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Development of numerical algorithm to guide solder joint structure and component structural design during manufacturing

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ABSTRACT

In order to improve the production technology of the lead-free BGA (Ball Grid Array) assembly, a numerical method is developed to predict the yield of the soldering process based on calculated stand-off stiffness curves and component warpage. The stand-off stiffness curve which reflects the relationship of the force and height of solder joints is obtained by solving the differential equations of the solder joint shapes of BGA solder joints using the Runge-Kutta method. The analytical expression of thermal warpage of component in free boundary constraint conditions is proposed based on the lamination theory of the elastic mechanics. The expression can reflect the material parameter variation with temperature and provide an effective calculation method to analyze component warpage with large changing temperature during soldering reflow process. Considering the manufacture deviation of volumes and the randomness of the positions of the solder joints, combined with the stand-off stiffness curves and the component warping deformation, the yield of the soldering process can be predicted. According to the types and positions of the failure solder joints, the production technology can be improved. Based on the stand-off curves of solder joints, the influence of the deviation rate of volume of the solder joint and diameter of pad on the yield of self-assembly are simulated. The optimal matching relations of the solder joint volume and the diameter of the pad with the 0.35 mm pitch and 0.3 mm pitch are analyzed.

Contents

1. Introduction

With the higher density of integration on ICs (Integrated Circuit), the impact on device reliability is of great concern [1–3]. The yield of the solder self-assembly during the reflow process is associated with the size

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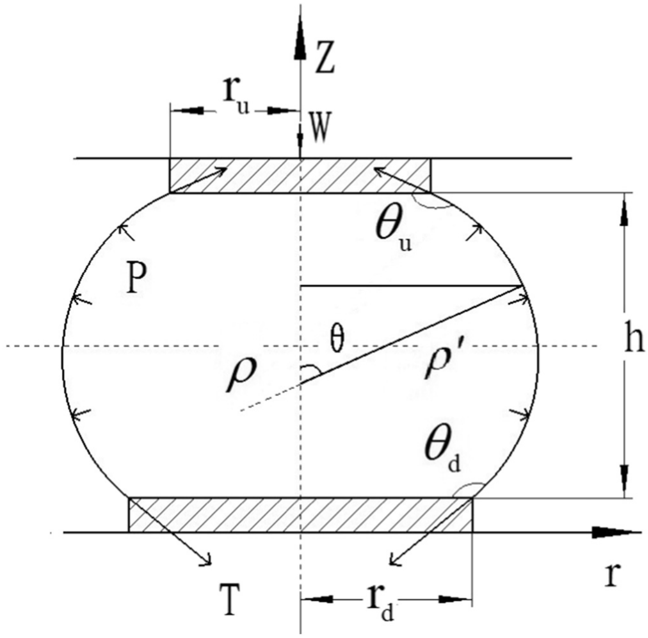

Fig. 1. The model of the liquid bridge.

of the solder ball, the pitch of solder balls and the component warping deformation [4]. The main failures of the solder self-assembly can be summarized to: bridging, open and head-in-pillow. However, head-in-pillow is mainly affected by the unreasonable temperature curve of reflow. Therefore, bridging and open are the main failures influence the yield of the self-assembly.

In microelectronic assemblies, for a specified solder material, soldering reliability has been found to be highly dependent on the solder joint shape [5,6]. The solder joint shape is characterized by the stand-off height, lower/upper contact angles of the joint, solder pad diameter and pad shape [7]. The problem of the interfacial-profile equation between two circular wettable boards was widely studied by Finn [8,9]. Brakke [10] proposed the software named Surface Evolver uses the gradient descent method to minimize the free energy of the system, which can also be applied to a wide range of problems. However, Surface Evolver has some shortcomings, such as the fact that surfaces are allowed to intersect with each other and convergence to a minimum energy level can be difficult to determine [11].

