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Growth behavior of tin whisker on SnAg microbump under compressive stress

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ABSTRACT

Tin whiskers with different morphologies form on SnAg microbumps under long-term compressive stress. High resolution transmission electron microscopy results reveal that dislocations and stacking faults can be found inside tin whiskers and the neighboring grains, and the twin boundaries are irregular regions with twinning dislocations. The dislocations can slip from the adjacent grains into the tin whisker grains through the twin boundaries, resulting in whisker growth under compressive stress. The findings are of great significance to the study of tin whisker on isolated Sn-based solders and provide insights into the reliability of 3D electronic packaging.

Tin whiskers have been studied for several decades, and are still a serious concern for the electronics industry. Sn or Sn-based alloys are still the primary electronic solders, whether it is traditional electronic packaging or 3D stacked interconnect applications. Sn materials are easy to form whiskers under various environment, like high temperature and humidity, thermal cycling, mechanical stress, and even room temperature storage [1–4], which will lead to short circuit of electronic devices. Sn-Pb solder was used to inhibit whisker growth for a long time, but it has been forbidden since 2006 because of the toxicity of lead [5]. Therefore, a variety of lead-free alloy solders, for example SnAgCu(SAC), SnAg, SnCu, have been developed, but none is able to suppress the growth of tin whisker effectively [6–8]. Although the addition of Bi [9] can inhibit the growth of tin whisker, it is not clear that whether Bi is harmful to the human body.

The growth behavior of tin whiskers has been extensively studied and there are many mechanisms for the formation of tin whiskers, for example, dislocation theory [10], oxidation crack theory [11,12], recrystallization theory [13], compressive stress theory [14,15], etc. Although there is no theory that can explain all phenomena, it is generally accepted that compressive stress is the driving force of tin whisker growth [16]. However, the origin of the stress may come from a variety of sources, including residual stress [17,18], oxidation and corrosion [19,20], intermetallic compound (IMC) growth [5,21–22], thermal cycling [2,23] and mechanical deformation [24–26]. Meanwhile, the long range diffusion of tin atoms is required during the growth of tin whisker [27]. Therefore, the growth of tin whisker is essentially the result of the continuous diffusion of tin atoms under the action of stress gradient.

However, most of literature research on tin whisker is focused on Sn-based coatings and films, board-level and flip-chip solder bumps [28]. There are scarce literature data for scaled-down isolated solders, and it is important to study the growth behavior of tin whisker on isolated solder volumes with the decreasing size of 3D stacked interconnect. K.N. Tu [29] reported that whiskers grew on a microbump with a diameter of 20 μm, consisting of a 10 μm SnAg on a thick Cu under bump metallurgy (UBM), after reflow and storage at room temperature for a while. But no whisker was observed after inserting Ni barrier layer to prevent IMC formation between SnAg and Cu. G. P. Vakanas [30] reported that “whisker-like” features were observed on 3D solder-capped Cu microbumps with a diameter of 20 μm after storage at high temperature and high humidity, which might be caused by local stress gradients induced by differential molar volumes between reactant metals and IMCs. Nonetheless, tin whiskers found by K.N. Tu were on a thick Cu UBM rather than Cu microbump or pillar, and the structure reported by G. P. Vakanas was “whisker-like” features rather than whisker. So, in fact, the phenomenon that tin whiskers form on solder-capped copper microbumps or pillar has not been reported in the literature.

The capped solders on Cu microbumps are inevitably under local stress induced by electricity and heat [31–34] in practical application. Electromigration of Sn-based Pb-free solder bump is able to accelerate the depletion of IMCs and UBM, which leads to significant damages to the joints [35–37]. Thermal cycling induces stress caused by the mismatch of coefficient of thermal expansion of different composition,

