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DESIGN AND FABRICATION OF NANOMETRIC LATERAL SCALE CONSISTING OF GaAs/InGaP SUPERLATTICE

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Abstract: Nanometric lateral scales with 25 nm pitch using GaAs/InGaP superlattice were designed and fabricated for realization of the-smallest-pitch-CRMs. The pitch of the scales was measured by a nanometrological AFM and uncertainty in pitch measurements was evaluated. The quality of the developed scales as CRMs was verified.

Keywords: nanometrology, pitch, CRM

1. INTRODUCTION

Nanometrology, one of the important basic technologies in nanotechnology, is progressing rapidly and establishment of standard in nanometrology is required recently. National Metrology Institutes (NMIs) have been developing atomic force microscopes (AFM), one of the promising nanometrological instruments, for nanometrological standard establishment [1-4]. National Institute of Advanced Industrial Science and Technology (AIST), National Metrology Institute of Japan (NMIJ) developed atomic force microscopes with high-resolution-laser interferometers in XYZ-axes (nanometrological AFMs) [5-7] and is providing a calibration service for the pitches (50 nm - 8 μm) of one-dimensional (1D) grating standards.

Not only calibration services, but also distribution of standards as certified reference materials (CRMs) is important. NMIJ developed prototype 1D-grating standards with pitches of 50 – 100 nm using an electron beam lithography method [7]. However, the electron beam lithography method has limitations to fabricate 1D-grating standards with much smaller pitches than 50 nm. Development of less than 50 nm-pitch scales is demanded for the 45 nm half DRAM pitch generation in the semiconductor technology.

Application of superlattice (multilayer) is one of promising solutions to develop nanometric lateral scales with smaller pitches [8]. In this report, we designed and fabricated “nanometric lateral scales” with 25 nm pitch consisting of GaAs/InGaP superlattice (multilayer) for realization of the-smallest-pitch-CRMs. Furthermore, we measured the pitch of the fabricated nanometric lateral scales using a nanometrological AFM and evaluated uncertainty in the pitch measurements.

2. SAMPLE AND INSTRUMENT

2.1. GaAs/InGaP superlattice

Superlattice is a multilayer made of several types of materials and the thickness of each layer is controlled by forming rate. Superlattice is calibrated by X-ray refrectometer (XRR) precisely and are used as nanometric depth scale[9]. In this report, nanometric lateral scale was developed using superlattice by cleavage of the superlattice substrate, polishing of the side wall of the cleaved substrate, and selective etching (fig. 1). GaAs/InGaP superlattice was adopted for the nanometric lateral scale since the selective ratio of wet etching was large. Fig. 2 shows a design of a nanometric lateral scale consisting of GaAs/InGaP superlattice. Firstly, GaAs/InGaP superlattice (cycle: 40, total thickness: 1 μm) was grown on a GaAs substrate. The thicknesses of GaAs monolayer and InGaP one were 10 nm and 15 nm respectively and one cycle of the GaAs/InGaP superlattice was25 nm. The GaAs/InGaP superlattice substrate was cut in 1 mm x 1 mm pieces. The side walls of pieces were polished and two pieces were glued facing each other by adhesive. Five glued pieces were mounted on a GaAs substrate base (size: 5 mm x 5 mm). The mount makes the nanometric lateral scale easier to be handled and adhesive parts become markers those indicate the scale pattern parts. The surface of the nanometric lateral scale was polished and GaAs layers were selectively etched by etchant. The etchant was mixture of concentrated sulfuric acid, hydrogen peroxide solution (30 %) and water and the ratio of the mixture was 1:10:1000. The etching rate ratio of GaAs to InGaP is more than 1000. The nanometric lateral scales were fabricated by Nippon Telegraph and Telephone Advanced Technology Corporation (NTT AT) based on the design.

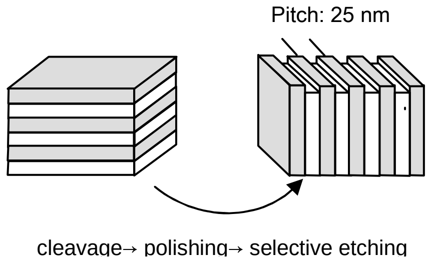


Fig. 1. Nanometric lateral scale consisting of superlattice.

