SPM-2002, Proceedings. P. 126

Peculiarities of nanooxidation on flat surface

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Nanometer scale oxidation of semiconductor and metal surfaces by scanning probe microscope is an important subject in progress of new nanoelectronic devices. This paper is deal with investigation of tip-induced local anodic oxidation of the titanium, gallium arsenic and silicon films. The number of parameters such as applied voltage, oxidation time and relative humidity was under consideration.

An atomic force microscope (Solver P-47H, NT-MDT) has been performed to carry out experiments at ambient conditions. The sample was cut from a silicon wafer with misorientation angle less than 1^0 from the (111) plane. A clean silicon surface was prepared by high temperature annealing in an ultrahigh vacuum chamber of reflection electron microscope. Cleaning process was controlled by an image mode of reflection electron microscopy. Direct REM observation allows to control roughness of the silicon surface. The sample was heated by passing a direct electric current. Using phenomenon of monatomic step rearrangement, induced by electromigration effect of silicon-adatoms, large flat terraces were fabricated on the silicon (111) surface. The average roughness of obtained terraces was measured by AFM less then 0.6 angstrom and the average distance between monoatomic steps (terrace width) - as 3-4 μm.

The sample holder has a contact pad to connect the sample to electric wires of microscope. Titanium film with 40-angstrom thickness on the silicon (111) surface was deposited from an electron gun evaporate in an UHV chamber at room temperature (Fig.1). Smooth gallium arsenic film, with roughness ~1 angstrom, was grown by liquid phase epitaxy method. AFM images were obtained in the resonant mode with platinum coated silicon cantilevers (ν=150 kHz).

AFM-image of the silicon (111) surface with titanium film, 40 angstrom in thickness, is shown on fig.1a. Notable that the titanium film uniformly cover the silicon (111) surface with a layer of natural oxide. So the system of regular lines replicated monoatomic steps on the silicon (111) surface is observed on the titanium film deposited on this surface (Fig.1b). The height of the lines is approximately 3 angstrom, the average roughness of the titanium film between lines is near 0,6 angstrom.

At ambient conditions with relative humidity less than 25%, local anodic oxidation produced by AFM-tip wasn't observed. With increasing of relative humidity up to 50%, the oxidation process was initiated but the permanent anodic oxidation occurred at relative humidity around AFM-tip more than 50%. The experiments on titanium, silicon and gallium arsenic oxidation, presented in this paper, were carried out at 50-70% relative humidity.

Titanium, silicon and gallium arsenic films were oxidized and sets of oxide lines were created via tip-induced local anodic oxidation with variation of oxidation duration from 10 to 1000 ms at 10 V applied voltage. On fig.2a, one can see typical AFM image of the oxide line set on the gallium arsenic (001) surface. On fig. 2b is shown crosscut of set of these lines. The same crosscut of oxide lines produced on titanium film, which has 80-angstrom thickness, is shown on fig.2c. One can see that at equal oxidation time and magnitude of applied voltage the height of oxide line on titanium films is higher than on gallium arsenic one approximately on 30%.

For close investigation of peculiarities of extra thin film tip-induced oxidation, the titanium film, 40-angstrom in thickness, was oxidized in wide range of oxidation time. The dependence of oxide line height on oxidation time is represented on fig.2d. One can see at oxidation time up to 5 ms data shows logarithmic character of oxide growth. This result is in good agreement with the first Mott model of oxidation. Because of small thickness of titanium film (40 angstrom), the saturation of titanium oxide growth observes in the oxidation time range 5-1000 ms. It corresponds to full oxidation of the titanium film under the AFM-tip. Increasing of the oxidation time caused extra growth of oxide lines. We speculate that it is the initial stage of silicon oxidation process through 60-angstrom titanium oxide film.

Also the similar investigations were carried out on the clean silicon (111) surface. The permanent tip-induced anodic oxidation of the silicon (111) surface with natural oxide coating was observed in wide range of applied tip-sample voltage and oxidation time. The height of the obtained oxide patterns was studied as a function of the applied voltage and the velocity of the tip movement.

From analysis of the oxide line height dependences on oxidation time and applied voltage magnitude, parameters for the anodic oxidation nanolithography were optimised. Fig.3 demonstrates example of a nanometer structure produced by tip-induced oxidation of 40-angstrom titanium film. One can see dielectric oxide lines with width of 50 nm and conductive channel between them with width of 20 nm.

Tip-induced local anodic oxidation of titanium, silicon and gallium arsenic films surfaces in ambient conditions is presented. It was found that the relative humidity is the critical parameter for anodic nanometer scale oxidation process. Oxide patterns on smooth titanium, silicon and gallium arsenic surfaces were obtained. The ability of using tip-induced oxidation method for fabrication nanoscale structure is demonstrated. The height of the oxide patterns is studied as a function of the applied tip-sample voltage and the velocity of the tip movement.