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ELECTRICAL PROPERTIES OF FRACTAL NANOFILMS OF POROUS SILICON

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Samples of porous silicon films grown by electrochemical etching have been investigated. Morphology of the films has been studied by use of scanning probe microscope NTegra Therna. We established that electrical properties of thin films of porous silicon are strongly influenced by various factors such as strength of current through a film, etc. Current-voltage characteristic of the porous silicon films has a strong non-linear and chaotic region in a certain range of voltage. Dependence of current on voltage corresponding to multiple electron tunneling can be used for development of generators of chaos with a broadband spectrum.

Keywords: electrical properties, fractal nanofilms, porous silicon film, microscopy, current-voltage characteristics.

Despite of the fact that porous silicon (PS) was firstly described in the second half of the last century, it remains one of the important objects of research in nanotechnology because of wide range of its applications. In [1,2], you can get more information about PS. Information about formation and using of PS is given in [3,4]. There are many methods growing of PS films [5,6,7]. Each of them has its advantages and disadvantages. It is well-known that optical properties of PS films depend on their thickness, porosity, shape and size of pores [8]. At the present time electrical properties of nano-sized PS films are studied insufficiently. Electrical properties of PS films grown by electrochemical etching in an electrolyte of HF and C₂H₂OH (1:1) have been described in [9]. Etching time was 15 minutes and the PS film had a thickness of several microns. The aim of our study is to investigate electrical properties of nanoscale films of PS obtained by etching within time range about 5 seconds.

EXPERIMENTAL RESULTS

Thin films of porous silicon were produced by electrochemical etching in an electrolyte which characterized by ethoxyethanol ratio HF: EE - 1:1.5. A *p-n* structure has been used as an initial substrate, concentration of n - layer was $10^{18} \div 10^{19} \text{ cm}^{-3}$.

Photomicrographs were obtained by use of optical and scanning electron microscopes.

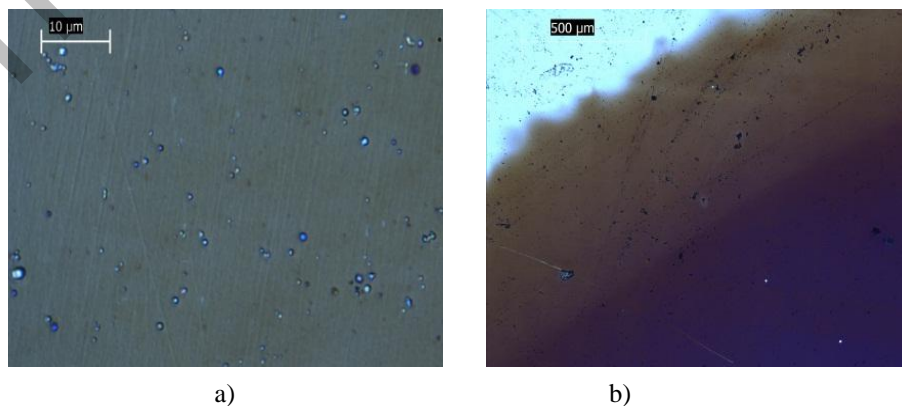


Fig.1. Results of optical microscopy: a) surface of the central part of the porous silicon film; b) boundary between the film of crystalline silicon and its etched region (dark).

Image of edge of the porous film is shown in Figure 1, b. Porosity increases near the center of the film. It corresponds to more dark regions in the figure. It means that thickness of the film changes. For more correct estimation of their thickness of the films we have studied them by use of scanning electron microscopy (SEM).

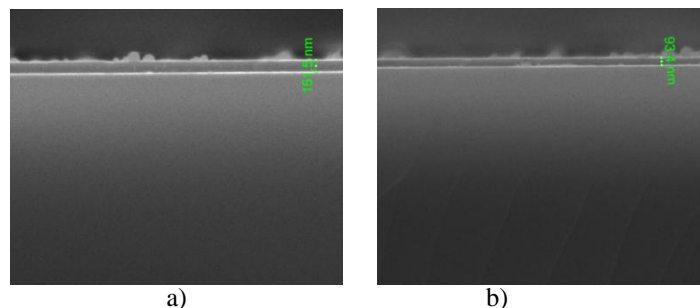


Fig.2. Microphotograph of a porous silicon film obtained by SEM:
a) closer to the center b) edge of the porous silicon film.

