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Non-Destructive Evaluation of Semiconductor Package by Electronic Speckle Pattern Interferometry

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This paper proposes non-destructive ESPI technique to evaluate inside defects of semiconductor package quantitatively. Inspection system consists of ESPI system, thermal loading system and adiabatic chamber. The technique has high feasibility in non-destructive testing of semiconductor and gives solutions to the drawbacks in previous technique, time-consuming and the difficulty of quantitative evaluation. In result, most of defects are classified in delamination, from which it is inferred to the insufficiency of adhesive strength between layers and nonhomogeneous heat spread. The 90% of tested samples have a delamination defect started at the around of the chip which may be related to heat spread design.

Key Words : Electronic Speckle Pattern Interferometry (ESPI), Semiconductor, Non-Destructive Testing, Quantitative Evaluation

1. Introduction

Semiconductor is key components in electro-mechanical devices, personal computer, image processing and others. The reliability of that is affected to the performance of electronic or mechanical system. These include large currents that flow into and out of the silicon chips and package, the high voltage between terminals, the amount of power which is dissipated as heat and the large temperature excursions that devices and package can undergo during operation (Shammas, 2003). Also, the package technology in the semiconductor has been headed to Ball Grid Array type with thinner and the use of environmental friendly package materials and adhesives makes complicated manufacturing process to rise up the defective proportion in package. In electronic packages, materials are generally stacked in layers, where there are some defects, delamination, void and inclusion those are resulted in performance of semiconductor. Therefore, it is important to know where a delamination or void is located and the size. The difference in the thermal expansion coefficient causes these materials to expand and contrast at different rates in heating and cooling, which is the main cause for the delamination defects. However, previous non-destructive testing techniques for reliability evaluation in semiconductor packaging have some drawbacks. Recently, the non-destructive scanning acoustic microscope (Kim, 2002) based on

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ultrasonic testing is a common detection method for delamination or crack in semiconductors (Goh, 2004; Jhang, 2002). But there are some drawbacks of time-consuming, the difficulty of quantitative evaluation and etc. In this paper, semiconductor inspection technique based on Electronic Speckle Pattern Interferometry (ESPI) and temperature control system is developed and applied to objects in service. ESPI is one of laser speckle interferometry with the advantage of non-contact, non-destructive, whole-filed, quasi-real time and high-resolution. In experiment, it is the basic idea that the surface thermal deformation at different rates in cooling is the clue to find inside defects. Inside defects are detected between 40 and 50℃ and it takes about 2 minutes to inspect a semiconductor. At first, objects with artificial defects are inspected by ESPI and microscopic ultrasonic testing which are compared to get the reliability of ESPI. Also, semiconductors with real defect are inspected by ESPI. The most of defects is classified in delamination between layers, which are estimated to be resulted from the insufficiency of adhesive strength between layers and the problem of heat spread.

2. Technical Description

Holographic interferometry has been a powerful technique in the measurement of surface displacement. A hologram has fringe patterns that represent the relative displacement of an object surface when the object is loaded. However, the process of analysis is very complicated. After that, several speckle interferometry techniques have been developed in which the recording and reconstruction processing is fairly simple (Cloud, 1995). ESPI is one of the methods. Electronic Speckle Pattern Interferometry (ESPI) is a common measurement method for vibration and surface displacement. Recently, the method has been applied for non-destructive inspection of delamination or crack failures in composite materials with reliable and high sensitive results (Richardson, 1998). The ESPI fringe pattern represents both the in-plane and the out-of-plane displacement. In this study, the interferometer sensitive to the out-of-plane displacement is used as shown in Fig. 1. In this figure, ϕ is initial phase before deformation. After deformation, $\Delta\phi$ is the phase induced by the change of object beam, which is related to surface displacement. The surface displacement of an object is measured quantitatively by using the 4-step phase shifting and unwrapping method (Malacara, 1998). In non-destructive testing, it is the basic idea that the surface deformation at different rates in any loading is the clue to find inside of surface defects. The defects are estimated quantitatively from the measured surface displacement. The line profile of surface displacement nearby defect has the critical changing point of slope and the length between critical changing points is considered as the defect size. In the case, the thickness effect can be neglected, because the thickness of package in Ball Grid Array type is with thinner than

