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Regular Article

Effect of Sn grain orientation on formation of Cu_6Sn_5 intermetallic compounds during electromigration

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ABSTRACT

The effects of Sn orientation and grain boundary misorientation on formation of Cu-Sn intermetallic compounds (IMCs) during electromigration were investigated. Significant anisotropic diffusion of Cu in Sn grains was observed. Interfacial Cu-Sn IMCs may grow rapidly, dissolve, or remain intact, depending on the angle of c-axis of Sn grains with the electron flow. In addition, grain boundaries did not play an important role in Cu diffusion because they are mostly cyclic twins.

1. Introduction

Beta-Sn (β-Sn) has a body-centered tetragonal structure and possesses anisotropic, thermal, mechanical and diffusion properties [1–4]. Sn grains are the matrix of main-stream Pb-free solders and thus the Sn grain orientation affect seriously the reliabilities of flip-chip joints and microbumps [5–7]. In particular, the effect of Sn grain orientation on electromigration (EM)-induced failure is a very important issue in flip-chip solder joints [6–9]. It is reported that Sn grains with c-axis cause fast formation of Ni_3Sn_4 intermetallic compounds (IMCs) and early failure in the solder joints [6]. However, anisotropic diffusion of Cu atom in Sn grains is seldom examined. In addition, Tasooji et al. reported that the effect of Sn grain boundary misorientation on electromigration is more significant than that of Sn grain orientation owing to the markedly higher diffusivity along grain boundary than that of lattice [10]. They found that Cu atoms diffused along high-angle grain boundaries and facilitated the dissolution of under bump metallization (UBM). Whether grain boundaries diffusion plays an important role in electromigration of solders is not clear. In this study, Cu/Sn-2.3Ag/Cu microbumps are fabricated and electromigration tests were conducted under current density of 4×10^4 A/cm^2 and 165 °C. Electron backscattered diffraction (EBSD) was utilized to investigated the effect of grain orientation and grain boundary on formation Cu_6Sn_5 IMCs.

2. Experimental

Cu/Sn-2.3Ag/Cu microbumps comprising 7 μm-Cu/16 μm-SnAg/7 μm-Cu and of 30-μm diameter were fabricated using thermal-compression bonding (TCB). The bonding of 10 N was achieved at 250 °C for 3 s. The sample was then cooled by an air gun at a cooling rate of about 10 °C/s.

A Daisy chain layout consisting of 40 microbumps was adopted for electromigration tests. The applied current density was 4×10^4 A/cm^2 at 165 °C. Current stressing was terminated when the resistance of the layout reached 2% of its initial value. After grinding and polishing, the microbumps were analyzed utilizing backscattered electron image (BEI, Supra 55 FE-SEM, Zeiss), and the Sn grain orientation was examined using EBSD (Oxford, equipped in Supra 55 FE-SEM, Zeiss) orientation image mapping (OIM) in the normal direction (ND, the direction vertical to the Si substrate). Image processing was conducted with TSL OIM Analysis 7. For easy understanding of the relationships between c-axis and electron flow in the microbumps, α-angle defined as the angle between the c-axis of Sn and ND is adopted to describe the orientation of Sn grains in this study.

3. Results and discussion

When the α-angle exceeds 70°, no obvious IMC formation was observed after electromigration tests. Fig. 1(a) shows the as-fabricated Cu/Sn2·3Ag/Cu microbump. The thicknesses of Cu_6Sn_5 IMCs at the top and the bottom of Cu-solder interface are 1.5 and 2.97 μm, respectively. The reason for the thicker IMC on the bottom side is attributed to Cu thermomigration during TCB. Fig. 1(b) and (c) presents the

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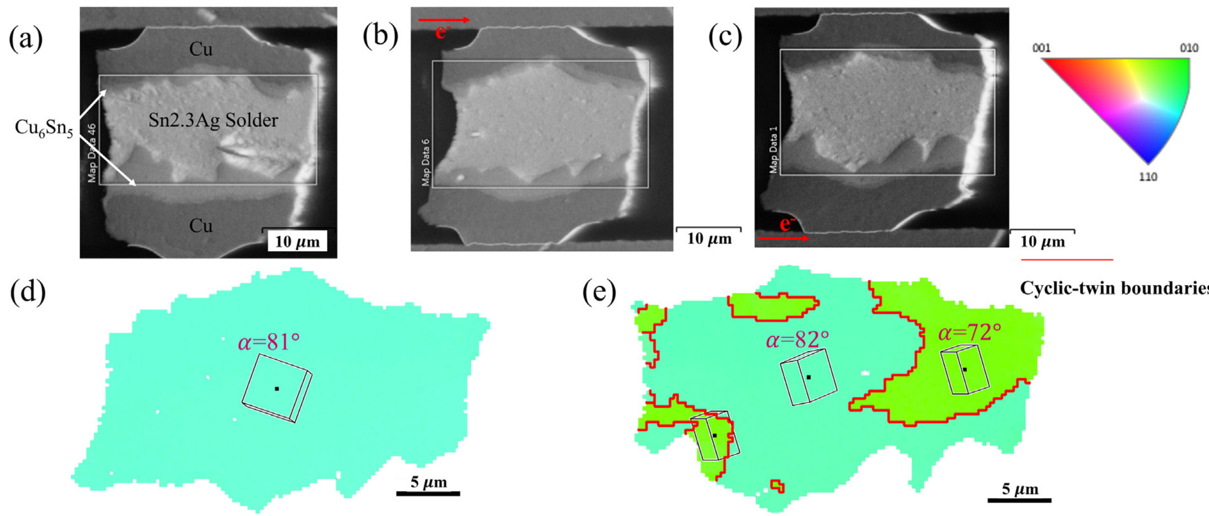

