The Method to Measure Si Thickness for Bond Line Thickness

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Abstract: Today, many semiconductor products are manufactured through the TSV process. At this time, It is important to manage the Bond Line Thickness because all of the stacked dies must be discarded due to a single contact failure. If we can measure the thickness of the silicon, the BLT in the wafer level package process can be estimated. In this paper, we propose a method to measure the thickness of silicon by using infrared ray. We designed the infrared light source to select the path of the incident light to the objective lens. And this optical system has a characteristic of moving in the opposite direction according to a change in height. By using this optical system, it is possible to calculate the correct in-focus position. By doing this, we present a method to measure BLT by measuring the distance between the top and bottom of Si surface.

1 INTRODUCTION

The Bond Line Thickness (BLT) is one of important measurement items for 3D Integrated Circuits (IC) (Patti, 2006) using Through Silicon Vias (TSV) (Topol et al, 2006) because each chip in the product is directly connected in the vertical direction. When the distance between the layers is increased, The defects such as a head in pillow (HIP) (Liu et al, 2010) (Son et al, 2016) may occur. These types of defects may weaken the electrical connections and reduce the reliability of the product. While it is almost impossible to observe bond joint between bump and pad, many semiconductor production plants manage the BLT to ensure die attach quality and reliability. However, even this method is impossible in the Wafer Level Package (WLP) process. Because it is difficult to measure the BLT sideways because of the neighboring dies. Therefore, we propose a method to measure the thickness of Si without destroying the mass production products. And the BLT in WLP can be measured using this method.

2 METHOD

Figure 1 is the cross-section diagram of chips stacked on the base wafer. The chip consists of a Si layer and metal layers. H is the height of the chip from the base wafer or a previous chip. h_m is the thickness of metal layers of H and h_s is the Si thickness of H. b_2 is BLT and it means the space between chips. The height of chip is sum of Si layer, the height of metal layers and the thickness of bond line. It is possible to calculate b. Generally, the thickness of metal layer is almost the same as the design value. And there are many methods to measure H. Therefore, The BLT in WLP can be estimated by accurately measuring the Si thickness.

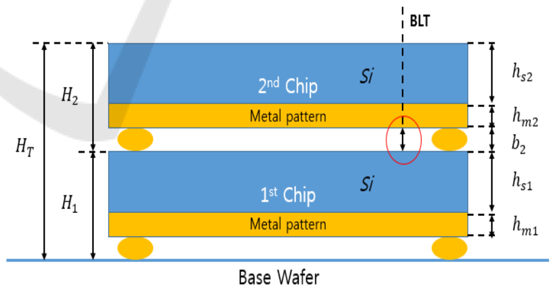

Figure 1: The cross-section diagram of chips stacked on the base wafer.

$$b_2 = H_T - H_1 - h_{s2} - h_{m2} \quad (1)$$

2.1 The Design of Optic

We designed an infrared optical system to measure the thickness of Si without damaging the wafer and chips. Infrared ray has good light transmission property for silicon, so we can get the images

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reflected by the opposite metal pattern through Si. The light incident on the silicon is divided into a signal reflected from the silicon surface and a signal reflected after passing through the silicon. The thickness of the silicon can be measured through the path difference between these two signals.
However, if the thickness of the chip is very large, the gap between the two signals becomes large and it is difficult to measure them simultaneously. And in the opposite case, it is also not easy to measure the distance between these two signals because they overlap each other.

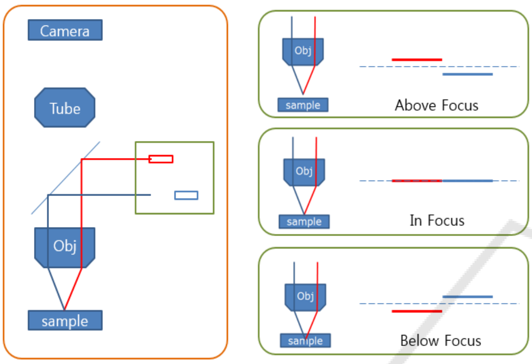

Figure 2: Left: a schematic diagram of an infrared optical system, right: the light paths with focus change.

To solve these problems, we designed optical paths of the light incident on the objective lens as shown in Figure 2 left. This optical system has the capability of confirming the position of the objective lens and focus state.
Figure 2 left is a schematic diagram of the optical system. It is possible to get the signals that move inversely to each other when the focus change. The results are shown in Figure 2 right. In the in-focus state, the light of the two paths is met at one point. However, when the focus changes up and down, it moves away from each other.

2.2 Measurement of Si Thickness

Figure 3 is a schematic diagram of image acquisition in silicon using the optical system of Figure 2. Since the infrared light source penetrates the silicon, infrared light be focused both the top surface of the silicon and the bottom of it. D is the distance between two different in focus position. h_s can be estimated by multiplying D and the coefficient of refraction of silicon and the angle of incidence of the beam.

