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DESIGN AND FABRICATION OF A STEP HEIGHT CERTIFICATED REFERENCE MATERIAL IN KRISS

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Abstract: Certificated reference material (CRM) has been used for calibration works in industry. The easy way to calibrate for reliable measurements is to compare with a CRM, which has a traceability chain from length standard. The design of a KRISS step height CRM has various patterns for checking of magnification, spherical aberration, and step height as well, which is available for multi-probe inspection machines in the manufacturing lines. The fabrication had been done by conventional optical lithography and dry etching technique with optimized conditions. In order to verify the step values, a white-light scanning interferometer was adopted with different magnification objectives. In this paper, the step values of 0.5 and 1.6 µm were realized with the standard deviation of less than 10 nm.

Keywords: step height, CRM, design, fabrication

1. INTRODUCTION

Optical metrological methods such as phase-shifting interferometery, low-coherence interferometry, confocal microscopy, vision system, etc have been exploited for micro-scale or sub micro-scale pattern inspections.[1,2] Since these measuring techniques are able to measure with high accuracy, it should be calibrated periodically for reliable measurements.[3-5] One of the easiest ways for these calibrations is to compare with a certificated reference material (CRM), which is already verified in national metrological institutes. It makes the uncertainty chain derived from length standard can connect well. In addition, it is easy to carry and handle in labs and industry.

The systematic errors or offsets can be corrected by determining the difference between a certified value of the CRM and a measured value simply. And this task should be executed periodically since the misalignment and long-term drift of the optical and mechanical components may be occurred. Since the optical interferometers are very sensitive to deviations along the optical axis, the vertical calibration is necessary using a standard step height CRM for reliable measurement. However, the lateral resolution is less strict relatively than vertical resolution because it can be determined by a pixel size and spacing of detector arrays or mechanical actuators. By adding some specific patterns for lateral calibration in the step height CRM, it can be enough to apply for general optical measuring machines. Furthermore, a step height pattern composed of a narrow and a broad width can be utilized for integrated optical inspection machines consisted of multi-probes with various magnifying lenses, which are operating on the production lines of semi-conductor, flat-panel display or nano/micro advanced technology devices.

In this paper, the design and fabrication of the step height CRM will be reported. The various patterns in the designed CRM are fabricated for vertical calibration and simple lateral calibration by using optical lithography and chemical etching processes. The step heights of 0.5, 2 and 4 µm are realized and measured by a white-light scanning interferometer. For the determination of the step height values, surface profiles in both thick and thin areas of the step height pattern were analyzed according to ISO 5436-1 guidelines.[6] And the surface roughness of the upper and bottom planes also was evaluated in terms of R_a.

2. DESIGN AND FABRICATION OF A STEP-HEIGHT CRM

A step height CRM was designed for multi-purposes, which are composed of patterns of; (a) step height measurement, (b) one-dimensional pitch measurement, (c) two-dimensional pitch measurement, (d) precision scales with the spacing of 20, 100 and 1000 µm, (e) checking of spherical aberration, (f) checking of magnification of objectives and (g) checking for distortion in Fig. 1. Figure 1-(a) shows the pattern for a step height, which consists of two quadrangle-shaped areas; thick and thin areas for low and high magnification objectives, respectively. And the thin area can also be used for calibration of an atomic force microscope (AFM) or a nano-profiler due to the narrow line-width of 10 µm.

Figure 1 (b) & (c) shows 1D- & 2D- grating with the pitch values of 20 and 40 µm, which can be used for checking the lateral resolution on the horizontal plane. These pitch values of 20 and 40 µm were choosen to minimize unwanted diffraction of an incident light. In order to find the location of a desired pattern easily with high optical magnification system, the scales with the equal spacing of 20 µm and equilateral triangle makers are inserted shown as Fig. 1 (d).

The patterns, Fig. 1 (e) & (g), were designed for checking the spherical aberration and distortion of the optical system, respectively. The circles of Fig. 1 (e) have the diameters of 30, 100, 200, 300, 500 and 1000 μm. The squares of Fig. 1(g) have the dimension of 100, 200, 600, 800 and 1000 μm.

