AFM contributions in epitaxy

A.V. Latyshev, D.V. Sheglov, E.E. Rodyakina, S.S.Kosolobov, D.A.Nasimov and A.L. Aseev

Institute of Semiconductor Physics SB RAS, 630090 Novosibirsk
Tel./fax: (3832) 331080, e-mail: latyshev@thermo.isp.nsc.ru

The possibility to create artificial materials with principal new properties has generated rehabilitated interest in the crystal growth. The most important part for modern nanoelectronics materials is epitaxial thin films. So the control of materials on an atomic level becomes of crucial interest not only for basic knowledge but also in relation to the minimization of electronic devices. In this point view atomic force microscopy (AFM) bears great potential for providing essential contribution to the so-called bottom-up approach to nano-technological applications.

Atomic force microscopy (Solver P47H and P7LS NT-MDT) has been applied to investigate stepped silicon surface morphology during epitaxial growth. The both contact and semi-contact modes were realized at ambient conditions. Wet-chemical etching procedure did not applied to the sample because it can effect on tip-sample interaction. Thereby, only standard cleaning treatments to the sample were used. All experiments were carried out at the room temperature.

For detailed inspection of surface structure, it is preferable to form large step-free areas with a width up to several micrometers. Keeping in the mind the complications to produce the terraces with the width larger than several hundred nanometers on the silicon surface, there were used the phenomena of kinetic instability of regular steps and surface patterning to increase the terrace width [1]. As results, terraces with the width up to 10 microns were organized by means of crucial rearrangements of equidistantly distributed monatomic steps. The flattening of the silicon samples in an ultrahigh vacuum (UHV) chamber was controlled by *in situ* reflection electron microscopy (REM). Epitaxial growth was carried out in the UHV-REM also.

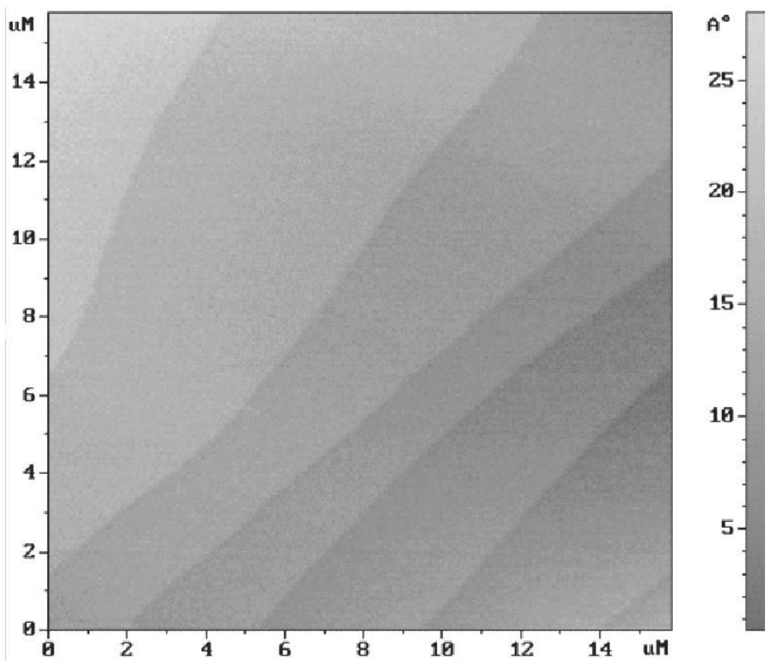

Fig.1. The typical AFM image of the silicon (111) surface after cleaning and flattening treatments.

Fig.1 demonstrates the typical AFM image of the stepped silicon (111) surface with enough large step free areas. The lines of this image are atomic steps, 0,31nm in height. Due to well-controlled redistribution of atomic steps the, some terrace has the width up to several micrometers in spite of the fact that the average interstep distance calculated from surface misorientation was less 40 nm. By the way the average roughness of the silicon surface with natural oxide measured by AFM was less than 0,6 angstrom at the area between monatomic steps [2].

