Effect of Bump Height on the Strain Variation During the Thermal Cycling Test of ACA Flip-Chip Joints

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***Abstract*—Flip-chip joining using anisotropically conductive adhesive (ACA) has become a very attractive technique for electronics packaging. Many factors can influence the reliability of the ACA flip-chip joint. Bump height, is one of these factors. In this work, the strain development during the thermal cycling test of flip-chip joining with different bump heights was studied. The effect of bump height is significant in the interface between the bumps and the pads. Bigger volume area of high strain is found for higher bump in the interface between the bumps and the pads. Our calculations show that there is practically no effect of the bump height on the strain variation in the bumps and in the pads.**

***Index Terms*—Anisotropically conductive adhesive, finite element, strains, stresses.**

I. Introduction

FLIP-CHIP joining using anisotropically conductive adhesive has attracted much interest for reasons of ultra-fine and low-cost capability [1]–[5]. One important issue whether this interconnection technology is suitable to be used in a volume production depends on the reliability of joints. Many factors can affect reliability such as the joint strength and the external environment. Sufficient bonding pressure and suitable design of the ACA assembly configurations will improve the mechanical contact between the bonded elements [3]. Efforts to reduce the external degradative effect on ACA joints include the selection of bonding materials based on their thermal, mechanical and electrical properties, for example using materials with small differences in coefficient of thermal expansion (CTE) [4], [5]. For ACA joining, the bumps and pads are made of hard materials such as Ni or Cu. The bumps and the pads are very strong mechanically that they can not easily be deformed by the external stresses found in their service environments. The interface between the bump and pad will play an important role in determining the juncture of the ACA joint and the joint strength. Therefore it is possible that the volume of adhesive in the joint will be one of the effects to influence the interconnection reliability. To study the effect of the adhesive volume in the structure indirectly Lai *et al.* [1] have investigated the effect of bump height. Their experiments indicated that for joints with rigid substrate an excessively high bump could induce poor reliability. This work studied whether the reason for the poor reliability of ACA flip-chip joints on FR4 rigid substrate is due to the effect of bump height on strain variation during the thermal cycling test.

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II. Sample Description

The finite element (FEM) analysis is based on the test chip shown in Fig. 1. The dimension of the chips was 7.5 × 7.5 mm, the bump size was 100 μm in diameter and the pitch was 450 μm. four different values of bump height are used, which are: 4 μm, 20 μm, 40 μm and 70 μm. The chip configuration is shown in Fig. 1.

The FE procedure is evaluated in two-dimensional plane strain idealization. The FE structure is given in Fig. 2 by assuming the thickness of the ACA layers between the bumps and the substrate pads is 3 μm. The FE is performed for half of the structure due to the symmetry in the geometry. The simulations are performed for a thermal load of a cyclic temperature change between -40 °C and 125 °C with 15 min hold time and 1.5 min ramp time.

The material properties are for all the materials except ACA film is given in Table I. The mechanical properties of ACA film is based on the measurements performed described in [6] (Detailed experimental results will be published). They have studied the mechanical properties of ACA films for different relative humidity values and for different temperatures. Note that the CTE of ACA film used in the simulation is $50 < \text{CTE} < 80$ (ppm). The typical curve of load $F(N)$ vs. deformation ΔL (mm) (at 60 °C, 0.02/min · strain rate, for three different relative humidity (RH) values) is shown in Fig. 3(a). The stress-strain curve at room condition for different temperatures is given in Fig. 3(b).

Fig. 3(a) shows the influence of the relative humidity on the mechanical properties of ACF tested with same strain rate and

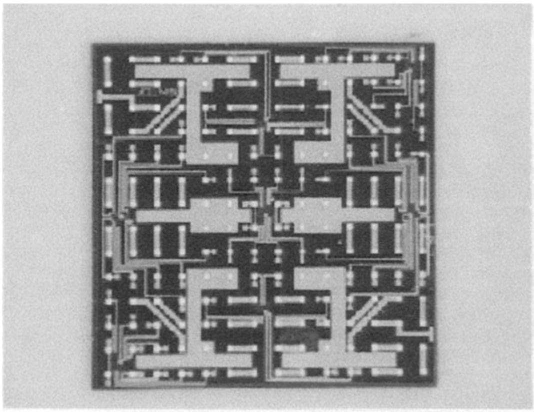

Fig. 1. Test chip.