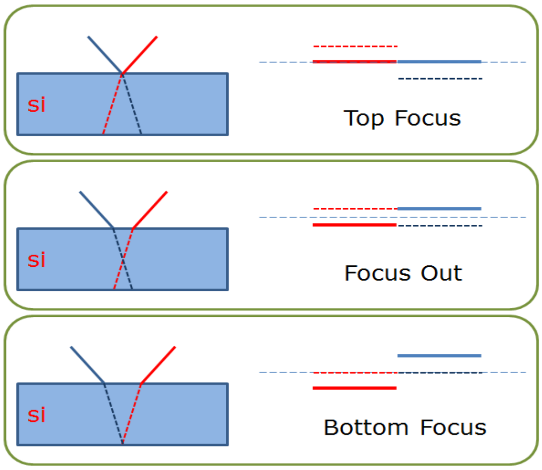

Figure 3: The path of light with different focus position.

Figure 3 is an image acquired at regular intervals in the height direction using the optical system of Figure 2. I(x,y) is the brightness value at the (x, y) pixel position of the image. And C is the y position of the straight line existing in the image. In order to measure C, we calculated the line profile in the y direction and find the center of gravity using the brightness of the image as the weight.

$$C = \frac{\sum I(x,y)\times y}{\sum I(x,y)} \qquad (2)$$

There are two straight lines in the image. C_1 is the position of the straight line calculated in the area on the left side and C_2 is the position of the straight line calculated in the right image. F means how the two straight lines match. This can be obtained from equation (3). At this time, let P be the position where F is the maximum value. This P means the position of in focus.

$$F = \frac{1}{1+|C_1-C_2|} \qquad (3)$$

n_1 is the refractive index in the air, and n_2 is the refractive index of the silicon. P_t is the point where F is the maximum on the silicon top surface and P_0 is the point where F is the maximum on the silicon bottom surface.

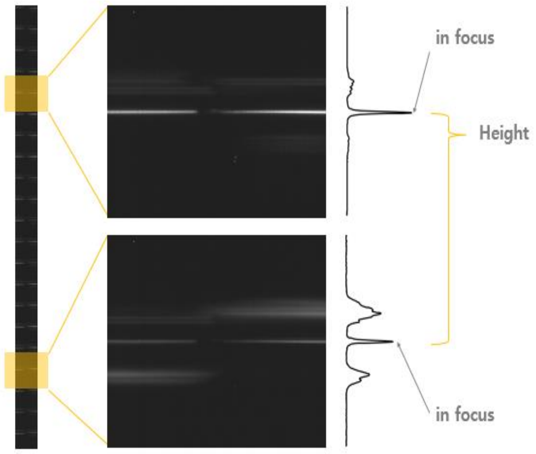

Figure 4: The image acquired from real sample.

And β is a coefficient according to the incident angle of the beam. This is easily measurable using samples already known in height. Therefore, the height of silicon can be obtained via equation (4).

$$h_s = (P_t - P_b)\frac{n_2}{n_1}\beta \qquad (4)$$

3 EXPERIMENT RESULTS AND ANALYSIS

In order to measure repeatability, the same positions were measured five times on each chip. Then, we calculated the variance of these values, and multiply this value by 3 to evaluate it on the 3σ. The repeatability average for these five chips is 0.67µm. In order to measure the accuracy, We measured the specific location of the chip five times. Then, the position was measured with a high resolution microscope and compared. The average accuracy from 5 chips was confirmed at 0.32µm. This result is shown in Figure 5.

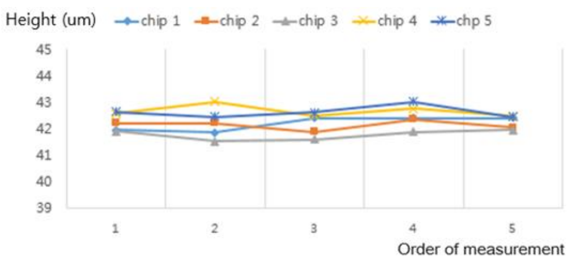

Figure 5: The results of measurement.

4 CONCLUSIONS

An infrared optical system was used to measure the thickness of silicon without destroying the wafer. Infrared illumination was investigated so that the path of light incident on the objective lens could be selected and the focus state could be confirmed. Then, the position of in-focus was calculated by adjusting the height so that the left and right lines match with the image acquired using this optical system. These operations were performed from the upper and lower surfaces, respectively, and the height difference was calculated, and the actual thickness was measured by multiplying this value by the coefficient corresponding to the refractive index of silicon and the incident angle of the beam. The repeatability of the thickness of the silicon measured in such a process is 0.67µm on the 3σ. The measurement accuracy was confirmed on average 0.32µm.

This value is three times better than the production process control standard 2µm. Therefore, by using the method proposed in this paper, it is possible to manage BLT process of wafer level package products.

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