Figure 2 demonstrates a lateral surface of a layer of etched PS thin film. The film is not heterogeneous. There are pores in the film. Dark color corresponds to argon medium. Two bright lines limit the lateral surface of the film. At the bottom we can see an image of crystalline silicon. The film thickness ranges from 80 nm to 200 nm due to the irregular current density. Morphology of the porous films has been studied by use of scanning probe microscopy (SPM) NTegraTherma.

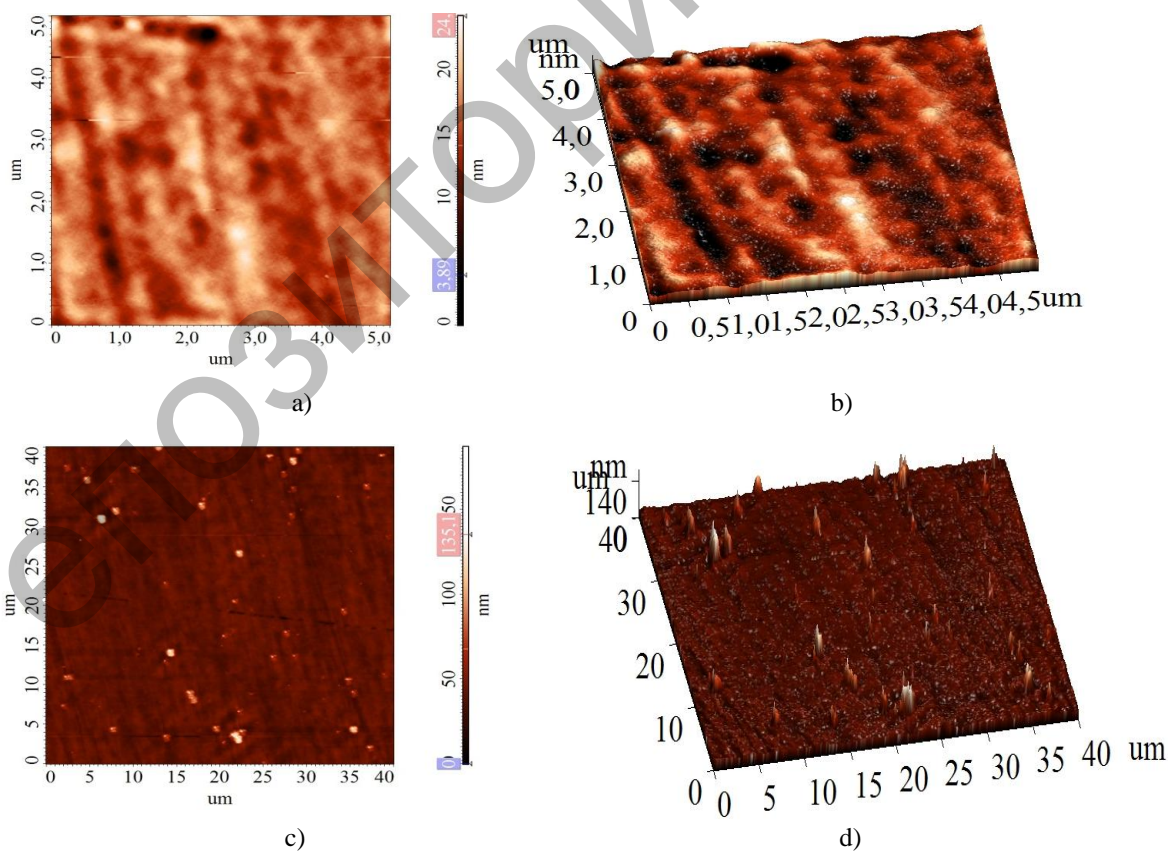


Fig.3. Results of scanning probe microscopy: a) two-dimensional image of a PS film, the resolution is 5-5 microns; b) a three-dimensional image of a PS film, resolution of 5-5 microns; c) a two-dimensional image of a PS film, resolution is 40:40; d) three-dimensional PS film image, resolution is 40:40 m.