By obtaining the pattern image of Fig. 1 (f) simply, the magnification of the optical system based on a conventional CCD camera with 640 × 480 pixels can be verified. The dimensions of this pattern are 1280 μm × 960 μm, 640 μm × 480 μm, 320 μm × 240 μm, 128 μm × 96 μm and 64 μm × 48 μm for up to × 100 objectives.

Based on this design, the patterns were fabricated by chrome on the glass substrate, which will be used as a reference mask for lithography process.

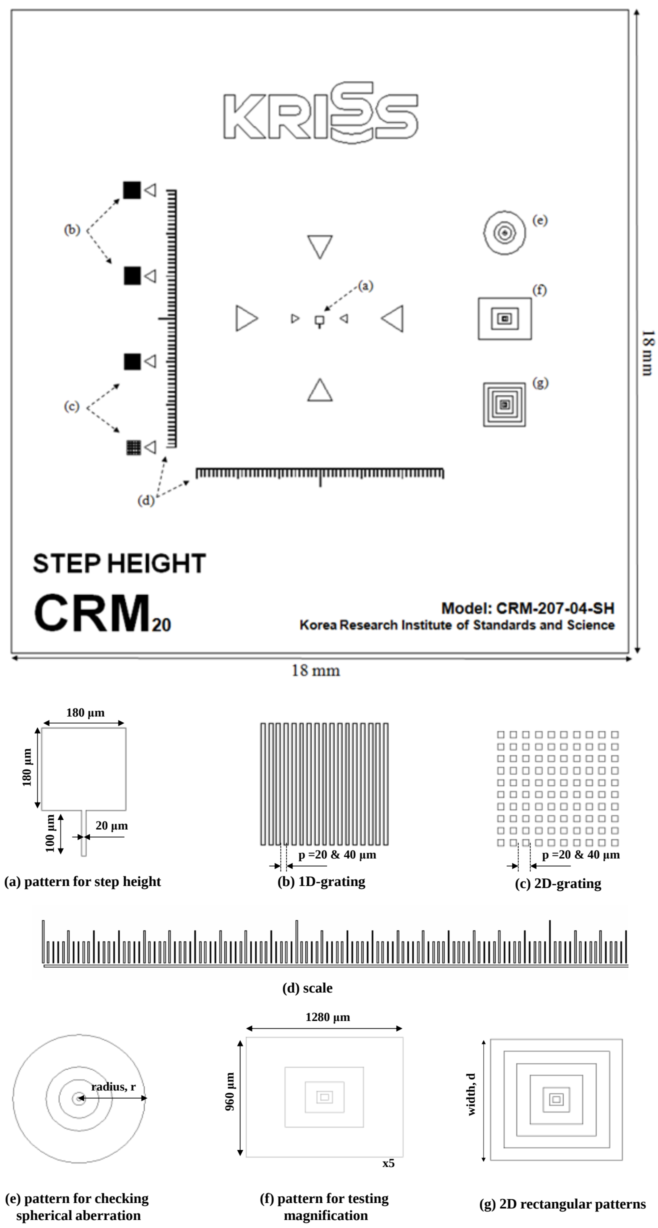

Fig. 1 Design of a KRISS step height CRM. (a) pattern for step height, (b) 1D-grating, (c) 2D-grating, (d) scale, (e) pattern for checking spherical aberration, (f) pattern for testing magnification of objectives and (g) 2D rectangular patterns [7]

The fabrication procedure of the step height CRM consists of 6 steps; (1) applying the negative PR(photo-resist) material to wafer surface, (2) optical lithography, (3) development process, (4) dry etching process, (5) removing process of particles and PR material and (6) metal coating on the wafer surface. Figure 2 show the summary of this procedure.

The bare wafer was installed on the rotation table to spread a negative PR material (AZ nLOF 2035 Photoresist) uniformly. The wafer was rotating with the two steps of 500 rpm for first 3 seconds and then 4000 rpm for 20 seconds. To complete the negative PR coating process, the wafer should be baked at 95 ℃ for 2 minutes.

