Comparing measurements of 1D-grating samples using optical diffraction technique, CD-SEM and nanometrological AFM

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Abstract:

A round-robin measurement was performed by three institutes for the pitch of 1D-gratings with a nominal value of 240 nm. Three different methods for the measurements, an optical diffractometer (OD), a critical dimension scanning microscope (CD-SEM) and a nanometrological atomic force microscope (nanometrological AFM) were used. Measurements uncertainty for each method was estimated and ranged from 0.14 nm to 1.0 nm for expanded uncertainty (k=2). Average values obtained for these methods matched closely with differences less than the expanded uncertainty.

Introduction

ITRS 2001 estimates that the next technology node will be achieved more than two years earlier than that estimated in 1999. As technology node in semiconductor industry has shrunk, importance of dimensional measurements in nanometer order (nanometrology) is now obvious. In addition, equivalency in certificated dimensions between countries has become a key in international trades or joint R&Ds. Since some products with nanometer-scale precision should be certificated on the basis of traceability to a national standard, a national traceability system in nanometer-scale standards is required.

Japan Quality Assurance Organization (JQA), Hitachi Science Systems, Ltd.(HSS) and NMIJ/AIST performed round-robin measurements of 240 nm-pitch 1D-gratings. Not only an optical diffraction technique (OD) and a nanometrological atomic force microscope (nanometrological AFM) but also a critical dimension scanning electron microscope (CD-SEM) was used for the comparison We have two aims of round-robin. One is to improve the technological ability in precision measurements for nano-scale standard samples. The other is to prepare for the establishment of a traceability system in Japan. We report the results of this round-robin measurements performed with OD, CD-SEM and nanometrological AFM.

Measurement methods

Samples

The 1D-gratings (HJ-1000, Hitachi co. ltd) were made of silicon wafer with a size of 4 mm×4 mm×t 0.3 mm[1]. The line and space with a nominal pitch of 240 nm was fabricated on Si (110) by optical interference lithography and an anisotropic etching. The gratings were mounted on aluminum disks, with a diameter and a thickness were

12 mm and 1.5 mm respectively, for the easy mounting in AFM. When OD or CD-SEM was used, the grating on the disk was mounted on a solid cylinder with a diameter and a height of 15 mm and 10 mm, respectively. Locations to be measured were defined as center spots of each nine regions of 1 mm × 1 mm in the center square of 3 mm × 3 mm of three samples (T002, T005 and T006).

Measurement instruments

An optical diffraction (OD), a CD-SEM and a nanometrological AFM were used for the round-robin by JQA, HSS, and NMIJ/AIST, respectively.

The OD system consists of a He-Cd laser (λ = 325 nm), a rotary table with an encoder, a laser power monitor and mirrors. Pitch values were obtained from angle difference between the positions of a specular beam alignment and a 1st diffraction beam alignment (both side of rotation).

The magnification scale of the CD-SEM was calibrated using another 1D-grating scale (HJ-1000) certificated by JQA. Single pitch between two adjacent lines of each 1 mm×1 mm area was obtained by analyzing a secondary electron profile and averaging over 10 times measurements.

XYZ scale of the nanometrological AFM was calibrated with a built-in three-axis interferometer in real-time[2][3]. The wavelengths of frequency-stabilized He-Ne lasers (λ = 633 nm) as laser sources of the interferometer were calibrated with an I_2-stabilized He-Ne laser.

Results and discussions

table 1: pitch values p [nm], combined standard uncertainty $u_c(x_i)$ [nm], expanded uncertainty (k=2) $U_{95}(x_i)$ [nm] and degree of freedom ν_{eff} (T002)

participant (method)	pitch value p [nm]	expanded uncertainty (k=2) $U_{95}(x_i)$ [nm]	degree of freedom ν_{eff}
NMIJ/AIST 1st (AFM)	239.97	0.262	12.6
JQA (OD)	239.90	0.140	20.1
HSS (CD-SEM)	240.3	1.0	16.2
NMIJ/AIST 2nd (AFM)	240.03	0.310	53.0

Obtained pitch value p [nm], combined standard uncertainty $u_c(x_i)$ [nm], expanded uncertainty (k=2) $U_{95}(x_i)$ [nm] and degree of freedom ν_{eff} for T002 sample are shown in table 2. These values are estimated based on GUM[4].

table 2: The reference value and expanded uncertainty of reference value (k=2) (T002).

reference value x_{ref} [nm]	expanded uncertainty (k=2) $U_{95}(x_{ref})$ [nm]
240.03	0.310

Pitch values obtained by NMIJ/AIST were defined as the reference values since the scale of the instrument is traceable to the international unit of length through He-Ne laser wavelength. Also, NMIJ/AIST (former NRLM)'s calibration ability of the pitch values was verified at supplementary keycomparison of 1D-gratings (CCL-S1, WGDM-7 DG Nano4)[5][6]. NMIJ/AIST measured a set of 3 gratings (T002, T005 and T006) twice at the first (NMIJ/AIST 1st) and at the last (NMIJ/AIST 2nd) of this round-robin. The difference between 2 measurement results has to be tested if it is statistically significant or not. As the results of tests for variance ratio and the difference of population mean value.

It became clear that population variance was equivalent and the difference of population mean value between two measurement results was not statistically significant. This means NMIJ/AIST 1st measurement results and NMIJ/AIST 2nd measurement ones were equivalent. Pitch values and expanded uncertainty obtained by NMIJ/AIST 2nd measurement were defined as the reference values and expanded uncertainty in this round-robin.

En number is one of guidelines of the consistency between obtained pitch values and the reference values. Table 3 shows calculated En numbers for OD (JQA) and CD-SEM (HSS) measurement. According to ISO/IEC GUIDE 43-1, an obtained value has a consistency if En number is less than 1. All En numbers are less than 1. We obtained consistency of all measured results.

table 3: En number (T002).

participant	En number
JQA	0.38
HSS	0.26

Major uncertainty components and their standard uncertainty for T002 grating are shown in table 4. Major uncertainty components in each measuring method are mostly derived from the measurement instruments. Further efforts should be paid to reduce these uncertainty components.

table 4 : Major uncertainty components and their standard uncertainty (T002)

participant (method)	major uncertainty component	standard uncertainty $u_c(x_i)$ [nm]
JQA (OD)	repeatability of rotary table	0.0470
	vertical angle correction at Bragg condition	0.0240
HSS (CD-SEM)	magnification calibration	0.5
	standard sample for magnificationcalibration	0.3
NMIJ/AIST (nanometrological AFM)	interferometer nonlinearity (cyclic error)	0.115
	uniformity of pitch patterns	0.041

Conclusions

JQA, Hitachi Science Systems and NMIJ/AIST conducted a round-robin measurement for the 240 nm-pitch of 1D-gratings using different measurement instruments, optical diffraction technique (OD), critical dimension scanning electron microscope (CD-SEM) and nanometrological atomic force microscope (nanometrological AFM). Obtained pitch values with three different methods matched within the expanded uncertainty. En values less than 1 for all results indicates the reasonable estimation of uncertainty. Therefore, the consistency of this round-robin was confirmed. These activities are parts of efforts toward an establishment of a traceability system in Japan.

References

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