UDC 530.1

STRUCTURE OF POROUS SILICON FILMS

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The present work is devoted to experimental and theoretical study of silicon films grown by metal-induced chemical etching. Photos of film surfaces were obtained by use of scanning electron microscope. It was shown that variation of etching time leads to changing of informational entropy of the films. This parameter increases for lateral sides of surfaces, and decreases for their top layers. This fact can be used for explanation of ambiguous effects at reflection of photons from surfaces of porous silicon films.

***Keywords*:** porous silicon, nanostructure, morphology, metal-induced chemical etching, informational entropy.

Introduction

Study of physical properties of porous silicon films is an important scientific problem because these films can be considered as a perspective material for developing of quick-operating systems, effective devices of optoelectronics and photonics. Wide application of silicon can be explained by its relative cheapness, stability of its structure at different temperature regimes, ecological safety, etc. [1, 2]. Silicon films are used as components of high-sensitive nanoelectronic devices such as memristors, sensors, solar cells, and so on. Films of porous silicon can be also used as a covering of solar cells [3]. Porous silicon films with different structure have different physical (including electrical and optical) properties. So, we have a possibility to use such films for development of differential electronic devices [4-9].

Nanocluster semiconductor films have scale-invariant, hierarchically self-similar, i.e. fractal structure [10, 11]. Geometrical size, shape, distribution of pores, thickness of porous layer define physical properties of porous films. So, study of surface structure of such films is a problem of interest.

Aim of the present work is experimental and theoretical study of influence of etching time on morphology of porous silicon films.

1. Experiment

Films of porous silicon have been grown by metal-induced chemical etching of p-type silicon substrates with resistivity 1-10 Ohm·cm. Etching time t has been changed from 1 to 100 minutes. Crystal direction of the films is (100). Morphology of surfaces of films has been investigated by use of scanning electron microscope (SEM) SUPRA 40-30-87. The films can be considered as the so called “white silicon” because of their good reflection properties.

Examples of SEM-images (top view) are shown in Figure 1. These images correspond to different values of etching time. Lateral sides of these films are shown in Figure 2.

(a) (b) (c) (d) (e)

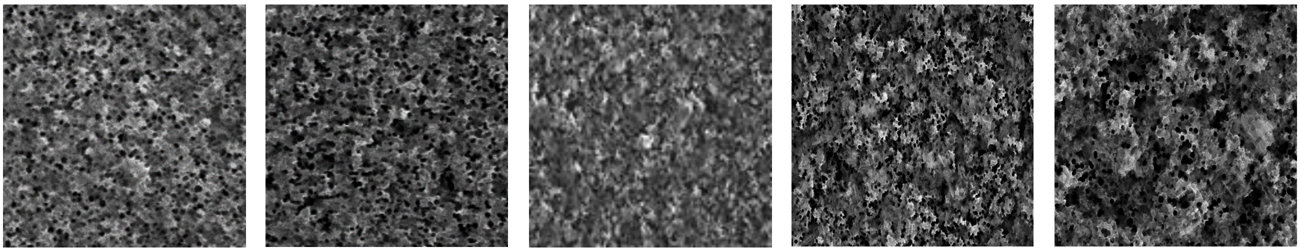

Fig.1. Influence of etching time on morphology of porous silicon films (top view) :
(a) t = 1 min, (b) t =3 min, c) t =10 min, d) t =30 min, e) t =100 min.

(a) (b) (c) (d) (e)

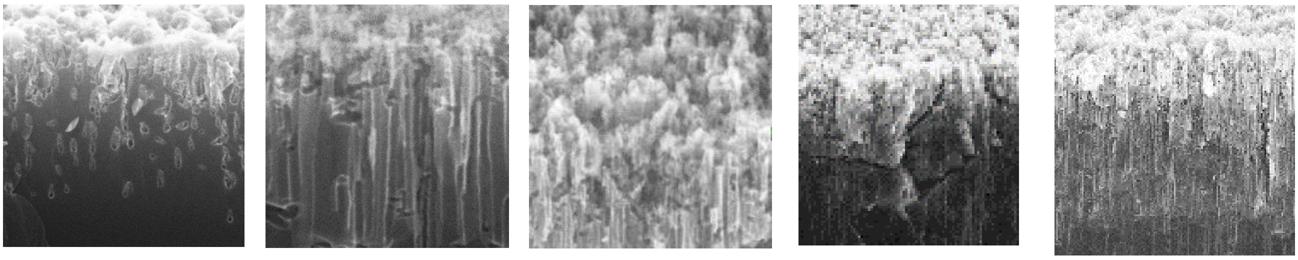

Fig. 2. Photos of porous silicon films (lateral view):
(a) t = 1 min, (b) t =3 min, c) t =10 min, d) t =30 min, e) t =100 min.

So, we can conclude that morphology of films (size and distribution of pores) depends on etching time. Growth of etching time leads to increasing of size of pores and formation of nanoscale clusters.

2. Results of numeric analyses

The surface morphology and cross-cleaved samples obtained in a scanning electron microscope MIRA 3LMU are shown in figure 2.

For quantitative description of influence of etching time on topology of silicon films we have used the following methods if image processing.

For calculation of numeric values of porosity we have transformed the original half-tone images of film surfaces to the new form. As a result, the transformed pictures contain only white and black pixels. Example of this transformation changing contrast of photos is shown in Figure 3. Let us designate number of white and black pixels as N_w and N_b, correspondently. So, porosity of a film can be described as

$$P = N_b / \left(N_b + N_w \right). \qquad (1)$$

Porosity of the image shown in Figure 3 is equal to 58%. We have applied this method for calculation of porosity of other films. Dependence of porosity of the films on etching time is presented in Figure 4. Line 1 corresponds to the top view of the films and line 2 describes structure of lateral surfaces of the films. Results of calculations have been approximated by use of polynomial approximation (degree of polynomial is 4).

