E-2-2 (Invited)
Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp772-773

Nanomechanical Characterization of Intermetallic Compounds in Miniaturized Interconnections

Jenn-Ming Song

Department of Materials Science and Engineering, National Chung Hsing University
Taichung 402, Taiwan
Phone: +886-4-22852482, E-mail: samsong@nchu.edu.tw

Abstract
In view of the recent technological developments as well as size miniaturization, more and more reliability challenges related to intermetallic compounds (IMCs) are encountered at all interconnection levels in electronic applications. IMC layers at the interfaces of solder joints may be beneficial in achieving a strong mechanical and chemical bonding between the solders and substrates, however, their often act as the fracturing path due to the brittle nature. A comprehensive knowledge of mechanical behavior of IMCs formed at the solder joints' interfaces is important. For that reason, nanoindentation was employed in this study for probing the mechanical properties of IMCs commonly formed at the solder joint interfaces. The relationships between work hardening exponent, strain rate sensitivity, creep resistance, and the ability against plastic deformation of a variety of IMCs were clarified.

1. Introduction

Intermetallic compounds (IMCs), which form at the interface between the solder and its bonding pad, play an important role in the integrity of the solder joint, and hence the reliability of electronic packages, especially when suffering high strain rate deformation. Due to the trend of size miniaturization leading to a greater proportion of IMCs to the total volume of the solder joints, a comprehensive knowledge of the mechanical behavior of IMCs formed at the solder joints' interfaces is urgent. However, the data on bulk materials are not reliable especially when the solder volume is smaller than 10^{-12} m^3. For that reason, nanoindentation has been employed for probing the mechanical properties of interfacial IMCs mainly due to their limited area [1-3]. As a depth sensing indentation technique, the applied load can be controlled at a constant value during testing, and the penetration of the indenter tip into the sample surfaces can be continuously recorded. Using a continuous stiffness measurement (CSM) technique, the hardness and Young's modulus during indentation can be obtained and the substrate effect thereby prevented.

This study investigated the mechanical behavior of intermetallic compounds of Cu, Ag, Ni and Au bases commonly observed at solder joint interfaces. The plastic properties including work hardening exponent, strain rate sensitivity, and creep resistance are the objects of investigation. The ratio of yield strength and elastic modulus (Y/E), the so-called yield strain, was used to correlate the above properties.

2. Results and Discussion

Fig. 1(a) show the relationship between work hardening exponent and the ratio of yield strength and elastic modulus (Y/E) of the IMCs. Y/E, the yield strain, is considered to be inversely proportional to the ability for plastic deformation of materials. On the other hand, a higher $(Y/E)^{-1}$ implies a greater plastic ability. Work hardening exponent, *n* value, which can be regarded simply as the increase in stress to cause plastic deformation, was defined as follows [4],

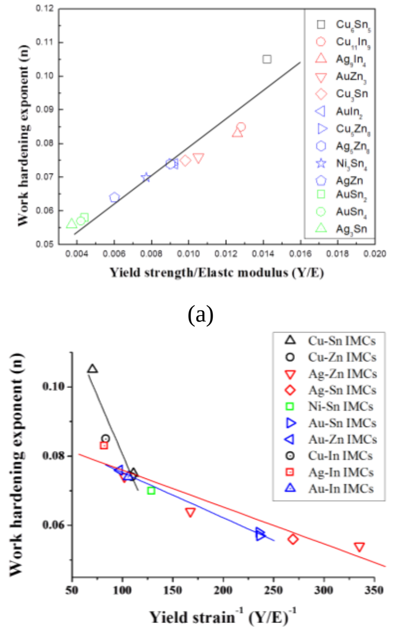
$$n = \frac{d \ln H}{d \ln \varepsilon} \qquad (1)$$

It can be observed that there exists a direct proportional relationship between the work hardening exponent and Y/E. If the IMCs are divided into groups according to the alloy compositions, *i.e.* Cu base, Ag base, Au base, as well as Ni_3Sn_4. Fig. 1(b) reveals that for each group the n value of all the IMCs decreased with an increase in $(Y/E)^{-1}$. Cu based IMCs showed a much stronger dependence of $(Y/E)^{-1}$ on n value compared with Ag and Au-based IMCs. This leads us to believe that the abilities for work hardening and plastic deformation behave inversely, and both of these two properties are related to the alloy bases, rather than structure and melting point of IMCs.

