Fatigue analysis of Pb-free solder interconnect

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Introduction

The most common solder alloy SnPb will soon be removed from electronic packages due to its toxicity. Apart from legislation, with developing technology, SnPb has been stretched to the limits of its physical capabilities. Therefore, there is an urgent need to find an alternative Pb-free solder, that can compete with the demands of miniaturization. Currently, SnAgCu is the most promising replacement due to its better creep resistance, longer fatigue life and stable microstructure. However, there is scarce quantitative data on material and mechanical properties of this new alloy.

Figure 1 *Commercial electronic products, BGA cross section and a failed solder bump.*

In BGA assemblies, failure is observed almost always at the bump/pad connection (Fig.1). Thus the bonding interface has crucial importance in solder joint reliability. The quality of this bonding interface is determined during reflow by the metallurgical reactions between solder (SnAgCu), and metallization (Ni/Au)[1].

Objective

The fatigue crack path between Ni/Au substrate and SnAgCu follows pre-known interfaces and the propagation can be split into normal and tangential components as shown in Fig.2 [2]. Such interfacial failure can be modeled effectively with the cohesive zone approach, describing normal (n) and tangential (t) traction-separation with springs.

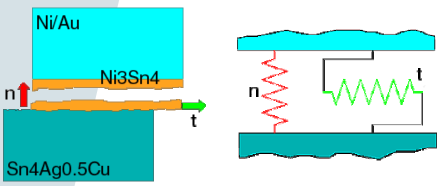

Figure 2 *(a)Crack paths between solder and substrate, (b)Cohesive zone element.*

The objective of this study is to conduct dedicated fatigue tests with Ni/Au-SnAgCu soldered specimens and use the experimental data to develop a cohesive zone based interfacial fatigue damage model.

Fatigue Tests and Modeling

Pure tensile and pure shear experiments are set up and specimens are cyclically loaded at various peak strain levels, which are used to fit the normal and tangential springs of the cohesive zones.

Figure 3 *Soldered joints on metallization substrate (Ni/Au).*

In the cohesive zone formulation, traction T is a linear function of the separation Δ. A damage variable D is introduced for the accumulation of damage throughout the cycling process described by an evolution law:

$$T_\alpha = k_\alpha (1 - D_\alpha)\Delta_\alpha \qquad (1)$$

$$\dot{D}_\alpha = c_\alpha |\dot{\Delta}_\alpha| \, (1 - D_\alpha + r)^{\mathrm{m}} \left\langle \frac{|T_\alpha|}{1 - D_\alpha} - \sigma_{\mathrm{f}} \right\rangle \qquad (2)$$

Individual fatigue tests are simulated by the finite element method. Cohesive zones are placed to interfaces where failure is observed. After a number of cycles, damage evolves at the bonding interfaces, thus peak stress decreases with successive cycles.

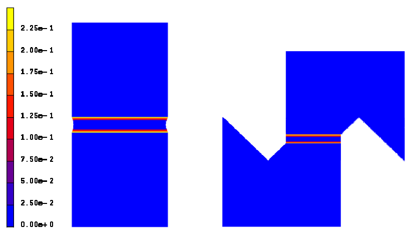

Figure 4 *Damage evolution in cyclic tensile and shear loading at bonding interfaces.*

Future study consists of applying the results obtained so far to a BGA solder bump and prediction of thermo-mechanical fatigue crack initiation and propagation.

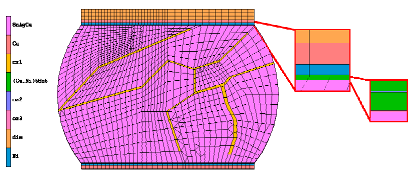

Figure 5 *BGA solder bump with microstructure and metallization.*

Conclusions

The solder/metallization interface is characterized under cycling loading. Using a cohesive zone approach to simulate interfacial solder fatigue damage is promising.

References:

[1] Erinç, M., Schreurs, P.J.G., Zhang, G.Q., Geers, M.G.D.: *Microelectronics Reliability* (44:1287-1292, 2004)

[2] Erinç, M., Schreurs, P.J.G., Zhang, G.Q., Geers, M.G.D.: *Journal of Materials Science: Materials in Electronics* (16:693-700, 2005)

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