Microstructural evolution of solder alloys

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Introduction

During its lifetime a solder joint which connects an electronic component to a substrate is subjected to cyclic temperature loads caused by the on and off switching of the electronic device. Because of differences between thermal expansion coefficients stresses and strains arise within the joint which can cause damage eventually leading to failure. Under the influence of temperature and stresses a heterogeneous coarsening process takes place continually changing the microstructure. The microstructure strongly influences the fatigue resistance and other mechanical properties of a solder alloy, necessitating the incorporation of its evolution when modelling solder joint behaviour.

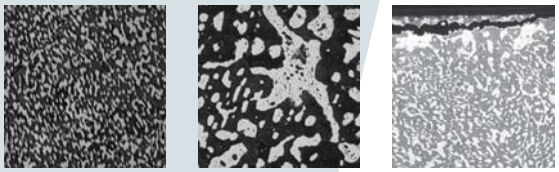

Figure 1. *Microstructures of a tin-lead-silver solder alloy, from left to right: as-cast, after thermal ageing, after thermal cycling.*

Objective

Modelling of the phase precipitation and coarsening process within a solder joint under the influence of thermomechanical cycling in order to make accurate life-time predictions.

Method

To describe the phase separation a diffuse interface theory is used, where it is assumed that the free energy is dependent on the local concentration c and a nonlocal concentration $\bar{c}$. The diffusion equation reads:

$$\rho \frac{\mathrm{d}c}{\mathrm{d}t} = \vec{\nabla} \cdot \left\{ \rho \, \mathbf{M} \cdot \vec{\nabla} \left[\frac{\partial \mathcal{F}_0}{\partial c} - a \left(\bar{c} - c \right) \right] \right\}$$

where a is related to the surface tension, ρ represents the density, $\mathbf{M}$ the mobility tensor, and $\mathcal{F}_0$ the configurational part of the free energy. As opposed to the Cahn-Hilliard model [1], where the nonlocal effect is represented by higher order *local* concentration gradients, here the free energy is dependent on a truly *nonlocal* parameter, calculated through a Helmholtz equation:

$$\bar{c} - \ell^2 \nabla^2 \bar{c} = c$$

where ℓ is a length parameter. The system of equations is solved using the finite element method.

Results

One and two-dimensional numerical calculations have been performed using model parameters of a tin-lead solder alloy. Figure 2 shows the development of the tin composition profile for a one-dimensional case after imposing a slight fluctuation on a homogeneous mixture.

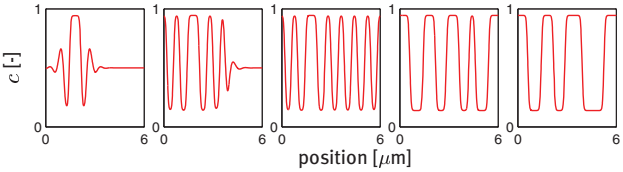

Figure 2. *One-dimensional example of phase separation and coarsening of a tin-lead solder alloy. Tin composition shown for t = 50 s, t = 100 s, t = 50 min, t = 10 hours and t = 115 days from left to right.*

Figure 3 shows the results of the two-dimensional numerical simulation of quenching tin-lead alloy from $T > 200°\mathrm{C}$ to $T = 140°\mathrm{C}$.

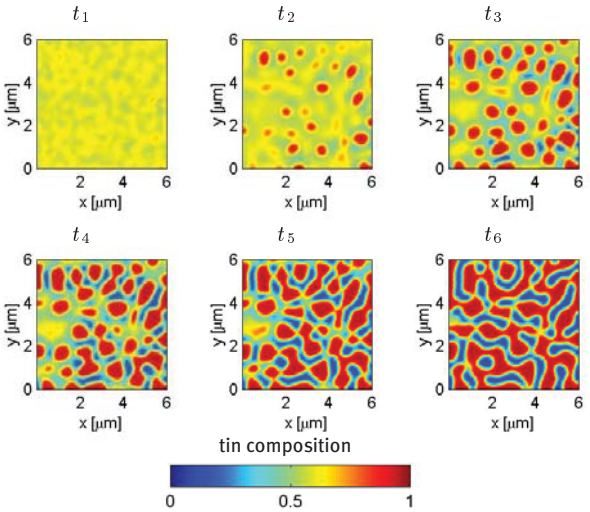

Figure 3. *Phase separation for a two-dimensional case.*

Conclusions

- The model is capable of simulating the phase separation and coarsening of a solder material.
- Numerical results for the two-dimensional case are qualitatively in good agreement with experimental results found in literature.

References:

[1] Cahn, J.W. and Hilliard, J.E.: *Free energy of a uniform system, I: Interfacial energy* (J. Chem. Phys. 28(2):258-267, 1958)

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