

# FAST THREE-DIMENSIONAL SHAPE MEASUREMENT BY COLOR-CODED ILLUMINATION

Chang Kyu Song<sup>1</sup>, Jeong Sik Kim<sup>2</sup>, Byeong Gwon Joo<sup>3</sup> and Min Gu Kang<sup>3</sup>

<sup>1</sup>Intelligent Machine Systems Center

Korea Institute of Machinery and Materials, Daejeon, Korea

<sup>2</sup>Kafus Co., Ltd., Chungnam, Korea

<sup>3</sup>Intekplus Co., Ltd., Daejeon, Korea

## INTRODUCTION

Three-dimensional (3-D) shape measurement plays an important role in information technology(IT) industries such as semiconductor industry and TFT-LCD industry. Some examples are BGA coplanarity measurement of semiconductor chip and spacer height measurement for TFT-LCD. One feature of these measurements is on-line inspection, so measurement time must be very fast. Light interference methods have been used for measuring 3-D surface profile. The white light scanning interferometry (WSI) is typical method. These interference methods are not suitable for on-line inspection because they need phase-shifting process. The color-coded illumination method does not need phase-shifting process so it is suitable for on-line measurement of semiconductor and TFT-LCD applications [1-6]. In this study, a color-coded illumination method for 3-D surface profile measurement is suggested and it is verified that this method is available for on-line measurement because it is simple and fast. The principle of the method is that color beam of rainbow pattern is projected onto the object and the reflected light beam goes to color line CCD camera in which the color has analyzed to Red-Green-Blue intensities. Then inherent characteristic of the color, hue, is calculated from RGB intensities and the height of the object coincident pixel of the camera is calculated from hue also. RGB intensities have phase difference of 90 degrees respectively so phase-shifting process does not need.

Experimental setup has been built and some experiments have been done. A prism and cylindrical lenses are used to make color beam and the beam size is 500 micrometers. It is showed that the beam size is related to measurement resolution and the thinner beam size leads to the better resolution, so how to make an optical system for thin beam size is mentioned. As a light source, both a halogen lamp of 150W and a metal halide lamp of 250W

have been used and the comparison has carried out in respect of measurement result. Some software algorithm has also been coded such that hue and height are calculated from captured RGB intensities.

## PRINCIPLE OF MEASUREMENT

In this study, color's proper characteristic, hue, is used. Light is projected onto the measuring object and the reflected light is acquired by CCD camera. The hue value is calculated by using CCD pixel intensity.

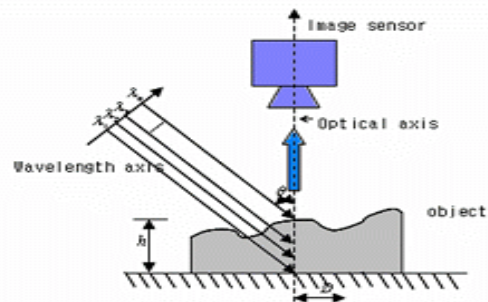


FIGURE 1. Optical geometry of the measuring system

Optical geometry of the measuring system is provided in Fig. 1. As the figure shows, there is measuring object which has shape's height variation in level of decades or hundreds micrometers. Multiple wavelength light is projected onto the measuring object tilting angle  $\theta$  with respect to optical axis and the reflected light is grabbed by image sensor. If the bandwidth of multiple wavelength is same as that of visible light, input light will show rainbow pattern. The image sensor is a sort of color CCD so outputs of image sensor are red(R), green(G), blue(B) intensities. Hue is calculated by using these RGB intensities.

In Fig. 1, if the multiple wavelength illumination light is projected on a point P then color distribution of P is represented as follows;

$$P = \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1)$$

Where R, G, B in equation (1) are red, green, blue intensities, respectively. There is achromatic point A which has equal color intensities with point P and represented as follows;

$$A = \begin{pmatrix} i \\ i \\ i \end{pmatrix} \quad i = (R + G + B) / 3 \quad (2)$$

The representation of the red color is in Eq. (3).

$$R = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \quad (3)$$

The hue value H at the point P can calculate by using the equation (1)~(3).

$$H = \cos^{-1} \left[ \frac{\langle P - A, R - A \rangle}{(|P - A|)(|R - A|)} \right] \quad (4)$$

Where the symbol  $\langle \rangle$  means scalar product. The height H of the P point can be represented by the function of hue value H.

$$Z = f(H) \quad (5)$$

It should be pointed out that the height H is determined by only H and does not relate with  $\theta$ . As the illumination light composed several coherent light or white light are generally used. White light from tungsten halogen lamp is separated by prism.

### EXPERIMENTAL SETUP

In this study, an optical system with prism is manufactured. Fig. 2 shows that prism transform the white light to rainbow pattern. After passing through the prism white light can be reformed rainbow pattern and a three-color line CCD camera is useful to capture the RGB intensities of the line of rainbow pattern.

