Microelectronics Reliability 54 (2014) 2053–2057

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Evaluating board level solder interconnects reliability using vibration test methods

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ARTICLE INFO

Article history:
Received 3 July 2014
Accepted 8 July 2014
Available online 10 August 2014

Keywords:
Solder interconnect
Vibration test
Reliability

ABSTRACT

In this paper, three types of accelerated test methods based on vibration loadings are conducted and compared for board level mechanical reliability evaluation. The first type is fixed frequency sine vibration. The second type is swept sine vibration within a narrow-band of frequency. And the third type is swept random vibration within a narrow-band of frequency. The PCB responses were recorded using a high speed strain data acquisition system. The eigenfrequency of test boards were obtained with the FFT (Fast Fourier Transform) of the strain data of the PCBs during vibration. The PCBs' responses under different tests are compared. The failure processes were monitored and characterized. Results show that the vibrating amplitude is highly dependent upon the frequency ratio. The variation of PCBs' eigenfrequency may cause the difference of loading amplitudes for fixed frequency vibration, which reduced the repeatability and comparability. The other two vibration methods within a narrow-band frequency could eliminate the influence from the frequency variation of the test boards. The differences of these methods are the loading density and repetitions. The failure processes of the three types of test methods are similar. Four failure stages were found from collected failure data. Weibull plot results show the characteristic life of the solder interconnects which are verified with loading repetition.

1. Introduction

Board level package reliability under mechanical shock has always been a great concern for electronic products. As a result of "short to market" demand for new electronic products, a great effort has always been made toward developing more efficient methods for reliability assessments. Vibration test methods have been widely used to evaluate the solder interconnects reliability. To produce large amplitude vibration loading, some test methods apply constant vibrating frequency at 1st eigenmode of the PCB [1–3]. Equivalent strain amplitude can be obtained by adjusting resonant vibration condition to be in accordance with JESD22-B111 standard for drop impact test [4]. Similar failure modes are also observed in failed samples of these two test methods. As the resonant vibration method is much more efficient and controllable than drop impact test method, it can be employed in studying the reliability of shock impact reliability. However, the eigenfrequency of each board can be slightly different, which may cause big difference of loading amplitude. Even the boards with the same dimension, layer structure and materials, can be different for different lots or manufacturers. Some vibration methods are proposed to set random vibration within a frequency band [2,5,6], which cover the eigenfrequency interval and induce the largest loading amplitude. However, evaluating reliability with different test methods require good understanding about the similarities and differences of these methods. There is still a lack of understanding about the failure process differences between different test methods.

In this paper, we conduct three types of vibration tests, fixed frequency sine vibration, narrow-band random vibration, and narrow-band swept sine vibration. The loading intensities and features are compared with the results of strain measurements. The failure processes are monitored with high speed data acquisition system. The failure feature and life data are analysed. We hope to provide more information for correlating the loading and failure of different vibration test methods.

2. Experimental methods and setup

The vibration test schematic is shown in Fig. 1. During a vibration test, the shaker provides fast loads to the rigid base periodically. The loading acceleration and the frequency could be set as testing parameters in vibration control system. Continuous and periodic acceleration cause the PCB rapid bending similar to the

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http://dx.doi.org/10.1016/j.microrel.2014.07.058
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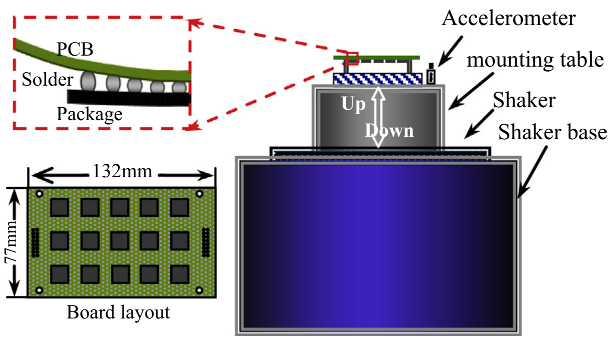

Fig. 1. Vibration tester and PCB assembly layout.

situation in drop test. The failure of the board level interconnect is mainly dependent on maximum peeling stress which is determined by the amplitude and rate of PCB deformation. The stress induced damage accumulates in each cycle. The failure cycle number could be predicted based on the maximum stress within the interconnect structure [7,8]. A larger amplitude and faster loading rate will produce higher stress to the board level assembly. Conducting harmonic vibration at the eigenfrequency of the board produces greatest PCB deflection and cause the largest stress to the interconnect. Test board used in this work is designed according to JEDEC standard JESD22-B111 (see Fig. 1).

