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Formation mechanism and orientation of Cu_3Sn grains in Cu–Sn intermetallic compound joints

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ABSTRACT

The formation mechanism and orientation of Cu_3Sn grains in Cu–Sn intermetallic compound (IMC) joints formed on polycrystalline and (100), (111) single crystal Cu substrates at 300 °C were investigated. The results showed that when IMC joints were composed of Cu_3Sn and Cu_6Sn_5 phases, columnar Cu_3Sn grains grew in clusters at the expense of Cu_6Sn_5 phase. In addition, the Cu_3Sn grains growth direction was parallel to the Cu_6Sn_5 grain boundaries in the middle layer of the IMC joints. When the Cu_3Sn grains from the opposite sides contacted each other, grain growth stopped. Some small equiaxed Cu_3Sn grains were found both at the Cu/Cu_3Sn interfaces and in the Cu_3Sn contact areas in the middle of the joints. A preferred orientation of Cu_3Sn (100) crystal plane being parallel to the Cu substrate was found, which was unrelated to the orientation of Cu substrates.

1. Introduction

Three-dimensional (3D) package is generally considered to be the primary packaging technique in the coming period due to its low power consumption, low signal latency and high density integration [1–4]. Through Silicon Via (TSV) is one of the most important technologies for 3D IC integration [5,6].

As a kind of low temperature bonding method, solid–liquid-interdiffusion (SLID) bonding provides low thermal stress, high melting point and highly reliable electrical interconnection for TSV technology [6]. Also the Cu/Sn/Cu system has been widely used in 3D integration. At present, the diameter of a TSV joint is about 10–20 μm [7] and will continue to decrease following the trend of higher-density integration. As a result, the joints are entirely composed of intermetallic compounds (IMCs) and the pads may be comprised of only one grain. Some findings recently have revealed that Cu_6Sn_5 grains had a preferred orientation with polycrystalline and single crystal Cu substrates [8–12]. Gong et al. [10] found that the scallop-type Cu_6Sn_5 grains forming on polycrystalline Cu substrate had a preferred orientation of the Cu_6Sn_5 (0001) plane being parallel to the Cu substrate. Results from Zou et al. [11] had shown that the prism-type Cu_6Sn_5 grains forming on (001) and (111) Cu substrates were elongated along two perpendicular directions and along three preferred directions with 60° angles. And this result was consistent with what Suh et al. [12] had obtained before. Shang et al. [13] found preferential growth of Cu_3Sn at the interface of SnBi/(100) Cu substrate by TEM. However, the preferred orientation was quite different from that found in this paper. Since anisotropic properties of Cu_6Sn_5 and Cu_3Sn grains [14–16] can largely influence the mechanical and electronic behaviors of Cu–Sn IMC joints, this paper investigated orientation of Cu_3Sn in Cu–Sn IMC joints on polycrystalline and on single crystal Cu substrates separately by the electron backscattered diffraction (EBSD) method.

2. Experimental materials and method

In this study, polycrystalline oxygen-free Cu and (100), (111) single crystal Cu with the sizes of $3 \times 3 \times 1$ mm^3 were employed as Cu substrates and 99.9% pure Sn foils with the thickness of 30 μm were used as solders to fabricate the sandwich structure Cu/Sn/Cu joint. Before soldering, the surfaces (3×3 mm^2) of the Cu substrates were grinded and polished to ensure the Cu/Sn bonding interfaces were clean and smooth. After being aligned with a specially designed clamp, the joints were bonded by SLID method at 300 °C with the bonding force of 20 N and argon protection for 10 min, 30 min, 45 min and 70 min. All the joints were air-cooled to room temperature. Afterwards, the cross sections of the joints were carefully ground and polished for EBSD measurement.

3. Results and discussion

Fig. 1 shows the cross-sectional SEM images of (100) Cu/Sn/Cu samples bonded at 300 °C for different time. In the beginning (Fig. 1a), Cu_6Sn_5 and Cu_3Sn layers near the residual Sn formed on the original Cu/Sn interfaces. The morphology of Cu_6Sn_5 grains was between prism-type and scallop-type. At the same time, Kirkendall

