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Numerical analysis of thermo-mechanical characteristics of solder joint depending on change in solder junction structure of MCP

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ABSTRACT

This study suggests an improved junction structure of solder joints that enable an increased junction area and enhance the reliability of solder joints. A finite element analysis was carried out to compare the thermo-mechanical characteristics of the solder joints before and after the improvement. In the suggested junction structure, holes were created in the existing Cu pillar bump to increase its junction area, compared to that of the existing junction structure, and to raise the solder quantity of the joint. Drawing from the analysis results of the thermo-mechanical characteristics on the existing junction structure and the newly suggested junction structure, it was confirmed that shear stress was reduced in the solder joint with the suggested junction structure, as it was lower by around 5–20 MPa in the suggested junction structure. It was also found that the final value of the equivalent stress during a thermal cycle was lower by around 30 MPa in the suggested junction structure. Moreover, in terms of its equivalent strain value, the suggested junction structure had a slightly higher value of elastic equivalent strain although it carried a lower value of plastic equivalent strain in the high-temperature range. Therefore, it is considered that the suggested junction structure will be advantageous in terms of its long-term reliability of thermo-mechanical characteristics.

1. Introduction

Owing to the development of 3D packaging technology such as multi-chip package (MCP), semiconductor package has become light, thin, short and small with high density and fine pitch [1–8]. In the existing junction structure of such solder joint, it is true that the ratio of solder's volume is reduced to decrease the size of an entire package and intermetallic compounds of joint [9] in case of die stacking, which results into a decline of reliability of solder joint. In particular, since a fine pitch size causes solder bridging, an existing junction structure has limitation in decreasing its package size. Recently Ki et al. [10] has reported an ultra fine pitch Cu pillar bump with a solder cap bump on Cu pillar bump. This study indicates that a junction structure with an ultra fine pitch Cu pillar bump below 40 μm diameter for TSV (through Silicon via) and Chip-on-Chip (CoC) can solve the problems of a solder bridging phenomena and a low mechanical strength caused by low standoff height.

Therefore, this study intends to suggest an improved junction structure, which was altered to secure a more reliable joint. In the suggested junction structure, holes were created in the existing Cu pillar pump to increase its junction area, compared to that of the existing junction structure, and to raise the solder quantity of the joint. The expected advantages of such suggested junction structure include: first, shear stress can be reduced due to an increase in its junction area. Second, a solder part with an increased ductility, caused by an increment of solder quantity, is expected to arrest a propagation of initial crack, in which occurs an intermetallic compound layer of joint interface. Therefore, this study intends to clearly investigate the thermo-mechanical characteristics of a solder joint in the improved junction structure through heat conduction and a thermal elasto–plastic finite element analysis, in order to examine the applicability of the improved junction structure. Moreover, this study compares the results with the characteristics of a solder joint in the existing junction structure.

2. Finite element model and analysis conditions

In this study, heat conduction and a thermal elastic plastic finite element analysis using commercial software ANSYS were carried out for two types of junction structures such as the existing