During a vibration test, solder resistance increase with its microstructure degradation [9]. And the solder resistance's increase indicates the gradually worse of solder joints integrity. An open circuit indicates the whole break of the solder interconnects. Strain measurements could precisely interpret the PCB dynamic deformation during mechanic shock. A high speed data acquisition system for virtual instrument is designed to conduct synchronal measurements of board strain and solder failure. NI-9237 simultaneous bridge module and NI 9239 analog input modules are used to construct the acquisition platform with CompactDAQ-NI-9188 chassis.

3. Experimental results and discussion

3.1. Fixed frequency sine vibration

As the board deformation is largely dependent on frequency ratio (see Fig. 2). The excited frequency at its eigenmode will induce the largest vibrating amplitude. To produce large amplitude deformation in a vibration with the fixed frequency, vibrating frequency is normally set very close to the eigenfrequency of the assembled board. Strain measurements are conducted to collect the PCB response during a swept sine vibration test. Strain data increase to the largest amplitude when the excited frequency of the shaker swept over the eigenfrequency of the board (Fig. 3). Strain data of the peak amplitude band were analysed using FFT to obtain the eigenfrequency (see Fig. 4). The numerical modelling result of PCBs' 1st eigenmode shows that the length direction dominates the board deformation.

The fixed frequency sine vibration test was conducted with a peak G-level of 20 g and an excitation frequency of 286.5 Hz. Strain measurements depicted the cyclic deformation induced by cyclic alternating vibration, see Fig. 5(a). To characterize the failure process of interconnects during harmonic vibration test, solder resistance is collected and converted to the percentage of breaking area, shown in Fig. 5(b) and (c). The cyclic resistance data is in accordance with the cyclic bending of the board. According to the recorded failure data, the whole failure process of the solder interconnects can be divided into four stages. And for 1st stage, there were no macro-cracks which cause clear breaking. For the 2nd stage, crack initiated and propagated very fast to more than 50% (within 1 s). For the 3rd stage, the propagation slowed down and the damage accumulated gradually. For the 4th stage, the solder interconnects became full open and failed. 1st and 3rd stages performed a typical feature of metal fatigue. While the fast crack propagation in 2nd stage performed obvious brittle break. Therefore, the failure of interconnects during harmonic vibration show a combination failure modes of impact and fatigue. Different factors dominate the failure modes during different stage of failure process. The 1st stage and the 3rd stage takes equally long period. Dye and pry observation of the crack area provided propagation process of solder interconnects during vibration loadings (see Fig. 5d). Cracks normally propagate from both outer-sides in board's length direction.

3.2. Vibration within narrow-band frequency

Fixed frequency sine vibration test method provides the loading with stable G-level and frequency. However, PCBs from different suppliers or lots may perform different eigenfrequencies. As the vibrating amplitude is highly dependent upon the board eigenfrequency, setting the vibrating frequency to one eigenfrequency may cause the variation of vibrating amplitude. Narrow-band frequency vibration test is proposed to eliminate the frequency uncertainty. The vibrating frequency is set within a frequency band width of 10 or 30 Hz including the predetermined eigenfrequency. The frequency data of two lots of PCBs are listed in Fig. 6. It shows that the eigenfrequencies are distributed within a band of 273–295 Hz. The

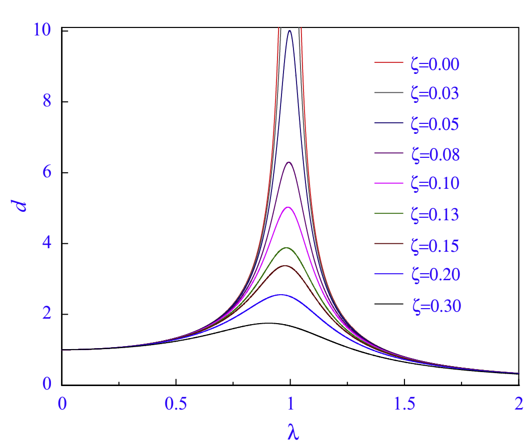

Fig. 2. Driving power coefficient (d) vs. frequency ratio (λ).

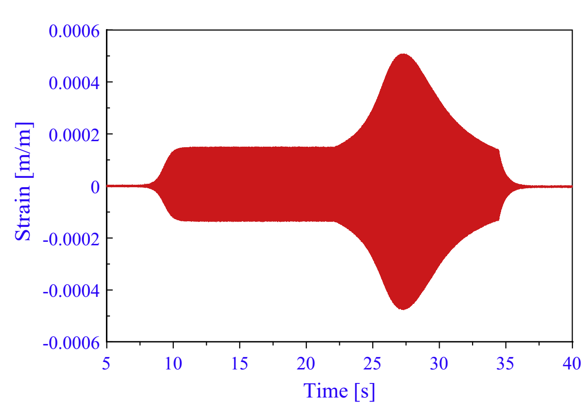

Fig. 3. PCB strain during swept sine vibration test.