one of the methods of resolving this
question. This project adopts chip on board (COB) which affixes chip on basis directly. There have many differences between thermal expanse ratios of different materials and produce enormous thermal stress, and then induce invalidation of structure. In brief, the research of thermomechanical coupling effect becomes very important and the measurement of thermal stress becomes a key technology.

Usually the FEM simulations and experiment measurement are often used to analysis the packaging thermal stress. FEM simulation method is high-veracity and high-resolution, but the amount of computation is too large and have little effect of theoretical guidance. In this paper, digital speckle correlation method is used to measure the thermomechanical coupling effect in COB packaging structures [2-3]. The experiment results are compared with both results of the FEM simulations and the theoretical model. There results are agreed well and it can be proved that DSCM can successfully be applied to analyze the thermomechanical coupling effect.

### Digital speckle correlation method and measurement system

Digital speckle correlation method (DSCM) is an appealing optical method to measure deformation on an object surface based on the modern digital image processing technology and optical measurement. However, the traditional optical measurements, such as photoelasticity, moiré holography speckle interferometry and etc, which need to pretreat the surface of object deformation from the interferometric fringe. Such techniques suffer from characteristic limitations and are commonly performed in the laboratory. In fact, the natural texture or the random artificial speckle on the object surface is the carrier of deformed information and they keep one to one in accordance with the object’s transformation. The method of digital speckle correlation can directly measure the transformation by tracking the gray value pattern in small local neighborhoods commonly referred to as subsets. Due to the advantages of automatic, non-contact, full field and real time, the method has been applied to the deformation measurement widely.

DSCM was first used by I. Yamaguchi [4], W.H. Peter and W.F. Ranson [5] to focus on the determination of surface displacements. The measurement method of digital speckle correlation is a technique for measuring surface displacements and strains based on the matching of pixel gray value between two digital images taken at different times in a deformation process. This is accomplished by capturing two digitized images of a random speckle pattern representing the undeformed and deformed states. For the randomization of the speckles, subsets comprising a wide variation in gray value are more uniquely identifiable than individual pixels. According to the statistical principle of the correlation, deformation measurement of each pixel location on the surface can be accomplished by virtue of determining the movement of the central point of subset.

The gray value of each pixel location among the subset can be read from the saved image. The measured displacement of a subset is accomplished mathematically through maximization of a normalized cross-correlation coefficient; by overlapping pixel subsets the full-field displacement information is obtained. According to the statistical concept, the correlation coefficient is showed as follow:

\[
C = \frac{\sum \sum [f(x,y) - \bar{f}] [g(x+u,y+v) - \bar{g}]}{\sqrt{\sum \sum [f(x,y) - \bar{f}]^2} \cdot \sqrt{\sum \sum [g(x+u,y+v) - \bar{g}]^2}}
\]

Where, to the given subset of m×n:

\( f(x,y) \) = the gray values of subset centered at the source point

\( g(x+u,y+v) \) =the gray values of subset centered at the target point
\( \mathbf{u}, \mathbf{v} \) = the displacements between the two images

\( \bar{f}, \bar{g} \) = the ensemble average

\( c \) = the correlation coefficient

when \( c = 1 \), the two subsets are correlative fully, and when \( c = 0 \), the two subsets are not correlative.

**Experiment**

Schematic of the optical system is shown in Figure 1. The system includes computer, Charge-Couple Device (CCD) camera, white light source, heater board, direct power supply and chip, etc. Temperature changed along with the heater board and the heater board is made adopt with the effectivity of Pletier [6-7]. Dimension of the heater board is 50.0 mm×50.0 mm×4.0 mm. The working voltage is 0-15V/DC and the temperature offered by heater board is within 0-150°C. The surface up and down are ceramic and they are smoothly. Place the sample on the heater board and spread some silicon between the sample and heater board to enhance the diathermancy. The direct power supply is connected with heater board and the temperature of the heater board could be controlled by transferring of the voltage of the power supply. The image collection card of computer is connected with the CCD camera. The deformation of sample induced by changing temperature could be captured by CCD camera.

