COMPLEX MODIFICATION OF SURFACE BY AFM PROBE: “TINE&MEMO” TECHNIQUE

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One of the promised methods for nanolithography is the tip-induced modification by a scanning probe microscopy, particular an atomic force microscopy (AFM). Also AFM becomes an important tool for the imaging surface down to the atomic scale even under the ambient condition. The advantage of an atomic force microscope is the possibility to modify the semiconductor or metal surface locally. The characteristic size of the nanomodification for this method varied from 10 to 100 nanometers at lateral directions. There are two basic methods of the nanofabrication with an AFM probe: the local anodic oxidation by applying oxidized potential [1] and “direct scratching” of the surface by an AFM tip [2]. The both methods have been tested by the fabricating of nanostructure objects. Unfortunately the local anodic oxidation of semiconductor and metal surfaces demonstrates the small modification depth, generally not more than 10 nanometers [3]. Also the “nanoscratching” allows to produce the modification only at 1-2 nanometers in the depth without observing changing in the tip shape [4]. We present results of the investigation of the simultaneous application of the local anodic oxidation and direct scratching to semiconductor surfaces by an AFM probe.

The atomic force microscope (Solver P47H) has been applied to fabricate nanopattern on semiconductor and metal surfaces. The both contact and semi-contact modes were realized at the ambient conditions. The standard silicon cantilevers and ones covered by conductivity metal films (Au, Ti, Pt) were used (ν=150÷450 kHz). The local anodic oxidation of the surfaces was took place under an applying voltage at the range –50 and 0 V between the tip and the sample.

The oxidation kinetics and the oxide line structure allow us to evaluate three basic limiting factors for the AFM-tip induced oxidation process. First one is the existence the natural oxide layer on the surface, which limits the anions diffusion to the bulk. Unfortunately there are no ways to remove completely the natural oxide on the silicon surface for AFM experiments at ambient conditions. Additionally an atomic clean surface obtained at UHV conditions is free from an adsorbated water making principal impossible the local anodic oxidation by the AFM lithography [1]. Our experiments for the minimization of the oxide cover didn't influence effectively on the deepness of the oxidation. However an effect of the natural oxide on the anodic oxidation may be minimized during well regulated scratching of the surface by a conductive tip under a voltage bias.

The second factor is mechanical stresses in and around a modified volume during the oxide growth, which restricts a cation diffusion to the reaction zone [1]. To minimize influence of the non-controled mechanical stress initiated by the increasing of the volume of the oxide comparing to the crystal one, we proposed to use an oscillation mode for the tip modification. The sharp AFM tip contacted mechanically to the oxidized area produces the partially destruction of the oxide film yielding a stress relaxation inside of the bulk near the tip contact. Moreover the defect generation initiated by the mechanical drubbing occurs preferable channels for a charge exchange during the oxidation process, which can increase the deepness of the oxide film.

And third one is the low potential (10V) applied between the substrate and the tip. Experiments with the increasing of the substrate-tip bias stimulated the unstable oxidation and defect generation making the tip-induced modification is not reproducible. However our studies show that applied to the tip voltage can be enlarge reasonably up to 50V optimizing water vapor or adsorbed water by means of control the humidity conditions [5,6].

Detailed analysis of physical aspects of the AFM-tip induced lithography presented behalf allows us to turn finally to established the novel method of the simultaneous Tip Induced NanoElectro-MEchanical MOdification (TINE&MEMO). Otherwise it was realized the method of the simultaneous applying to the AFM-tip the both mechanical pressure and electrical bias in an oscillation mode (semi-contacted one), which allow to destroy an natural oxide layer on the surface and annihilate mechanical stresses in the volume.

TINE&MEMO-based nanolithography was successfully realized for fabrication of nanoscaled devices [7]. For example, an electron interferometer was fabricated by figurative cutting of the conductive layer of the heteroepitaxial AlGaAs/GaAs system (Fig.1). The Aaronov-Bohm oscillation period was measured from precision conductivity is corresponded to the effective radius 90 nm. So small interferometer size allows increasing the operational temperature of the device up to one order [8].

In conclusion we demonstrated advantages of the simultaneous nanoscale local anodic oxidation and the direct scratching of semiconductor surfaces by the AFM probe. The depth of such nanomodification increases in 3-4 times beside standard local oxidation modifications and in ~10 times besides the simple direct scratching of the surface by the tip. Resistance measurements of the initial conductive channel show critical resistance increasing after cutting of channel at room temperature.

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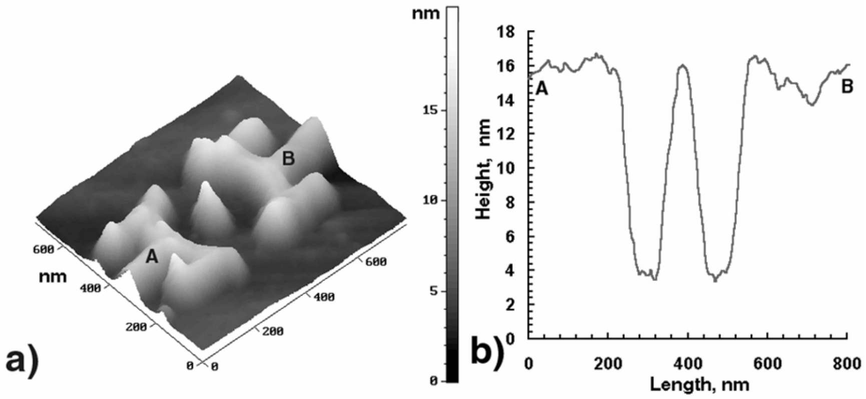

Fig.1. Topographical AFM-image of AlGaAs surface pattern of an electron interferometer, which was lithographically defined by TINE&MEMO-based technology (a). Line scan through the interferometer (b).