Optics and Lasers in Engineering 93 (2017) 9–18

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

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

A general strategy of in-situ warpage characterization for solder attached packages with digital image correlation method

Yuling Niu*, Huayan Wang, S.B. Park

Opto-mechanics and Physical Reliability Laboratory, State University of New York at Binghamton, Vestal, NY 13850, USA

ARTICLE INFO

Keywords:
3-D digital image correlation
In-situ measurement
Warpage characterization
Solder ball attached packages
Facet size and step
Image correlation quality

ABSTRACT

Recently, 3-D Digital Image Correlation (DIC) is widely applied to the reliability analysis of electronic packages, which particularly characterizes the in-situ deformation of ball grid array (BGA) packages. During the image correlation procedure, many parameters influence the accuracy and data integrity of measurement result. Facet (subset) size is the principal parameter and has been studied with much effort. However, the solder balls, which are built on the substrate surface, make the scenario different with the conventional 3-D DIC experiment for the planar samples. The undulant surface generates more obstacles for the successful image correlation. In order to summarize an effective solution of 3-D DIC measurement method for solder balls attached packages, camera angle, facet size and facet step are studied with different BGA packages and different stereoscopic camera systems to achieve the best correlation quality. Also, a novel surface treatment method is introduced to guarantee the surface speckles are generated uniformly on the fluctuant surface.

1. Introduction

Achieving higher integration level of electronic packages demands an effective in-situ warpage characterization method to guarantee the interconnectors' reliability during the reflow process [1–3]. From the aspects of economy and efficiency, conventional reflow method is always selected during the packaging assembly process [4–6]. About 200 °C temperature gap of reflow method generates severe warpage [7–9] and puts the interconnectors at risk of failure [10]. The non-contact and totally in-situ advantages made the 3-D digital image correlation (DIC) a perfect choice to understand the electronic package behavior, especially warpage, during reflow process. It helps to learn the package behavior at each temperature load to analyze the effects of different components and materials of the packages. Compared to the accustomed in-situ warpage measurement technique, like Shadow Moiré [11–13], 3-D DIC is equipped with higher out-of-plane measurement sensitivity (± 1/64,000 of field of view), multi-plateau measurement capability, simpler surface treatment requirement and more uniform heat sources without any gratings on the sample surface in a convection chamber [14–16]. In light of the benefits, 3-D digital image correlation is widely applied in packaging reliability analysis area and becomes the JEDEC standard for package warpage measurement method [17–19].

Upon the birth of digital image correlation technique, many efforts have been made to understand the potential errors during both experiment steps and data post process. Starting from sample preparation step, the speckle size, density and the contrast ratio are the main concerns on the specimen surface [20–23]. During the experiment, the rigid body motion and the out-of-plane deformation may affect the focal quality and generate errors for the displacement calculation [24]. At the post data process, the selection of facet (subset) size, which is the fundamental correlation unit, attracts researchers' attentions and has great effect on the result deviations [25–28]. These works provide good guidance in each DIC measurement step and improve the accuracy of the image correlation result.

However, the objectives of these DIC parameter studies concentrate on the planar tensile test samples. Another important application realm for the 3-D DIC is the warpage measurement of electronic packages. There is no general solution to assist parameter adjustment for the electronic packaging samples. To carry out the in-situ warpage measurement of solder ball attached packages with 3-D DIC, the conventional strategy is to remove the solder balls mechanically or melt the solder balls on the substrate surface to generate a flat surface before the experiment [29,30]. It is destructive and poses the risks of damaging the copper pad. In Fig. 1(a), the blue part is the surface scratch on the copper pad, which is generated by removing the solder balls mechanically. Otherwise, the measurement result suffers from the remaining roots of the melted solder balls on the sample surface (Fig. 1(b)).

To avoid these issues, the warpage measurement of 3-D DIC is attempted to be executed directly with the solder balls on the substrate surface. Through adjusting the camera angle, facet (subset) size and facet (subset) step, a general selection strategy of these parameters is collected and summarized. The minimum facet (subset) size is con-

* Corresponding author.

http://dx.doi.org/10.1016/j.optlaseng.2017.01.008
Received 14 July 2016; Received in revised form 1 December 2016; Accepted 13 January 2017
0143-8166/

