Journal of ELECTRONIC MATERIALS, Vol. 36, No. 12, 2007 *Letter*
DOI: 10.1007/s11664-007-0284-4

Microstructure Development of Mechanical-Deformation-Induced Sn Whiskers

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The development of the microstructure of mechanical-deformation-induced Sn whiskers on electroplated films has been examined using a focused ion beam system (FIB). The 6-μm-thick matte Sn films were compressed by using a ZrO_2 ball indenter under ambient conditions. After compression, tin whiskers and small nodules were found adjacent to, and several grains further away from, the indents. The cross-sectional microstructures of the indents and whiskers indicate that the lateral boundaries of the newly created grains caused by recrystallization are the main routes for stress relaxation.

Key words: Sn whiskers, FIB, microstructure, grain-boundary diffusion

Whiskers are single-crystal filament-type grains. Sn whiskers have frequently been found in electronic products. Long whiskers could cause short circuits, and they are important for the reliability of electronic products. Compressive stress is the major driving force for the growth of tin whiskers. The sources of compressive forces are interfacial reactions, thermal cycling, oxidation, and electromigration, and have been examined quite intensively.[1–6]

In flexible electronic and optoelectronic packaging, leads of flexible flat cable/flexible print circuit (FFC/FPC) connectors and electroplated thin films are joined together by mechanical locking.[7] Mechanical compressive forces in the flexible packaging joints may result in whisker formation. These forces are introduced during whisker-formation acceleration tests,[4–6] but few studies of the mechanisms of whisker formation induced by mechanical deformation can be found in the literature.[5,6]

The study examined mechanical-deformation-induced whiskers by using a focused ion beam (FIB) system (FB-2100, HITACHI, Tokyo, Japan). The specimens were two kinds of 6-μm-thick Sn films electroplated with 10 and 20 A/cm^2 current densities, respectively. Under ambient conditions, the films were fixed on a stage and compressed by a 900-μm-diameter ZrO_2 ball with 300 g-force.[6] After compression, the indenter was removed carefully and the films were examined immediately.

Figure 1a is the top view of the 10 A/cm^2-electroplated Sn film compressed for 240 h. Neither whiskers nor nodules are observed in the deformed region that was in close contact with the ZrO_2 ball. As shown in Fig. 1a and b, whiskers and nodules are formed on the undeformed region encircling the indent. Longer curved whiskers can be found at the region closer to the indentation site while those formed several grains away from the indent are shorter. The electronic industry would especially like to prevent the formation of the longer curved whiskers due to their higher possibility of causing short circuits.

Figure 1c and d shows the FIB cross-sectional micrograph and the schematic diagram of the whisker shown in Fig. 1a and b, respectively. No grain boundaries are found along the Sn whisker, indicating that it is a single crystal. The varying brightness along the whisker is an artifact of the FIB system. It can also be observed that the Sn whisker grain is not in direct contact with the substrate, which is different from most of the other Sn grains. Striations are observed on the surface of the

(Received March 25, 2007; accepted August 16, 2007; published online September 19, 2007)

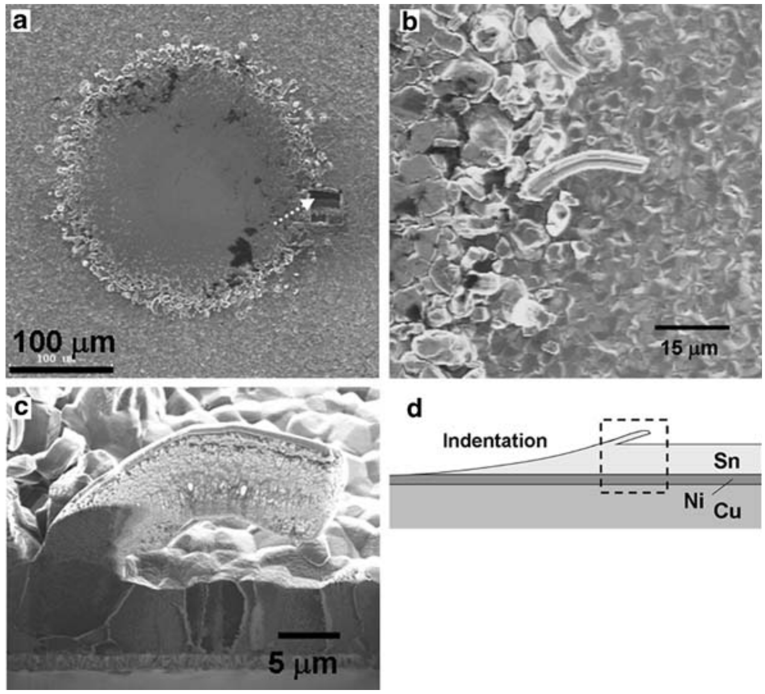

Fig. 1. Specimen of the 6-μm-thick 10 A/cm^2-electroplated Sn film compressed by a ZrO_2 ball for 240 h: (a) the top-view morphologies, (b) a close-up of the whisker and nodules region, (c) FIB cross-section of the Sn whisker shown in (b), and (d) schematic diagram of the selected region shown in (c).