Then the negative PR coated wafer was installed with the gap of only 20 μm from the reference mask mentioned in Section 2.1. This task was for vacuum mode optical lithography process. Since the most dominant factor of this process was an exposure time, the simple tests were fulfilled to determine the proper exposure time by checking the surface quality of wafers according to the exposure time. In our experiments the exposure time was determined as 8.5 s with a lamp power of 870 W after repeated tests. After that the wafer was baked again to harden the area which is not exposed at 115℃ for 120 s.

Next, in order to remove the unexposed area on the wafer efficiently, it soaked in the developing solution (AZ300 HIF) and be waved for a minute. It’s very important for obtaining high quality surface to make sure that there are not any dusts and particles on the wafer.

In the etching process the penetration depth of a silicon wafer can be controlled by gases in use, plasma strength, etching time, etc. Among the various conditions, the only two factors of gases in use and etching time were modified. For 0.5 μm step height, the gases of CF_4 and Ar were used with the ratio of 100:50. The etching time was 250 s at He pressure of 20 torr. For 1.6 μm step height, the CF_4 gas was replaced with SF_6 and C_4F_8 to get more etching gain and straightness of gas flows. The ratio of SF_6, Ar and C_4F_8 was 80:40:80. At that time, the etching times were modified to 250 s. The source power was 500 W at the wavelength of 0.5 μm with the bias power of 60 W, which was same as all experiments. Therefore, various step height values can be realized by modifying the two parameters of gases in use and etching time easily.

Since this CRM was supposed to be used mainly for optical measuring techniques, the surface of the CRM is better to have metal-coated for high reflectivity. And it also have very fine surface roughness. In this paper, the chrome thin film was coated on the patterned wafer by using the CVD (chemical vapor deposition) process.

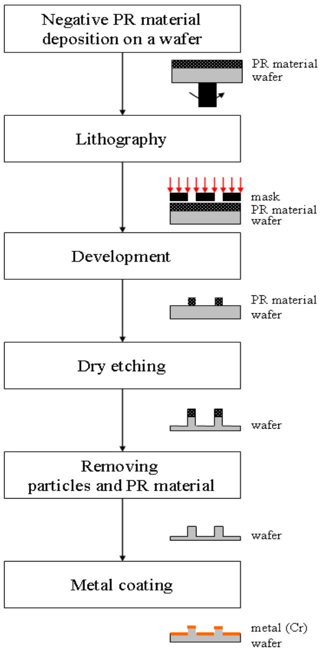

Fig. 2 Fabrication process of a step height CRM [7]

3. STEP HEIGHT MEASUREMENT AND DISCUSSION

The step height can be defined as the offset between the linear fitted lines of upper surface and bottom surface of a groove according to the ISO 5436-1 guideline. The surface profiles can be expressed simply as

$$Z_{upper}(x) = A\ x + B + h/2 \qquad (1.1)$$

$$Z_{bottom}(x) = A\ x + B - h/2 \qquad (1.2)$$

where, A and B represent slope and offset of the linear fitted profile, h is a step height value, respectively. Therefore, the step height, h can be determined simply by subtracting the eq. (1.2) from eq. (1.1).

And the analysis length for the step height should be three times of the width of the groove shown as Fig. 3 (a). In order to avoid the influence of any rounding of the corners, the upper surface on each side of the groove should be ignored for a length equal to one-third of the width of the groove. The surface at the bottom of the groove is chosen only over the central third of its width. The portions to be used for determining the step height are those shown at A, B and C in Fig. 3 (a).

The pattern for a step height consists of two parts, thick and thin, shown as Fig. 1(a). The four different areas (A1, A2, A3 and A4 in Fig. 4) were selected for determination of the step height in the thick part. The areas of A1, A2 and A3 in Fig. 4 have 120 step-shaped profiles at each in 120 μm × 200 μm. The step height can be calculated by taking offset of linear fitted lines on the bottom and upper surface. Since the other area in the thick part, A4 is groove-shaped the step height can be obtained easily by using equations of (1.1) and (1.2). Therefore the representative value of the step height in the thick part can be evaluated by averaging the four different values at A1, A2, A3 and A4 in Fig. 4. Here, the area of A1, A2 and A3 were not analyzed according to the ISO 5436-1 guideline, but these values can be consideral information when the measurements are done at the edges practically. White-light scanning interferometer with an ×10 interference objective was used for these measurements because it's difficult to extract the step height in the narrow area of A5 in Fig. 4 due to the low spatial resolution.