Peculiarities of the initial stages of epitaxial growth silicon, germanium, gold, and cooper were studied as a function of temperature, supersaturation and step configurations. Step-step interaction, step-doubling and step faceting were under consideration. Step propagation and growth instability were analyzed during growth and various manipulation of vicinal surfaces. Atomic growth mechanisms and driven force for surface growth instability were studied during strain and stress, adsorbates and surfactant, homo- and heteroepitaxy.

The role of both bulk and surface point defects in the growth is still unclear. That stimulates us to investigate the surface structure used rapid quenching, which provides the interaction of bulk point defects with the surface. Large singular parts of the silicon (111) surface were created to reduce the influence of monatomic steps to structure reconstruction on the surface. The triangle negative islands were registrated on the (111) surface after quenching (Fig.2). The depth of this islands was measured by AFM to be equal to 0,09±0,03 nm. One can see a denuded zone near monatomic steps is free from negative triangular islands. An existence of denuded zones indicates on the strong influence of monatomic steps on the elementary processes on the crystal surface. The part of the surface area covered by negative islands was equal to 35±5 % regardless of initial temperature of quenching, which was varied in the range of 900–1300^{0}C. The effective activation energy of island nucleation was deduced from temperature dependence of the island density to be equalled to 0,35±0,05 eV. Thence it was stated, that negative islands were characterised by the (7x7) structure. In according to the high temperature *in situ* STM investigations adatoms on the surface is not limiting factor for formation the structure (7x7). Analysing the geometric modelling of the (7x7) structure and data of our measurements, we assumed that the namely formation of surface vacancies is one of the limiting factors for formation of the (7x7) surface structure.

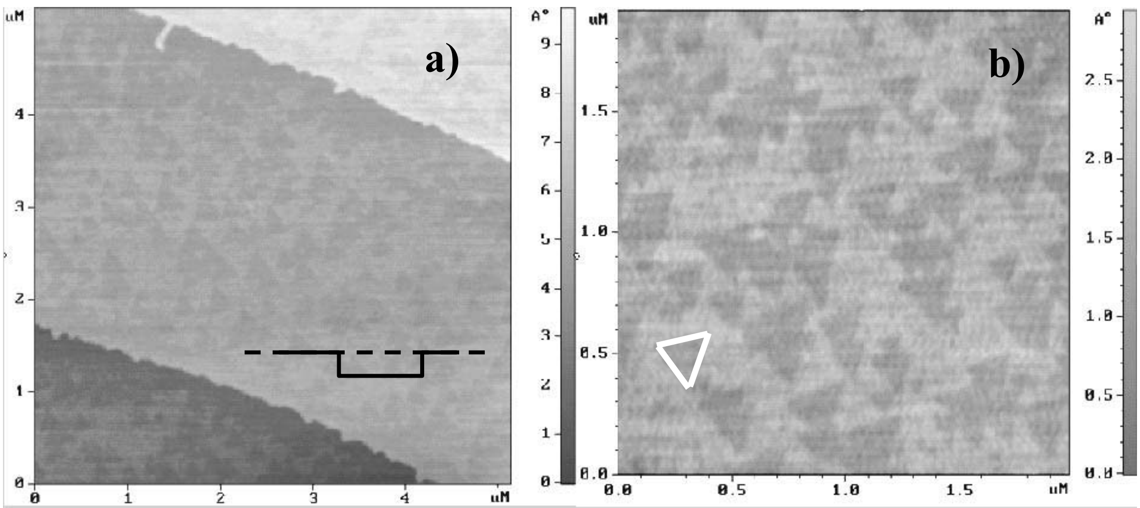

Fig.2 Topographic AFM images of the silicon (111) surface after quenching from 1250^{0}C to room temperature. The form of the triangular islands is shown on top-right corner of AFM image (a). Schematic triangular in (b) demonstrates the three crystallographic (110) direction.