According to SPM study we can see a strong heterogeneity in surfaces of PS films. We can also notice that threadlike bumps are located on the surface of the films.

For the investigation of electrical properties of the film of PS we deposited contacts to its surface. Regularities of current flow through a non-uniform surface structure of the PS have been studied.

Current-voltage characteristic of the film of PS contains a non-linear dependence of current on voltage. In this area current rapidly decreases into several units, and we can also observe oscillations of current. Further, current increases with increasing of applied voltage.

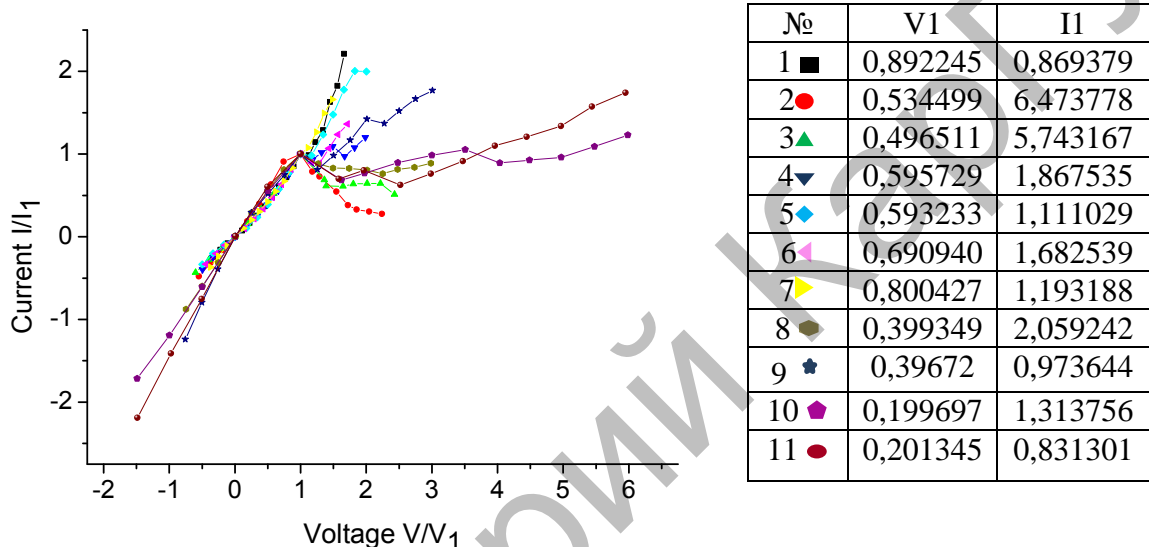


Fig.4. Current-voltage characteristics in the relative variables. I1, V1 - current and voltage corresponding to the first peak.

At recurrence of the experiences (after passing a current with considerable value) we can notice a reducing of depth of minimal value of current (Fig. 4).

DISCUSSION

It is known that dependence of current on voltage for non-linear elements has the area with negative differential resistance (a derivative of voltage by current). It plays an important role in electronics and measurement techniques [10].

Current-voltage characteristics of nano-films have oscillation peaks (Fig. 4). Decreasing of current with increasing of voltage corresponds to existence of structures with negative differential resistance. As usual, this effect can be explained by the phenomenon of electron tunneling through a potential barrier. Porous silicon films have quantum-sized dotted, linear, and flat structures with different potentials of electric field. Due to leakage of electrons through these potential barriers and according to the uncertainty principle, number of states allowing electric current reduces. It leads to reducing of current and to formation of a peak in current-voltage characteristic despite of increasing of voltage. Increasing of voltage also leads to formation of additional peaks. It caused by existence of structures with higher potential barriers.

In addition, current-voltage characteristics of nanostructured porous silicon films and conventional tunnel diodes have significant differences [11]. Our experiments show that distance between peaks (in relative units of voltage) is less by an order. These peaks are sharper and have a resonant character. These facts and figures 1-3 let us to suggest that nano-films have a fractal structure with hierarchical structures characterized by different geometric scales. The corresponding potentials of electric field can be considered as non-linear fractal measures [12,13,14].

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