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Mechanical Behaviour of Grains in SnAgCu Solder Joints

Jicheng Gong, Changqing Liu,
Paul P. Conway and Vadim V. Silberschmidt

Wolfson School of Mechanical and Manufacturing Engineering
Loughborough University, UK

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Background

- Lead-free solder
- Thermal induced load due to mismatch of CTE
- Typical method to predict reliability of solder joints:
 - Modelling mechanical behaviour of solder joints in electronics under thermal cyclic load through FEA
 - Predict the number of cycles to failure based on fatigue model (eg. Coffin-manson equation)
- A accurate constitutive model to describe mechanical behaviour and corresponding fatigue model are required

Microstructure of a micro- SnAgCu joint

- Most constitutive model and fatigue model are based on bulk specimens
- A micro- joint contain few grains
- β -Sn, the matrix of SnAgCu solder, has a contracted body-centred tetragonal structure, promising considerable anisotropic behaviour

Anisotropic mechanical behaviour of SnAgCu single crystal

- Three types of anisotropic behaviour are expected: elastic behaviour, thermal expansion and inelastic behaviour
 - The former two can refer to Matin, M. A. et al.
 - This presentation focuses on the last one
 - Both the size and cooling condition's effect on grain features are studied
 - A shearing mechanical test is performed to study these features on inelastic behaviour of SnAgCu solder joints
-
- Matin, M. A. et al, "Correlation between thermal fatigue and thermal anisotropy in a Pb-free solder alloy," Scripta Mater., Vol. 53, No. 8 (2005), pp. 927-932

Sample preparation

- $d = 1\text{mm}$, $b = 0.1$ and 1mm , respectively, which corresponds to solder joints of BGA and flip chip

Temperature profile

- The cooling rates near the melting point are 0.13°K/s and 4.5°K/s , respectively. Their heating and cooling condition are the same before 718s (around 493°K)

Results

- A large joint ($b = 965\mu\text{m}$) formed at the slow cooling rate (0.13°K/s).

Shearing test

Polarized image

- A large joint ($b = 965\mu\text{m}$) formed at the slow cooling rate (0.13°K/s).

- A small joint ($b = 82\mu\text{m}$) formed at the slow cooling rate (0.13°K/s).

- A large joint ($b = 1015 \mu\text{m}$) formed at the rapid cooling rate (4.5°K/s).

Polarized image

- A large joint ($b = 1015\mu\text{m}$) formed at the rapid cooling rate (4.5°K/s).

- A small joint ($b = 108\mu\text{m}$) formed at the rapid cooling rate (4.5°K/s).

Discussion

- For bulk specimens, their mechanical behaviour results from the contribution of all grains. Their behaviour exhibits an average phenomena. Therefore, the constitutive model is isotropic and their fatigue life concentrate at certain value
- For a micro- joint, the mechanical behaviour depends on local microstructure. Therefore, their fatigue life distributes smoothly
- The reliability of micro- joints is determined by the weakest microstructure
- It important to proposed a model to describe this lattice orientation-dependent behaviour

A constitutive model for SnAgCu micro-joints

$$\dot{\gamma}_{\alpha} = A_{\alpha} (\tau_{\alpha})^n \exp\left(\frac{Q_{\alpha}}{RT}\right)$$

$$\tau^{(\alpha)} = \mathbf{s}^{(\alpha)} : \boldsymbol{\sigma}$$

$$\dot{\boldsymbol{\epsilon}}_{ld} = \sum_{\alpha=1}^N \dot{\gamma}_{\alpha} \mathbf{s}_{\alpha}$$

$\mathbf{s}$ - Schmid tensor

- Certain slip systems can be activated during loading
- The inelastic behaviour is the sum of deformation due to each slip system

Flip chip electronics: global model

Entire Package

Without silicon chip

Deformation of the flip chip under thermal cyclic load

Thermal cyclic load

Equivalent stress

Simulation Results: submodel

Traditional model

Single crystal joint

- The Mises equivalent stress gradient in single crystal is larger than that in traditional model based on bulk specimens

Stress components in single crystal joint with different grain orientation

- Stress components are different when the grain orientation varies

Results for bi- and multi-crystalline

Conclusions

- From the size of $100\mu\text{m}$ to $1000\mu\text{m}$, the smaller a solder joint is, the less number of grains it contains.
- The faster a cooling rate is applied, the finer substructure in the solder grains is obtained. However, the size of grain is not significantly sensitive to the cooling rate in the range of 0.13°K/s and 4.5°K/s .
- The non-thermal activated inelastic behaviour of $\text{Sn}_{3.8}\text{Ag}_{0.7}\text{Cu}$ grains is considerably lattice-dependent for a micro-joint.

Thank you!

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