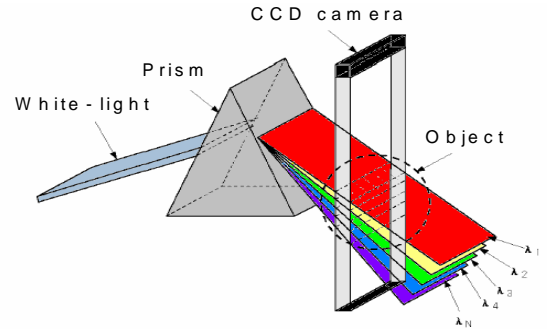


FIGURE 2. The optical system with prism.

The conceptual diagram for optical system is showed in Fig. 3 and photography of optical system is showed in Fig. 4. A halogen lamp of 150W and a metal halide lamp of 250W are used as optical source and a prism located in front of an illumination lens. Role of the illumination lens is to maintain focal distance and magnification of the light. After passing through the prism light source is separated to rainbow pattern and pass a cylindrical lens. The cylindrical lens makes beam size thin.

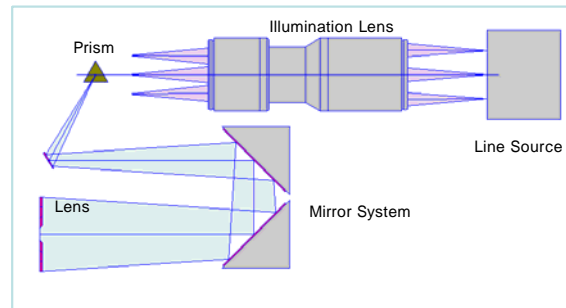


FIGURE 3. Configuration of the optical system

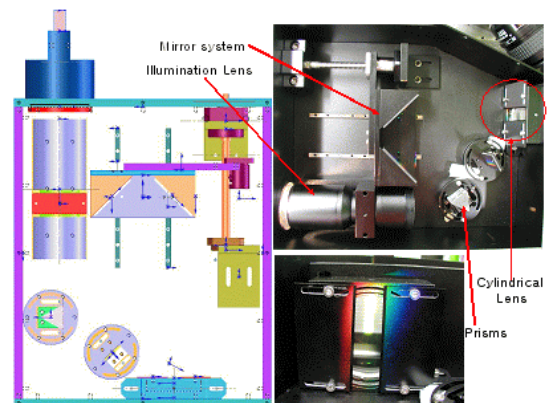


FIGURE 4. Photography of the optical system

The whole measurement system is composed of optical system, moving stage, three-color line

CCD camera and PC as provided in Fig. 5. Color beam from optical system is linearly projected on surface of the object and when the stage is moved color beam is scanned the whole surface area. Used frame grabber is Metro II of Matrox and line CCD is HVSOLO of Hanvision. The moving stage is constituted of ballscrew and LM guide and controlled by PC-based motion control board (MEI).

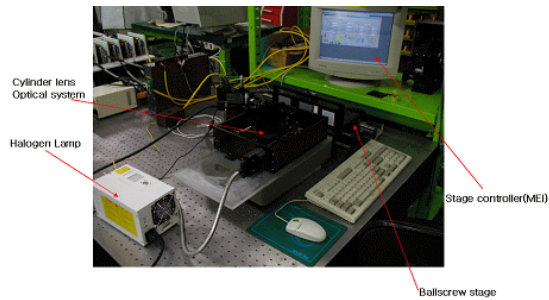


FIGURE 5. Photography of the measurement system

This color-coded illumination method has an advantage for in-line measurement. Since phase of R, G, B has been shifted previously so the moving stage is not necessary to stop for phase shifting but to scan at uniform speed. This uniform scan capability is the key for in-line measurement.

In this system, phase difference of R, G, B should be 90 degrees in each other. But Initial phase difference of RGB is not equal 90 degrees. The three-color line CCD camera has a function to change the color space as provided in Fig. 6. So equally-phase-shift RGB can be acquired by adjust camera's transformation matrix. Fig. 7 showed that initially white light(Left) is captured by CCD camera(Center) and is transformed phase shift image(Right).

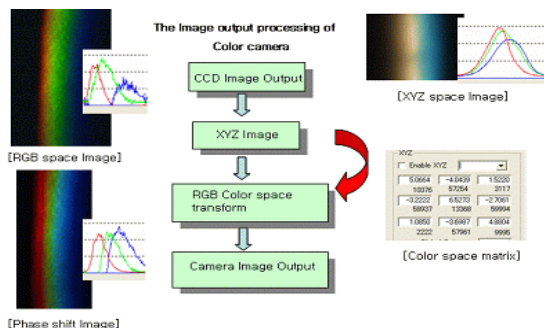


FIGURE 6. Color space transformation process of the color line CCD camera.

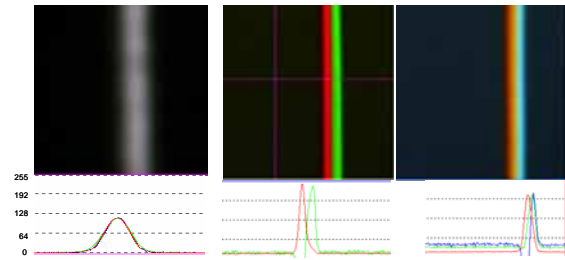


FIGURE 7. R,G,B phase shift processing.

