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Characterization of Stress–Strain Response of Lead-Free Solder Joints Using a Digital Image Correlation Technique and Finite-Element Modeling

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The stress–strain response of miniaturized Sn-Ag-Cu (SAC) lead-free solder joints in the thickness range of 80 μm to about 1.1 mm was studied. A high-resolution three-dimensional (3D) digital image correlation system was used for *in situ* measurement of displacement and strain fields in the solder joints during tensile testing. These measurements showed that the localization of plastic strain and stress buildup occurs mainly at the interface of the solder. With increasing solder gap thickness the size of the plastically deformed zone in the solder increases, resulting in transformation of a brittle interfacial fracture to a ductile fracture within the bulk of the solder. The experimental deformation plots of solder joints and strain-rate-dependent tensile tests on bulk solder material were used to establish a new constitutive material model for the solder. This strain-rate- and pressure-dependent material model was implemented in ABAQUS through the user subroutine CREEP. In agreement with the experiments, the finite-element method simulation revealed a pronounced thickness effect leading to higher tensile strength of thinner solder joints.

Key words: Lead-free solder joints, constraint effect, plastic deformation, digital image correlation, material modeling, FEM simulation

INTRODUCTION

Solder joints in microelectronics are manufactured in a large variety of geometries and material combinations and count as one of the critical sites concerning the reliability of electronic devices. Due to this high relevance, in recent years numerous studies on the microstructural characteristics and investigation of the physical and thermomechanical properties of lead-free solders have been published. Still, evaluation of the structural integrity and thermomechanical response of lead-free solder joints in actual devices is a challenging task requiring reliable experimental and numerical methods to establish lifetime prediction models.[1,2]

Several studies have shown that there is a relationship between the size, microstructure, and strength of solder joints.[1,3–5] Reducing the gap size results in a strong increase in the yield and tensile strength of solder joints and in a decrease of their ductility.[4,5] In addition to the effect of constraint on the mechanical properties of joints, microstructural features should also be considered. With reducing joint size, a finer microstructure with increased hardness may be expected due to the higher cooling rate. Another influencing factor is the higher ratio of interfacial intermetallic compound (IMC) to the gap size in thinner joints, which may result in brittle interfacial cracking.[1]

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