AFM investigations of nanometer-scale metal clusters formation on silicon surface

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Introduction

Due to development of nanoelectronics, a noticeable attention is paid to formation of nanometer-sized metal clusters. Metal nanoclusters are being used in such single-electron systems as single-electron transistors and multi-island tunneling lines [1]. Thin semiconductor films, partly covered with metal particles, are widely used as high-sensitive gas sensors [2]. One of traditional methods for forming such clusters is vacuum sputtering of ultra-thin metal films on conditions of low interaction between substrate and adsorbed atoms. This work deals with nanometer-scale metal cluster array formation on silicon surface by laser and magnetron sputtering of ultra-thin films. Our interest to such structures caused, mainly, with possibility of use such structures as shading masks for ion etching.

Results and discussion

Arrays of nanometer-sized clusters of aluminium, indium and copper were formed during precipitation of extra-thin films onto silicon clusters by vacuum laser and magnetron sputtering. Growth velocities in different sputtering modes were previously determined by deposited films thickness measuring with methods of optical interferometry and X-ray reflectometry. Polished silicon plates of [111] orientation were used as substrates. Substrates were prepared by standard methods using organic dissolvents. Surface morphology of obtained samples was investigated with atomic-force microscope "Solver P47", produced by NT-MDT company (Zelenograd, Russia), in contact and tapping modes. Size of obtained islands and their surface density were determined from AFM images of samples.

Excimer laser, produced by "Lambda Physik" company, served as radiation source of radiation of 248 nm wavelength (Kr-F gas mixture, pulse duration 20 ns, pulse repetition frequency 20 Hz, pulse energy 200÷300 mJ) for laser sputtering. Deposition was executed in vacuum volume of VUP-5 plant (residual gas pressure ~10^{-5} torr). Experiments of In clusters formation were carried out. Thin metal films (effective thickness 0.25 nm) were deposited onto silicon substrate at room temperature. AFM investigations showed formed In clusters 80 nm diameter, 2÷3 nm height and about $5 \cdot 10^8$ cm^{-2} surface density on the sample surface. Besides, experiments showed appearance of some number of large (1÷5 mkm diameter) metal drops along with nanometer-sized clusters. Apparently, these drops conditioned with local melting of sputtering target and transportation of liquid phase to the sample under laser irradiation.

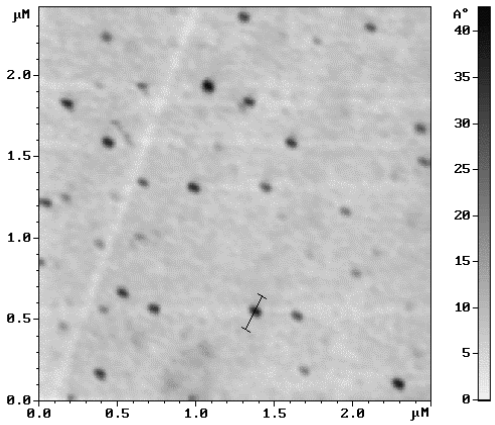
For magnetron sputtering a DC magnetron was used. Sputtering takes place in vacuum volume of VUP-5 plant in argon media (working pressure ~$6 \cdot 10^{-3}$ torr). Parameters of obtained structures (cluster size and surface density) dependence on growth conditions (deposition rate, substrate temperature, deposition time) was investigated. Substrate temperature during deposition process was variated in the range 25 – 400 °C. We fixed appearance of In and Al clusters at room temperature already.

Pic. 1 shows AFM image of silicon surface with clearly seen aluminium clusters. A profile of vertical section of a cluster is shown on Pic. 2. As it can be seen, clusters have the following characteristics for the sample: 2 – 4 nm height, 70 – 100 nm diameter, about $5 \cdot 10^8$ cm^{-2} surface density. Surface morphology of regions between clusters corresponds to initial silicon substrate morphology.

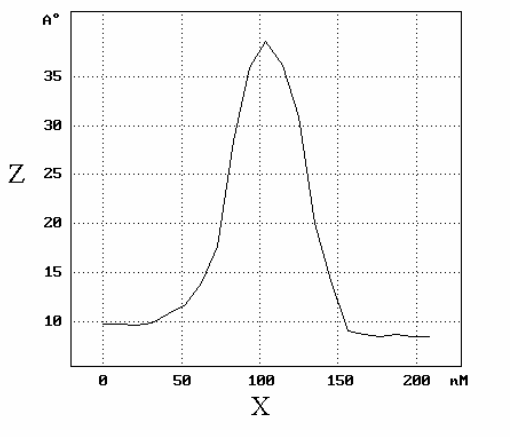
Our investigations allowed to set up, that the main parameter, essentially affecting on metal cluster's size, is substrate temperature during metal deposition. As the growth temperature rises, cluster's size enlarges (Pic. 3). The fact may be explained with increase of metal adatom's surface diffusion rate, which runs to increase of clusters growth rate and decrease of

number of appearing germs. Similar cluster's parameters dependence on temperature has been obtained in paper [3] for metal clusters formation on polymer film surface.

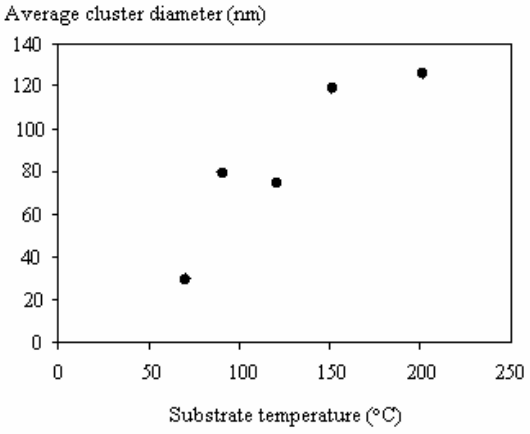
Pic. 4 shows AFM image of indium clusters.



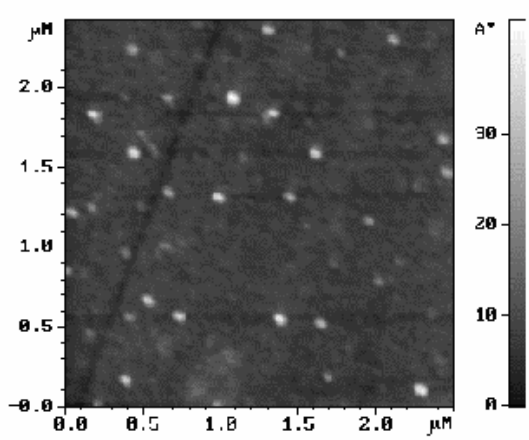
Pic. 1. AFM image of aluminium clusters. Black color on image corresponds to maximal relief height.



Pic. 2. A profile of vertical section of a cluster marked with a segment on Pic. 1.



Pic. 3. Temperature dependence of average diameter of aluminium clusters on silicon surface.



Pic. 4. AFM image of indium clusters. White color on image corresponds to maximal relief height.

For small quantities of deposited matter an array of separated clusters appears on substrate surface. With increase of deposition time (effective film thickness) both growth of existing clusters and appearance of new germs take place. Number and size of clusters increase until coalescence of clusters and formation of a solid film at effective film thickness of 3 – 5 nm.

Conclusion

Nanometer-scale metal cluster array on silicon surface formation features by laser and magnetron sputtering have been studied. Arrays of Al, In, Cu clusters 20 – 200 nm size and 10^8 – 10^{11} cm^{-2} surface density have been obtained. It is shown that size and surface density of clusters essentially affected by deposition process parameters and duration.

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