Based on the trigonometrical theory, out-plane displacement can be obtained by measuring of in-plane displacement, and then the elastic thermal stress of the chip is evaluated when the application of the temperature field is repeated. With normal viewing, the in-plane displacement \( \mathbf{u} \) due to thickness change \( \Delta h \) is given by:

\[
h(x, y) = k\mathbf{u}
\]

(2)

Where \( k \), which can be obtained by calibration, is an optical coefficient related to the configuration of the system. The value of \( k \) can be evaluated by calibration of the system.

**Experiment Results**
The sample adopted in the experiment is made by adhering chip to FR4 basis directly. The dimension of chip is 5.0 mm×5.0 mm×0.35 mm and the dimension of the FR4 basis is 7.0 mm×7.0 mm×0.75 mm. The special red bond is used to conglutinate the chip and the basis. The facing of a quilt of the chip provide a high quality speckle pattern and Figure 2 shows the speckle pattern.

By adopting the digital speckle correlation method, the deformation information on the surface of the specimens has been gained and the Figure 3 is the in-plane displacement of the specimens at the voltage of 8 volt. Based on the measurement theory, we can see that out-plane displacement can be obtained by measuring of in-plane displacement. Figure 4 shows the result of calibration and then we can obtained the parameter $k=16.77363$.

Based on the calculation result, the out-plane displacements were obtained in this experiment, and then the deformations of the sample warpage were achieved. In this experiment, we also used the FEM simulation method to analysis the displacement of the sample. In order to analysis the thermomechanical coupling effect in COB packaging structures effectively, the theoretical model was used to simulation the thermal deformation of the structure. The model of plane13 was adopted in case of the planar stress suppose. Give an example as the surface deformation of the sample at the
temperature of 55°C. Figure 5 and Figure 6 show the surface deformation and the surface elastic thermal stress respectively. Compared results of experiment testing, FEM simulation method and theoretical model, we can see that these results are agreed well. It can be observed that due to the limit of the measurement system and the effect of the noise, there has some errors focus at the edge of the chip. It also can be observed from figure 6 that the thermal deformation and elastic thermal stress of chip surface from theoretical model and FEM simulation are agreed well, but the experiment result is not as smoother as other methods. The experiment result was affected by the surroundings noise but the current is accord with the theoretical model result as a whole. The experiment results are proved that DSCM can successfully be applied to analysis the thermomechanical coupling effect and the theoretical model was also verified by the result of FEM simulations and experimental testing. The experiment results provide an availability consult to the design of MEMS apparatus.

Figure. 4. The result of calibration

Figure.5. Comparision of the results of surface distortion
In this experiment, we adopt digital speckle correlation method to analyse the thermomechanical coupling effect in COB packaging structures. Based on the trigonometrical theory, the out-plane displacement can be obtained by measuring of in-plane displacement, and then the elastic thermal stress of the chip is evaluated when the application of the temperature field is repeated. DSCM is a non-contact, whole field method and it is appropriate to measuring the thermomechanical coupling effect. Furthermore, the FEM simulation method and theoretical model are all used to analysis this matter and results of three methods are agreed well.

Chip packaging is a typical structure of multilayer materials and has the thermomechanical coupling effect obviously. A deformation at micron degree would induce a serious breakage and it is important to analysis the thermomechanical coupling effect of packaging structure.

The experiment results are proved that DSCM can successfully be applied to analysis the thermomechanical coupling effect and the theoretical model are also verified by the result of FEM simulations and experimental testing. The experiment results provide an availability consult to the design of MEMS apparatus.

Acknowledgments

Funding from project 10472026 supported by National Natural Science Foundation of China and project 2006CB300404 supported by National basis research program of China are gratefully acknowledged.

References