Scripta Materialia 119 (2016) 9–12

Contents lists available at ScienceDirect

Scripta Materialia

journal homepage: www.elsevier.com/locate/scriptamat

Regular Article

Fracture reliability concern of (Au, Ni)Sn_4 phase in 3D integrated circuit microbumps using Ni/Au surface finishing

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ARTICLE INFO

Article history:
Received 6 October 2015
Received in revised form 22 February 2016
Accepted 23 February 2016
Available online 2 April 2016

Keywords:
Crack
Kirkendall voids
Microbump
Reliability
(Au, Ni)Sn_4

ABSTRACT

Au surface finishing on Ni layer in solder joints can lead to the replacement of β-Sn by (Au, Ni)Sn_4 phase in microbumps. A thorough crack in (Au, Ni)Sn_4 is found after the sample being annealed at 150 °C for 1000 h. Phase transformation of (Au, Ni)Sn_4 to Ni_3Sn_4 and $AuNi_2Sn_4$ is observed. This transformation will lead to −10.5% volume shrinkage and may result in tensile stress, which becomes the reason for a thorough crack formation. Kirkendall voids have been found at the interface between Ni_3Sn_4 and electroplated Ni layer. Marker movement indicates that there was a dominant Ni diffusing flux.

Mobile technologies which enable broad applications with wider data bandwidth, faster response, lower power consumption, and smaller form factors are in demand with the trend of big data and internet of things. Three-dimensional integrated circuit (3D IC) packaging, which combines chip technology and packaging technology by stacking chips together, leading to thinner, smaller, yet higher performance, is currently one of the most promising ways to extend Moore's law. The major challenging technical issue in 3D IC is the vertical interconnection between stacking chips in z-direction. To do so, new structure components in packaging technology have been introduced. They are the through-Si-via (TSV) chips and the microbump solder joints [1–4]. Microbumps are the smallest size solder joints, with diameter of 5–20 μm, developed to interconnect TSV chips vertically for integration in z-direction. (See Figs. 1– 4.)

As the size of solder joints shrinks, many unexpected problems tend to occur. For example, the mechanical properties of solder joints will deteriorate as the percentage of intermetallic compound (IMC) becomes prevailing in the joint with Cu under bump metallization (UBM) [5]. To slow down the Cu–Sn IMC formation, Ni layer has been adopted as an UBM layer above Cu, since Ni–Sn reaction rate is much slower than that of Cu–Sn. However, a new IMC phase of (Au, Ni)Sn_4 or (Pd, Ni)Sn_4 has been found in Pb-free solder microbumps [6,7]. The formation of this phase is due to the surface coating of Au/Pd used on the Ni layer in microbumps. During soldering, the Au/Pd layer dissolves into solder rapidly, forming intermetallic compound (Au, Ni)Sn_4 and (Pd, Ni)Sn_4, causing embrittlement problem [8–11]. The problem can be effectively alleviated by using a thinner layer of Au/Pd in traditional flip chip solder joints, so that the fraction of Au/Pd in the entire solder joint will be less that 5% in order to avoid the well-known problem of "cold joint", in which a large fraction, over 25%, of the brittle $AuSn_4$ or $PdSn_4$ phase forms. However, in microbumps, as the volume shrinks 1000 times as compared to that of flip chip solder joints, the concentration of Au/Pd in solder will be too high [12,13]. In this paper, we will report the fracture reliability concerns of this phase, (Au, Ni)Sn_4, in microbumps. A thorough crack across the entire microbumps and Kirkendall voids at the interface between Ni_3Sn_4 and Ni layer have been found after the microbumps were annealed for a long time.

Test samples as-received and provided by Qualcomm were polished and Fig. 1(a) shows the image of a microbump with (Au, Ni)Sn_4 phase before annealing. Fig. 1(b) shows the corresponding image of a microbump after being annealed for 1000 h at 150 °C. A thorough crack propagated across the microbump. Fig. 2(a) shows the FIB-ion beam image of one microbump with (Au, Ni)Sn_4 phase. The black square frame indicates the area that is shown in the TEM images in Fig. 2(c) and (d). By comparing Fig. 2(a), (c) and (d), we can see that the upper and lower Ni layer have different morphology. The grain size in the upper side Ni layer varies from about less than 100 nm to 1 μm, which is electroplated Ni. The lower side Ni layer seems to be amorphous, corresponding to electroless plated Ni(P). Also, phase transformation has been found after the sample being annealed at 170 °C for 500 h, as shown in Fig. 2(b). By EDS detection, the new phase has the chemical formula of $AuNi_2Sn_4$. This new phase has a brighter contrast in FIB-ion beam images than the (Au, Ni)Sn_4 phase.