At initial stages of the heteroepitaxial growth various superstructures are formed depending on the kind and thickness of deposited atoms, substrate orientation and temperature. The interaction of superstructure domains with individual monatomic steps of substrate surface may be investigated successfully by AFM also. During deposition of copper at 720^0C the domains of the (5x5) superstructure was induced by Cu appear at the initial stage of heteroepitaxial process. The increasing of the superstructural domains leads to attachment of domain boundary to monoatomic step. After that a shifting the atomic steps restricted by the domain was found as further domain expanding. The completion of surface reconstruction leads to the step bunching with increasing the height and decreasing the density of substrate steps. The non-uniform polynucleation of superstructure domains and a diffusion exchange between neighboring steps are the necessary conditions for step bunching induced by surface reconstruction. The effect of step bunching is reversible.

Typical AFM image of the silicon surface after step bunching induced by cooper deposition represented in the fig.3a. The average height of the introduced steps (step bunches) is 1-2 nm. Thereby each bunch consists from several monatomic steps. We speculate that different contrast at the phase shift AFM image (Fig.3b) points to different direction of surface reconstruction induced by Cu appear at the initial stage of heteroepitaxial process. One can see just three kind of contrast intensify. This fact speaks for (5x5) surface reconstruction, which characterized by three dedicated directions. This pattern demonstrates the broad opportunities for AFM phase shift images applying in the surface superstructures analysis.

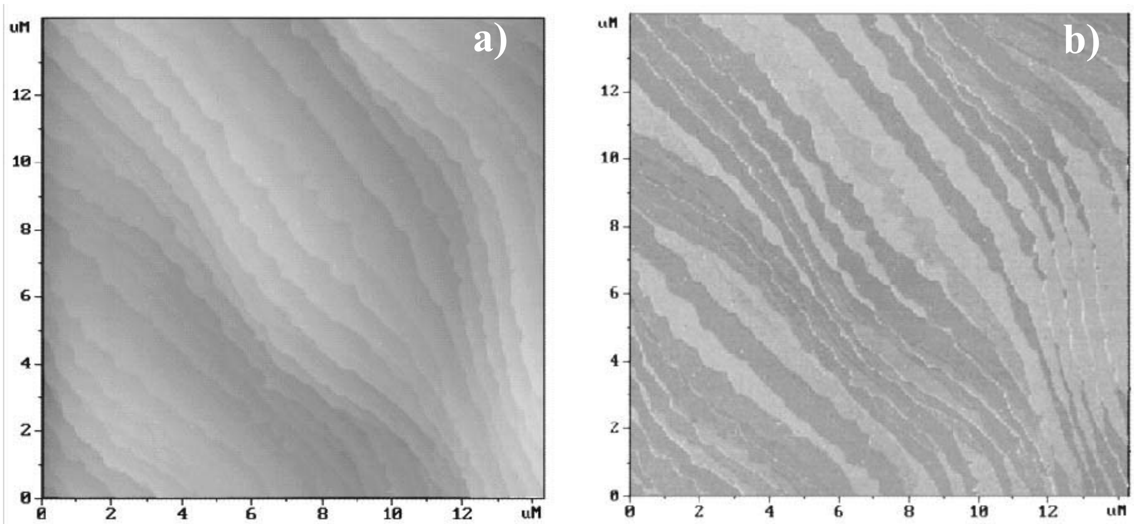

Fig.2 Topological (a) and phase shift (b) AFM images of the silicon (111) surface after copper deposition.

The obtained results were compared with ones of ultrahigh vacuum reflection electron microscopy and high-resolution transmission electron microscopy and provide new opportunity for better understanding of the atomic processes during growth on semiconductor surfaces including self-assembling and self-ordering.

This work has been partly supported by RFBR (01-02-17464) and by the programs of “Physics of Solid Nanostructures”. We would like to acknowledge in the sample preparations of A.E. Dolbak.

[1] S.S.Kosolobov, A.L.Aseev, A.V.Latyshev, Fizika i Tehnika Poluprovodnikov, Vol 35, No 9, 2001, pp. 1084-1091.

[2] D.V. Sheglov, A.V. Prozorov, D.A. Nasimov, A.V. Latyshev and A.L. Aseev, Phys. Low-Dim. Struct. 5/6 (2002) pp.239-247.