Low Temperature Cu-Sn and Sn-Sn Bonding Development for 3D Interconnect Applications

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Abstract

Cu-Sn and Sn-Sn bonding for 3D interconnects at low temperature (243°C) were investigated. It is found that bonding results strongly depend on bonding temperature. Surface morphologies, which determine the bond quality, of Sn with Ti or Cu as an adhesion layer were studied. Thickness of Sn layer is found to affect the bonding results of Sn-Sn bonding. These results provide useful guidelines and information for low temperature bonding in 3D interconnect and packaging applications.

1. Introduction

Three-dimensional integrated circuits (3D IC) is a promising candidate to extend “Moore’s law” [1]. One of the key technologies used in 3D integration is bonding technology. Therefore, the development of bonding materials and structures for both mechanical and electrical interconnections is the success factor to achieve a strong 3D structure. Direct Cu-Cu bonding can provide sufficient bonding strength for electrical connection but the required bonding temperature is higher than 300°C [2]. This paper reports the investigations of Sn and Cu for bonding at 243°C to meet the low thermal budget [3] requirement.

2. Experimental procedures

Cu and Sn thin films were deposited on wafers by sputter, E-gun, or thermal evaporation on Ti adhesion layer. The wafers were diced into 1cm*1cm for chip-level bonding under atmosphere environment. Before bonding, the use of HCl to clean the surface of oxide layer was optional. Chips were bonded face-to-face with a force of 100nt for 50 min at 243°C. The morphologies of metal films and bonded interfaces were investigated by SEM.

3. Results and discussion

Table-I shows the bond results of 5 different bonding conditions. Group-1 sample is actually bonded although the delamination is shown. In Figs. 1(a) and (b), the top-view morphologies from both sides show that the Sn layer was transferred to Cu side after delaminating, indicating Sn was assembled and bonded with Cu to possibly formed IMC [4]. However, the weak adhesive ability between Sn and Ti resulted in the delamination failure.

In addition, using HCl to clean surface of oxide layer in advance is helpful for bonding temperature higher than Sn melting temperature since the surface oxide can be effectively removed. However, bonding temperature below Sn melting temperature will degrade bonding results after HCl cleaning due to the serious roughness condition. Fig.2 shows a failure bond due to the serious Sn roughness from surface cleaning before bonding.

The poor wetting ability between Sn and Ti was investigated during sample preparation by thermal evaporation. Figs. 3(a) and (b) show the thin Sn layer assembled and formed spheres while depositing on Ti adhesion layer. Since the morphology of Sn layer actually affects bonding results, it is important to fabricate a smooth and continuous film. Figs. 4(a) and (b) show Sn morphologies of different thickness with the uses of Ti adhesion layer. Obviously it shows that the thicker the Sn layer is, the larger the sphere will be formed. Eventually, those spheres will merge together and form smooth and continuous film.

In addition, Cu layer between Sn and Ti was studied to improve the morphology of Sn layer [5]. Figs. 5(a) and (b) show the Sn morphologies of different thickness with a Cu layer. The thin Sn layer deposited on Cu is continuous and smooth. Therefore, in order to increase adhesive ability, Cu/Ti is suggested to be deposited between Sn and Si. Bonding tests for groups 2 to 5 were then fabricated based on this concept of structure.

Group 2 and group 3 samples indicate that successful Cu to Sn bonding at temperature of 243°C, for both bonding structure with different thickness. A successful bonding result of group 2 at temperature higher than Sn melting was shown in Fig. 6.

Group 4 and group 5 were designed for Sn/Sn bonding test with different Sn layer thickness. By comparing the test results between group 4 and group 5 at bonding temperature higher than Sn melting, it is indicated that thicker Sn layer does help in bonding. This bond failure comes from that the bonding materials for actual contact were scallop IMCs, which were formed before Sn melted [6].

4. Conclusions

This study reports the research of Cu-Sn and Sn-Sn bonding. Bonding results strongly depend on temperature during Cu-Sn and Sn-Sn bonding, especially if the bond temperature is higher than melting point of the metal. In addition to bonding temperature, thickness of Sn layer also affects bonding results during Sn/Sn bonding. The morphologies of Sn layer deposited on Ti or Cu were examined. Increase of Sn thickness is helpful to improve the Sn morphology with a Ti adhesion layer, while thin Sn layer deposited on Cu adhesion layer is continuous and smooth.

Acknowledgements

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References

[1] E. Beyne: Symposium on VLSI technology, April 2006.

[2] K.N. Chen, et al: Digest of IEDM, Dec 2006

[3] K. Sakuma, et al: Proceedings of the 57th IEEE Electronic Components Conference, 2007, p. 627

[4] B. Lee, et al: Journal of Electronics Materials, Vol. 40, No. 3, 2011

[5] H. Liu, K. Wang, K. Aasmundtveit, and N. Hoivik: Electctronic Components and Technology Conference, 2010, p. 853

[6] N.S. Bosco, and F.W. Zok: Acta Materialia 52 (2004) 2965–2972.