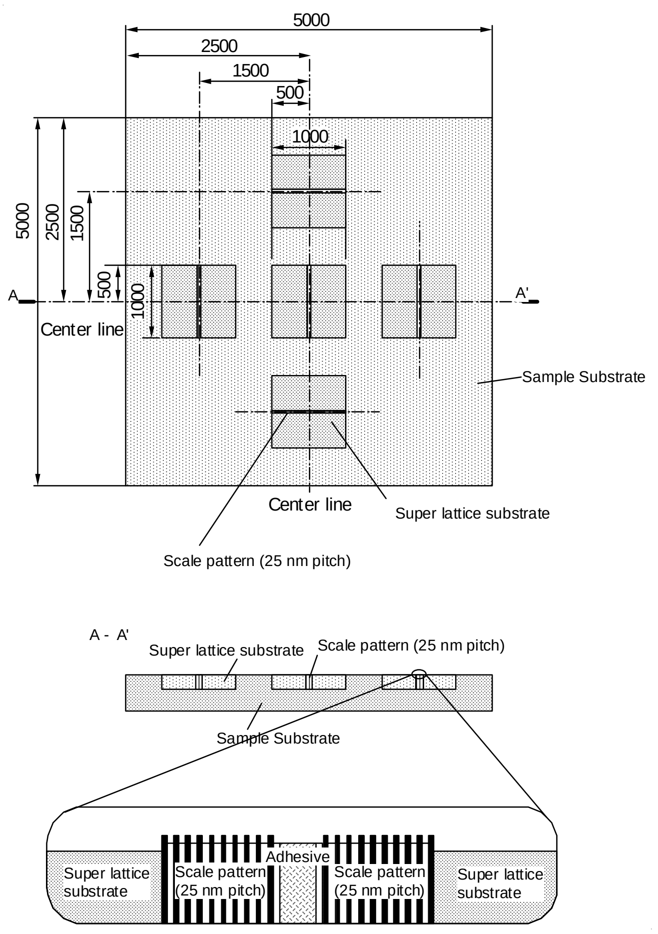


Fig. 2. Design of nanometric lateral scale.

2.2. Nanometrological AFM

Nanometrological AFM was used for pitch measurement of the developed nanometric lateral scale. The precise information of the nanometrological AFM is described elsewhere[5-6] . The nanometrological AFM consisted of an XYZ-axes interferometer unit, a stage unit and an AFM probe unit. The probe unit comprised an XY leaf spring stage and a Z tube scanner. The scanning range of the stage unit was approximately 17.5 μm (X) x 17.5 μm (Y) x 2.5 μm (Z). A three sided moving mirror as a target of the interferometer unit was set on top of the Z tube scanner. The interferometer unit was a homodyne type one and had four optical optical paths on each axis. The theoretical resolution of the interferometer unit was approximately 40 pm. The laser sources of the interferometer unit were frequency-stabilized He-Ne lasers with a wavelenght of 633 nm. The laser frequency was calibrated using an I_2-stabilized He-Ne laser, prior to the pitch measurement. The atomic force between a cantilever probe and a sample surface was detected using a conventional optical lever method. The nanometrological AFM was driven in AC mode [10]. The XY scan was servo-controlled using interferometer signals and the Z-axis displacement was monitored by the interferometer in Z-axis. The pitch calibration was traceable to the unit of length by using the nanometrological AFM.

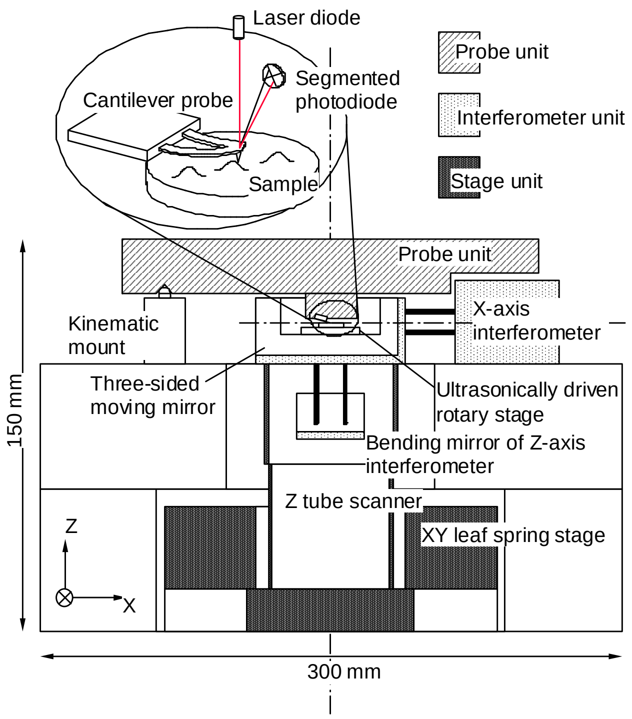


Fig.3. Nanometrological AFM [6].

