Microelectronics Reliability 80 (2018) 29–36

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Experimental analysis of Sn-3.0Ag-0.5Cu solder joint board-level drop/vibration impact failure models after thermal/isothermal cycling

Jian Gu[a,b], Jian Lin[a,*], Yongping Lei[a,*], Hanguang Fu[a]

[a] College of Materials Science and Engineering, Beijing University of Technology, 100 Ping Le Yuan, Chao Yang District, Beijing 100124, China
[b] China Electric Power Research Institute, 13 Hao Tian Bei Da Jie, Fang Shan District, Beijing 102401, China

ARTICLE INFO

Keywords:
Solder joint
Failure performance
Drop/vibration
Thermal/isothermal cycling

ABSTRACT

Sn-3.0Ag-0.5Cu board-level lead-free solder joint drop (1000*g*, 1 ms)/vibration (15*g*, 25–35 Hz) reliability after thermal (− 40–125 °C, 1000 cycle)/isothermal (150 °C, 500 h) cycling was reported in this study. The failure performance of solder joint and testing life were analyzed under design six testing conditions (1. Single drop impact, 2. Order thermal cycling and drop impact, 3. Order isothermal cycling and drop impact, 4. Single vibration 5. Order thermal cycling and vibration 6. Order isothermal cycling and vibration). The results revealed that the pre-cracks initiation during thermal cycling do not affect the solder joint drop impact reliability, but decrease the vibration reliability. The formation of voids weaken both drop and vibration reliability of solder joint. After thermal cycling, the crack initiated from β-Sn near IMC layer, and continued propagation through the same path when under second in order vibration impact. But propagation path turn to IMC layer when under second in order drop impact. The drop life increases from 41 times to 49 times, and vibration life decrease from 77 min to 45 min. After isothermal cycling, the formation of voids let the cracks occurred at IMC layer under second in order no matter drop impact or vibration. The drop and vibration life is 19 times and 62 min respectively.

1. Introduction

Solder joints serve as mechanical and electrical connection for components and circuit board [1,2]. It suffers complicated loading when electronic product under working condition, such as electrical, thermal and mechanical loading [3–5]. So the reliability problem of solder joint is always a popular investigative area for manufacturers or consumers. However, smaller size and higher function demands for electronic products will damage this problem enormously [6–9]. Because the smaller size of solder joint directly decrease the connection intensity, and higher function of electronic products need the higher density of solder joint which will increase the service temperature and electric current density as well. So, it's important to study the solder joint reliability under various loading conditions. This research will benefit for enhancing mechanical and electrical properties, and predicting working life [10,11].

Under drop impact, a fraction of the kinetic energy of the product will be converted to sound and frictional heat energy, a portion to elastic and plastic strain energy in the product housing, and the rest to elastic and plastic strain energy of the interior components including PCB, BGA and solder joint (mainly) [12]. So the solder joint is the key point for product failure. The typical failure mode of solder joint under drop impact (1500*g*, 0.5 ms) is brittle fracture, and cracks along the intermetallic compound (IMC) layer [13,14]. But it will enhance the testing cost if research the failure of solder joint under product level drop impact. Also the design of product effects the testing result obviously. The failure of solder joint derives from the bending of PCB. So the method of study the failure of solder joint under board level drop impact is the efficient way. It not only reflect the failure mechanism of solder joint under drop impact, but also can provide the meaningful result for the product design. Under vibration impact, the failure modes generally are converted from ductile fracture to brittle fracture with the increase of vibration intensity [15]. Many articles have been published about the reliability of solder joint under drop/vibration impact, such as the various impact condition, package structure, materials and so on [16–18]. But there is one question need to be taken into attention that mostly experiment results focused on the single loading condition, which cannot reflect the solder joint failure mode under real service condition due to the neglect of thermal effect. Under thermal/isothermal cycling [19,20], the failure of solder joint was induced majorly by (1) Sn, Cu atoms unequilibrium diffusion, (2) the coefficient of thermal expansion of various materials mismatch, which is a slowly

* Corresponding authors.
E-mail addresses: gujian1208@emails.bjut.edu.cn (J. Gu), linjian@bjut.edu.cn (J. Lin), yplei@bjut.edu.cn (Y. Lei).

https://doi.org/10.1016/j.microrel.2017.10.014
Received 16 June 2017; Received in revised form 23 September 2017; Accepted 15 October 2017

