Journal of ELECTRONIC MATERIALS, Vol. 42, No. 6, 2013
DOI: 10.1007/s11664-013-2517-z

Mechanical Characterization of Lead-Free Sn-Ag-Cu Solder Joints by High-Temperature Nanoindentation

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The reliability of Pb-free solder joints is controlled by their microstructural constituents. Therefore, knowledge of the solder microconstituents' mechanical properties as a function of temperature is required. Sn-Ag-Cu lead-free solder alloy contains three phases: a Sn-rich phase, and the intermetallic compounds (IMCs) Cu_6Sn_5 and Ag_3Sn. Typically, the Sn-rich phase is surrounded by a eutectic mixture of β-Sn, Cu_6Sn_5, and Ag_3Sn. In this paper, we report on the Young's modulus and hardness of the Cu_6Sn_5 and Cu_3Sn IMCs, the β-Sn phase, and the eutectic compound, as measured by nanoindentation at elevated temperatures. For both the β-Sn phase and the eutectic compound, the hardness and Young's modulus exhibited strong temperature dependence. In the case of the intermetallics, this temperature dependence is observed for Cu_6Sn_5, but the mechanical properties of Cu_3Sn are more stable up to 200°C.

Key words: High-temperature nanoindentation, intermetallics, lead-free solder, Sn-Ag-Cu solder

INTRODUCTION

The elimination of lead from electronics due to its detrimental effects on the environment and health is pushing component manufacturers to use Pb-free alloys.[1–8] Replacing Sn-Pb with Pb-free solders has resulted in widespread study of materials properties, processing technology, and reliability.[9,10] During service, interconnects will be exposed to relatively high temperatures, and the thermomechanical reliability of solder joints will be greatly affected by the mechanical properties of the individual microconstituents in the solder alloy; For instance, in the case of Sn-Ag-Cu (SAC) lead-free solder alloys, the solder contains three phases: a Sn-rich β-Sn phase, and the intermetallic compounds (IMCs) Cu_6Sn_5 and Ag_3Sn. The microstructure consists of Sn-rich dendrites surrounded by a eutectic mixture of β-Sn and Ag_3Sn, with small amounts of Cu_6Sn_5. Reflow of the solder material on Cu typically results in formation of Cu-Sn intermetallic layers at the solder–Cu interface, which can influence the properties of the solder joint. Therefore, new methods are required to assess the mechanical properties of these phases, not only at room temperature but also at the high temperatures encountered in service.[9,11]

Previous studies have mainly focused on the room-temperature mechanical response of the individual phases.[1,2,9,12–14] In this paper we report on high-temperature nanoindentation measurements of Young's modulus and hardness of several microconstituents in a Sn-3.9Ag-0.7Cu solder, in order to study the temperature dependence of the individual phases. Knowledge of the mechanical properties of individual phases as a function of temperature will be invaluable for obtaining a better understanding of the temperature-dependent behavior of these materials. It will also be invaluable in developing accurate constitutive equations for modeling solder joint behavior.

(Received September 6, 2012; accepted January 21, 2013; published online March 5, 2013)