The dependence of strain rate on hardness, strain rate sensitivity *m*, was defined as [4]

$$m = \frac{d \ln H}{d \ln \dot{\varepsilon}} \qquad (2)$$

where H is the hardness measured at different strain rates. It is interesting that if strain rate sensitivities of the IMCs are gathered according to the alloy base, an proportional relation between m value and $(Y/E)^{-1}$ can be found (Fig. 2), indicating that an IMC which is highly plastically-deformable will be strengthened more at a higher strain rate. It can also be derived from Fig. 2 that compared with other alloy bases, most of the Cu based IMCs possessed lower m value and $(Y/E)^{-1}$. This implies that Cu based IMCs lack the plastic ability, and are less strengthenable subject to high speed deformation. Both of these lead to a fragile nature for Cu based IMCs when subjected to mechanical shock or impact.



(a)

(b)

Fig. 1 The relationship between work hardening exponent and (Y/E): (a) for various kinds of IMCs and (b) in terms of the IMC groups

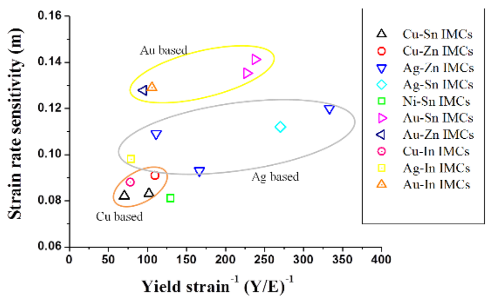


Fig. 2 The relationship between strain rate sensitivity and $(Y/E)^{-1}$ in terms of the IMC groups

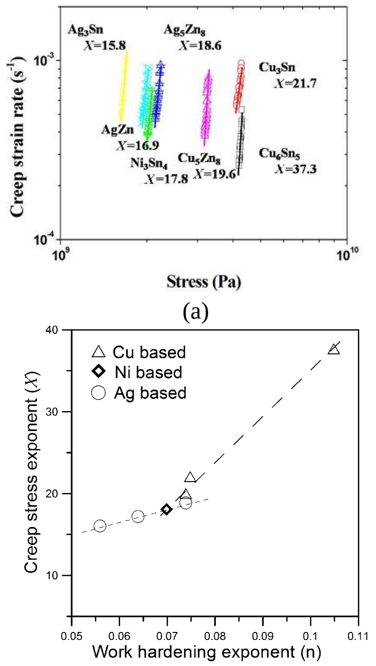
For measurements of creep during the constant load segment (5 mN for 200 sec) of nanoindentation testing, the change in penetration depth was recorded. The distance between the test points was 50μm at least. During the creep test, the strain rate and the stress were determined from the following equations respectively. For an isothermal test, the steady-state creep rate is normally affected by a power function of the stress and can be represented as [5]

$$\dot{\varepsilon} = \frac{dh}{dt}\frac{1}{h(t)} = k\sigma^{x} \qquad (3)$$

$$\sigma = \frac{P}{A} \qquad (4)$$

Linear regression was performed and the results are presented in Fig. 3(a), where the slop corresponds to the creep stress exponent. The comparison given in Fig. 3(b) depicts that *X* was proportional to the work hardening exponent and seemed to show no clear correlation with the structure or the melting point of IMCs. It could also be found that the change in the *X* value of Cu based IMCs was more dependent on work hardening than the Ag based group.

There are a number of possible mechanisms which may contribute to the creep of IMCs, *e.g.* diffusional process, dislocation glide and climb, as well as grain boundary sliding [6]. The above results reveal that an IMC with higher *Y/E* and work hardening ability, representing a greater ability to impede the dislocation slip, was capable of resisting indentation creep, and the creep deformation in this study was likely dislocation-controlled.



(a)

(b)

Fig. 3 (a) Creep strain rate versus hardness for different interfacial IMCs, and (b) relationship between the creep stress exponent (*X*) and work hardening exponent (n).

3. Conclusions

Cu based IMCs showed a much stronger dependence of $(Y/E)^{-1}$ on work hardening exponent and creep stress exponent than the other IMCs. They are less strengthenable subject to high speed deformation, which may lead to a fragile nature when subjected to mechanical shock or impact

Acknowledgements

This work was supported by Ministry of Science and Technology of R.O.C. through the contract No. NSC 97-2221-E-259-003

References

[1] X. Deng, N. Chawla, K. K. Chawla, M. Koopman, *Acta Mater*., **52** (2004) 4291.
[2] M. A. Dudek and N. Chawla, *Intermetallics*, **18**(2010)1016
[3] J. M. Song, B. R. Huang, C. Y. Liu, Y. S. Lai, Y. T. Chiu and T. W. Huang, *Mater. Sci. Eng. A* **534**(2012)53
[4] C. Fisher-Cripps, Nanoindentation, 2nd ed. (Springer-Verlag, New York, 2004) p. 146.
[5] Y. C. Lin, J. W. R. Teo, S. K. Tung and K. H. Lam: *J. Alloy. Compd*. **448**, 340 (2008).
[6] G. Sharma, R. V. Ramanujan, T. R. G. Kutty and P. Prabhu: *Intermetallics* **13**, 47 (2005).