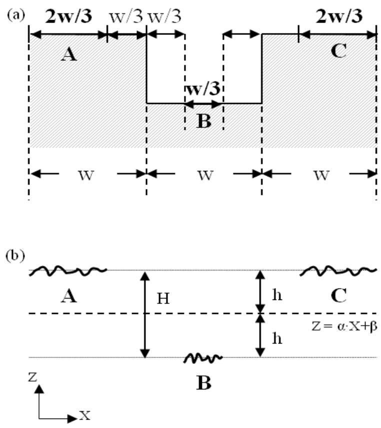

Fig. 3 Definition of a step height of a groove (a) selected portions for determining a step height, (b) definition of a step height from the linear fitted lines

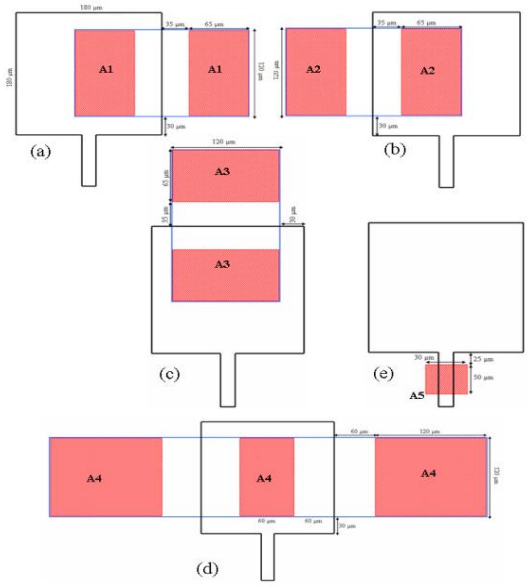

Fig. 4 Selected area for determination of step heights; (a) A1 area, (b) A2 area, (c) A3 area, (d) A4 area and (e) A5 area [7]

For determination of the step height in the thin part, A5 in Fig. 4, ×100 interference objective was replaced to realize high spatial resolution. The step height determination process also was followed by ISO 5436-1 guidelines in the area of 30 µm × 50 µm with selected 200 profiles.

26 CRM specimens on the wafer were made at the same time, and then the step height measurements for every specimen were also accomplished. The lithography and etching process can lead some distortions or un-uniformity at the outer areas caused by pressure un-uniformity and optical aberrations or distortions. In this paper only 12 specimens in the center area were adopted. In order to check the fabrication and metal coating quality, the surface roughness on the upper and bottom planes of specimen #5 and #8 in Fig. 5 were evaluated based on the definition of R_a. Table 1 and 2 shows the summary of the measurement results for step height of 0.5 µm and 1.6 µm. And several tests gave the fabrication and measurement result as table 3 including the step height of 0.5 µm and 1.6 µm.