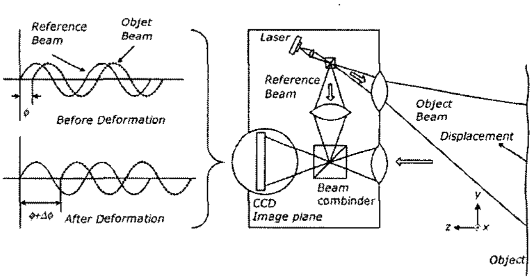


Fig. 1 Interferometer for out-of-plane displacement sensitive ESPI

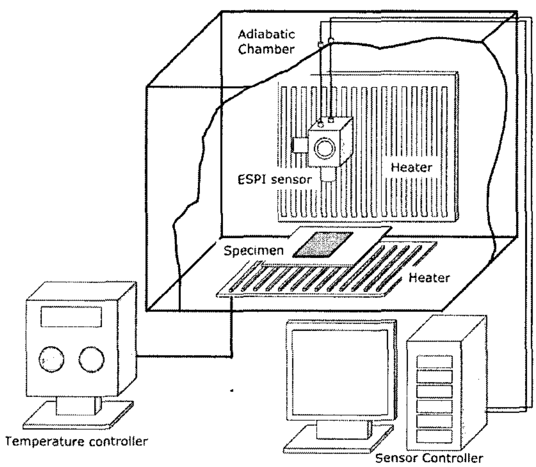


Fig. 2 Semiconductor package inspection system

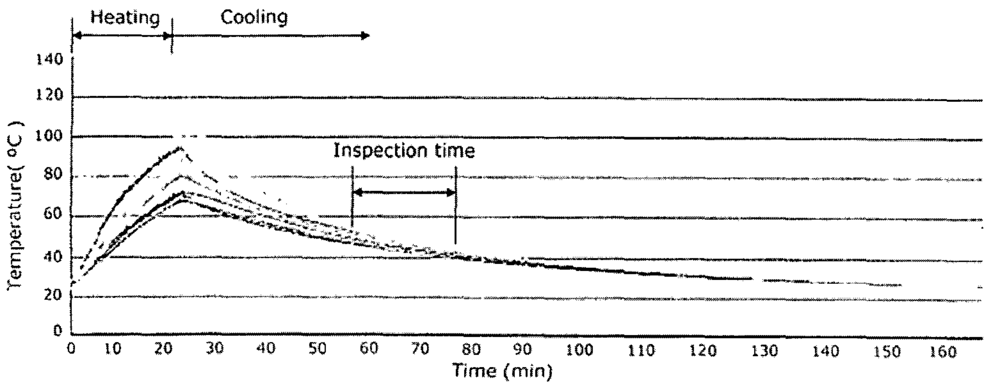


Fig. 3 Temperature distributions inside of chamber

0.3 mm. The experimental setup consists of ESPI system, adiabatic chamber, heating system and temperature control system. The configuration of inspection system is shown by Fig. 2. Two states before and after deformation induced by thermal loading are recorded and subtracted by image processor of ESPI system. Therefore, the temperature control system is important role in the control of thermal deformation of object. Since the package is thin within 0.3 mm, heating direction has influence on the results, adiabatic chamber supports surround temperature which is falling very slow with about 0.1℃. To take the temperature distributions, 36 channels of K-type thermocouple are equipped inside of chamber and the temperature is measured with real-time by the system. Two states before and after deformation in the condition of stable air current and temperature are recorded on. Fig. 3 shows the temperature distribution inside of chamber. Temperature rises to 100℃ by heating system and falls down to room temperature. In testing, defects are detected very well at the temperature from 50 to 40℃, maybe, which is related to material property of package.