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http://dx.doi.org/10.1016/j.scriptamat.2016.02.025
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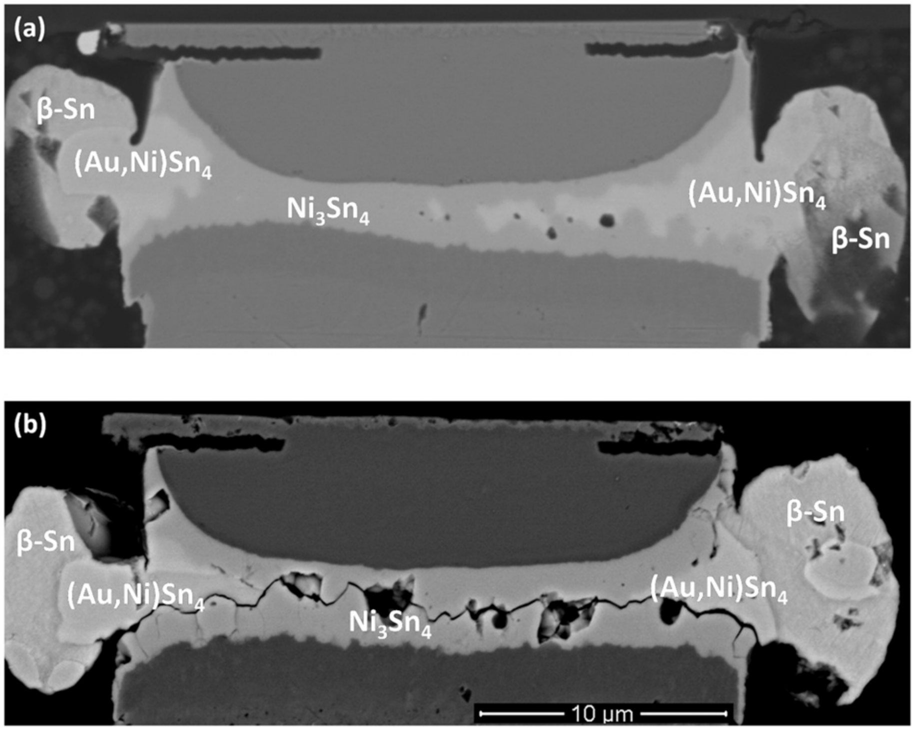

Fig. 1. SEM images to show the thorough crack (a) before, and (b) after the annealing of 1000 h at 150 °C.

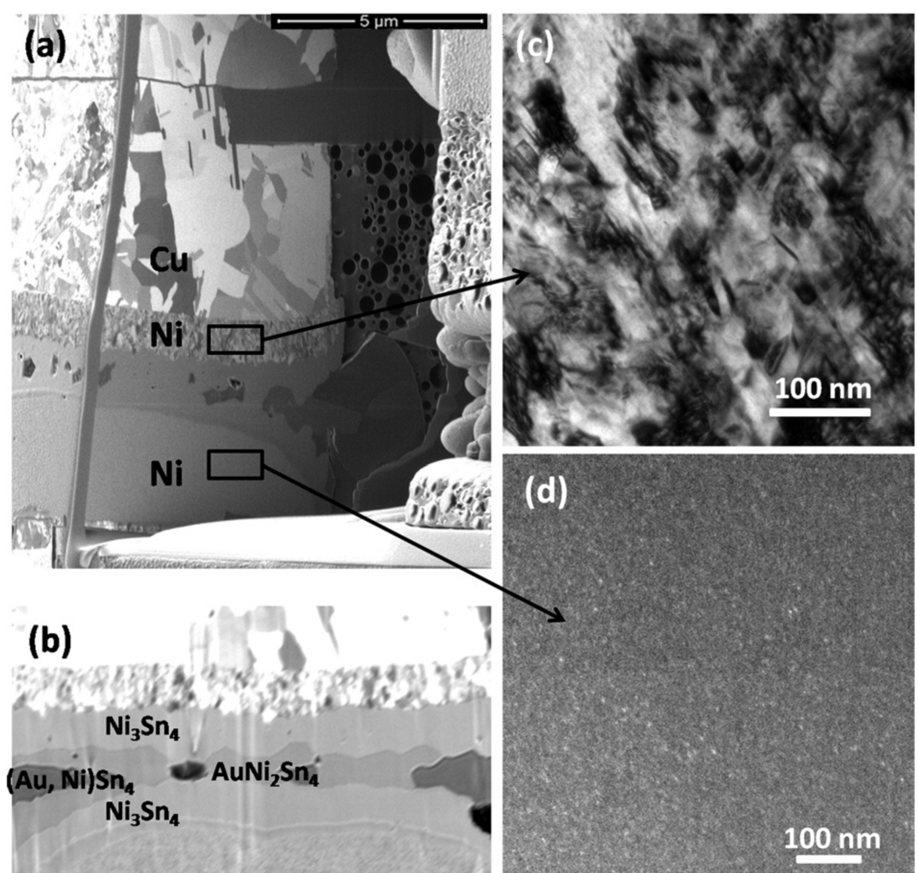

Fig. 2. (a) FIB-ion beam image of one microbump, (b) FIB-ion beam image of one microbump after being annealed at 170 °C for 500 h, (c) and (d) TEM images of the upper and lower Ni layers, respectively.