Microelectronics Reliability xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Power electronic assemblies: Thermo-mechanical degradations of gold-tin solder for attaching devices

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ARTICLE INFO

Article history:
Received 22 June 2016
Accepted 6 July 2016
Available online xxxx

Keywords:
High temperature applications
Power modules assembly
Severe ageing cycles
Reliability
AuSn 8020
Voids
Solder cracking
Intermetallics growth
FEM simulations

ABSTRACT

The eutectic $Au_{80}Sn_{20}$ solder alloy has been applied in semiconductor assemblies and other industries for years. Due to some superior physical properties, Au/Sn alloy gradually becomes one of the best materials for soldering in electronic devices and components packaging but the voids growth in AuSn solder joints is one of the many critical factors governing the solder joint reliability. Voids may degrade the mechanical robustness of the die attach and consequently affect the reliability and thermal conducting performance of the assembly. Severe thermal cycles [−55 °C/+175 °C] have highlighted degradations in AuSn die attach solder. The inspection of as-prepared die-attachments by X-ray and SEM (observation of cross-section) shows that the initial voids sizes were increased and a propagation of transverse cracks inside the joint between voids has appeared after ageing, it was featured also the existence of the IMC typical scallop-shape morphology with the phase structure of $(Ni, Au)_3Sn_2$ on as-reflowed joints. In this paper, we evaluate the origin of these degradations and ways to address them.

1. Introduction and context

The investigation into the use of Pb-free solders as a replacement for the commonly used Pb–Sn solders has been initiated by environmental concerns over the use of lead in microelectronic packaging applications [1,2].

In general, high-tin alloys are available as lead-free solder alloys. However, only a few of the alloys that can replace high-Pb solders have high melting temperatures. One candidate is the eutectic 80Au–20Sn solder (71Au–29Sn by molar content); this hard solder has an attractive melting point of 280 °C. Despite the continuous effort in electronic industries to produce better die bonds, voids have persistently existed in the bonding layers. These voids have been identified non-destructively using X-ray and destructively by sectioning and polishing [3].

The presence of voids reduces the reliability of the devices. It is well known that voids in the solder layer tend to generate localized stress on the die-attach, which may cause cracking when they are subjected to thermal cycling. Furthermore, excessive IMC growth may have a negative effect on the joint strength due to its brittle nature and kirkendall voids resulted from unbalance diffusion of different atoms [4]. Therefore, ageing degradation of the solder joint in electronic packages is critical concern in microelectronics industry.

In the present study we conduct an interfacial reaction study on Cu/Si_3N_4/Cu AMB-substrate. We evaluate the interfacial reaction behaviors during rapid temperature cycling (RTC) [−55 °C/+175 °C].

The results of detailed study on the interfacial reaction linked with microstructural evolution will expand understanding of the reliability of AuSn solder joint.

2. Experiments description

2.1. Description of the test vehicles

The test vehicles used in this study are composed of 15 A–1200 V SiC diodes from CREE assembled on AMB-substrates made of Si_3N_4 ceramic with copper metallization, nickel plated and gold finish.

The power semiconductor die is bonded on the substrate using AuSn solders (see Fig. 1). Thicknesses and materials of different layers of the substrate are illustrated in Table 1.

2.2. Accelerated ageing

The test vehicles were aged by rapid temperature cycling (RTC): thermal cycling from −55 °C to +175 °C, 20 minute dwell time for

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http://dx.doi.org/10.1016/j.microrel.2016.07.028
0026-2714/© 2016 Published by Elsevier Ltd.

Please cite this article as: F. Arabi, et al., Power electronic assemblies: Thermo-mechanical degradations of gold-tin solder for attaching devices, Microelectronics Reliability (2016), http://dx.doi.org/10.1016/j.microrel.2016.07.028

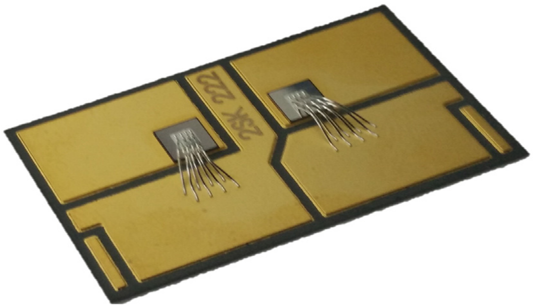

Fig. 1. Test vehicles, showing the SiC die (4.79 × 4.79 mm^2) connected with 8 aluminum wire bonds.

high and low temperature levels and 10 °C/min slope for the transition between the two levels (Fig. 2).

Wired bonding chips were used in order to monitor the thermal characterization of the assembly during the ageing test. All test vehicles were put into the thermal chamber before ageing. Regularly, after 500 cycles, some samples were selected to undergo a protocol of destructive analyses (shear, microsection) or non-destructive ones (X-ray, EDX, acoustic microscopy, thermal characterization).