3. Results and Discussions

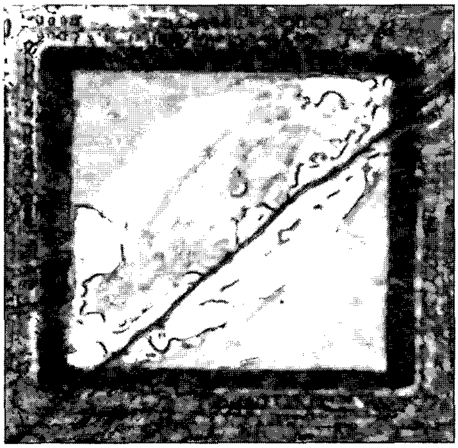
Two kinds of semiconductor, PBGA (Plastic Ball Grid Array) and SBGA (Super Ball Grid Array) are prepared. Two types of specimen with artificial defects and with unknown defects in service are tested.

3.1 Comparison with scanning ultrasonic microscope

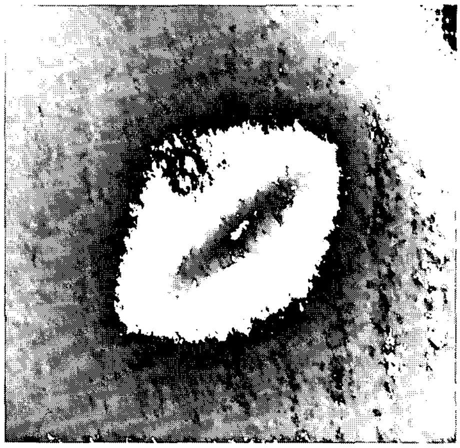
Although ESPI is successful technique in non-destructive testing filed, it is needed to confirm the reliability for application to inspection of semiconductor due to the first try. Artificial defect is introduced inside of semiconductor by impact testing machine and the defect is detected by the proposed inspection system which is compared with ultrasonic testing method. Inside temperature of chamber is supported at 50℃ and falls down slowly by temperature control system. Fig. 4 shows the results of scanning ultrasonic microscope and ESPI. The defect is a crack with a diagonal line and delamination is observed around crack in Fig. 4(a). The delamination defect colored with ( ) and crack size can be estimated from Fig. 4(b), (c) and (d) The quantitative result (24.5 mm) of scanning ultrasonic microscope which is estimated by interpolation is compared with that (23.6 mm) of ESPI which is directly obtained by speckle fringe pattern analysis. However, it is that the important difference between two methods is time-consuming. In ESPI, it takes about 2 minutes to get high-resolution image, on the contrary, in scanning ultrasonic microscope, it takes more than 10 times.

3.2 Inspection of real defects

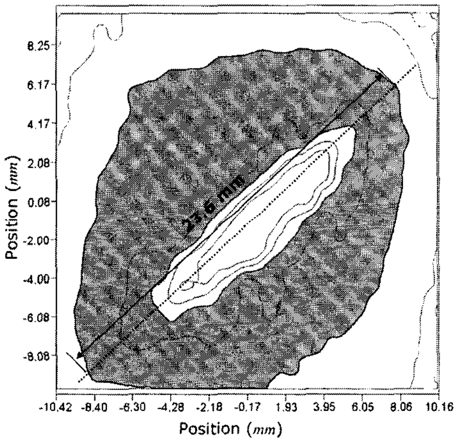
The failure samples in service which are offered from semiconductor manufacture are inspected. The difference of thermal expansion coefficient