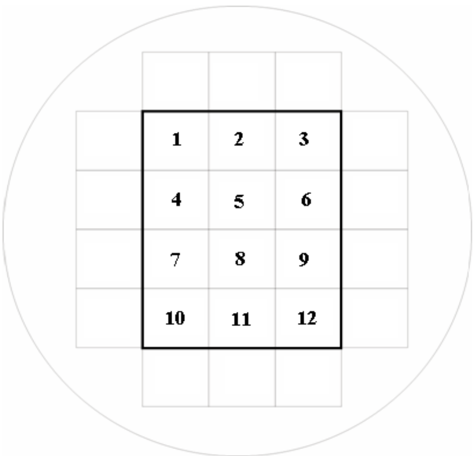

Fig. 5 Arrangement of CRM specimens in a wafer

Table 1. Measurement result of 0.5 µm step height

sample number	step height (µm)					
	thick				thin	offset
	A1	A2	A3	A4	A5	
1	0.504	0.505	0.505	0.505	0.511	0.006
2	0.500	0.500	0.502	0.503	0.503	0.000
3	0.499	0.497	0.501	0.500	0.498	0.002
4	0.501	0.498	0.501	0.503	0.508	0.005
5	0.496	0.497	0.497	0.499	0.502	0.003
6	0.494	0.493	0.495	0.498	0.498	0.000
7	0.495	0.496	0.494	0.496	0.503	0.007
8	0.492	0.491	0.492	0.498	0.498	0.000
9	0.491	0.490	0.491	0.494	0.491	0.003
10	0.494	0.491	0.492	0.495	0.499	0.004
11	0.490	0.489	0.490	0.492	0.495	0.003
12	0.488	0.487	0.488	0.492	0.492	0.002
average value				0.498	0.500	0.003
standard deviation				0.004	0.006	0.002
roughness of upper surface (R_a)					0.002 µm	
roughness of bottom surface (R_a)					0.002 µm	

Table 2. Measurement result of 1.6 µm step height

sample number	step height (µm)					
	thick				thin	offset
	A1	A2	A3	A4	A5	
1	1.585	1.589	1.592	1.586	1.569	0.017
2	1.597	1.600	1.602	1.596	1.578	0.018
3	1.596	1.599	1.598	1.596	1.580	0.016
4	1.601	1.599	1.603	1.600	1.580	0.015
5	1.616	1.614	1.613	1.612	1.597	0.015
6	1.610	1.611	1.612	1.609	1.592	0.017
7	1.608	1.606	1.611	1.607	1.586	0.020
8	1.614	1.615	1.616	1.614	1.596	0.018
9	1.612	1.612	1.616	1.611	1.593	0.015
10	1.601	1.598	1.601	1.599	1.584	0.016
11	1.611	1.613	1.616	1.611	1.594	0.016
12	1.610	1.609	1.616	1.609	1.594	0.015
average value				1.604	1.587	0.017
standard deviation				0.009	0.009	0.002
roughness of upper surface (R_a)					0.002 µm	
roughness of bottom surface (R_a)					0.002 µm	

Table 3. Summary of measurement result

step height (µm)	ratio of etching gases	lamp power / bias power	etching time (s)	step height (µm)	
				thin	thick
0.5	CF_4:Ar	500 W	250	0.500	0.0498
	100:50	/ 60 W		0.002	
0.9	SF_6:Ar:C_4F_8	500 W	200	0.873	0.875
	80:40:80	/ 30 W		0.002	
1.5	SF_6:Ar:C_4F_8	500 W	250	1.476	1.488
	80:40:80	/ 60 W		0.012	
1.6	SF_6:Ar:C_4F_8	500 W	280	1.587	1.604
	80:40:80	/ 60 W		0.017	

4. CONCLUSION

Comparison with a CRM is one of the easiest ways for precision calibration in industry, which can be kept the traceability chain from length standard. It should be done periodically since systematic errors or offsets may occur in long-term. Since optical measuring techniques based on the interference phenomenon have ultra-high resolution of sub nm along the optical axis, vertical axis calibration is necessary for reliable operations.

In this paper, we designed the step height CRM combined with various special patterns, which are available for spherical aberration, distortion, scale, magnification test, and pitch measurement. By adjusting the fabrication conditions such as etching time, lamp power and bias power, gases in use, etc. the step height of 0.5 and 1.6 µm were demonstrated.

White-light scanning interferometer was used for verification of step height CRMs with ×10 and ×100 magnification objectives. The mean values of the step height of 0.5 µm and 1.6 µm in the thin area were 0.500 µm and

1.587 µm, respectively. The deviation of these step heights were 0.006 and 0.009 µm for the step height of 0.5 µm and 1.6 µm, respectively. For the thick area, the mean values of the step heights of 0.5 µm and 1.6 µm were 0.498 µm and 1.604 µm, respectively. The deviation of these step heights were 0.004 µm and 0.009 µm for the step height of 0.5 µm and 1.6 µm, respectively. And the surface roughness of CRMs was less than 5 nm for all samples, which could be neglected.

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