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Transformation-Induced Plasticity in Sn-In Solder Joints

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The research reported here concerns the contribution of transformation-induced plasticity (TRIP) to the shear deformation of Sn-x wt.%In solders with Cu or Ni metallization, where the In content (x) ranges from 9 wt.% to 15 wt.%. In this concentration range the high-temperature γ-phase (hexagonal structure) transforms to the low-temperature β-phase (β-Sn structure) on cooling, and the transformation can be martensitic. The results show that Sn-9In and Sn-11In solder joints do exhibit TRIP that significantly enhances their ductility when tested at temperatures between the deformation-induced martensite temperature (M_d) and the stress-induced martensite temperature (M_y). For Sn-9In, $M_d \approx 105°C$, and the TRIP effect is optimal near $M_y \approx 80°C$, where the total elongation reaches ~100% when the substrate metallization is Cu. The TRIP elongation is less spectacular with Ni metallization because of weakness at the solder–substrate interface. Sn-11 wt.%In joints also show extensive TRIP effect, with an M_d temperature near 60°C, and an M_y of 35°C or less. The total elongation of 11 wt.% In joints on Cu reaches 350% at 35°C. Sn-15 wt.%In joints with Cu metallization also have excellent ductility at low temperature, with total elongation of ~50% at 35°C. In this case, however, the excellent ductility is due to the fine-grained, two-phase microstructure of the solder rather than any TRIP effect.

Key words: Pb-free solder, TRIP, shear test, superplasticity, solder joint

INTRODUCTION

Reliable solder contacts are critical components of modern microelectronic devices. Since mechanical failure via fracture or thermal fatigue is a common failure mode, the mechanical integrity of solder joints is of particular concern. In recent years concern over the toxicity of lead has forced a shift from the familiar, generally reliable Pb-rich solders to Sn-rich, Pb-free compositions whose mechanical properties are not well known, and are sometimes inferior.[1] There is, therefore, reason to explore metallurgical options in Pb-free solders that may lead to improved mechanical properties.

From this perspective, Sn-rich Sn-In alloys are interesting because they exhibit martensitic phase transformations that may be useful to improve mechanical behavior.[2] According to the equilibrium phase diagram, at ambient temperature Sn-rich Sn-In alloys have the β-Sn structure for 0 at.% to 3 at.% In and a simple hexagonal (γ) structure for 14 at.% to 22 at.% In.[3] Raynor and Lee[4] proposed that these two structures can transform into one another through simple atomic displacements. Koyama et al.[5,6] investigated the phase transformation mechanisms between the simple hexagonal γ structure and β-Sn and found clear evidence of martensitic transformation. They measured the martensite start (M_s) and austenite start (A_s) temperatures as a function of composition. In prior work we confirmed their results for Sn-7 wt.%In and Sn-9 wt.%In alloys by measuring the electrical resistance of bulk wire on heating and cooling.[7]

A martensitic transformation in a solid typically involves a change of shape; that is, it introduces a transformation strain that includes a shear. There are always multiple choices for the principle axes of

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