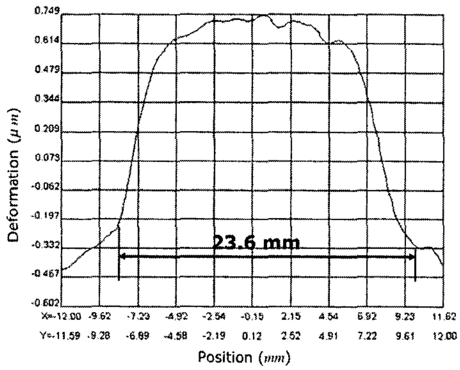
(a) C-scan result



(b) ESPI Phase map



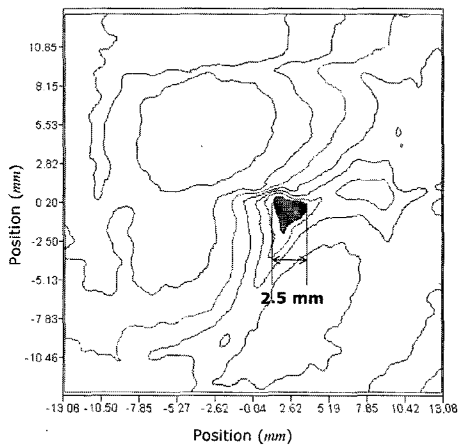
(c) Contour line of surface displacement from ESPI



(d) Quantitative evaluation from line profile of (c)

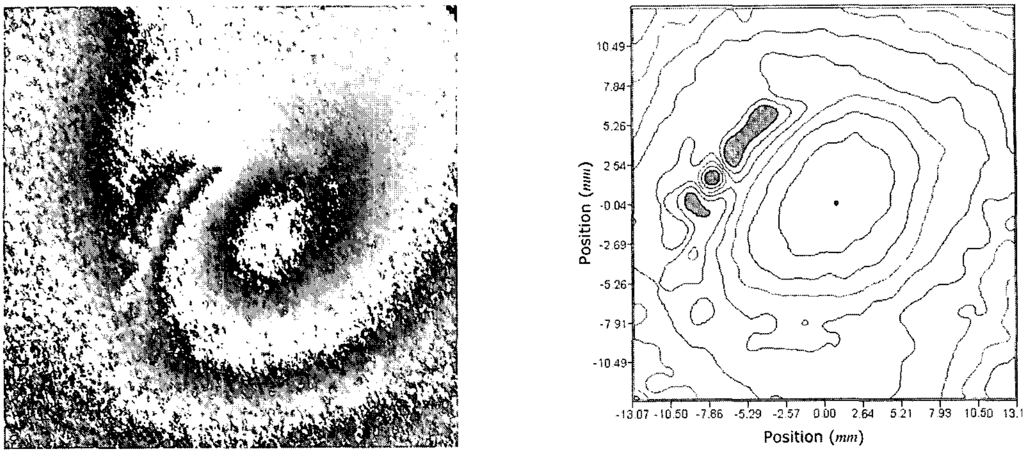
Fig. 4 Comparison of ESPI and scanning ultrasonic microscope

(a) ESPI Phase map of inside impact-damaged defect



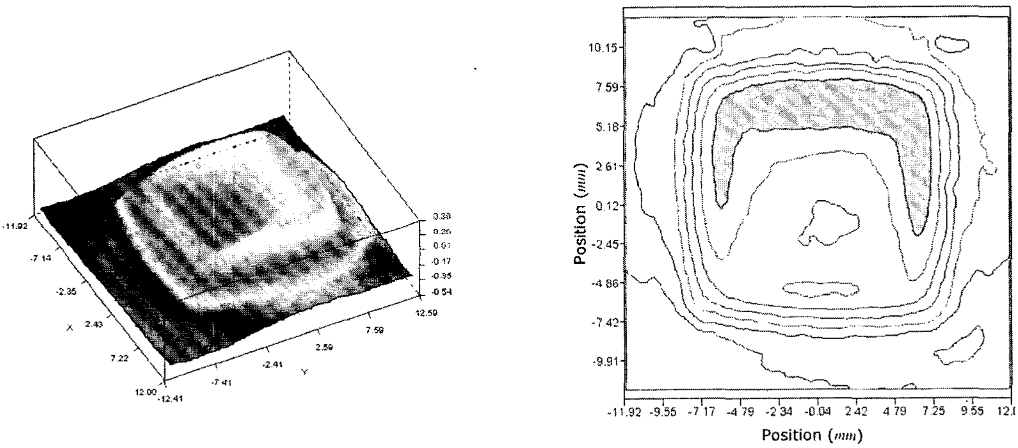
(b) Quantitative evaluation of inside defect from contour line

