Handling of Multi-reflections in Wafer Bump 3D Reconstruction

Jun Cheng*, Ronald Chung†, Edmund Y. Lam‡, and Kenneth S.M. Fung§
*Shenzhen Institute of Advanced Integration Technology
Chinese Academy of Sciences/The Chinese University of Hong Kong, Shenzhen, China
Email: jun.cheng@siat.ac.cn
†Department of Mechanical and Automation Engineering
The Chinese University of Hong Kong, Hong Kong, China
Email: rchung@cuhk.edu.hk
‡Deptartment of Electrical & Electronic Engineering
The University of Hong Kong, Hong Kong, China
Email: elam@eee.hku.hk
§ASM Assembly Automation Ltd., Hong Kong, China
Email: smfung@asmpt.com

***Abstract*—In advanced electronic manufacturing that involves say die-to-die bonding, microscopic surfaces like solder bumps on wafers have to be inspected in 3D. However, because the bumps are of hemispherical shape, light projected onto the bumps could be reflected and illuminate other regions. Such multi-reflections could greatly disturb the intensity distribution in the image data and limit the use of gray level intensities for accurate 3D reconstruction of the bumps. In a previous work, we described a new solution mechanism that was based upon the concept of binary pattern projection, but unlike the traditional mechanisms which use an array of light sources it uses only a single light source. The light source in combination with a binary fringe grating could induce binary pattern on the target surface to be imaged, and the displacements of the binary fringe grating could allow the binary pattern to be varied. In this work, we describe under that solution framework how multi-reflections could be detected and the correct binary signals could be restored. Experimental results on solder bumps validate the feasibility of the proposed approach.**

***Index Terms*—3D reconstruction, wafer bump, multi-reflection, binary pattern projection**

I. Introduction

In advanced electronic manufacturing that involves say die-to-die bonding, microscopic surfaces like solder bumps on wafers have to be inspected in 3D. Yet the tiny size and often highly specular and textureless nature of the surfaces make the task difficult. The size of the entire inspection system is also required to be small so as to minimize restraint on the operation of the various moving parts in the manufacturing process.

There have been a few non-contact optical shape measurement methods proposed in the literature, which can be classified into two groups: scanning and non-scanning techniques. The scanning techniques are represented by laser triangulation [1], [2] and confocal microscopy [3]. Both of them however require complex hardware to function. The measurement processes are also time-consuming because they require one-dimensional, two-dimensional, or three-dimensional scanning to cover the entire surface of the object. Typical non-scanning techniques include Moiré interferometry [4], [5] and fringe pattern projection combining phase shifting [6], [7], [8], [9]. Recently, Gühring [10] pointed out that phase shifting has however a series of drawbacks such as (1) that the phase cannot be recovered precisely while dealing with surfaces with inhomogeneous reflectance function; and (2) that intensity values at a pixel are influenced by those of its neighbors. In summary, the primary limitation is that they obtain three-dimensional information based on analyzing gray-level fringes on the surface. Therefore they suffer from both image brightness saturation and high sensitivity to noise.

Besides, because the shape of every bump is hemispherical, light projected onto bumps could be reflected and illuminate other regions, and such multi-reflections which are observable from Fig. 1 as those small bright dots could greatly disturb the gray level intensity values. All the above limit the accuracy of reconstructing the surface profile by the use of gray level intensities, and in turn by the phase shifting mechanism or the alike.

In an earlier work we proposed a novel mechanism for reconstructing wafer bump surface in 3D [11], [12]. The mechanism was based upon the concept of binary pattern projection, but unlike the traditional mechanisms which use an array of light sources it uses only a single light source. The light source in combination with a binary fringe grating could induce binary pattern on the target surface to be imaged, and the displacements of the binary fringe grating could allow the binary pattern to be varied. More precisely, by shifting the fringe grating in space and every time taking a separate image of the illuminated surface, each position on the illuminated surface would be attached with a binary code in the sequence of the images taken. With a suitable design of the binary fringe grating, the binary code would be unique for each bump surface position. With such binary codes,

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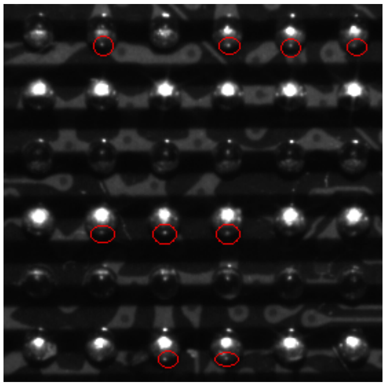

Fig. 1. Typical image of a wafer captured by pattern projection system, which displays the problem of multi-reflections which are highlighted in red circles.

correspondences between image positions and positions of the fringe grating could be established. 3D information about the bump surface could then be obtained over these coded points via triangulation.