2.3. Measurement conditions and evaluation of uncertainty

The center piece of five ones in nanometric lateral scale was selected and AFM images were obtained at the four locations in the center piece as shown in fig. 4. The scanning range was approximately 2 μm (X) x 2 μm (Y), the number of scanning lines were twenty and scanning speed was approximately 0.4 μm/s. The cantilevers used in the pitch measurements were fabricated by Olympus Co., Ltd

(OMCL-AC160TS). At the measurement location 1, measurements were repeated three times to evaluate the uncertainty caused by the repeatability of measurements at the same measurement location. Measurements were performed just once at the other three measurement locations 2, 3 and 4. The pitch was calculated using the center gravity of method. The precise information about definition of pitch in the center gravity of method was noticed elsewhere[6, 7].

Uncertainties in pitch measurements were evaluated on the basis of the "Guide to the expression of uncertainty in measurement (GUM)"[11]. The standard unceraties caused by all sources were evaluated and the expanded uncertainty was calculated from the standard uncertainties. All sources of uncertainty in the pitch measurements and the evaluation method for the pitch measurements are described elsewhere precisely [6, 7].

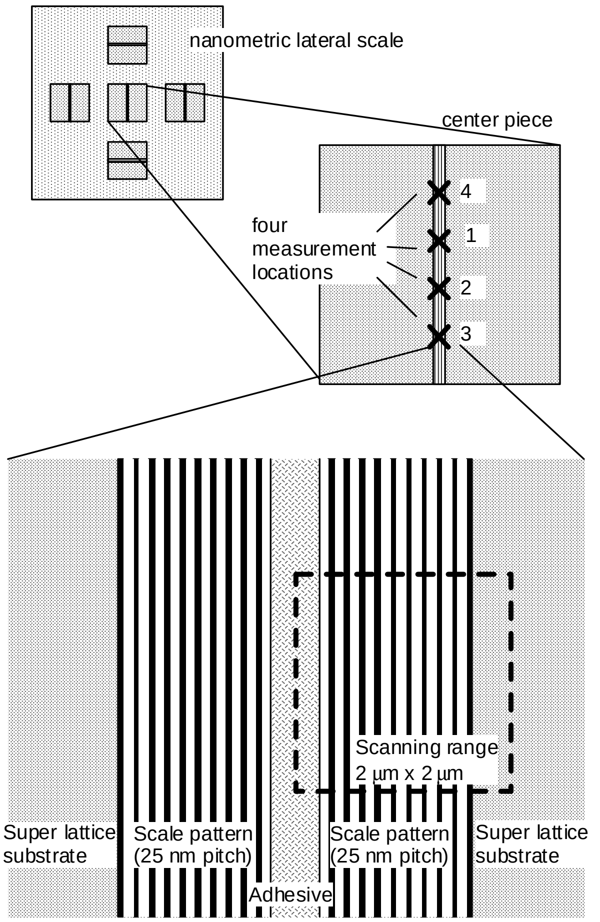


Fig.4. Measurement locations

3. RESULTS OF PITCH MEASUREMENTS AND UNCERTAINTY EVALUATION

3.1. Pitch measurement results

The pitch measurements of the developed nanometric lateral scale were carried out using the nanometrological AFM. Fig. 5 shows an AFM image (scanning range: 2 μm) and line profiles of nanometric lateral scale. In fig. 6 (a), the left, the center and the right parts are adhesive, scale pattern and super lattice substrate respectively. The scale pattern part is convex since the etching rate of GaAs in superlattice was lower than that of GaAs plane. Fig. 6 (b) is an expanded figure of the scale pattern part. The slope of approximately fifteen cycles close to the adhesive part is larger than that of approximately twenty-five cycles close to the substrate. This was caused by the difference of the polishing rate between adhesive and GaAs/InGaP superlattice substrate. In this study, approximately twenty-five cycles close to the substrate were used for pitch calculation. The pitch value in one measurement location was defined as the average of approximately five-hundred single pitches in one location. Table 1 shows the obtained pitches at all measurement locations.