## EXPERIMENTAL RESULTS

A measurement result for height standard (195 $\mu\text{m}$ ) by the color-coded illumination method is provided in Fig. 8. In this experiment the halogen lamp of 150W is used as light source and stage scanning speed is 30mm/sec. Used beam size is 500  $\mu\text{m}$ . If thinner beam size is used, system resolution will be better but phase difference between RGB is not uniform so accuracy of the measurement result gets worse. In Fig. 9 RGB phase distribution of the 300  $\mu\text{m}$ , 500  $\mu\text{m}$ , 700  $\mu\text{m}$  beam size is showed. The phase distribution of 300  $\mu\text{m}$  beam size is composed so this beam size is not suitable for color-coded measurement.

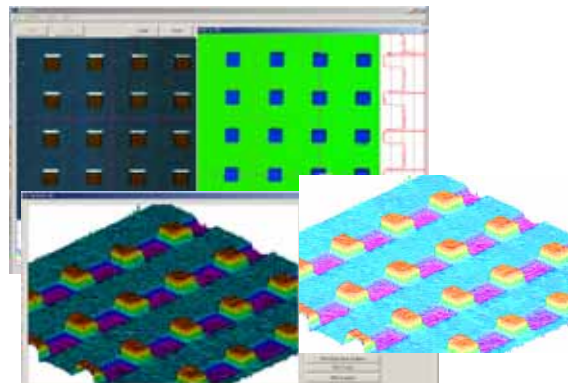


FIGURE 8. Measurement result for 195  $\mu\text{m}$  height standard with halogen Lamp of 150W.

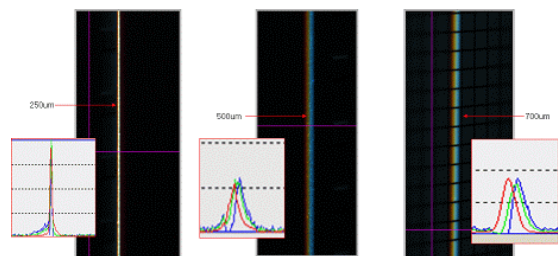


FIGURE 9. Phase of R,G,B with respect to beam size.

The surface roughness of the measured surface in Fig. 8 is very rough. This reason is that the

light after passing the optical system has small power so it is necessary to raise the camera gain to 6X but this gain setting leads to noisy result. Solution of this problem is power up of light source.

The measurement result for same standard with metal halide lamp of 250W is provided in Fig. 10. Surface roughness is better than that of halogen lamp.

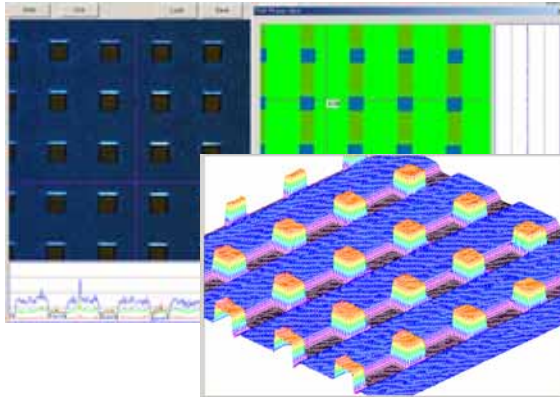


FIGURE 10. Measurement result for 195um height standard with metal halide Lamp of 250W.

## CONCLUSIONS

In this study a color-coded illumination method for measuring micro features is suggested. This method is used previously phase shifted color so very suitable for in-line measurement which needs fast measurement. It is possible to scan the measuring object because the color-coded illumination method does not need phase-shifting process. An optical system composed of prism and some lenses is manufactured and computer program code is implemented. To prove usefulness of this method experiments has been done. The measurement results of halogen lamp and metal halide lamp are compared and these experiment results showed that the color-code illumination method is useful for measurement of hundreds of micrometers features.

## REFERENCES

1. Weiyi Liu, Zhaoqi Wang, Guoguang Mu and Zhiliang Fang, 2000, Color-coded projection grating method for shape measurement with a single exposure, *Applied Optics*, 39: 3504-3508.
2. E. Hasman, V. Kleiner, 2001, Color-coded optical profilometry with  $>10^6$  resolved depth steps, *Applied Optics*, 40: 1609-1616.

3. Gerd Hausler and Dieter Ritter, 1993, Parallel three-dimensional sensing by color-coded triangulation, *Applied Optics*, 32: 7164-7169.
4. H. Fan, H. Zhao, and Y. Tan, 1997, Automated three-dimensional surface profilometry using dual-frequency optic fiber phase shifting method, *Opt. Eng.*, 36: 3167-3171.
5. S. Tang and Y. Hung, 1990, Fast profilometer for the automatic measurement of 3-D object shapes, *Applied Optics*, 29: 3012-3018.
6. Liu, W.-y., Yu, D.-y and Hou, Q.-h., 2002, 3-D Dynamic Object Shape Measurement by Using Color-coded Method, *Optoelectronics Laser*, 13: 169-172.