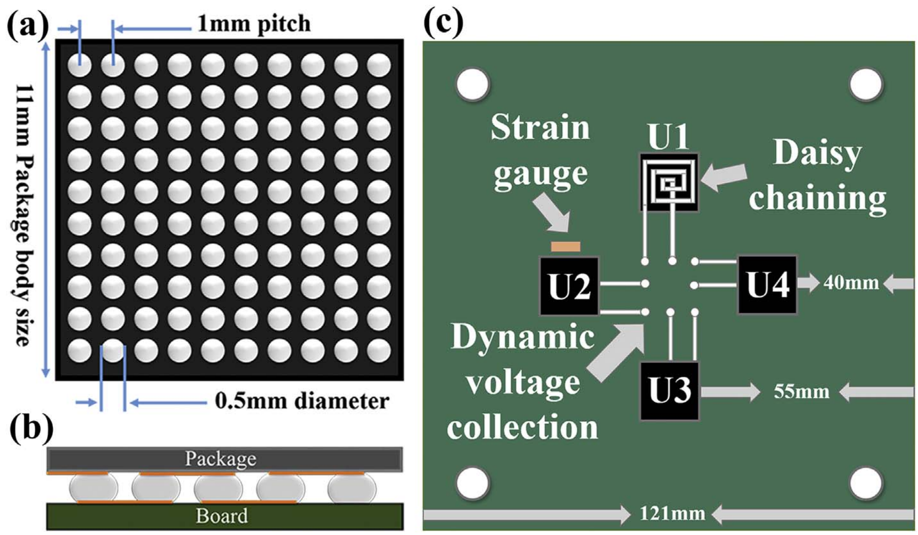

Fig. 1. (a) BGA sample configuration (b) schematic side-view after the board assembly (c) schematic illustration of the test board.

Table 1
Test board stack-up and material.

Board layer	Thickness (μm)	Material
Solder mask	20	LPI
Layer 1	35	Copper
Dielectric 1–2	65	RCC
Layer 2	35	Copper
Dielectric 2–3	190	FR4
Layer 3	35	Copper
Dielectric 3–4	65	RCC
Layer 4	35	Copper
Solder mask	20	LPI

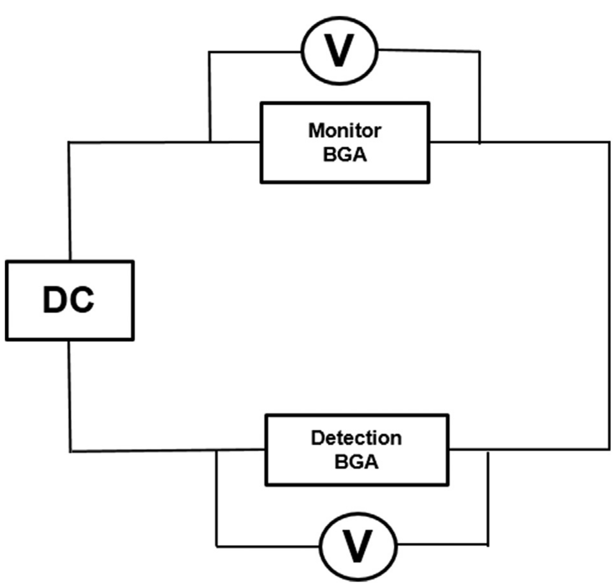

Fig. 2. Schematic illustration of the dynamic voltage monitoring system.

failure process. So the solder joint failure mode may be changed if we combine various loading together. But this experiment method needs high demand for thermal test equipment due to the huge inertance impact force during drop/vibration impact, especially for drop impact (a few test organizations have vibration and temperature combinational test equipment). Zhang et al. [21] studied the effect of elevated temperature on PCB responses and solder interconnect reliability under vibration loading, and reported that temperature significantly affects PCB frequency-strain responses causing the differences of vibration loading intensity. For drop impact, it's hard to combine temperature together in the same time. Lee et al. [22] designed a test method that Cu trace coil were embedded at the fourth layer of the PCB, and a fixed elevated temperature can be controlled at 80 °C by input electric current (Joule heat). But it cannot control the thermal cycle. Zhang et al. [23] designed a sequential thermal cycle and drop impact method to researched the failure mechanism of Sn-Ag-Cu lead-free solder interconnections. From a practical standpoint, the accident drop impact mostly occurred after a period of service. On the one hand, this method solved test equipment problem. So it's an effective test method to study the effect of thermal/isothermal cycling on the reliability of board level solder joint under drop/vibration impact.

In this paper, Sn-3.0Ag-0.5Cu (SAC305) board-level lead-free solder joint drop (1000g, 1 ms)/vibration (15g, 25–35 Hz) reliability was studied after thermal (− 40–125 °C, 1000 cycle)/isothermal (150 °C, 500 h) cycling. The failure mode and test life of solder joint under order thermal/isothermal cycling and drop/vibration was compared with single drop/vibration, and the failure mechanism was discussed.

2. Experimental procedures

As shown in Fig. 1(a), the samples used in this study were 11 mm × 11 mm body size BGAs, with 10 × 10 arrays and a total of 100 solder joints. The solder ball diameter was 0.5 mm, and they were arranged in the package with a 1 mm pitch, which is the distance between the center-points of each solder ball. The composition of the solder balls used in this study was SAC305. The package side had a silicon die attached and a Ni layer. Each solder joint was connected in daisy-chained, as revealed in Fig. 1(b). Fig. 1(c) shows that four independent CABGA packages (10 × 10 matrix, daisy chain connector) were mounted on a square test board, which was connected to a fixture (350 × 350 × 25 mm) with four screws. Between the board and the fixture, a 10 mm standoff was added to allow for PCB bending. The thickness and material for each layer of PCB were shown in Table 1.

A novel and simple method was developed to measure the dynamic voltage of the daisy-chained solder joints in real time during the impact [24]. The schematic circuit is illustrated in Fig. 2. Two identical BGA units were used for measuring the voltage. One of them was placed in the test board and denoted as detection BGA (R1). The second BGA unit was left in a safe position and denoted as monitor BGA (R2, R1 ≈ R2,