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Creep and Mechanical Properties of Cu_6Sn_5 and $(Cu,Ni)_6Sn_5$ at Elevated Temperatures

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Cu_6Sn_5 is the most common and important intermetallic compound (IMC) formed between Sn-based solders and Cu substrates during soldering. The Cu_6Sn_5 IMC exhibits significantly different thermomechanical properties from the solder alloys and the substrate. The progress of high-density three-dimensional (3D) electrical packaging technologies has led to increased operating temperatures, and interfacial Cu_6Sn_5 accounts for a larger volume fraction of the fine-pitch solder joints in these packages. Knowledge of creep and the mechanical behavior of Cu_6Sn_5 at elevated temperatures is therefore essential to understanding the deformation of a lead-free solder joint in service. In this work, the effects of temperature and Ni solubility on creep and mechanical properties of Cu_6Sn_5 were investigated using energy-dispersive x-ray spectroscopy and nanoindentation. The reduced modulus and hardness of Cu_6Sn_5 were found to decrease as temperature increased from 25°C to 150°C. The addition of Ni increased the reduced modulus and hardness of Cu_6Sn_5 and had different effects on the creep of Cu_6Sn_5 at room and elevated temperatures.

Key words: Intermetallic compounds, nanoindentation, mechanical properties, lead-free solder

INTRODUCTION

The continuous performance demands and progress of three-dimensional (3D) electrical packaging technologies has led to increased Joule heating and accompanying operating temperature[1] of lead-free solder joints. Moreover, the volume fraction of IMCs in a typical lead-free solder joint has increased, and interfacial IMCs account for a larger fraction of the joint microstructure because of the minimization of solder joints in 3D integrated circuits (ICs).[2] The diameter of a solder joint in a traditional ball grid array (BGA) is typically around 100 μm, although this is expected to reduce to approximately 1 μm in 3D ICs.[3] In this scenario, the solder alloys can conceivably be completely consumed and a solder joint may consist of a few grains of intermetallic compounds (IMCs).[2,3] As a result, the deformation behavior of a lead-free solder joint is determined by the mechanical properties of the IMCs rather than the solder alloys.[4]

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Cu_6Sn_5 is an important intermetallic compound (IMC) because it is commonly formed during interface reactions between most Sn-based solders and Cu substrates.[5] For solder joints in 3D ICs, Cu_6Sn_5 is expected to be the dominant phase in the joint microstructure even after the aging processes. Thus, the mechanical properties of Cu_6Sn_5 play a determinant role in the overall deformation of a solder joint in 3D ICs. The mechanical properties of Cu_6Sn_5 have been studied both experimentally and theoretically during the last decade.[6–9] Nanoindentation has been proven as a suitable method to investigate the mechanical properties of IMCs formed in diffusion samples,[6] at the solder–substrate interface,[7,9] and in bulk IMCs formed by solidification and diffusion.[10] These previous experimental results are in good agreement with