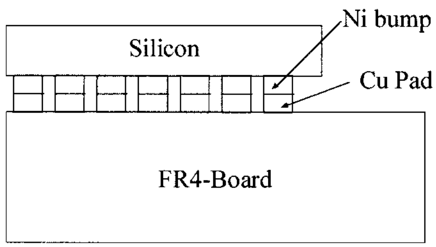

Fig. 2. Schematic picture of flip chip package used in stress analysis.

TABLE I
MATERIAL PROPERTIES AT ROOM TEMPERATURE

Material	Young's Modulus (GPa)	CTE ppm/°C	Poisson's ratio
Silicon	131	2.8	0.28
Ni	199.5	14	0.3
Cu	129.5	17	0.3
FR4 in plane	20	18	0.15
Out of plane	3	40	0.15

same temperature 60 °C. It shows that the mechanical strength increases as RH decreases. Shown in Fig. 3(b) the Young's Modulus decreases as the temperature increases.

III. NUMERICAL RESULTS

Fig. 4 shows the Von Mises stress distribution for the flip chip structure when the temperature load is at $T = -40\,°\mathrm{C}$. The maximum value of the Von Mises stress is located at the outmost joints (shown by MX in the picture). The same results are also obtained for the same structure when the temperature load is at $T = 125\,°\mathrm{C}$ that the maximum value of the Von Misses stress is found at the outmost joint.

Fig. 5 shows the strain fields at the outmost joint when $T = 125\,°\mathrm{C}$ distribution for case of 20 μm. bump height. The top figure is the strain ε_{xx}, the middle figure is the strain ε_{yy} and

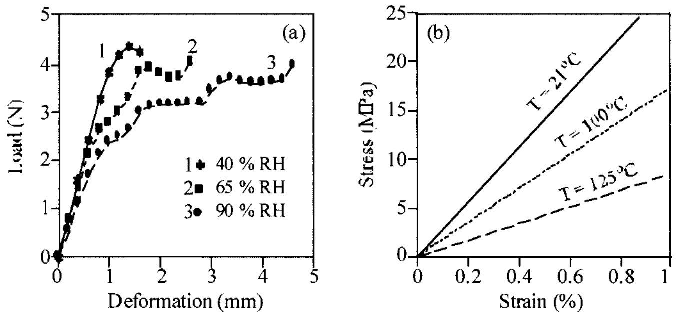

Fig. 3. (a) Load versus deformation curves at 60 °C, 0.02/min.strain rate, for three different relative humidity values. (b) The stress-strain curve at room condition for three different temperatures.

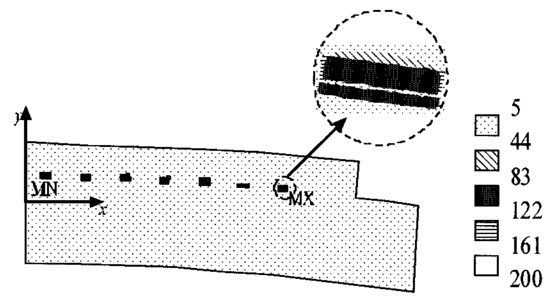

Fig. 4. Von Mises stress distribution for the flip chip package at $T = -40\,°\mathrm{C}$. The stress unit is MPa.

the bottom figure is the shear strain ε_{xy}. The contours are chosen between -0.02 to 0.02 for the pattern boxes given in the figure and the strain is more than 0.02 if the color is black. We use the same contours for all the strain figures. Figs. 6 and 7 show the same figure as Fig. 5 but for case of 4 μm bump height and 40 μm, respectively.

The main features of the simulations are as follows.