Therefore, for most studies about the yield of the solder self-assembly based on solder shape modeling, only one or two solder joints were studied [12]. The manufacture deviation of solder balls and the component warpage are inevitable. Only one or two solder joints cannot represent the yield of the solder self-assembly. According to the solving of the solder shapes, for a solder ball with specific volume, the relationship of the stand-off height and the capillary force can be obtained. It is important in the self-assembly process.

Generally, a package structure is composed of several layers. Because these layers have considerably different CTEs (coefficient of thermal expansion), different elongations with the temperature change of each layer will lead to component warpage [13,14]. The thermal warpage not only influences the welding yield but also has greatly influences the fatigue life of solder joints [15]. The shadow moiré and projection moiré techniques are widely used methods for measuring PWB (printed wire board) warpage [16]. However, theoretical analysis method of warpage is not so much. Wei Tan [17] discussed the warpage of PCB (Printed Circuit Board) using the classical laminated plate theory. However, considering the material symmetry of PCB, only PCB cannot warp with temperature. The warpage of PCB is caused by the component and solder ball.

Because of unavoidable deviations in the manufacture of the volume of solder joints, the profiles of the formed joints are different. If a large solder joint located on a position with a small warpage deformation, it may be easily bridging with the nearby solder joint. If a small solder joint located on a position with a large warpage deformation, it will be easily open. Considering the randomness of the volumes and the positions of the solder joints, normal distribution model of solder bump volume is used. According to the volume and the position of a specific bump corresponding to the stand-off stiffness curve with the same volume, the total force of all the bumps can be obtained. When the total force is equal to the gravity of the component, the equilibrium position of the self-assembly is obtained. Thus, the solder height of each bump can be easily got. If the solder height is out of range of its stand-off stiffness curve, it can be regarded as a failure bump.

In this work, the stand-off stiffness curves with different stand-off heights and different stand-off volumes are obtained by solving the differential equations of the solder joint shapes of BGA solder joints. The component warpage in the reflow process is analyzed based on the lamination theory of the elastic mechanics. The solder joint volume distribution is a normal distribution assigned by random numbers. The types and the positions of the failure solder joints are found and the corresponding improving methods are proposed.

2. Analysis of BGA solder joint shape and the stand-off stiffness

2.1. Prediction of the BGA solder joint shape

It is widely accepted that the Young-Laplace Equation can express the shape of a static liquid without container [18,19]. The equation can meet the minimization of liquid surface tension and liquid surface area. Fig. 1 shows a liquid bridge and some necessary parameters. Solid material at the shadow part is the wettable material, while the others are not wettable materials.

The following geometric parameters describing the liquid bridge are shown in Fig. 1:

h: stand-off height
r_d: radius of contact pad on substrate
r_u: radius of contact pad on component
θ_d, θ_u: contact angle on substrate side and component side
W: the weight of components or the force applied on upper solder pads
p: internal pressure
T: surface tension coefficient

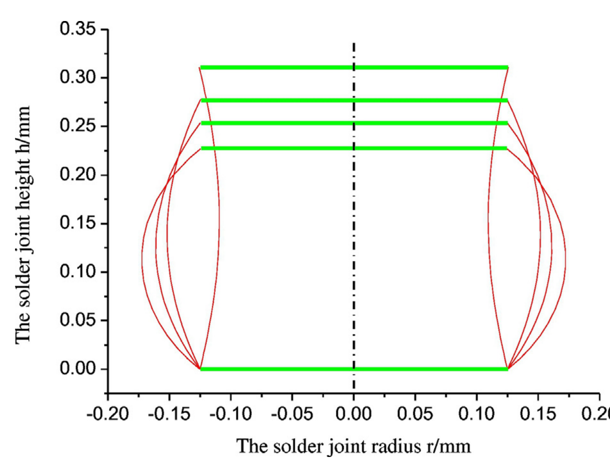

Fig. 2. The simulated bump shapes with different solder joint heights. (For interpretation of the references to color in this figure, the reader is referred to the online version of this article.)