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Effect of Intermetallic Compounds on Pressure-induced Tin Whisker Formation

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Summary

This paper presents the effect of intermetallic compounds on tin whisker formation induced by pressure. FEA was carried out to evaluate the effect of IMC on the stress evolution in the plating which induces tin whisker. Since the IMC can prevent creep of the plating, higher stresses are generated near the IMC. It can explain the behavior of pressure-induced tin whisker from other experimental study. IMC network enhances the restriction of IMC to creep of the plating. If the IMC network is non-uniform, the behavior of stress evolution is changed. It means that whisker formation may be affected by the dispersion of IMC network strongly.

Introduction

As a result of the migration to lead-free electronics, the adoption of tin-rich finishes has created a reliability concern pertaining to the formation of conductive whiskers, which can bridge adjacent conductors and lead to current leakage and electrical shorts. Since the spacing between conductors is of the order of a few hundred microns, and tin whiskers have been known to grow up to a few millimeters in length, tin whiskers pose a serious risk to its reliability.

It is believed that compressive stress, generated within the tin plating, is a necessary, but not sufficient, factor influencing tin whisker growth. Compressive stresses can be induced by mechanical, thermal and/or chemical effects. In particular, whiskers can be sometimes induced by pressure, which accelerates the growth of tin whiskers [1]. In the case of fine-pitch connectors with pure tin or high tin alloy finishes, mating pressure between the connector elements can produce pressure-induced tin whiskers. Since stresses in the plating increase with pressure, the atom transport forming tin whiskers accelerated by gradient of stresses.

For the pressure-induced whisker, a creep-based tin whisker model was proposed to explain experimental data [2]. When a contact load is applied to a surface of plating, the material below the pressured area is expanded in the orthogonal directions (Poisson effect) due to the deformation of the plating. Since the melting point of tin plating is relatively low, the plating creeps even at room temperature. This induces a multiaxial stress concentration outside the pressured area. Though stress relaxation occurs, multiaxial stress components remain as residual stresses, which act on grain boundaries of the plating. These can cause stress-induced atom migration and the formation of whiskers.

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The behavior of whisker growth is affected by microstructures such as grain size and orientation [3], intermetallic compounds, and/or grain boundaries. These microstructures may cause a lack of uniformity in the deformation mechanism of plating. In particular, since whisker diameters are observed to be similar with grain size, these dispersions of microstructures becomes one of major factors influencing to whisker growth.

This paper will present the effect of intermetallic compounds in tin or high tin alloy finishes on pressure-induced tin whisker. Since creep properties of finishes are the key of pressure-induced tin whisker, the elastic-plastic-creep analysis was performed to investigate the effect of intermetallic compounds.

FEA models with IMC

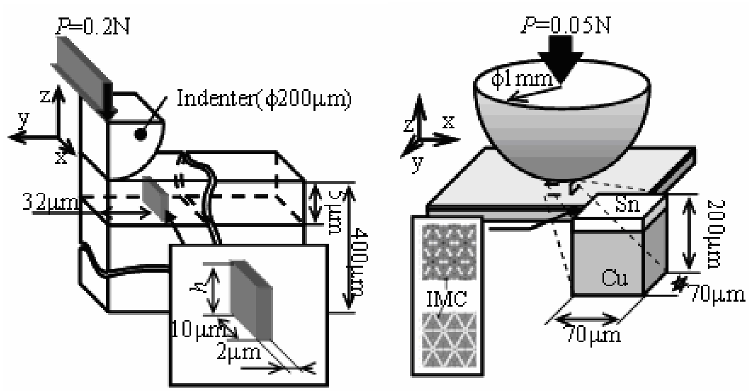
Intermetallic compounds (IMCs) play a role to prevent the deformation of the plating since IMC is hard material compared with tin. Since they are usually formed the interface between a plating and a substrate or along grain boundaries, it is a difficult to observe the behavior of the IMC experimentally. In this study, FEA qualification was carried out to evaluate the effect of IMC on stress evolution in the plating. Figure 1 shows the analysis model. The plating is formed on the substrate (phosphor bronze). IMC plates of Ni_3Sn_4 are modeled in the plating [4]. A load is applied on the center of a rigid indenter in 15 s and the dwell time is set to be 240 hours.