In this paper we address how under the mechanism the problem of multi-reflections could be handled. There are two parts to it: detection and correction. The objective of multi-reflection detection is to detect the regions that are influenced by multi-reflection so that we know 3D reconstruction in those regions are unreliable. The objective of multi-reflection correction is to eliminate the influence of multi-reflection and restore the correct information for 3D determination.

The organization of the presentation is as follows. In Section 2, we outline how to eliminate the influence of multi-reflection. In Section 3 we show some experimental results that demonstrate the validity of proposed approach. Concluding remarks are presented in Section 4.

II. Multi-reflection Handling

A. Essence of Binary Pattern Projection System

As shown in Fig. 2, when light is projected onto point B, it will reflect to point A and reach the camera. Therefore, light from B will cause great disturbance of A. Our binary system however could greatly reduce the probability of having a disturbance. In Case I, the light is blocked by the grating so that it cannot reach point A. But light can pass through the grating and illuminate B and then reflected to A. Thus, multi-reflection from B to A will cause a disturbance. In Case II, both A and B are blocked by the grating, so there is no multi-reflection B to A. In Case III, both the direct light and the multi-reflection light from B to A will illuminate A at the same time. However, since we view the data in only the binary sense the multi-reflection will not cause disburance at point A. In Case IV, multi-reflection from B to A is blocked by the grating, and there is no disturbance. From the above analysis, it could be concluded that only Case I will be problematic to our 3D reconstruction, while both Cases I and III could cause error in gray level intensity-based methods.

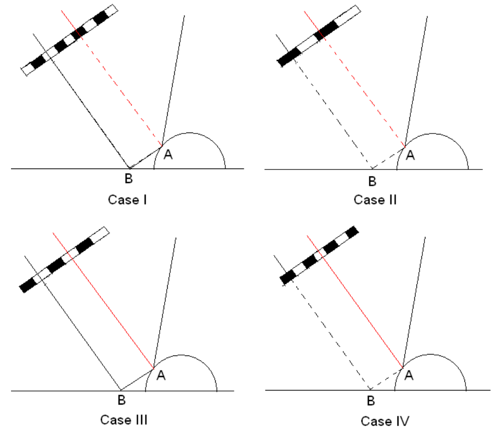

Fig. 2. Typical image of a wafer captured by pattern projection system, which displays problems of image saturation, multi-reflections, and intensity blur or dilution.

B. Detection

For our binary pattern projection based mechanism can establish the correspondence between the reference plane and the inspected surface by codewords obtained from the captured image sequence. These codewords are only determined by the fringe grating portfolio and the grating shifting strategy. A fixed fringe grating portfolio and fixed shifting strategy will produce a fixed valid codeword set Ω. Once the inspected surface is influenced by multi-reflections, the codeword obtained at those positions will change and might not be in the valid codeword set Ω. More precisely, for any arbitrary position P on the inspected surface, a codeword C_P at P can be obtained from the image sequence. If $C_P \notin \Omega$, then C_P is an invalid codeword, which means P might be illuminated by multi-reflections. Fig. 3 illustrates an example of valid codeword set produced by shifting a particular binary grating. The valid codeword set is $\Omega = \{011111, 001111, 000111, 000011, 000001, 100000, 110000, 111000, 111100, 111110\}$. For example, if a position P is disturbed by multi-reflection and the codeword C_P is changed from 000011 to 010011, then its being influenced can be easily detected. Experiments show that many of the multi-reflections can be detected this way.

C. Correction

Because our approach is a binary one, the intensity values in the images will be read as either 1 or 0, which will not be as vulnerable to disturbance as the gray-level intensities. When a number of binary stripes are projected onto an inspected surface, the projected fringes on the image will also be stripe-like. However, if there are multi-reflections, the stripes will appear as ones with some isolated noises. Shown in Fig. 4

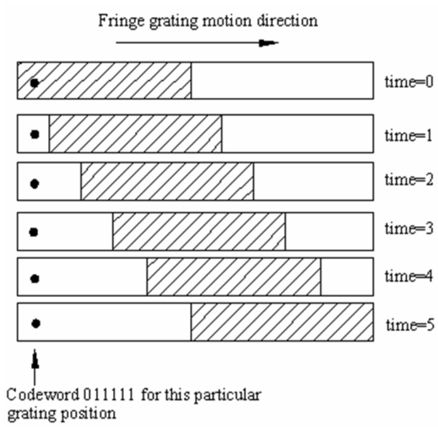

Fig. 3. An example of valid codeword set produced by shifting a particular binary fringe grating.

are some isolated bright regions in black stripes. These bright regions are induced by multi-reflections, and should have their intensity values resume to that of the containing stripe. This way, by identifying the stripe boundaries in the image data correctly (using a method we described in [13]), disturbance from multi-reflections could even be corrected.

