ФИЗИКО-МАТЕМАТИЧЕСКИЕ НАУКИ

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PHOTOELECTRIC PROPERTIES OF SEMICONDUCTOR STRUCTURE OF POROUS SILICON FORMED BY METAL-STIMULATED ETCHING

Summary. The photoelectric properties of a semiconductor structure sample with an antireflective porous silicon film obtained by the method of metal-stimulated etching are studied. The photocurrent spectra of samples obtained by the method of metal-stimulated etching and electrochemical anodic etching were compared. In the studied structure, with an increase in the applied voltage, a monotonic increase in photocurrents is observed. The photoelectric properties of the resulting structure are influenced by the processes of recharging traps. The studied sample can be used to create highly sensitive photodiodes and in solar energy.

Key words: porous silicon, antireflection film, the photocurrent spectra, traps, nanowires.

Introduction

Porous silicon (por-Si) is currently a promising material in modern optoelectronics. The use of the por-Si antireflection film in semiconductor structures allows one to create high-quality photoelectric converters for solar energy [1]. Based on por-Si, it is also possible to create devices designed to enhance Raman scattering [2], generate and detect radiation in the terahertz range [3]. These areas are relevant for molecular analysis problems.

Recently, a lot of research has been done on the mechanisms of formation and surface morphology of these structures. Despite this, less attention is paid to the electrophysical and photoelectric properties [4]. Therefore, this work is relevant.

The aim of this work is studying the photoelectric properties of this structure.

Sample manufacturing technology

A por-Si sample was formed by metal-stimulated etching. The substrate for this sample is phosphorus doped electronic conductivity monocrystalline silicon with the (100) surface orientation and a resistivity of $\rho = 4{,}5\ \Omega\cdot\text{cm}$. At the first stage, a silver film was created, for which an aqueous solution of Ag_2SO_4 (0.3%), HF (40%), and C_2H_5OH (92%) was used in a ratio of 15:1:5. The duration of the first stage was 1 min. At the second stage, silicon was etched using a solution of H_2O_2, HF (40%) and C_2H_5OH (92%) in a 4:2:1 ratio. The thickness of the obtained por-Si film was 9.1 μm. For electrical measurements, indium contacts were formed on the por-Si film and on the opposite surface of the silicon substrate.

In order to study the photoelectric properties, the photocurrent spectra were measured at T = 300 K using an experimental setup consisting of an UM-2 monochromator, a selective B3-38 voltmeter, and a shutter with a disk rotation frequency of 70 Hz. A halogen lamp was used as a light source. Lighting was carried out along the normal to the front surface of the sample. The sample was included in the measuring circuit in the photodiode mode.

The current–voltage characteristic (I – V) and capacitance–voltage profiling (C – V) of the sample were measured without illumination using an E7-20 immittance meter (OJSC MNIPI, Belarus).

Experiment Results and Discussion

An analysis of the I – V characteristic of the investigated semiconductor structure (Fig. 1) shows that the obtained sample has rectifying properties. Forward bias corresponds to the application of forward voltage to por-Si. The direct branch of the I – V characteristic of the structure is exponential. The rectification coefficient, defined as the ratio of stresses in the forward and reverse direction, at U = 1 V is 718.65.

