Progress of white light interference profilometry by using atomically-smooth mirror

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Abstract. It is shown that using of the method of partial correlogram scanning and the atomically-smooth surface as interferometer reference mirror allow to improve the longitudinal resolution of profile measurement up to 30 picometers and to decrease the systematic error caused by the optical aberrations more than an order. The results of measurement of silicon (111) surface containing monatomic steps 0.314 nm in height with longitudinal resolution 30 picometers are presented.

1. Introduction

Measuring a height of a surface relief with nanometer resolution is an actual problem both in scientific research and industrial production [1]. For this purpose the well known methods of phase shifting interferometry (PSI) are used. These methods are based on the phase value calculation for the light scattered in the interferometer arms [2]. Typically, PSI measurement systems use Michelson, Linnik or Mirau interferometers [3, 4]. As a rule an interferometers, designed for surface nanorelief measurement, contain a flat optical mirrors made by spraying of Al on high quality glass substrate as a reference surface. The roughness of such mirrors is about 2 nm. To provide subnanometer height resolution the reference mirrors must have lesser roughness.

Significant progress was achieved by using of the molecular beam epitaxy (MBE) technology for formation of flat smooth solid state surfaces [5]. In this case there is a real opportunity to create an atomically-smooth surface. By authors opinion to decrease the influence of a reference mirror roughness on a measurement result the most perspective way is to use an atomically-smooth surface as a reference mirror of an interferometer.

The paper describes the experimental results of measurement of surface relief of special silicon specimen with height of surface structure of one monoatomic layer, obtained by the nanoprofiler MNP-1 [6]. The results of using of atomically-smooth surface as interferometer reference mirror in the measurement system MNP-1 are presented in the paper. The application of such reference mirror under using the method of partial correlograms scanning allows us to decrease the error of surface nanorelief measurement and significantly improve the resolution capability by height up to tens picometers.
2. Interferometric profiling with subnanometer resolution

Test specimen was created by using MBE technology and contains monatomic terraces with atomically-smooth surface [5]. The height difference between neighbour terraces is equal to interatomic distance of crystal lattice of silicon (3.14 Å).

Morphology of specimen surface was analyzed by the method of partial correlogram scanning by means of nanoprofiler MNP-1 [6]. This measurement system was developed and produced at TDI SIE SB RAS. The system consists of optomechanical module 1, electronic module 2 and computer 3 with specially designed software (figure 1).

Figure 1. Nanoprofiler MNP-1: 1 – optomechanical module, 2 – electronic module, 3 – computer.

Preliminary measurement of the specimen was carried out using atomic force microscope (AFM). Measurement results are shown in figure 2, a. Figure 2, b represents the results of the specimen’s first measurement performed by nanoprofiler MNP-1. Central round region contains isolated atomic terraces (figure 2, a). However, this structure is not resolved in the reconstructed 3D model. It happened because of the reference mirror of MNP-1 interferometer is more rough than measured structure. Root mean square (RMS) roughness \( R_q \) of the profile in central region of the reconstructed 3D model (figure 2, b) is about 1 nm.

To decide this problem and suppress the instrumental function of the interferometer it was proposed to use the differential measurement of specimen surface. For this purpose two measurements were performed with small (about 20 \( \mu \)m) displacement in transverse direction and then the profiles obtained were subtracted one from another. The result of differential measurement is presented in figure 2, c and allows us to register monatomic terraces on specimen surface. But it is difficult to obtain the reliable information of structure height from this data.
Figure 2. Silicon specimen surface with monoatomic terraces: (a) AFM-image, (b) reconstructed 3D model of surface measured by MNP-1, (c) differential measurement result obtained by MNP-1.

3. Measurements using atomically-smooth mirror

To increase the height resolution of nanoprofiler MNP-1 the special silicon sample, containing wide and extremely smooth surface area, was proposed to place in the reference arm of the interferometer and to use it as a reference mirror.

This sample contains the surface region (atomically-smooth singular terrace) with an average roughness $R_a$ below 0.03 nm [5]. Atomically-smooth region of the surface in the form of ellipse has sizes $200 \mu m \times 160 \mu m$ (figure 3).

Figure 3. Microphotograph of atomically-smooth region of silicon sample used in the reference arm of MNP-1 interferometer.

After installation of atomically-smooth surface in the interferometer reference arm the measurements of silicon specimen containing monatomic terraces were performed again. Figure 4 represents the measurement result of the same surface area, as in Figure 2, a, obtained by MNP-1 with atomically-smooth reference mirror.
Figure 4. Result of silicon specimen measurement using atomically-smooth reference mirror: (a) 3D profile, (b) height distribution.

The height distribution plot shown in figure 4, b gives us the possibility to estimate the height resolution of this measurement as less than 30 picometers. The resolution means RMS of measured height values in the atomically-smooth region. Thus, the usage of atomically-smooth reference mirror allows us greatly increase the height resolution and to measure the height of monoatomic steps.

4. Conclusion
The experimental results of the measurement of surface relief of special silicon specimen were presented. Differential measurement, carried out by nanoprofiler MNP-1, allows us to reduce the influence of instrumental function and to detect monoatomic structures.

For improvement of height resolution of MNP-1 the special silicon sample containing wide and extremely smooth surface area (atomically-smooth mirror) was proposed to use as a reference mirror of interferometer.

The results obtained show that using of the atomically-smooth surface as a reference mirror of interferometer and the method of partial correlogram scanning drastically improves the height resolution of the nanoprofiler up to 30 picometers and allows us to visualize monatomic terraces on silicon surface.

References
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