1) The strain distribution in the joint is not symmetric and the maximum strain ε_{xx} is located in the adhesive layer. The value of the strain for the outmost joints at A is higher than the strain located at B (A and B are shown in Fig. 5).
2) Strain ε_{xx} in the bumps and in the pads are in the same order of magnitude, the strain (xx is between -0.004 and 0.004 in these area.
3) Shear strain ε_{xy} is very high (more than 0.02) in the adhesive area and in the PCB substrate and is very small (less than 0.001) in the pad and in the bump. Figs. 6 and 7 show the same figure as Fig. 5 but for case of 4 μm bump height and 40 μm respectively. The effect of bump height can be seen in the strain changes in the interface between the bumps and the pads. The volume fraction covered by high strain value (shown by black contours) is more for higher bump. The effect is significant for the stress and the strain distributions in the y and in the shear directions. The effect of the bump height could not be found in the bumps and in the pads.
4) All the figures show that the maximum strains are located at the interfaces in the adhesive area or in the PCB substrate. This large strain is due to the CTE mismatch of the Silicon die and the composite substrate. The deformation of the bump is negligible.

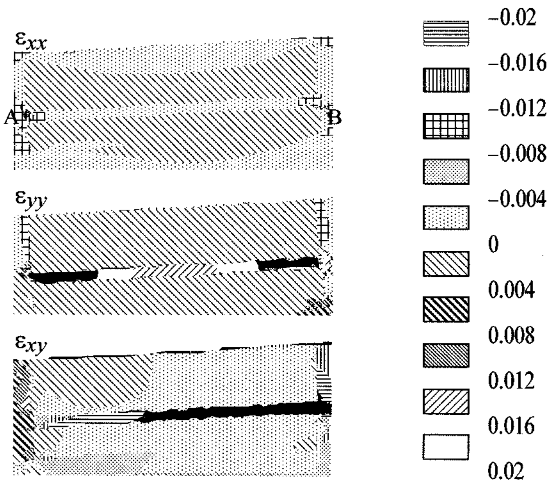

Fig. 5. Strain distribution at the outmost bump for case of 20 μm bump height. Top: strain ε_{xx}. Middle: strain ε_{yy}. Bottom: shear strain ε_{xy}.

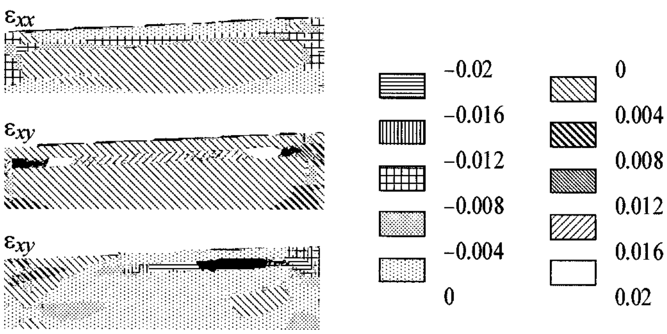

Fig. 6. Strain distribution for case of 4 μm bump height. Top: strain ε_{xx}, Middle: strain ε_{yy}. Bottom: shear strain ε_{xy}.

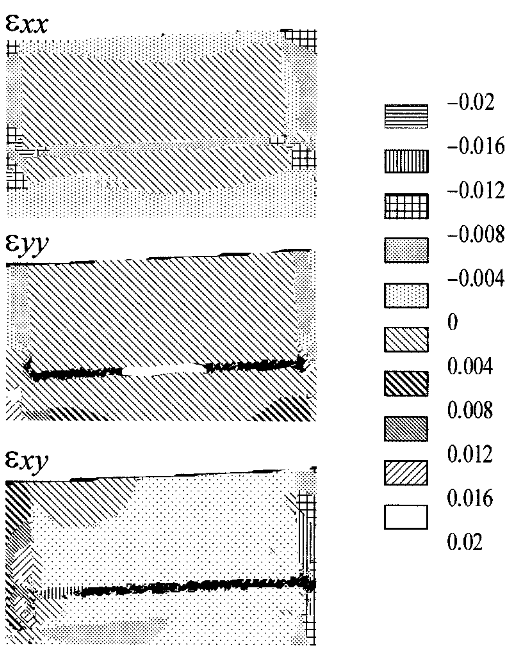

Fig. 7. Same as Fig. 5 but for the case of 40 μm bump height.