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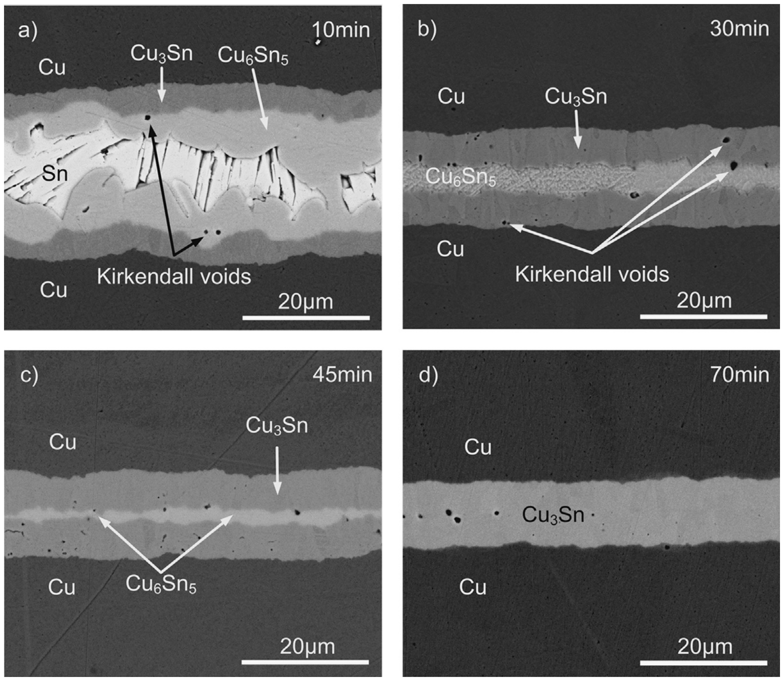

Fig. 1. Cross-sectional SEM images of (100) Cu/Sn/Cu samples bonded at 300 °C for different time: (a) 10 min, (b) 30 min, (c) 45 min, and (d)70 min.

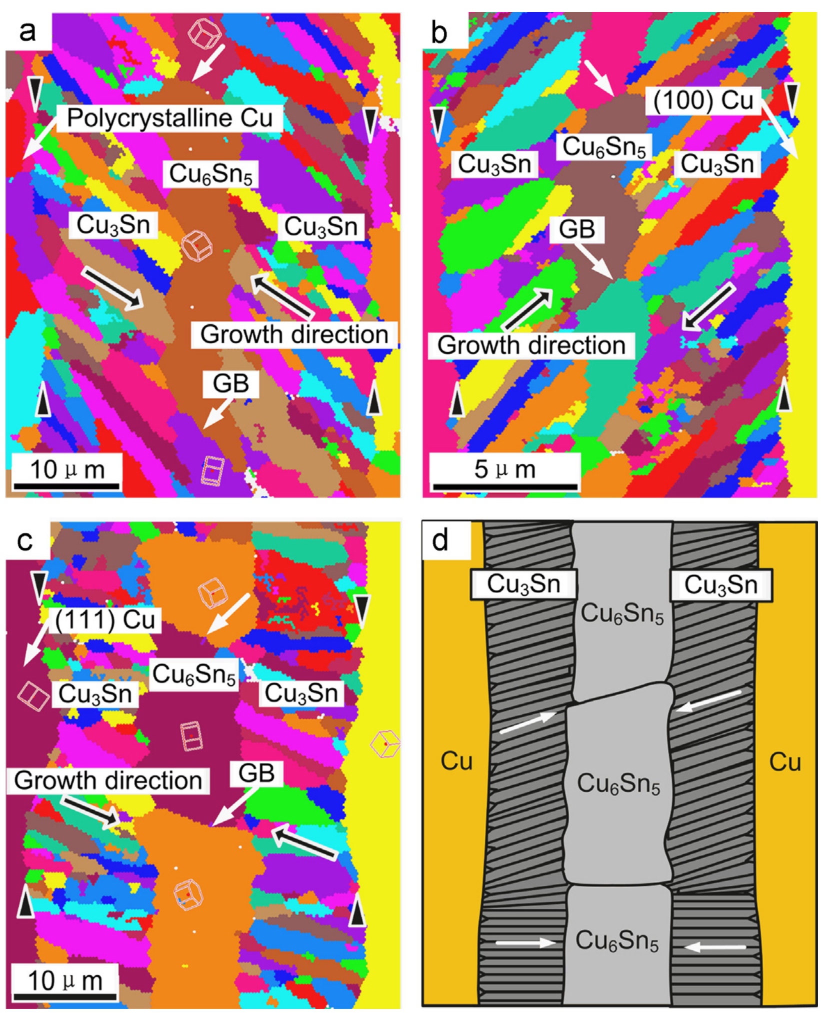

Fig. 2. Cross-sectional grain mapping images of Cu/Sn/Cu samples bonded for 30 min on various kinds of Cu substrates: (a) polycrystalline Cu, (b) (100) Cu, and (c) (111) Cu. (d) Schematic diagram for the joint after 30 min.