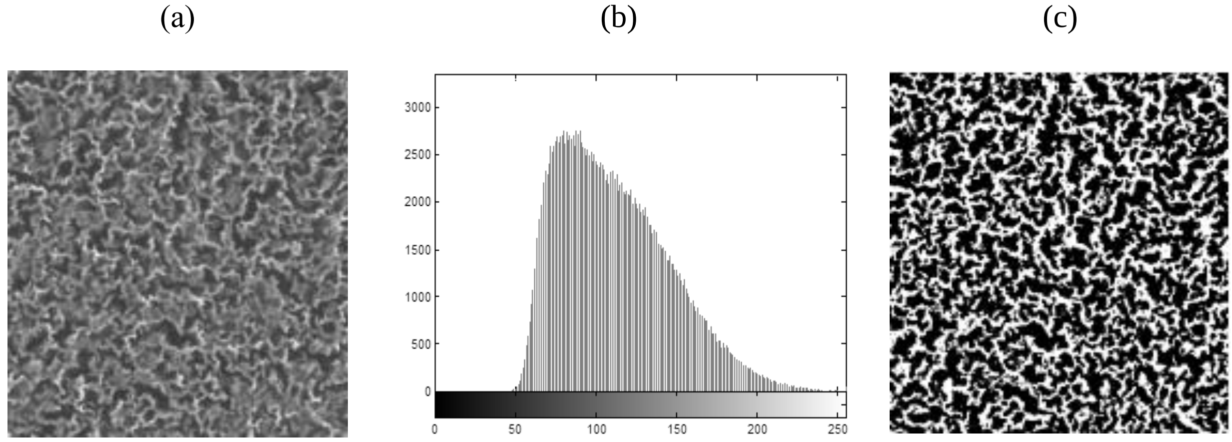

Fig. 3. Original image of a surface of porous silicon (a), histogram for brightness of pixels (b), image containing only white and black pixels (c).

Description of systems with dynamical chaos is possible on the base of the informational-entropic analysis. Thus, for quantitative description of regularity of film structure we can use the following expression written as

$$S = -\sum_{i=1}^{N} P_i \ln P_i, \; i = 1, 2, 3... \tag{2}$$

Here S is informational information, P_i is probability of $i-$th event. Figure 5 demonstrates the dependence of informational entropy on etching time.

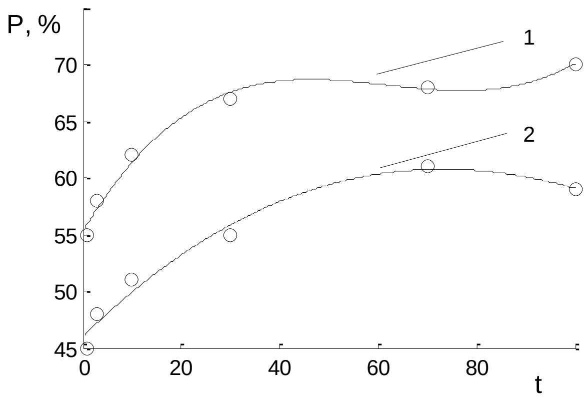

Fig. 4. Dependence of porosity of films on etching time: 1 – top view, 2 – lateral view.

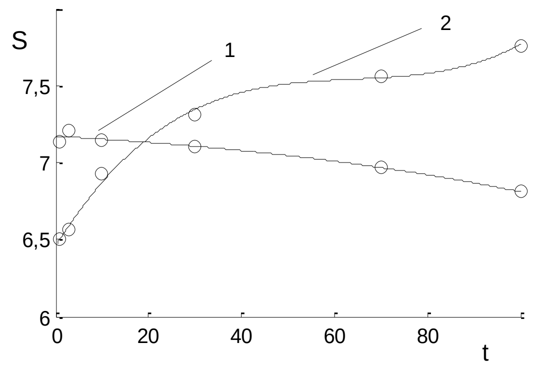

Fig. 5. Dependence of informational entropy on etching time: 1 – top view, 2 – lateral view.

Results of numeric analysis of Eqs. (1) and (2) let us make a conclusion that porosity of films increases until saturation (for top view and lateral view). From Figure 4 we can see that porosity of top layers of the films is greater than porosity of their lateral surfaces (difference is about 10-15%). Informational entropy of lateral side of films increases at growing of etching time.

Surface layer of the films is characterized by increasing of informational entropy in case of increasing of etching time (Figure 5). So, we can conclude that structure of surfaces of porous silicon films (top view) became more regular at increasing of etching time, but shape of pores and their distribution on lateral surfaces became more disordered.

3. Conclusion

Influence of etching time on structure of silicon films has been investigated experimentally and theoretically. Growth of etching time leads to increasing of porosity to its saturation. We can observe this for top and lateral layers of the films, but porosity of a top layer is greater than porosity of the corresponding lateral surface of the film. Increasing of etching time leads to disordering of structure of lateral surfaces of the films, but their top layers became more regular. It can be caused by processes of self-organization of structures in the films at increasing of their number. Results of the present work can be applied for the description of electrical and optical properties of nanostructured semiconductors.

ACKNOWLEDGEMENTS

The research was supported by the grant for Fundamental Research 3209 / ГФ4.

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Article accepted for publication 04.04.2017

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