3. Results and discussions

3.1. Evolutions of the interface during (RTC) thermal ageing

After the first read out of samples (500 cycles of thermal ageing), the initial voids sizes (Fig. 3-a) were increased, each initial void has been expanded as shown in (Fig. 3-b), it was observed that the contrast is different between the initial voids and their expansions (Fig. 3-b) which means that the thickness of initial voids is greater than the thickness of their expansions and that was proved using cross-section. The voids sizes haven't changed between 500 and 3000 cycles but a propagation of cracks inside the joint have appeared (Fig. 3-c), it was observed that the important cracks are transverse and propagated between voids, and it is well known that cracks in the joint layer are usually longitudinal but not transverse as in the current case (Fig. 3-c).

Table 1
Thickness of different layers of the assembly.

Layer	Material	Thickness (μm)
Bottom metallization	Cu	200
Ceramic	Si_3N_4	320
Top metallization	Cu	300
Plating	Ni	5
Finish	Au	0.05
Die attach	AuSn	50
Die	SiC	350

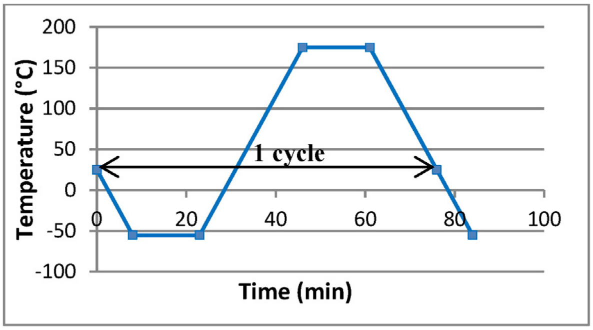

Fig. 2. Profile of thermal cycling.

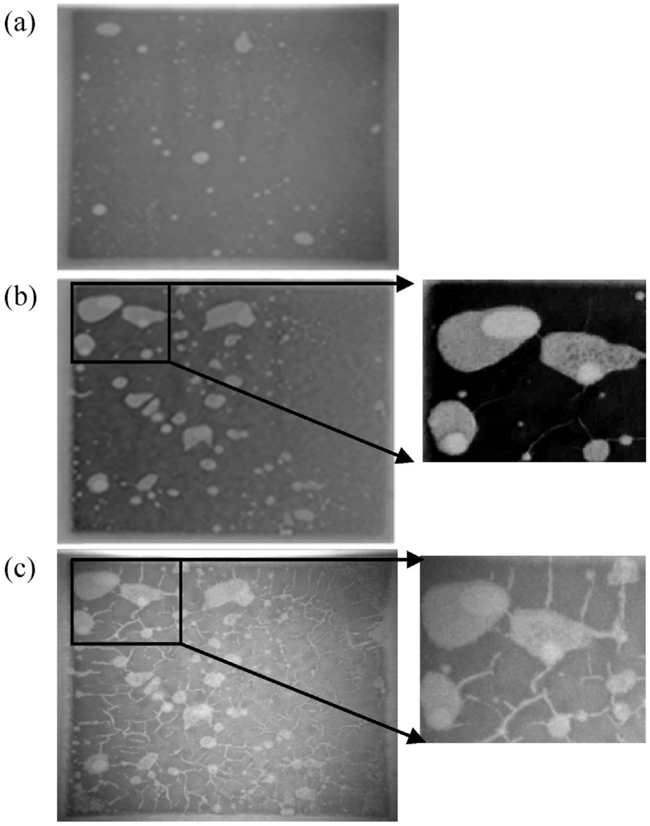

Fig. 3. X-ray images of the same test of vehicle after a) 0 cycles, b) 500 cycles, and c) 3000 cycles.

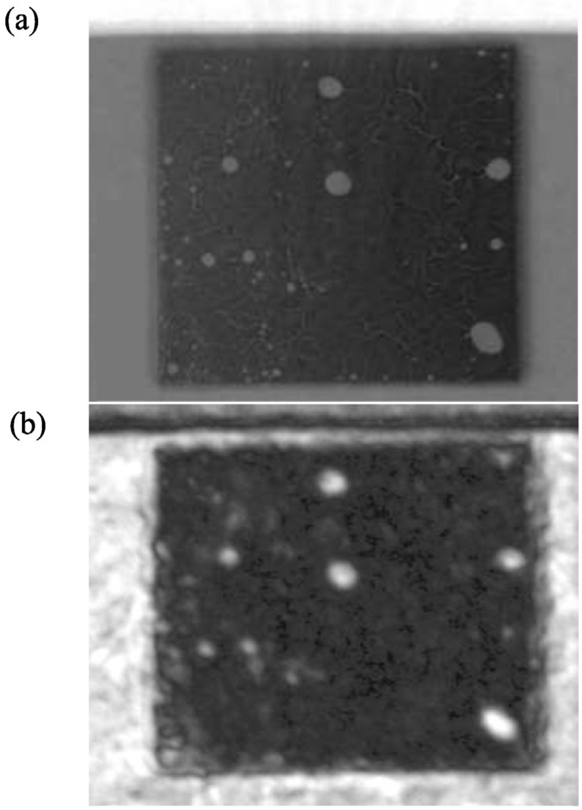

Fig. 4. Images of the same test of vehicle after 2000 cycles. a) X-ray and b) SAM.

Please cite this article as: F. Arabi, et al., Power electronic assemblies: Thermo-mechanical degradations of gold-tin solder for attaching devices, Microelectronics Reliability (2016), http://dx.doi.org/10.1016/j.microrel.2016.07.028