FEA models were constructed for three cases: (a) single IMC model, (b) IMC network model (c) heterogeneous IMC network model. In single IMC model, an IMC is modeled in the plating and a columnar indenter with a radius of 0.1 millimeters was used. Thickness of the plating was 5 microns and height of IMC ranges from 1 to 5 microns. Both sides of the indenter and the finished substrate are subjected to the symmetrical constraint. A load is 0.2 N.

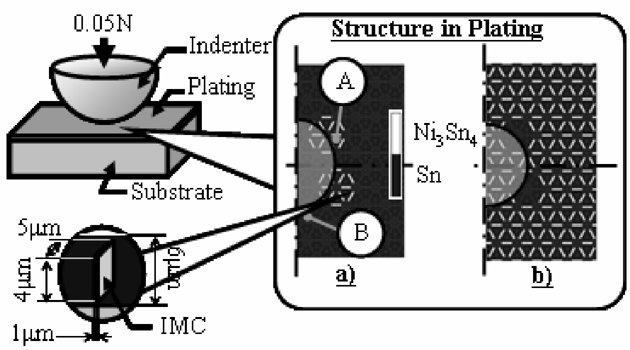
The IMC network model consists of triangular grains with the grain size of 10 μm and IMCs are formed along each grain boundary. The sizes of FEA model are $70\times70\times200$ microns and the thickness of plating is 6 microns. A sphere ball was indented at the center of the model. Two models of jointed IMCs and individual IMCs were examined. Each grain and IMC is assumed to be isotropy. The focus of study is put on the geometry of IMC network.

In the heterogeneous IMC network model, the IMCs are formed partly to examine the effect of the IMC dispersion on stress evolution. The crystal grain was assumed to be a triangular prism of one-side 10 μm, and IMCs are distributed near the contact area. The size was set to thickness 1 μm, width 5 μm, and height 4 μm to plating thickness 6 μm. An applied load is 0.05 N. Stresses were evaluated at the center of triangular grains.

In three models, the plating is assumed to be elastic-plastic-creep body. Material properties are taken from the nanoindentation test (See Table 1). The substrate and IMC are assumed to be the isotropic elastic body. The commercial solver MSC.MARC was used and eight-node solid element was used for mesh division. There is a contact between the indenter and the plating, and no friction was considered.



(a) Single IMC model (b) IMC network model



(c) Heterogeneous IMC model

Figure 1: Analysis models with IMCs.

Effect of intermetallic compounds on stress evolution

Figure 2 shows contour maps of minimum principal stresses for the IMC thickness of 1, 3 and 5 microns. Stresses show compressive in the plating near the contact area. High stress concentration appears in the vicinity of the intermetallic compound. The IMC prevents the deformation of the plating since it is hard material compared with tin or high tin alloys. When the IMC is small (h=1 μm), the effect on the deformation of the plating is small. As the IMC becomes larger, the deformation is restricted by the IMC and the plating deform between the surface

Table 1: Material Property.

	Ni3Sn4	Sn	Phosphorus bronze
Yung`s modulus E (GPa)	113.3	22.8	110
Poission`s ratios ν	0.48	0.3	0.3
Yield stress σ_Y(MPa)	1192	113	
Creep index n		5.1	
Creep constant A (1/MPa^{n}s)		1.2×10^{-12}	

and the IMC. Then, the stress gradient becomes high. Since stress-induced atom transport is driven by the stress gradient acting on the grain boundaries, the IMC accelerates the atom transport. It means that irregular IMC can be whisker initiation site.