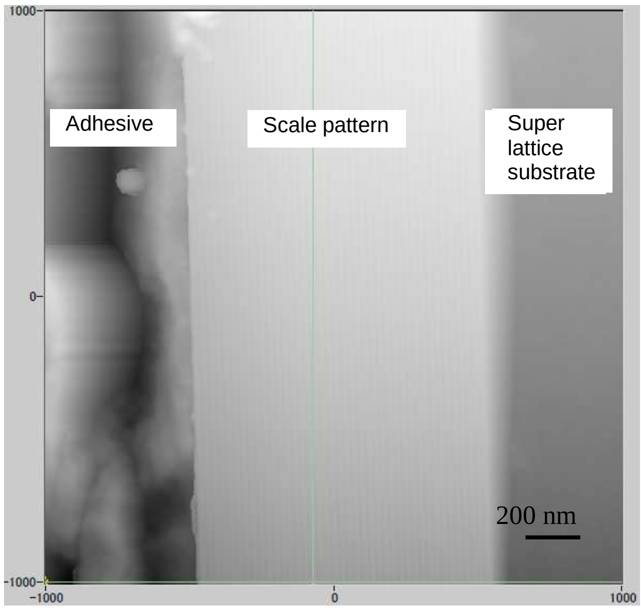
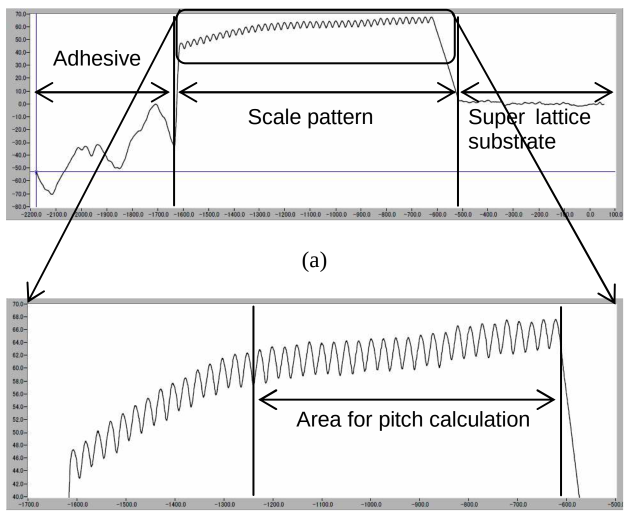


Fig.5. AFM image of nanometric lateral scale.



(a)

(b)

Fig.6. Area for pitch calculation.

Table 1. Pitch at each location.

Measurement location		Pitch (nm)
1	1	25.20
	2	25.21
	3	25.22
2		25.17
3		25.21
4		25.37

3.2. Uncertainty in pitch measurements

Uncertainty in pitch measurements was evaluated. Major sources of uncertainty were interferometer nonlinearity, nonuniformity of sample, interferometer resolution, stability of laser frequency and repeatability of measurements as shown in table 2. Other minor sources were Abbe error, compensation by refractive index of air (temperature, pressure, humidity and CO_2 density), thermal expansion of scale and change in optical path. The average pitch of the nanometric lateral scale and the expanded uncertainty (k = 2) were 25.24 nm and 0.29 nm, respectively.

Table 2. Major source of uncertainty and standard uncertainty.

Major source of uncertainty	Standard uncertainty (pm)
Interferometer nonlinearity	115
Nonuniformity	87
Interferometer resolution	22
Stability of laser frequency	12
Repeatability	7

4. CONCLUSION

Nanometric lateral scale (design pitch: 25 nm) consisting of GaAs/InGaP superlattice was designed and fabricated. The pitch of the lateral scale was measured by a nanometrological AFM and uncertainty in pitch measurement was evaluated. The average of pitch and expanded uncertainty (k = 2) were 25.24 nm and 0.29 nm respectively. It became clear that the GaAs/InGaP superlattice can be applied to nanometric lateral scale as the candidate CRMs. Some items to be studied are raised as following, (1) bonding method without adhesive, (2) not only GaAs/InGaP superlattice but Si/SiO_2 one. In the near future, the above items to be studied will be solved and nanometric lateral scales will be distributed as CRMs.

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