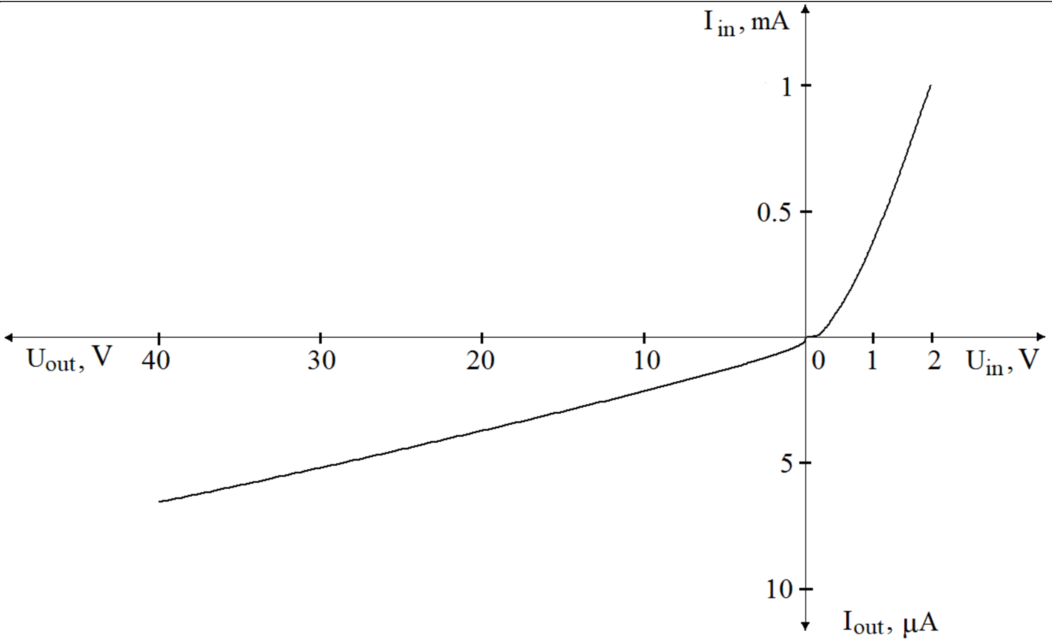
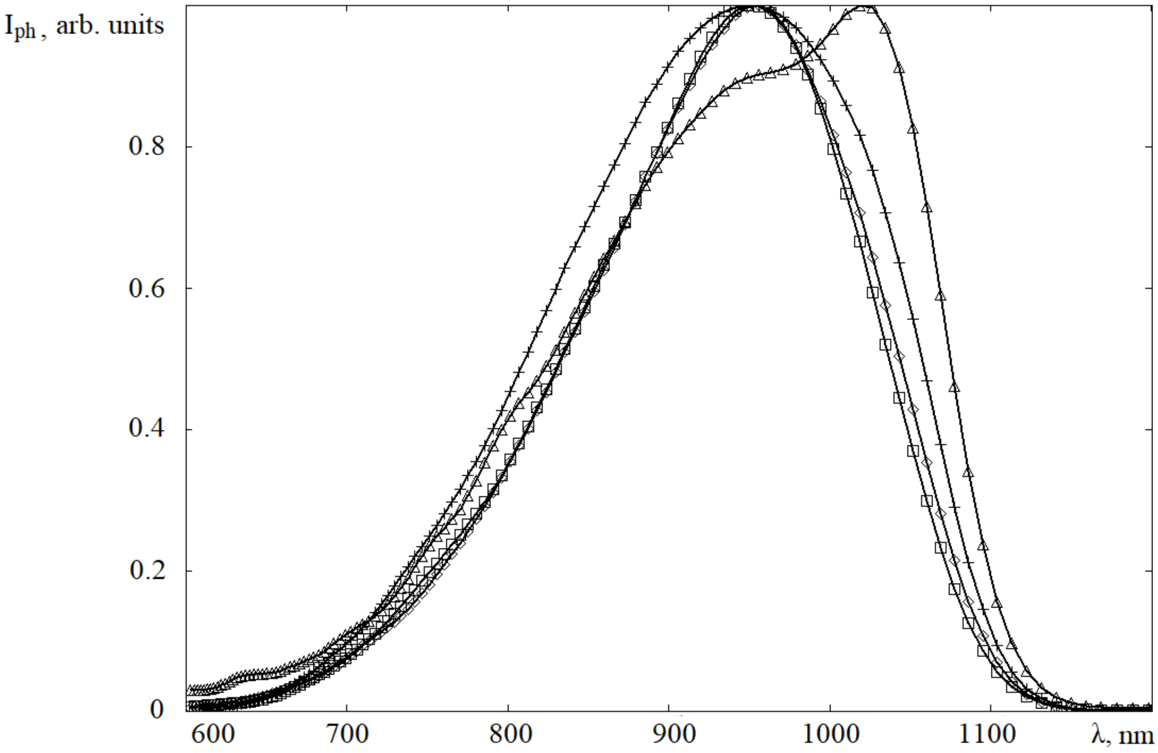
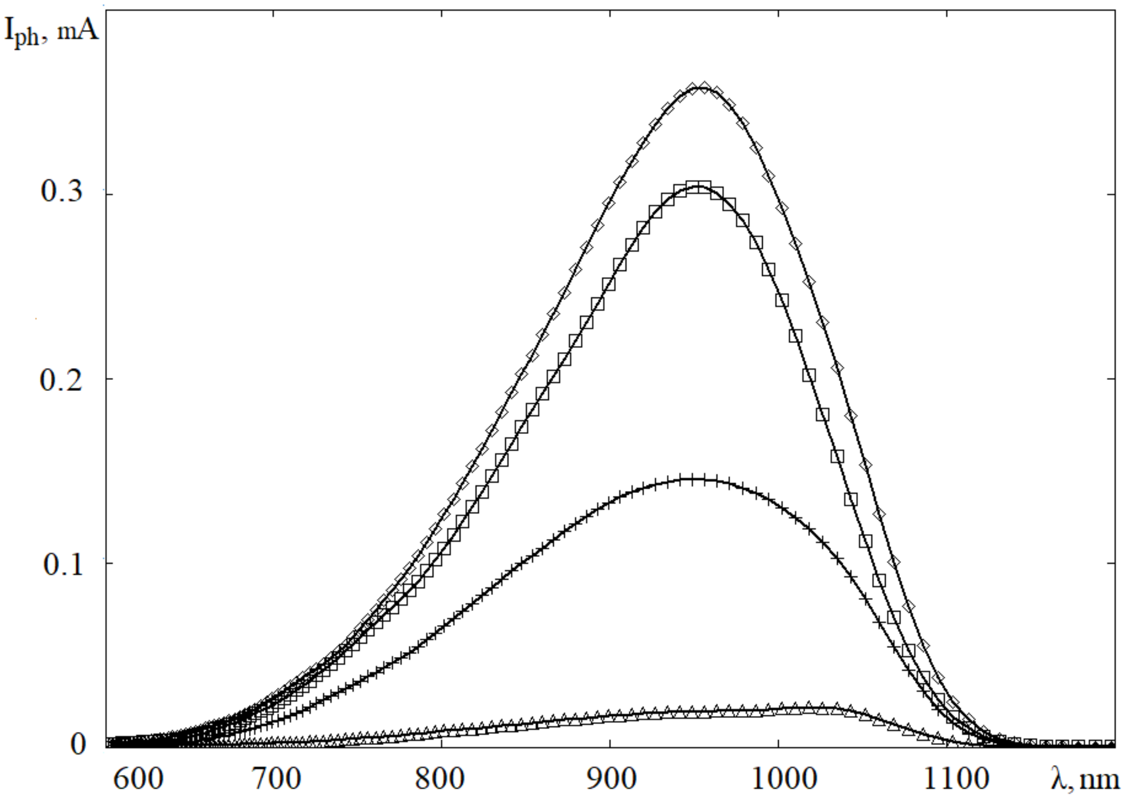


