STRUCTURE OF ALUMINUM THIN FILMS ON SILICA SUBSTRATE

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Aluminum thin films on silicon substrate were studied by a scanning tunnelling microscopy technique. The data obtained with spatial resolution 1nm revealed a - romboidally ordered thin film structure near the border aluminum-silicon and porous in the island's upper parts. The structure was analyzed applying dangling bonds mechanism. Volt-ampere curves demonstrated strong dependency from the film thickness and were interpreted as nanoscale effects.

Keywords: aluminum film, tunnelling microscopy, dangling bonds

1. Introduction

Since first "classical" STM scans of silica surfaces [1] researchers realised that Si lattice faces are intrinsically structured. The rhomboidal pattern on [111] lattice surface was analyzed by introduction dangling bonds and adatoms which had been actively studied [2]. Further studies confirmed importance of the dangling bond properties for silica surface properties. For example, coupling between two dangling bonds was studied which resulted in extra energetic states in the band gap [3]. Metastable and stable Si dangling-bond defect creation in hydrogenated amorphous silicon was investigated too [4-5]. Two dangling bonds were found to be a strong candidate for a charge cubit for quantum computing [6]. Dangling bonds could significantly influence the thin film structure deposited on a silica substrate that can be later studied by scanning microscopy. Scanning atomic force microscopy and scanning tunneling microscopy were proven to be extremely useful experimental techniques for characterization of thin films on metal or semiconductor substrate [7]. The technique allows obtaining the films' valuable characteristics on interatomic distance spatial resolution level. Since

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recent nanotechnological advances many research groups have intensely studied the nanoislands films [8].

Aluminum and alumina film's properties are especially interesting because the aluminum together with copper, gold and aluminum-copper alloys is an essential part of most modern electronic devices. The current research with alumina thin films is mostly conducted in a few main directions. The important part of aluminum film's problems is related with alumina layers on bulk aluminum. The layers have high protective mechanical and electrical parameters which are the key factor of the bulk aluminum properties. This seems to be the reason of the variety of studies with alumina films. For example, scanning tunnelling microscopy revealed particularities of crystalic lattice structure [9]. Data of numerical simulations lead to understanding ultarafast aluminum oxidations processes in time frames of a few tens picoseconds [10] or during longer transition times [11].

Alumina films properties have been studied theoretically, particularly it concerns their crystal lattice structure modification types [12], or connections between the lattice types [13]. Alumina-aluminum properties have been also numerically analyzed from the point of view of contacts between the alumina lattices and a metal [14] or between the layers with different level of ordering [15, 16].

Aluminum films properties have been studied mostly by applying scanning tunneling microscopy or electron microscopy techniques. For example in [17-19] a hexagonal atomic structure was found in aluminum films. Scanning tunneling microscopy was applied for investigation of plasmons on the aluminum-alumina contact [20]. Atomic force microscopy which has comparatively low spatial resolution has been applied in order to study stability of aluminum nanoislands formation [21, 22] and deposited aluminum film thermoexpansion as a function of electrical current [23].

The goal of this research is to continue the study of aluminum island films deposited on silica using atomic force and tunneling scanning microscopy techniques.

2. Paper contents

Aluminum islands films on silica substrate were thermally deposited in vacuum. The equipment is directly installed in the vacuum chamber which allowed control of the aluminum temperature, deposition speed and substrate temperature. The substrates which have been used for the films depostion were carefully cleaned and polished silica plates (the roughness was about 4-6 nm). The deposition time interval was a few seconds, and the pressure in the vacuum chamber reached 10^{-5} torr during the deposition process. A microscope INTEGRA NT-MDT allowed conducting measurements in atomic force

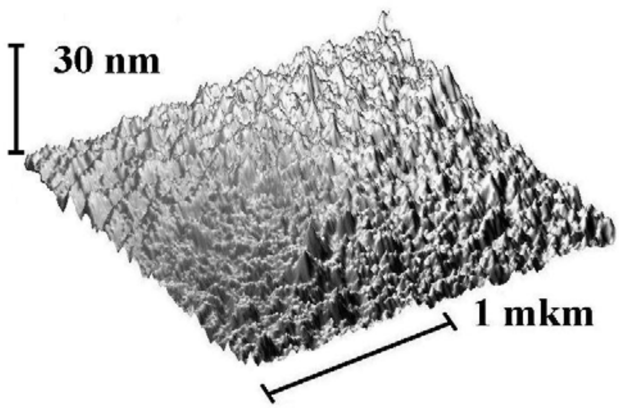

Fig. 1. Atomic force microscopy scan of surface of aluminum islands films on silica substrate.

microscopy and tunneling microscopy regimes was used for precise surface topology study. Atomic force microscopy measurements have been conducted both in contact and semicontact regimes. Measurements' spatial resolution has been determined by cantilever tip curvature and reached 40 nanometres in horizontal direction. Scanning tunneling microscopy spatial resolution reached up to 1 nanometer.

