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Mechanisms of Creep Deformation in Pure Sn Solder Joints

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The work reported here concerns the creep of pure Sn solder joints with Cu metallization (Cu||Sn||Cu). Steady-state creep tests in shear are combined with electron backscatter diffraction (EBSD) analysis of the evolution of the microstructure during creep to clarify the deformation mechanism and the nature of the microstructural evolution. The creep behavior of the joint changes significantly with temperature. At low temperature (65°C), two distinct creep mechanisms are observed. Low-stress creep is apparently dominated by grain boundary sliding, as evidenced by the low stress exponent ($n \approx 4$), low activation energy ($Q \approx 42$ kJ/mole), and significant grain rotation during creep. High-stress creep is dominated by bulk deformation processes, evidenced by a high stress exponent ($n \approx 9$), an activation energy like that for bulk diffusion ($Q \approx 70$ kJ/mole), and a relatively fixed microstructure. At high temperature all aspects of its behavior are consistent with deformation by bulk creep mechanisms; the stress exponent and activation energy are high ($n \approx 5$ to 7, $Q \approx 96$ kJ/mole), and despite significant grain coarsening, the microstructure retains (and strengthens) a fixed [001] texture. The results suggest that a "segmented" constitutive equation of Dorn type is most suitable for the low-temperature behavior, while a "hyperbolic" constitutive equation may be preferable at high temperature.

Key words: Tin, creep mechanism, Pb-free solder

INTRODUCTION

The mechanical properties and, hence, the reliability of a solder joint depend strongly on its microstructure, which evolves under the influence of temperature and stress during service. In lead–tin solders with two-phase microstructures the coarsening of the eutectic lamellar structure with temperature and stress is apparent on metallographic examination, and leads to longer slip lengths that facilitate the nucleation of fatigue cracks that lead to failure.[1,2] In contrast, the Pb-free solders that are increasingly used today, such as Sn-Ag-X near-eutectic alloys and Sn-rich Sn-Cu alloys, are predominantly Sn with only a small volume fraction of intermetallic compounds (IMCs). While the distribution and evolution of the IMC phases in these alloys have been widely investigated,[3–8] changes in the Sn matrix phase are subtle and difficult to detect with conventional metallography, and are not as well understood. The studies that have been done suggest that the evolution of the Sn microstructure can have a strong influence on deformation and fracture; for example, Telang et al. observed that the deformation of β-Sn is heterogeneous and sensitive to the strain and temperature history, with significant effects on creep deformation and thermomechanical fatigue.[9] Ding et al. studied the deformation mechanism of pure Sn through *in situ* experiments using scanning electron microscopy (SEM), and noted that the dominant mechanism of deformation can change with strain rate. Grain boundary sliding was an important deformation mechanism at lower strain rates, while deformation at higher strain rates was dominated by conventional bulk mechanisms, as evidenced by the appearance of slip lines at the surface of the specimens.[10]

Due to the fact that ambient temperature is already a high homologous temperature ($T/T_m > 0.5$) for solder, high-temperature creep is a dominant mechanism of

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