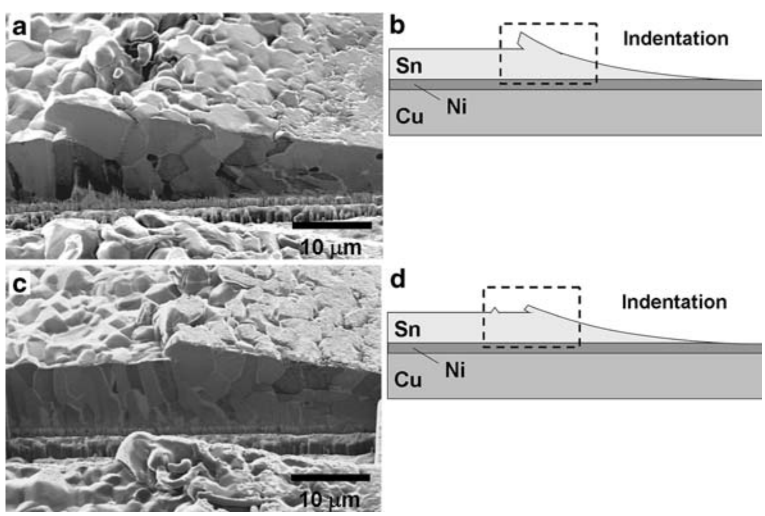

Fig. 2. Specimen of the 6-μm-thick 20 A/cm^2-electroplated Sn film compressed by a ZrO_2 ball for 20 h: (a) FIB cross-section at the deformed/undeformed boundary, (b) schematic diagram of the selected region shown in (a), (c) FIB cross-section of a small nodule, and (d) schematic diagram of the selected region shown in (c).

long whisker, as shown in Fig. 1b. These are similar to the growth facets found in the single-crystal growth of silicon, which is a result of preferred orientation growth,[8] and is an indication that the whisker is indeed a single crystal.

Figure 2a shows the FIB cross-section of the 20 A/cm^2-electroplated Sn film compressed for 20 h. As illustrated in Fig. 2b, the right-hand side of Fig. 2a is the deformed region while the left-hand side is undeformed. The plated columnar structures are retained in the undeformed region. However, in the deformed region, the original plated columnar structures of Sn were destroyed and the grain structures observed in Fig. 2a result from deformation and recrystallization. The grains in the deformed region are flatter and have more horizontal

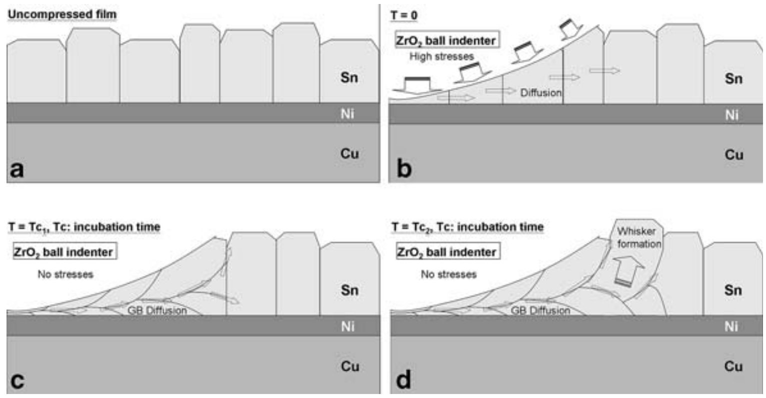

Fig. 3. Schematic diagram for the microstructure development in the mechanically deformed region.

grain boundaries along the direction of the deformed surface. These grain boundaries provide good diffusion channels for atoms and cause the whisker growth shown in Figs. 1c and 2a.

As can be seen in Fig. 1a, some nodules are formed several grains away from the nodules and whisker crammed region. Figure 2c is the FIB cross-section micrograph of the Sn film compressed for 20 h along the small nodule as illustrated in Fig. 2d. Compared with that in Fig. 2a, the microstructure in Fig. 2c is more equiaxed and the whisker grown at the deformed/undeformed fringe is not as significant. A well-known example of an equiaxed structure is the eutectic Sn-Pb electroplated film. Sn-Pb electroplated films exhibit good resistance to whisker formation through uniform swelling.[2] The diffusion rate of Sn through the uncompressed film with the more equiaxed structures shown in Fig. 2c is higher and the accumulation in the whisker at the fringe is relatively smaller.

Under mechanical compression, large stresses are exerted on localized regions. As shown in Fig. 3, recrystallization in the mechanically deformed region creates many new grain boundaries. More of the new born grain boundaries are along the horizontal directions and provide faster diffusion routes of atoms. Sn whiskers at the fringes are formed with the Sn atoms diffuse through the grain boundaries from the compressed regions. However, if the Sn in the undeformed region is not with columnar but with equiaxed structure, more diffusion routes in the undeformed Sn would reduce the accumulation of Sn atoms at the deformed–undeformed fringe and the Sn whisker growth is less significant.

The experimental results clearly indicate that compressive stress induce the formation of whiskers, while their growth depends on the grain microstructures and the grain-boundary distribution. Bending of films in leaded devices also generates compressive stress and thus could result in whisker formation. However, in the case of leaded devices, a tensile region would be created spontaneously together with the compressive region. Moreover, the grain structures of the films would affect the critical stresses for whisker formation as well. Much work is still needed for a quantitative translation of the compression test result in this study to the degree of bending in leaded devices.

ACKNOWLEDGEMENTS

The authors wish to acknowledge financial support from the young researcher interchanging project of the Interchange Association (Japan) and the National Science Council (Taiwan), and equipment funded by the JEITA project (Japan).

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