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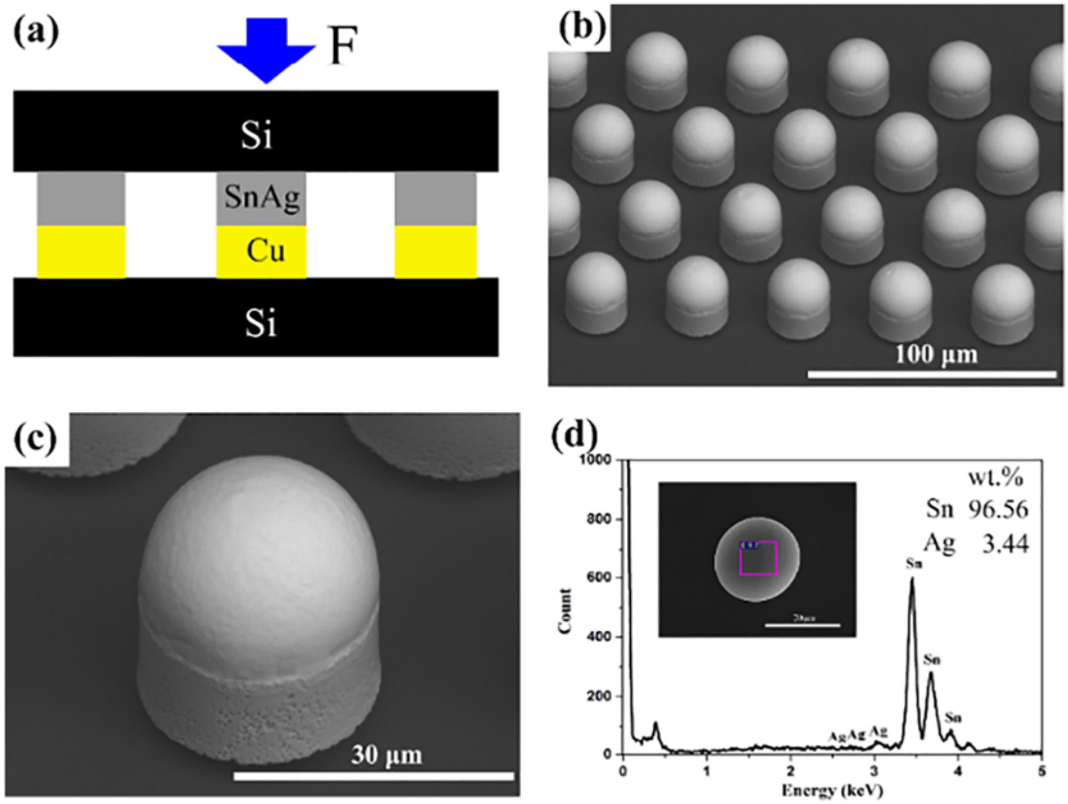

Fig. 1. (a) Schematic diagram of microbumps under compressive stress. (b, c) SEM images of microbumps with different magnifications; (d) EDS of SnAg capped solder.

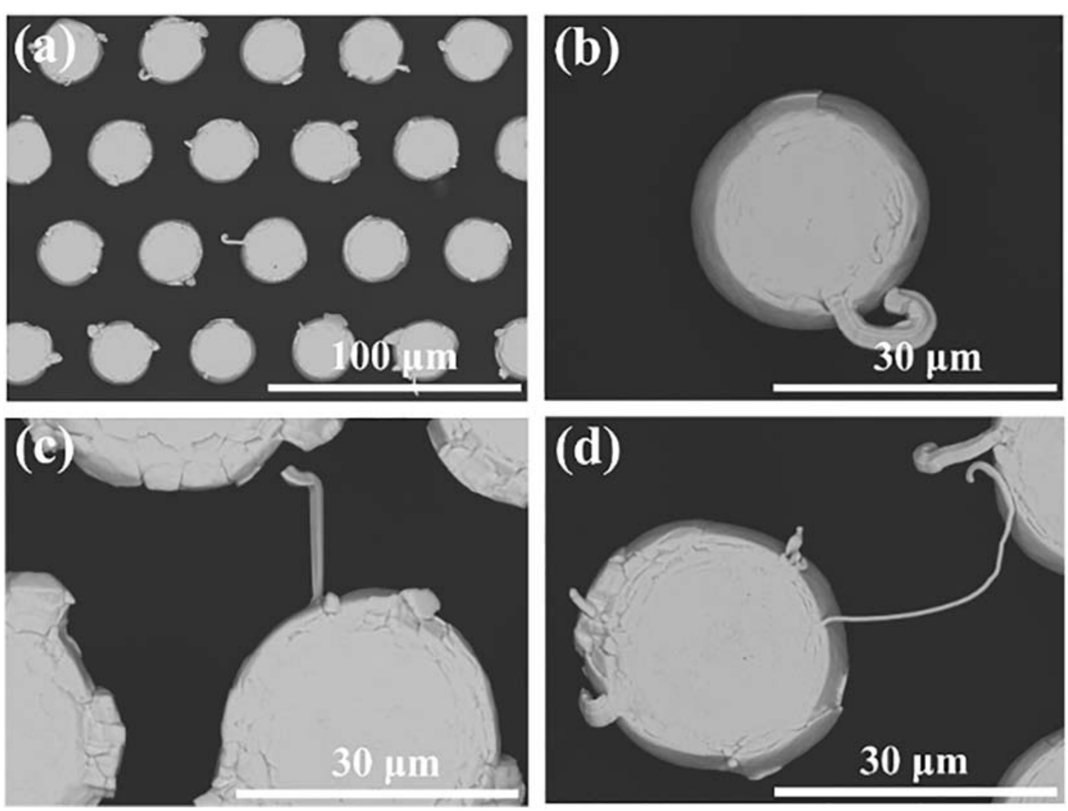

Fig. 2. SEM micrographs of tin whiskers on SnAg capped microbumps after pressure test. (a) SEM micrographs of microbumps after plastic deformation. (b, c, d) SEM micrographs of different shapes of tin whisker on microbumps.