Aluminum nanoislands film surface topography obtained by atomic force microscopy semicontact measurements are presented on Fig. 1 (The film was obtained by thermal deposition during 20 seconds). The islands' sizes on the picture vary distinctly from tens to a few hundred nanometers. The data points out a complicated island nanoscale topology. In order to study the islands' structure more carefully we applied scanning tunneling microscopy technique. Typical scan results with space resolution near of 1 nm are presented on Fig. 2. It should be noted first of all, the dark background on the picture, which has lower electric conductivity comparing with neighboring regions, is originated from silica substrate. Secondly, the distinct rhomboidal gray structure (additionally marked by four white straight lines) with the height above the substrate roughness seems to be formed by alumina thin layers. The porous aluminum monoatomic layers exist just near the substrate surface and its' rhomboidal shape is influenced by silica face centered cubic lattice. The atomic scale details of aluminum atoms deposition is presented on Fig. 3. Filled there designate Si atoms of the crystal lattice (bigger are ones-upper layer, smaller - lower layer), bigger hollow circles mark Si adatoms, filled black circles mark Al adatoms of deposited film. The

huge filled circles mark possible places where aluminum adatoms can be placed on [111] lattice edge. The crossed bonds (—|—) designate the bonds which presumably are brocked during Al ad atoms deposition on Si surface.
Finally, the film structure in the places with higher thickness has nonrhomboidally ordered porous structure. The latter structure seems to be a

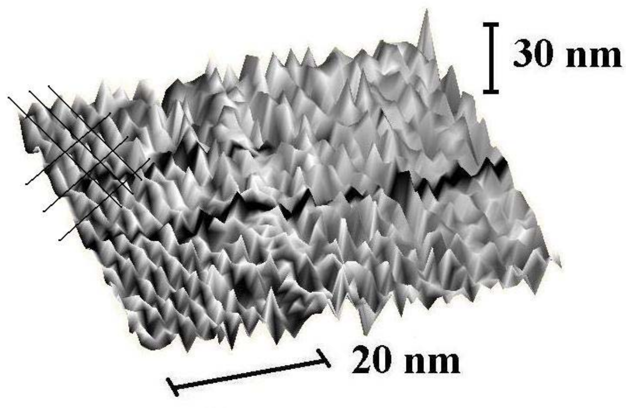

Fig. 2. Scanning tunneling microscopy scan of surface of the aluminum island on silica substrate. Spatial resolution is 1 nm.

typical for more thick aluminum films. A typical surface profile of a thicker aluminum film obtained by scanning tunneling microscopy is presented on Fig. 4. The spatial resolution of the surface profile is near of 5 nanometers. The film

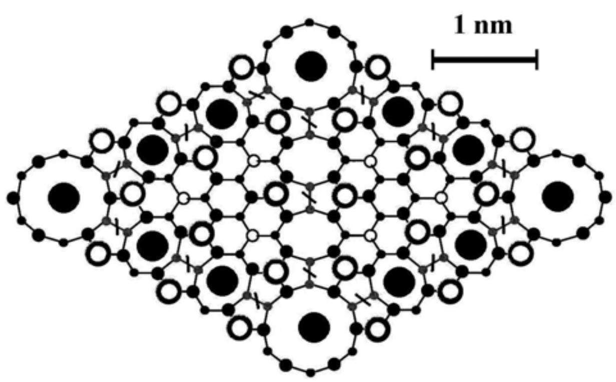

Fig. 3. Scheme of silica substrate surface of (111) orientation

deposition was made during longer time intervals (1 minute). As a result the film is thicker comparing to results on Fig. 2, also isolated islands merged to form a more homogenous bulk structure.