Fig. 1. I – V of the sample

The photocurrent I_{ph} is measured in the photodiode mode (reverse bias is applied to the sample). The spectra of the photocurrent at different values of U are shown in Fig. 2. The band gap E_g of the semiconductor was determined from the long-wavelength edge of the spectra (Fig. 2a) and is equal to 1.12 ± 0.01 eV. This value corresponds to E_g for monocrystalline silicon. This is due to the fact that as a result of metal-stimulated etching, there is practically no nanostructuring of the surface region of the silicon wafer. Quantum nanowires have nanometer sizes, but the quantum-size effect is not observed due to the large number of traps.



a)



b)

Fig. 2. Photocurrent spectra at different voltage values
(△ — 0 V, + — 1 V, □ — 5 V, ◇ — 10 V) of the sample

The half-width of the spectra of the sample $\Delta\lambda_{0,5}$ changes with increasing voltage U (Table 1). The change in $\Delta\lambda_{0,5}$ from the side of the short-wave region is explained by the fact that the absorption of short-wave radiation is carried out mainly in the near-surface region of the semiconductor structure. This part of the spectrum has the greatest sensitivity to surface defects. The influence of near-surface traps on the photo current causes a change in $\Delta\lambda_{0,5}$ from the side of the short-wave region.

The decrease in the half-width of the spectra $\Delta\lambda_{0,5}$ in the U range from 0 to 1 V from the side of the long-wave region is characterized by the influence of traps located in the deeper region of the structure on the photocurrent. With a further increase in U, the long-wavelength part of the spectrum ceases to change.

The nature of the photocurrent spectra of the structures studied in this work differs from the spectra of por-Si samples fabricated by electrochemical anodic etching [5]. In [5], with an increase in U from 0 to 1 V, the half-width of the spectrum decreases from the side of the short-wavelength region. With a further increase in U, the width of the region of spectral sensitivity ceased to change. Therefore, near-surface traps play the main role in this process. The long-wavelength part of the spectrum remains almost unchanged.

Table 1

THE RESULTS OF THE STUDY OF THE PHOTOELECTRIC CHARACTERISTICS OF THE SAMPLE

U, B	I_{ph}, μA	$\Delta\lambda_{0,5}$, nm
0	22,6	248
1	145,4	246
5	303,6	204
10	357,5	161

The increase in the photocurrent with increasing U is explained in terms of the photodiode mode of operation of the investigated semiconductor structure (Fig. 2b). In structures obtained as a result of electrochemical anodic etching, if U increases from 0 to 1 V, I_{ph} occurs. With a subsequent increase in U, the value of I_{ph} doesn’t change [5]. At the same time, in the structure studied in this paper, with an increase in U, a monotonous increase in I_{ph} occurs. This indicates a higher efficiency of por-Si structures obtained by metal-stimulated etching.