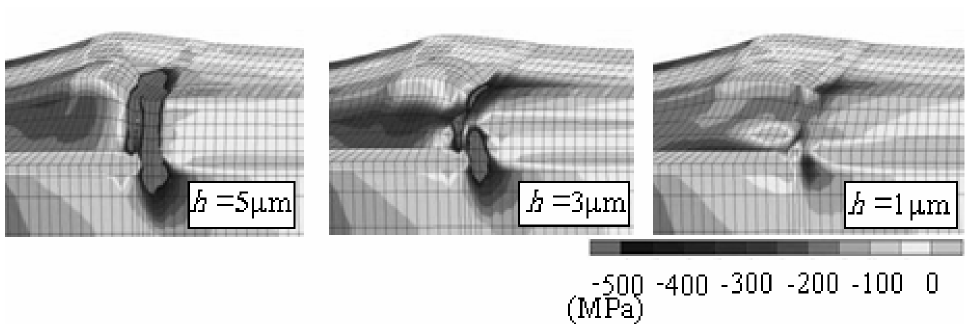
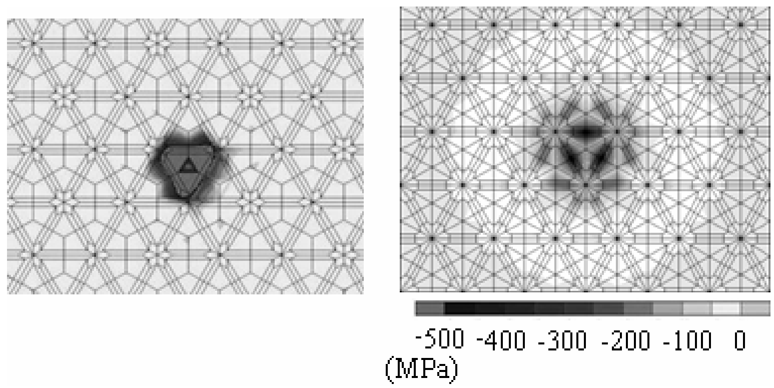


Figure 2: Contour maps of minimum principal stresses near the IMC.

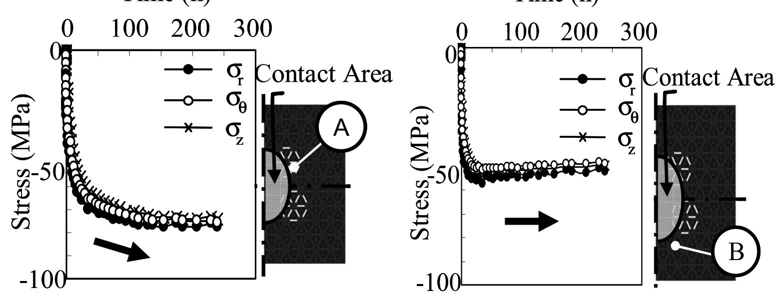
Figure 3 shows contour maps of minimum principal stresses in IMC network models. Thickness of IMCs is 5 μm. When IMCs are jointed at triple junctions, higher stresses appear below the contact area. Since IMC network restrict creep of the plating and since stress concentrated area is small, higher stress gradient is generated near the contact area. When IMCs are formed individually, stresses near the contact area are mitigated. However, stress evolution appears outside the contact area. The size of effective area is within a few grains.

Figure 4(a) and (b) show the stress evolution in the regions A and B of inhomogeneous IMC model, respectively. In the IMC-formed area (Point A), compressive stresses increases even if stress relaxation occurs. This phenomenon is similar with uniform IMC models. On the other side, if IMC is distributed non-uniformly, stresses in no IMC area stop increasing in the middle stage. It means that stress evolution at the point B is affected by IMCs at the point A even if the point A is far from the point B.



(a) Jointed IMCs (b) Individual IMCs

Figure 3: Effect of IMC network.



(a)Point A (b) Point B

Figure 4: Effect of heterogeneous IMC network.

Conclusion

The effects of IMC on stress evolution in the plating can fall into two cases. When IMC grows over the whole plating, IMC within the plating layer prevents the creep deformation of the plating. Since stresses concentrates due to the restriction of IMC, pressure-induced whisker is possible to grow near the IMC. The network of IMC enhances its effect. However, when the size of IMC is small, its effect becomes smaller. When IMC grows up, the restriction of deformation can produce the high stress gradient, which is a driving force of pressure-induced tin whisker formation.

Another effect is the effect of heterogeneous IMC network. In the case of uniform IMC model, stresses increase as a function of time. Though stresses increase as a function of time in the IMC-formed area, stresses in the non-IMC area are mitigated. It means that the heterogeneous network affects the stress evolution in the plating strongly. Tin whiskers are known to grow singularly from a lot of observations. Obtained results imply that the heterogeneous structure of IMC affects whisker formation.

References

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