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Crystal Plasticity Finite-Element Analysis of Deformation Behavior in Multiple-Grained Lead-Free Solder Joints

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The elastic and plastic anisotropy of the tin phase in a Pb-free tin-based solder joint has a very important effect on the reliability of solder joints. The crystal plasticity finite-element (CPFE) method takes into account the effect of anisotropy, and it can be used to solve crystal mechanical deformation problems under complicated external and internal boundary conditions imposed by inter- and intragrain micromechanical interactions. In this study, experimental lap-shear test results from the literature are used to calibrate the CPFE model. The spatial neighbor orientation relationships of the crystals were assessed by studying four different sets of orientations using a very simple model to establish a basis for further development of the model. Average shear strain and Schmid factor analyses were applied to study the activity of slip systems. Further optimization of model parameters using comparisons with experiments will be needed to identify more suitable rules for stress evolution among the 10 slip systems in Sn. By suppression of some of the slip systems the CPFE model is able to simulate heterogeneous deformation phenomena that are similar to those observed in experiments. This work establishes a basis for an incremental model development strategy based upon experiments, modeling, and comparative analysis to establish model parameters that could predict the slip processes that lead to damage evolution in lead-free solder joints.

Key words: Lead-free solder, tin, slip systems, anisotropy, crystal plasticity finite element, model

INTRODUCTION

Due to the awareness of the health hazards associated with the toxicity of lead, the use of Pb in consumer products has been greatly reduced. Now, tin-based solders are used for the assembly of electronic systems.

Anisotropy is important in all structural metals, but it is unusually strong in Sn, making Sn-based solder joints one of the best examples of the influence of anisotropy. The fracture probability in lead-based solder alloys is quite different from that in lead-free solder alloys, mostly because of the anisotropy present in the tin phase.[1–3] In lead–tin-based solder alloys, the location in the solder joint that is most prone to failure can be predicted, but the crystal structure of tin in lead-free solder alloys can greatly affect damage initiation and evolution. This is because the coefficient of thermal expansion (CTE) plays an important role in thermomechanical loading of solder joints, leading to significant axial as well as shear strains acting on joints.[4] Residual stresses are generated during the initial cooling, and subsequent thermal cycling can cause dislocation motion. Figure 1 shows the anisotropy in the CTE and Young's modulus.[1–3] The crystal structure of tin has a body-centered tetragonal structure (a squashed

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