IV. Thermal Strain Measurement of ACA Joint

A MicroDAC—a deformation measurement method based on correlation algorithms—was applied to local deformation measurements on the IC structures. In-plane surface strain fields of components under thermo-mechanical load are determined from optical and electron optical micrographs. Speckle photographic basics are used to extend in-plane deformation measurement. The high resolution of scanning electron microscopes allows measuring local strain fields inside such small structures of characteristic size of 50 μm and less. A correlation-based image-processing algorithm is then applied to determine a set of local pattern displacements between two object states, and finally whole displacement fields are measured. The software is able to track local structures with a subpixel accuracy of approximately 10 nm.

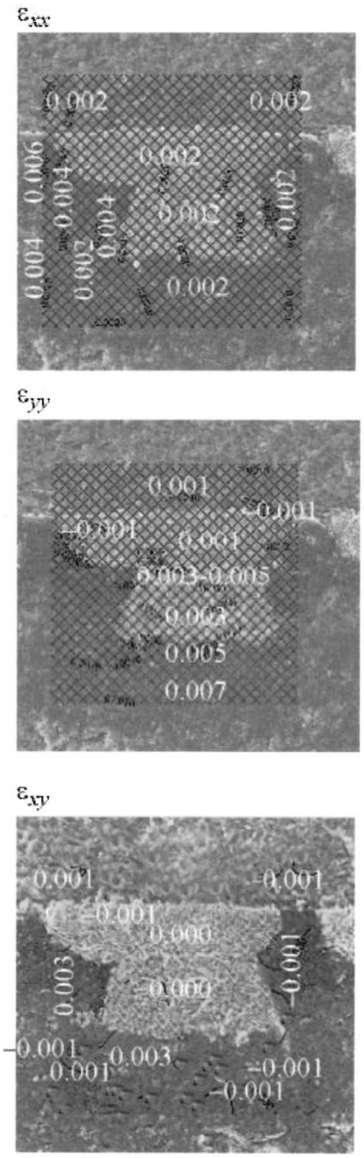

Fig. 8. Thermal strain measured by MicroDac.

Fig. 8 shows the strain fields measured by MicroDAC for one ACA joint heated from room temperature to 116 °C. The strain fields is for the second bump from right side (note that the measurement is performed for different test chip other than test chip shown in Fig. 1). The general situation for this joint is that there is no essential shear in the field of measurement and strain ε_{xx} and ε_{yy} increase toward the polymer substrate.

In addition, a relatively high strain ε_{xx} is localized in the interface between bump and the pad. The measurements indicate that: global thermal mismatch between board and silicon is not transferred in a high shear at the outermost bump interconnects.

V. Discussion and Conclusions

Our calculations and the experiments show that the strain is highest for the outmost joint. The experiments indicate that the dominant strain is in the normal direction. Our measurements give relative high strain (0.003) in the x direction in the pads region, which is not found in the calculations. Strain ε_{xx} is localized in the interface between the bumps and the pads. Relatively low value shear strain (<0.001) is measured in the outmost joints. The effect of bump height is significant only in the interface between the bumps and the pads. Bigger volume area of high strain is found for higher bump. There is practically no effect of the bump height on the strain changes in the bumps and in the pads. The effect of bump height is different for ACA joints than for solder joints. For solder joints increasing the bump height (stand-off) will increase the fatigue life of joints because a high bump can relax the shear stresses in the corner regions of the solder [7]. However, this is not the case for ACA flip-chip joints. We have shown here that the effect of the bump height in ACA joints will only be limited to the interface area between the bump and the pad. Therefore bump height is not a controlling factor for the ACA joints reliability. However Lai *et al.* [1] showed that for ACA joints with rigid substrates, an excessively high bump (bump height of 70 μm) could induce poor reliability. The reliability problems of having high bump can occur since excessively high bump can easily cause a porous structure in the ACA layers [1]. Both measurement and simulation indicate that the strain is highest for the outmost joint and the normal strain ε_{xx} and ε_{yy} are in the same order of magnitude. Compare to the experiments our calculations show high shear strain in the bump and in the pad. The reason for uncoincident may come from both measurement accuracy and ACA parameters used in our calculations. Further work is necessary to include some features that are not included at present such as: 1) Effect of particle size and particle distributions on the strains and stresses variation and 2) effect of the planarity of the substrate, bumps, and pads.

Acknowledgment

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