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Phase-Field Modeling and Experimental Observation of Microstructures in Solidifying Sn-Ag-Cu Solders

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A multiphase-field model coupled to a thermodynamic database has been successfully applied to model the microstructure evolution during solidification of ternary Sn-Ag-Cu solders, revealing up to five different phases. Simulations were performed in two dimensions (2D) in the bulk volume of the solder as well as at the interface with a copper substrate, addressing the length scales of both dendritic and eutectic structures. Primary dendrite spacing and secondary arm spacing of Sn dendrites in the bulk solder volume match well with experimental observations. The eutectic spacing of Ag_3Sn lamellae and their thickness also match experimental data, while the thickness of the Cu_6Sn_5 lamellae is slightly larger than found by experiment. Nucleation and growth of Cu_6Sn_5 on a Cu substrate lead to superficial dissolution and roughening of the substrate, with the size of the Cu_6Sn_5 largely determined by its nucleation conditions.

Key words: Multiphase-field model, thermodynamic databases, nucleation, intermetallics, substrate reaction, scallop formation

INTRODUCTION

Soldering might be thought of as a mature technology, as a wide range of electronic products have been in production for decades. However, there are still two major challenges for standard Pb-Sn-based solders, and also in processing and application of new-generation lead-free solders: reliability and integration density.

These issues may be considered as independent for low integration densities. In this case, "reliability" essentially refers to the "lifetime" of a single solder joint. For increasing integration densities, possibly comprising some thousands of solder joints, "reliability" in the future will also be closely linked to productivity: a single substandard joint will result in the rejection of an entire system. Failure, i.e., lack of reliability, essentially occurs at the scale of the microstructure of the solder joint, making understanding and control of microstructure formation essential to achieving reliable solder joints.

The scope of the present article is the investigation and simulation of some aspects of microstructure formation in lead-free solders. The focus is on the Sn-Ag-Cu (SAC) alloy system, which, because of its comparatively low melting temperature, competitive price, and good mechanical properties, is most likely to replace lead-containing solders. Much experimental research into the microstructure of SAC is available regarding bulk solidification microstructures,[1–5] solidification on substrates,[6–8] solid-state aging,[9] various process/reflow conditions,[10] and also behavior under mechanical load, such as grain boundary sliding/creep.[11–13] However, much more effort is needed to gain a thorough understanding of the behavior of the alloy and the evolution of its microstructure, especially in relation to more complex loading and boundary conditions in technical joints, e.g., for modern automotive electronic and mechatronic systems.

Only powerful numerical simulations will provide a description of the microstructures in ternary and even higher alloyed metallurgical systems occurring

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