The dependences C = f (U) at reverse bias for different frequencies of the measuring signal are determined by the barrier capacitance of the structure (Fig. 3).

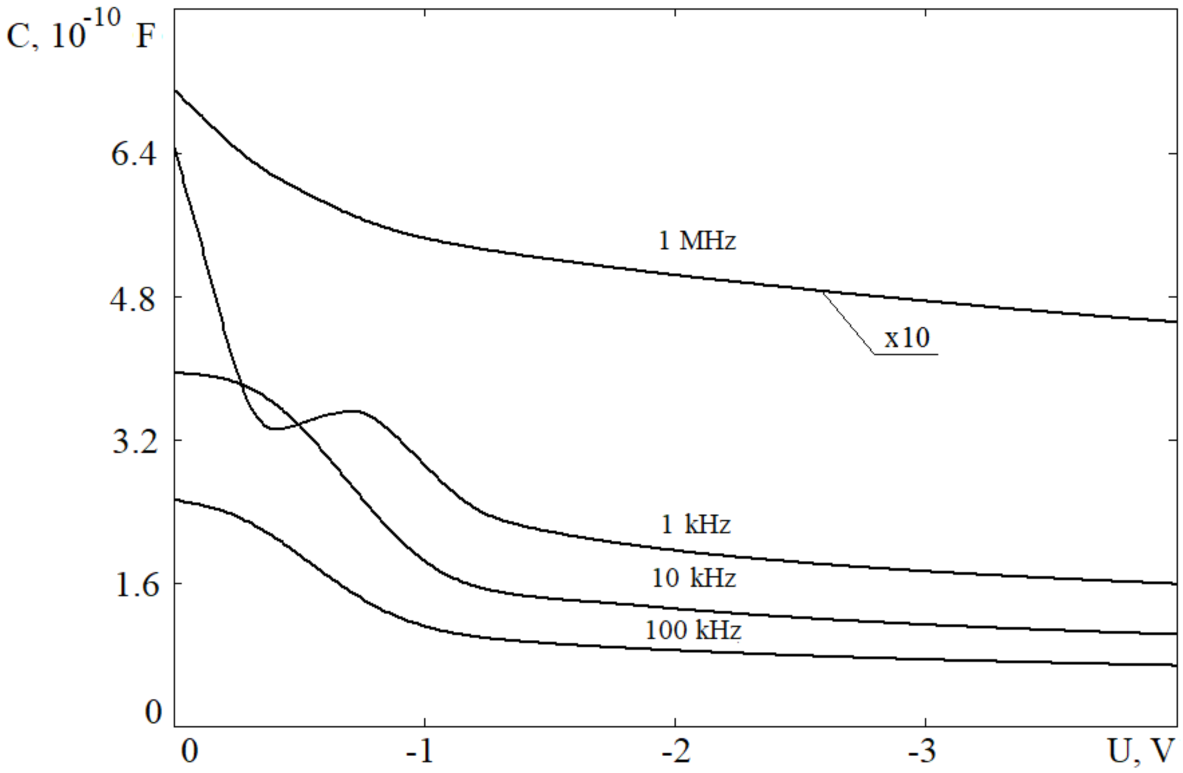


Fig. 3. Frequency dependence C – V at reverse bias for different frequencies of the measuring signal of the sample

In the studied structure, an increase in capacity is observed with a decrease in frequency (Fig. 3). In the case of low frequencies, the processes of recharging deep centers contribute to the capacitance, because have time to follow the signal. With an increase in frequency, they cease to have time to recharge and don't contribute to the measured capacity. Thus, the electrophysical properties of the structure are noticeably influenced by traps with deep centers. For structures with por-Si films obtained by electrochemical and chemical dyeing etching, the electrophysical characteristics are also determined by trap recharging processes [4, 6]. Defects with both shallow and deep levels can act as traps [7, 8].

Conclusions

Thus, the main factor influencing the photoelectric properties of the structure under study is the recharging processes of traps with small and deep energy levels localized both on the surface of the por-Si film and in deeper layers. A significant advantage of the obtained structure is its simple manufacturing technology and the possibility of creating photosensitive structures with a large surface area, which is important in solar energy. The investigated structure can also be used to create highly sensitive photodiodes.

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