Table I Bonding results of 5 different conditions, including bonding temperature, materials, and metal stack thickness.

	Cu-Sn bonding						Sn-Sn bonding			
	Group 1		Group 2		Group 3		Group 4		Group 5	
Structure for bonding	Cu Ti Si	Sn Ti Si	Sn Cu Ti Si	Cu Ti Si	Sn Cu Ti Si	Cu Ti Si	Sn Cu Ti Si	Sn Cu Ti Si	Sn Cu Ti Si	Sn Cu Ti Si
Thick-ness	2000Å 100Å	5000Å 100Å	4000Å 4000Å 100Å	2000Å 100Å	8000Å 7500Å 500Å	2000Å 100Å	4000Å 4000Å 100Å	4000Å 4000Å 100Å	8000Å 7500Å 500Å	8000Å 7500Å 500Å
243℃	O		O		O		X		O	

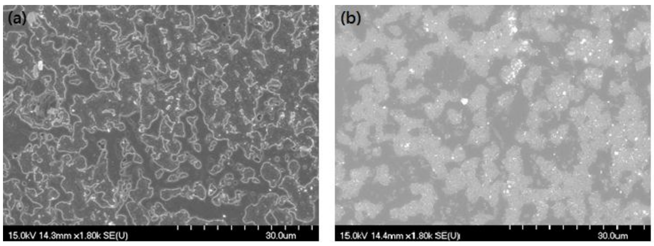

Fig. 1 Top-view SEM images of (a) Cu side (b) Sn side from group 1 sample bonded at 243°C and then delaminated.

Fig. 2 Cu-Sn bond failure samples from group 1 with HCl cleaning bonded.

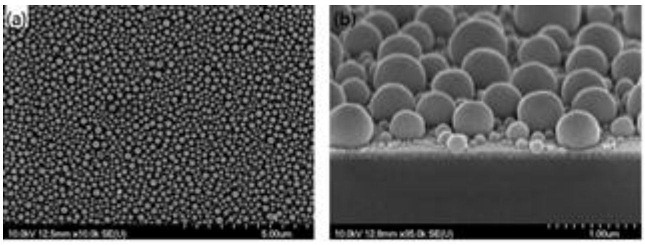

Fig. 3 (a) top-view (b) tilt-view SEM images of Sn deposited on a Ti adhesion layer

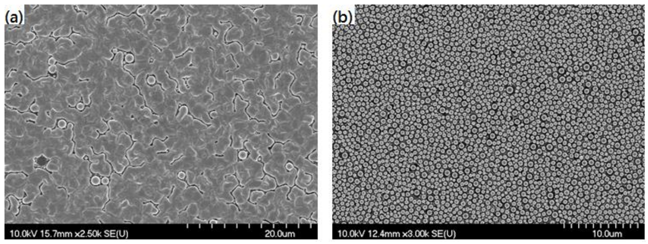

Fig. 4 Top-view SEM images of (a) 600 nm and (b) 400 nm Sn deposited on a Ti adhesion layer.

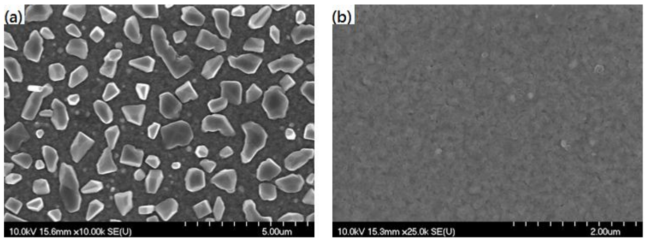

Fig. 5 Top-view SEM images of (a) 600 nm and (b) 100 nm Sn deposited on a Cu layer.

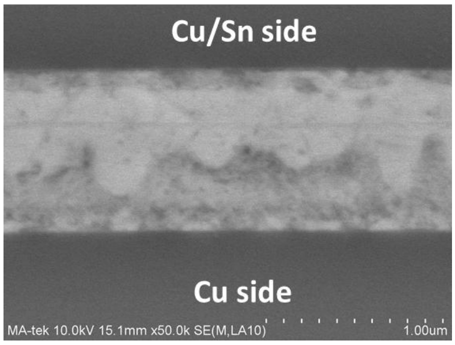

Fig. 6 Cross-sectional SEM image of one group 2 sample bonded at 243°C

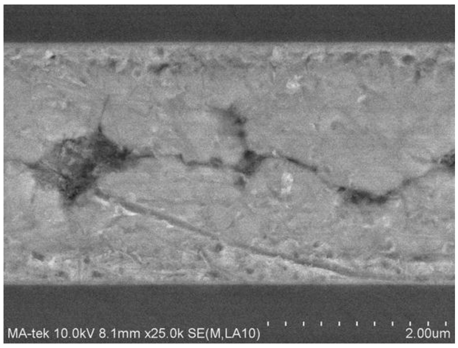

Fig. 7 Cross-sectional SEM image of one group 5 sample bonded at 243°C.