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MODELING OF SOLDER JOINT DEFECTS THROUGH A LEVEL-SET APPROACH

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Abstract. Due to the inherent nature of flip-chip assembly, the solder joints lie beneath the device and therefore are not amenable to visual inspection. Hence, it is important at the design stage to ensure that solder defects such as joint separation or joint shortening do not occur in the assembly. As a first step, the solder joint is modeled using a level-set approach. Unlike conventional front-tracking approaches, the levelset method handles complicated profiles arising from merger/separation of solder joints naturally without user intervention. The model was established to determine the upper and lower limit on optimal solder volume as a function of a specific assembly configuration and is used to avoid such defects.

Key Words. levelset, solder-joint, flip-chip.

1. Introduction

Flip-chip/BGA assembly is gaining increasing importance in electronic packaging due to the area array nature of assembly, providing an option for high I/O assembly, a smaller foot print to accommodate a larger number of I/O in a smaller area, and gang-bonding to achieve multiple assembly simultaneously. However, these advantages come with a price. Due to the inherent nature of the flip-chip assembly, the solder joints lying beneath the device are not amenable to visual inspection and subsequent repair because of the obvious difficulty in visual inspection in establishing a defect free assembly. Some of the inspection approach is used for flip-chip application are: backside thinning coupled with metallization illumination [1], characterization through acoustic microscopy [10, 19], and the use of x-ray [23]. Even with these techniques, it is often very difficult to determine some of the solder defects such as necking/separation of a joint. As a result, assembly with a joint defect can be known only after the fact with hardly any option to rectify it. Therefore, it is important at the design stage to ensure that such defect do not occur in the assembly. The typical sources of solder defect in flip-chip/BGA assembly can be broadly placed in two categories (1) not enough solder at a specific site - resulting in lack of joint formation and (2) too much solder at a site - resulting in shortening of neighboring joints. The effect of solder volume is magnified by other process variables such as placement accuracy. These defects occur due to various designing and processing constraints. For example, the designer tends to specify the cylindrical/hour-glass shape for solder joint design in order to reduce stress in the joint and improve its fatigue life. This is created by using a spacer to create a

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required gap between the chip and substrate [12]. However, controlling the gap is very difficult. This difficulty is compounded by the board deformation that takes place during reflow [14] and the volume distribution and constraint on placement accuracy [13]. Therefore in such a case, it is important to understand the acceptable limits on the gap as a function of design and manufacturing constraints. Reviewing existing models [7, 8, 18, 17, 11], shows that all of the model are designed to address ideal or successful joint formation. Heinrich et al.[9] presented non-dimensional profiles for avoiding solder defects and Singler and Zhang [20] [modeled the solder bridging problem using SURFACE EVOLVER]. Goldmann[5] developed physical model and heuristic equations to describe separation of a molten axisymmetric solder joint. In Evans and Spruck [3, 4] have rigorously described the generalized evolution(including topological changes) of hypersurfaces moving according to their mean curvature by using the notion of "viscosity solutions" of nonlinear PDE's. All these models including those based on SURFACE EVOLVER are solved using front tracking or similar approach i.e. the interface front is evaluated at each iteration. SURFACE EVOLVER, developed by Ken Brakke, represented a versatile surface profile modeler developed. It is a finite element model based on minimization of total energy. It has the ability to compute solder joint model with complicated pad geometry. However, Surface Evolver can only model only joint separation and not joint merging. Modeling of joint separation requires artificial removal of grid points from the computational domain. Thus, the goal is to develop a computational model that can address both joint separation and joint merging to simulate process defect. In this paper, a unified approach that can model both separation and merging has been proposed. It is based on an alternative approach to front tracking - namely, the Level Set Methods. As mentioned earlier, the goal is to develop the numerical technique to simulate solder joint defect due to merging and separation. Later, the model is applied to a set of specific case studies. No attempt has been made to generate a more general result associated with flip-chip solder joint. This is an issue we will address in the future.

2. Level-Set approach to solder profile modeling

The levelset approach was originally developed by Osher and Sethian [15]. In this method, a level-set function $\boldsymbol{\phi}(\boldsymbol{x},t)$ represents the interface as the set where $\boldsymbol{\phi}(\boldsymbol{x},t)= 0$. As is by now well known, this method eliminates the problem of repositioning the points during the numerical calculation and is capable of capturing geometric properties of highly complicated boundaries including topological changes without explicitly tracking the interfaces. Also, it can easily extend to 3-dimensional problems. The key advantage of level-set approach is that, the surface merges and separates naturally (see Figure 1(b)). The basic idea behind the level-set method is embedding the moving interface to one higher dimensional set - this is the level set. What this means is following. Consider the closed moving interface $\partial\boldsymbol{\Omega}(t)$ in $\mathbb{R}^n$ with co-dimension one. We associate with $\boldsymbol{\Omega}(t)$ to a signed distance function $\boldsymbol{\phi}(\boldsymbol{x},t)$ which is a Lipschitz continuous, satisfying:

$$\begin{aligned} &\boldsymbol{\phi}(\boldsymbol{x},t) = 0 \quad for \quad \boldsymbol{x} \in \partial\boldsymbol{\Omega} \\ &\boldsymbol{\phi}(\boldsymbol{x},t) > 0 \quad for \quad \boldsymbol{x} \in \boldsymbol{\Omega} \\ &\boldsymbol{\phi}(\boldsymbol{x},t) < 0 \quad for \quad \boldsymbol{x} \in \overline{\boldsymbol{\Omega}}^c \end{aligned} \tag{1}$$

where $\boldsymbol{x} \in \mathbb{R}^n$, $t \in \mathbb{R}^+$ (see Figure 2). From the definition of $\boldsymbol{\phi}(\boldsymbol{x},t)$, the zero level set $\{(\boldsymbol{x},t)|\boldsymbol{\phi}(\boldsymbol{x},t) = 0\}$ is the interface of the moving object. This means that moving the interface is equivalent to updating the zero level set of with same