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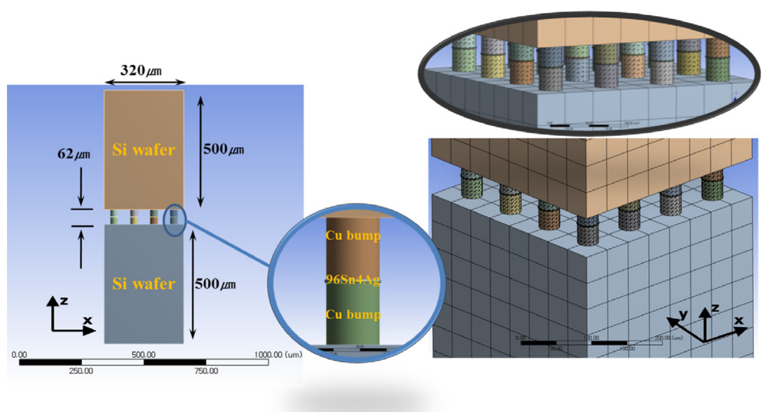
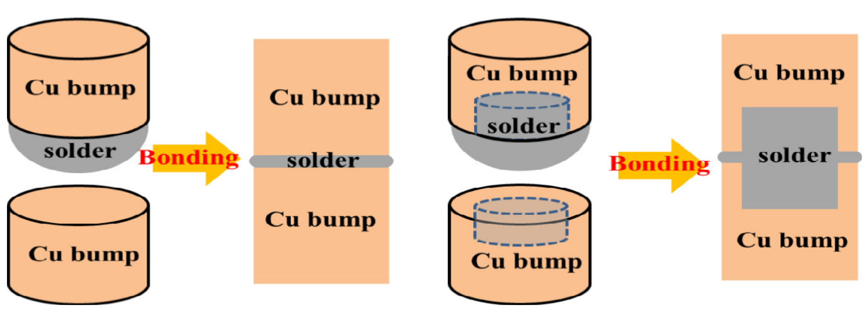
junction structure, in which holes were not created in the Cu pillar bump, and the suggested junction structure with holes that were created in the Cu pillar bump, in order to compare and evaluate the thermo-mechanical characteristics (shear stress, equivalent stress and equivalent strain) of a joint. Fig. 1 shows the configuration of a FE analysis model for the existing and suggested junction structures; (a) is a dimension and a FE mesh division of the analysis model, (b) is the shape of a solder joint and (c) is the shape of a pillar bump, respectively. Fig. 2 shows an arrangement of solder and bump on wafer. As shown in the detailed analysis model of Fig. 1, 16 pillar bumps with a diameter of 30 μm and the height of 30 μm were placed at the interval of 50 μm pitch on silicon wafer with the thickness of 500 μm. The bumps were joined together by a 96Sn–4Ag solder that had the thickness of 2 μm. For a finite element analysis, the model was meshed to 96,978 nodal points and 45,548 elements in total. Particularly, the joint interface between the Cu pillar bump and the solder, where a relatively high thermal stress was expected, was meshed more finely.

The heat input conditions as shown in Fig. 3 include temperature range of −40 to 125 °C, ramped time of 15 °C/min and dwell time of 15 min based on the JEDEC A104D [11]. Under these conditions, the analysis was made for one cycle while the room temperature was set at 22 °C. In addition, an acceleration of gravity (−9.8066 m/s^2) in the height direction (z direction) was taken into consideration for each analysis step in order to realize the effects of its own package weight. The inner diameter of the Cu pillar bump with holes was determined considering the condition obtained from the preliminary analysis. This condition demonstrates that a plastic deformation did not occur when a stress of 3 MPa or less was applied to the junction surface at a room temperature.

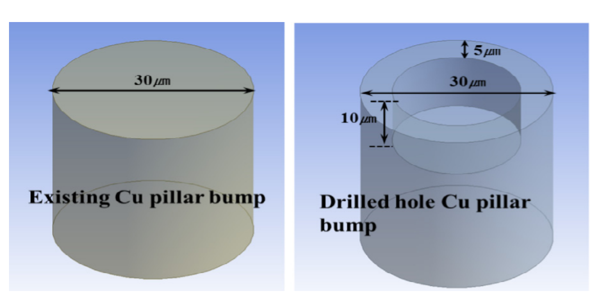
Recent studies reported on the evaluation of the thermal–mechanical characteristics of a solder joint and TSV structure by finite element analysis. In such cases, the material properties of underfill were not considered according to the temperature or they were taken into consideration at a room temperature. However, it is possible to assume that the material properties of underfill



(a) Dimension and FE mesh division of analysis model(left: dimension, right: FE meshed model)



(b) Shape of solder joint(left: existing junction structure, right: suggested junction structure)



(c) Shape of pillar bumps(left: existing junction structure, right: suggested junction structure)

Fig. 1. Configuration of FE analysis model for numerical simulation.