A nanoisland volt-ampere curves are presented on Fig. 5. It characterizes both the metal-semiconductor contact phenomena and aluminium layer peculiarities. The curves do not give the island's conductivity exact values.
First of all note, the electrical current flows through the tunnel threshold that leads to exponential dependency of current value on the threshold parameters (height and spatial characterystics). Secondly, we do not know the exact needle tip area, and the curve shapes allow mainly quality characterizing the peculiarities

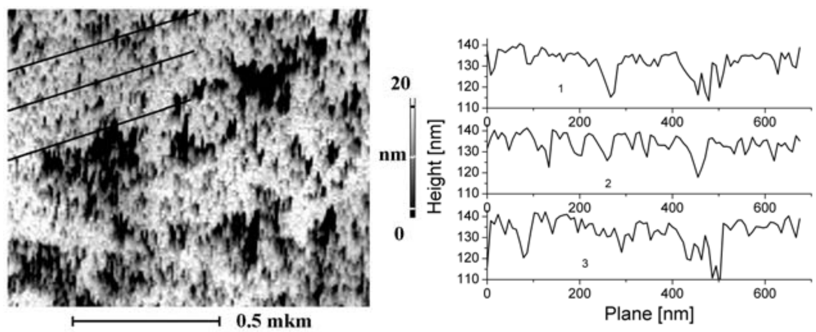

Fig. 4. The scanning tunneling microscopy scan of surface of aluminum islands' films on silica substrate. Spatial resolution is 5 nm (left). Cross-sections plots (right) marked on the scan by straight lines

of current flow through a nanoisland. For example the slopes of the volt-ampere curves are higher for nanoislands' thicker spots if voltage is negative. The similar

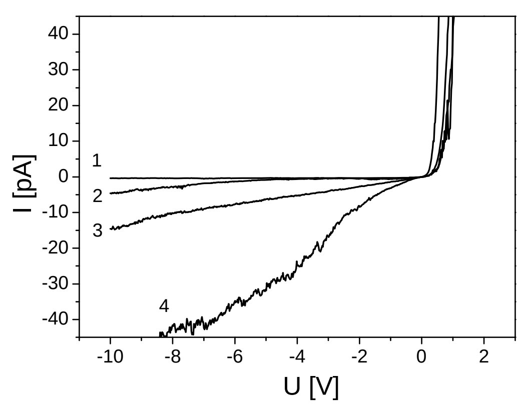

Fig. 5. Volt-ampere curves measured in various part of the aluminum islands; thickness is < 5nm (1), ≈10nm (2), ≈ 15nm (3), and ≈ 20 nm (4)

dependencies had been observed. These features were explained with charge tunneling through Schottky barrier [24, 25]. The metal-semiconductor contact micro-characteristics can influence drastically the volt-ampere curves of slopes in Schottky diodes [26]. However the connection between nanoislands' topological structure and volt-ampere curves of slopes has to be studied further. As we can see from the results of scanning tunnelling microscopy the nanoisland layer is representing itself a cellular porous structure with wall thicknesses in a few atomic layers. It could result in other quantomechanicl effects as a result of electrical current flow through a nanowire [27]. For example, electrical current oscillations as functions of nanowires conductivity were registered in [28, 29]. The oscillation appearance in wires with a few interatomic distance cross-sections were interpreted due to aluminum peculiarities as sp- metal. Secondly, maximums on the volt-ampere curve are originated from the nanowires parts that have different number of atoms in its' crossection (a quantomechanical inner effect). The observed oscillations can be explained as the electrical current flows through the cellular structure walls with different cross-sections (1, 2, … 10, 11, 12… interatomic distances), though interpretation of the electrical current flow features is becoming more intricate due to the complex topology of nanoislands. If regard a nanoisland as an electrical element the scheme of their structure can be represented as the 3D net constructed from resistors.

Research of thin aluminum films can be made by studying the alimina layers on its' surface due to its' high mechanics values and low conductivity influences which is part of aluminum properties. Scanning tunneling microscopy is not an effective way to study alumina surface because of its typical dielectrical properties. Atomic force microscopy technique allows determining the alumina surface shape with relatively low spatial resolution.

6. Conclusions

The scanning tunneling microscopy techniques despite its' relative experimental complicatedness have demonstrated a high effectiveness for aluminum nanoislands characterization. The presented results describe properties of an interface layer in the islands near the substrate surface. The layer has an ordered structure which was influenced by the substrate crystallic lattice symmetry. The presented results indicate interface to Si substrate Al atoms are deposited to 7x7 rhomb edges which are not filled with Si adatoms. The technique allows analyzing of the volt-ampere curves in islands films' parts with different thickness. Further film studies by scanning tunneling microscopy may be directed toward obtaining large amount of volt ampere curves in different islands' parts and comparing the data with the islands' surface shape. These results can be used for chips with nanoscale integration level design.

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