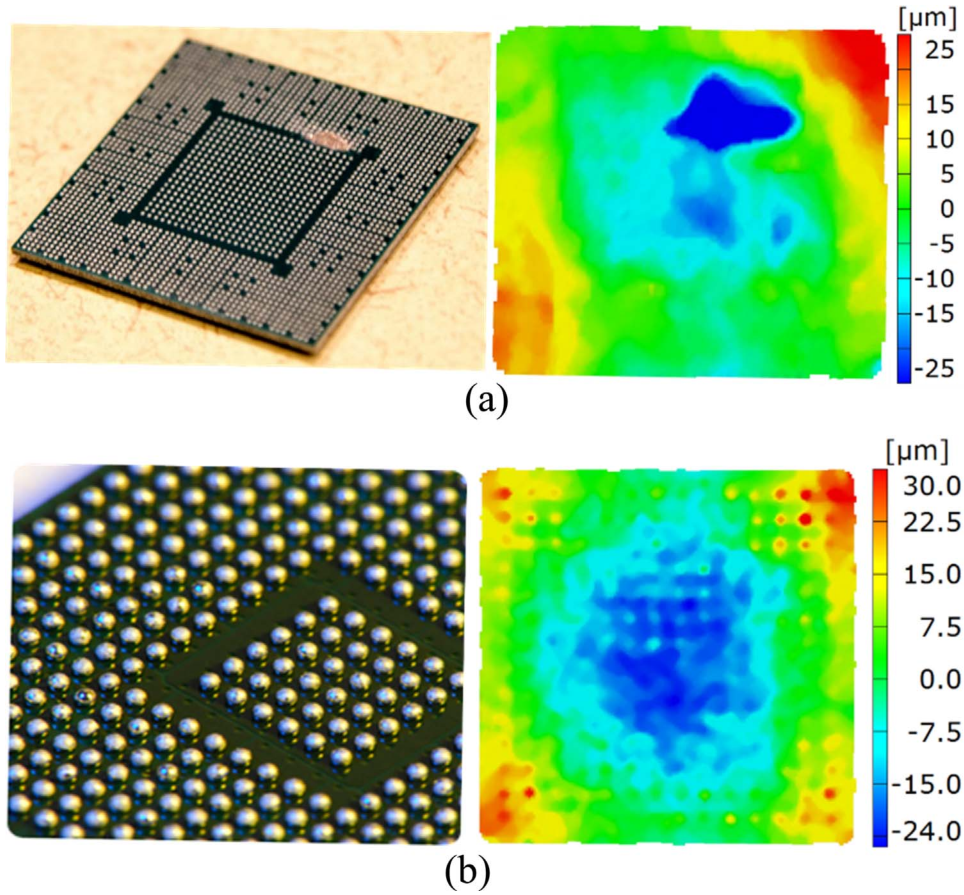

Fig. 1. (a) Surface scratch due to the solder ball elimination on copper pad; (b) The warpage contour of BGA package with the remaining roots of solder balls.

firmed with the literatures to guarantee the systematic error in a low level [25,27,28]. Then the optimal facet size is studied with the standard of data integrity. By measuring three BGA packages with different dimensions and solder ball diameters, the feasibility and effectiveness of this method is demonstrated.

2. Experiment methodology

3-D DIC does not require white painting on the entire sample surface, while the sample surface is required to display patterns or features to be distinguished and traced. For the object surface that has no feature, artificial speckles should be generated on the sample surface. The conventional speckle generation method is dusting. For a flat surface, such as the printed circuit board or metal plate, dusting guarantees formation of a uniform layer on the surface. However, the existence of solder balls on the substrate surface make it impossible to uniformly apply the paint material to cover the substrate surface (Fig. 2). It will produce initial errors due to the surface treatment process.

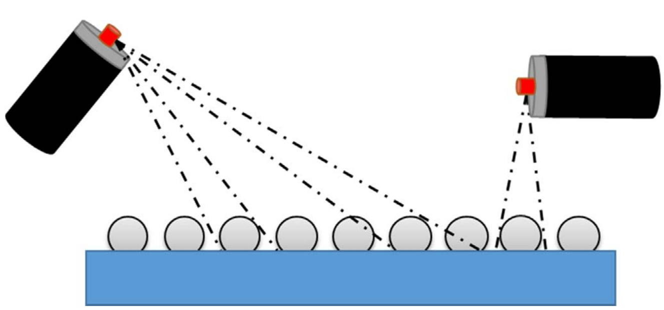

Fig. 2. Schematic of painting process on the BGA package with the solder balls blocking the substrate surface.

To uniformly cover the substrate surface with features, carbon coating is introduced to generate fine black patterns on the fluctuant surface. Originally, this technique helps improve the samples' conductivity of scanning electron microscopy (SEM) test. Carbon powders are equally distributed on the sample surface in the electric field. It guarantees the production of uniform black layer to prevent optical dulling of solder balls (Fig. 3(a)). To generate contrast patterns to be recognized, white spraying patterns are applied on the substrate surface later (Fig. 3(b)).

After settling the pattern generation method, the next issue is to adjust different parameters to achieve optimal image correlation quality. For the successful image correlation, many parameters influence the correlation result, such as the speckle size and density, camera angle, facet size and step, calibration deviation, image contrast ratio and camera shutter time. These factors raised many concerns from previous works to understand their effects on the correlation deviation. During the actual experiment operation, the speckle size and density are hard to resize. The pattern quality and the contrast ratio mostly rely on the investigator's judgement. To some extent, the references of these factors can only improve the accuracy theoretically, not practically. So, this study concentrates on the adjustment of camera angle, facet size and facet step, which can be readily controlled and resized. Considering that the stereoscopic systems have different pixels, the optimal facet size is summarized in a proportion format, instead of a certain pixel amount, to guide all the current 3-D DIC systems to utilize the result based on their system capacity.