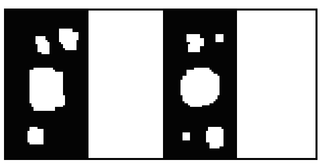

Fig. 4. Bright dots in black stripes are induced by multi-reflections and need be rectified.

Following are a summary of our algorithm:

(i) Use boundary detection algorithm to detect the stripe boundaries.

(ii)In the black stripes, detect the isolated bright regions.

(iii)Set these isolated bright regions to black.

III. Experimental Result

To illustrate the performance of the proposed approach, we have performed experiments on micro-surfaces of hemispheric shape (the wafer bump array). A Ronchi grating with period 200 microns and an incident angle $\theta = 30^\circ$ of projection was adopted. The projection system consisted of an illuminator and several sets of lenses. The grating was shifted in space 5 times, each time by 20 microns. The magnification of the projection system was 3 times, which means the projected pattern would be enlarged 3 times to have a period of 600 microns on the inspected surface. The imaging system had a magnification of 0.75 times, a resolution of 1000×1000, and a pixel size of 7.4 micron $\times$ 7.4 micron in the CCD sensing array.

We projected the same fringe pattern onto a wafer containing many solder bumps. With 5 shiftings of the grating and imagings of the illuminated object, we got the image sequence (shown in Fig. 5) comprising 6 images.

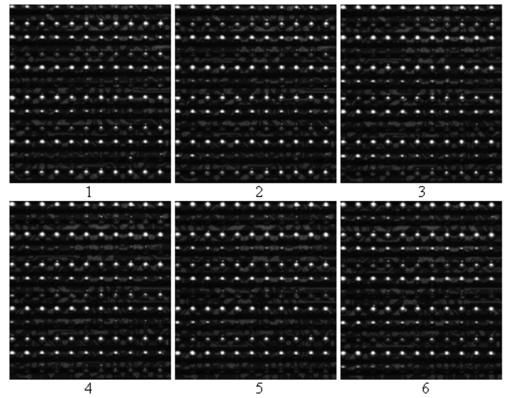

Fig. 5. Image sequence of the solder bumps under projection of a binary pattern. These images were captured by shifting the grating in one-tenth period increments.

It can be observed that many regions in the image data were disturbed by multi-reflections. The first image of the sequence was tried to demonstrate the feasibility of the proposed approach. Fig. 6 illustrates the binarization result of the first image, in which there are many small bright regions in dark bars caused by multi-reflection. Fig. 7 shows the binarization result of the first image, from which we can see that the disturbance from multi-reflections has been eliminated.

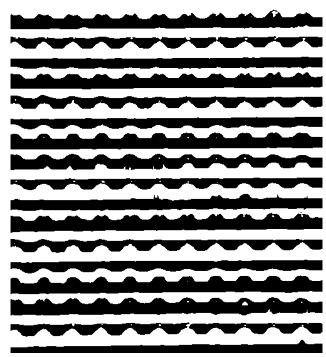

Fig. 6. Binarization result of the first image, from which we can see there are many small bright regions in dark bars caused by multi-reflections.

Using the proposed algorithm, a 3D profile of wafer as shown in Fig. 8 can be reconstructed.

IV. Conclusion and Future Work

The problem of multi-reflections has been addressed in details. The adoption of binary approach itself already reduces much the probability of having disturbance from multi-

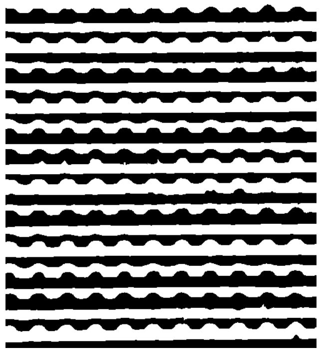

Fig. 7. Binarization result of the first image adopting the proposed method to eliminate the influence of multi-reflections.

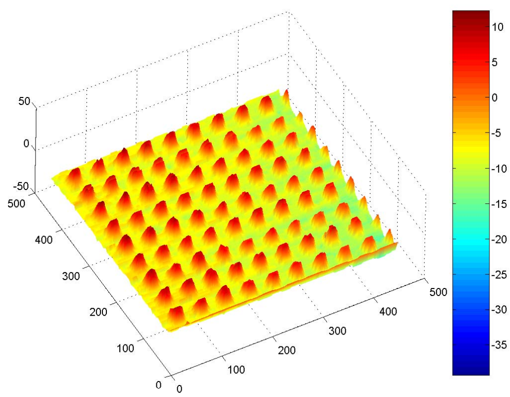

Fig. 8. 3D reconstruction of wafer using the proposed approach.

reflections. Mechanisms that can detect and correct the disturbance have also been described. Experiments on real wafer bumps demonstrate that the approach is effective. Future work will be about how optimal binary fringe pattern could be designed to deal with the multi-reflection problem even more efficiently.

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