8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

NUCLEATION AND GROWTH OF VOIDS IN SOLDER JOINTS OF MEMS

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Key Words: *Kirkendall effect, solder alloys, vacancy diffusion, void nucleation, void growth, plastic deformation, damage, creep*

ABSTRACT

The functional unit of Micro-Electro-Mechanical-Systems (MEMS) is typically a Si-chip, however, different metallic joints are required to provide electrical and mechanical connections. If such connections, *e.g.*, solder joints and plated through holes, fail this will typically cause failure of the whole MEM. The setup is illustrated exemplarily in Figure 1 for a Flip Chip packaging. Solder balls as well as small joints, which are typically made of Sn-containing alloys (*e.g.*, Sn-Ag or Sn-Ag-Cu), hold the multi-layered unit in position and provide electrical conductivity between the coppered layers. “Aging” of the solder alloy, such as phase separation, coarsening and the growth of intermetallic compounds, as well as the formation and growth of pores and cracks significantly effects the life expectation of the joints and considerably influences the reliability of the MEMS.

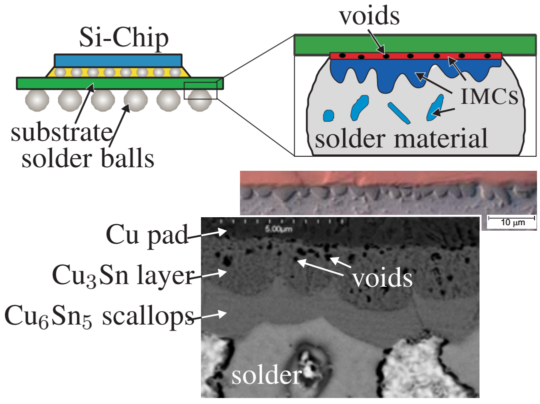

Figure 1: Intermetallic compounds (IMCs) and KIRKENDALL voids in microelectronic packages, lower photo from [1].

Intermetallic compounds develop due to interfacial reactions when, during manufacturing, the (molten) Sn-rich solder wets the copper pad. In particular, Cu_3Sn and Cu_6Sn_5 compounds form and grow as a consequence of thermal and mechanical loading during service. Additionally, KIRKENDALL voids nucleate because neighboring compounds change in a way that the volume of one region grows and the volume of another phase reduces. In case of Sn-based solders such regions are typically Cu_3Sn and Cu_6Sn_5 compounds from where the diffusion of Cu into the Sn-rich solder is much *faster* than the inverse diffusion of Sn. Because of the unbalanced Cu-Sn diffusion vacancies are left behind which coalesce to form KIRKENDALL voids. Additional vacancies and defects in the crystal lattices are generated by plastic deformation of the solder material and assist in the process of void growth and material degradation.

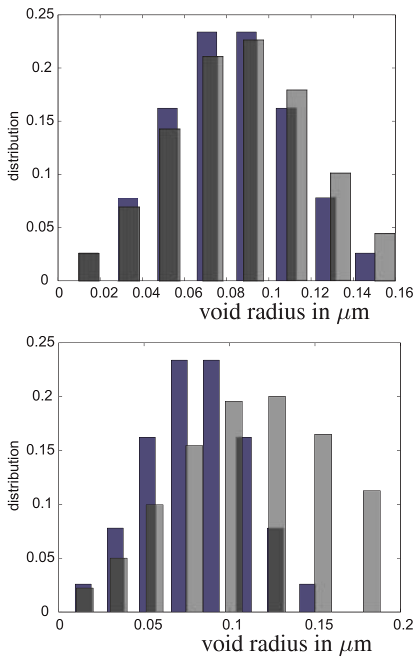

Figure 2: Development of an initially GAUSSian void distribution after 1 and 5 thermal cycles, cf.[4].

In this contribution we present a constitutive model to predict the condensation and growth of KIRKENDALL voids in time-dependent elastic-plastic metals as typical for microelectronic solder joints. Extending the modeling of void growth in visco-plastic materials introduced in [2] here the condensation of vacancies contributes to void growth, too, cf. [3]. Thus the constitutive model accounts for the effects of vacancy diffusion, surface tension and rate-dependent plastic deformation on ensembles of (spherically idealized) voids. It turns out that nano-voids collapse, whereas voids which are small but exceed a critical radius (of a few vacancies) grow driven by diffusion effects. On the other hand the growth of bigger voids is primarily driven by elastic-plastic deformation of the void surrounding material. We found that work hardening plays a minor role and, as expected, creep decelerates the void growth. Furthermore we studied the temporal development of void ensembles under thermal cycling, cf. Fig. 2. The presented model for void growth is employed to (numerically) solve the balance of a void size distribution function. We found that the evolving distribution initially resembles the ones known from LSW theories, whereas the distribution during proceeded loading evolves such that the amount of large voids drastically increases. Such behavior correlates to experimental studies on KIRKENDALL voids. The constitutive model is incorporated in a finite-element program to study the mechanical behavior of solder joints under realistic loading regimes and to improve the prediction of live time and strength of microelectronic joining connections.

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