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Microstructure evolution of tin-lead solder

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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. Soldered connections on a printed circuit board, a wave soldered resistor and a ball grid array.

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:

$$\rho \frac{dc}{dt} = \vec{\nabla} \cdot \left\{ \rho \mathbf{M} \cdot \vec{\nabla} \left[\frac{\partial \mathcal{F}_0}{\partial c} - \kappa (\bar{c} - c) + \frac{\partial \mathcal{F}_e}{\partial c} \right] \right\}$$

where κ is related to the surface tension, ρ represents the density, $\mathbf{M}$ the mobility tensor, and $\mathcal{F}_0$ and $\mathcal{F}_e$ the configurational and elastic part of the free energy respectively. 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

Two-dimensional numerical calculations have been performed using model parameters of a tin-lead solder alloy. The results have been quantified and compared with experimental data.

Simulation

Experiment

Figure 2. Microstructure evolution of tin-lead solder during static ageing at 150°C.

Figure 3. Development of the surface area during static ageing of tin-lead solder at 150°C.

Conclusions

- The model is capable of simulating the phase separation and coarsening of tin-lead solder.
- Numerical results for the two-dimensional case are quantitatively in good agreement with experimental results.
- Mechanical loading is found to influence bulk compositions, the interfacial width, and the diffusion speed

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)