Fig. 1. (a) Cross-sectional SEM image for an as-fabricated Sn-Ag microbump with Cu UBMs. Microstructural changes observed after electromigration by 4×10^4 A/cm^2 and 165 °C for 65 h (b) with a downward electron flow and (c) with an upward electron flow. (d) OIM image for the microbump in (b); and (e) OIM image for the microbump in (c).

microstructures of two microbumps after the electromigration test with opposite electron flow of 4×10^4 A/cm^2 at 165 °C for 65 h. Comparing Fig. 1(b) and (c) with Fig. 1(a) revealed no obvious changes in interfacial IMC thickness, regardless of the directions of electron flow. Fig. 1(d) illustrates the EBSD OIM image for the microbump in Fig. 1(b). The image pole figure (IPF) is also shown in the figure. The Sn lattice is labeled schematically in the grain. The solder consists of a single grain with α-angle of 81°. Fig. 1(e) presents the OIM image of the microbump in Fig. 1(c). There are four grains in this cross-sectional structure, but all of them have α-angles exceeding 72°. In addition, the grain boundaries in this microbump are all cyclic twins, as labeled in Fig. 1(d), and there is little IMC formation along the cyclic-twin boundaries. Owing to the high-angle grains and cyclic twins, the diffusion of Cu in the two microbumps is very slow, resulting in no obvious change in interfacial IMC thickness of the microbump after current stressing. However, extensive formation of Cu-Sn IMCs occurred in the Sn grains with low α-angles.

Fig. 2(a) and (b) presents two microbumps after the same current stressing conditions with an opposite electron flow. Extensive formation of Cu_6Sn_5 IMCs was observed with serious dissolution of Cu in the cathode end of both microbumps. Some of the IMCs even bridged the joints. Fig. 2(c) shows the EBSD results for the microbumps in Fig. 2(a). The remaining grains with extensive IMC formation have α-angles of 13° and 10°. However, the grains on the left-hand side have α-angles of 82° and 59°, and they did not have obvious IMC growth. Fig. 2(d) illustrates the grain orientation for the remaining grains in Fig. 2(b). As can be seen, the grains have low α-angles of 17° and 25°. Taken together, these results indicate very rapid IMC formation in grains with low α-angles and different IMC formation behavior in grains with intermediate α-angles.

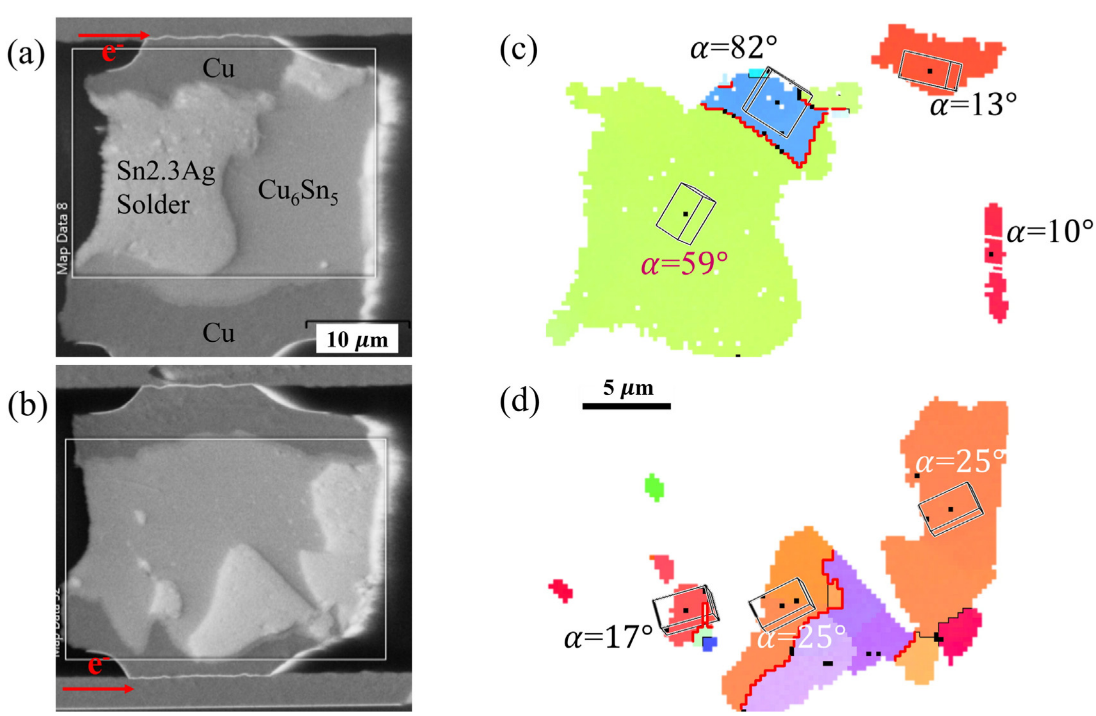

Fig. 2. Rapid formation of Cu-Sn IMCs in low-α-angle grains after current stressing of 4×10^4 A/cm^2 and 165 °C for 65 h. SEM image for the microbump (a) with a downward electron flow and (b) with an upward electron flow. (c) Corresponding OIM for the microbump in (a) and (d) corresponding OIM for the microbump in (b).