Fig. 5 Inspection of impact-damaged defect ( )

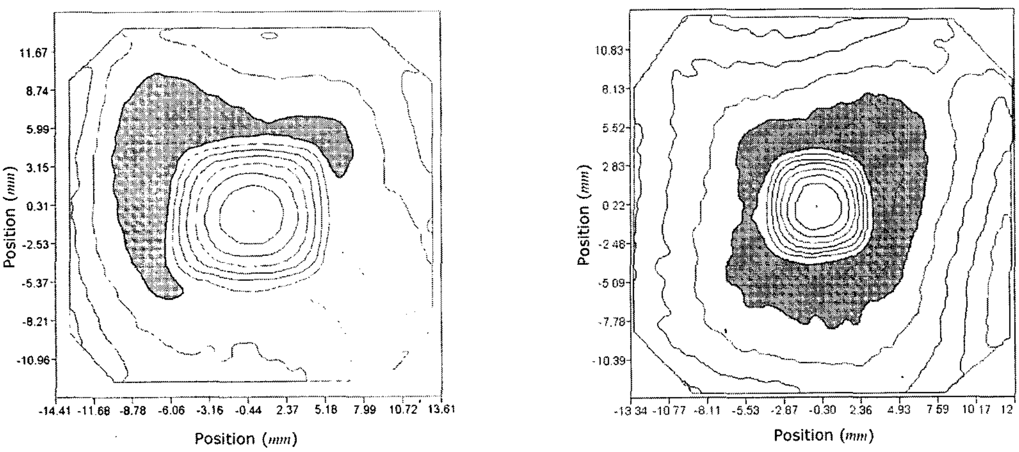


(a) ESPI phase map (b) Contour line of surface displacement

Fig. 6 Inspection of void defect ( )



(a) Starting from the edge of package



(b) Starting from the center of package

Fig. 7 Inspection of delamination defect ( )

between component materials in heating and cooling processing causes thermal stress that gives defects. Fig. 5 and 6 show inspection results of damage that occurs as a result of operator's failure which is within 10% of total life time. Fig. 5 shows inspection results of impact-damaged specimen, ESPI phase map (a), and contour line (b) of out-of-plane displacement. Small void defect, estimated as 2.5 mm, is in the center of sample. Fig. 6 shows void defect inside of package, which is inferred to thermal shock of silicon chip by overvoltage. In this case, it is supposed that the inside of semiconductor is burn in local and adhesive is melted between layers contact to silicon chip. Fig. 7 shows inspection results of damage that occurs between 10 and 60% of life time as a result of misuse, abuse or the other external causes. The 90% of tested samples in the period have delamination defects between layers on silicon chip which is estimated to cause for the insufficiency of adhesive strength by cyclic thermal loading above the growth of defect in manufacturing process.

4. Summary

This paper proposes non-destructive ESPI technique to evaluate inside defects of semiconductor package quantitatively. Inspection system consists of ESPI system, thermal loading system and adiabatic chamber. Inside defects of package are inspected and estimated quantitatively from the measured surface displacement. The line profile of surface displacement nearby defect has the critical changing point of slope and the length between critical changing points is considered as the defect size. In experiment, artificial defect is inspected by the proposed system, which is compared with scanning ultrasonic microscope technique quantitatively. In ESPI, it takes about 2 minutes to get high-resolution image, on the contrary, in scanning ultrasonic microscope, it takes more than 10 times. And also, semiconductors failed in service are inspected. Most of defects are classified in delamination, from which it is inferred to the insufficiency of adhesive strength between layers and nonhomogeneous heat spread. The technique has high feasibility in non-destructive testing of semiconductor and gives solutions to the problem of existing technique, time-consuming and the difficulty of quantitative evaluation. However, the proposed technique has left the limitation that classification and evaluation of inside defects are dependence on high-skilled inspector.

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