Investigation of multilayer samples of porous silicon with periodic structure by spectroscopic ellipsometry

T.V. Veremeichyk[1], **O. V. Makarenko[1]**, **V. B. Shevchenko[1]**, **S. Y. Ivanchuk[1]**

[1]*Department of Physics, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine*
Corresponding author: veremei4ik.taras@gmail.com

Introduction

Porous silicon is a material with a wide range of applications in various industries, including electronics, alternative energy, biomedicine, etc. Porous silicon is used for the manufacture of light-emitting diodes, photovoltaic converters for solar energy, ultra-high frequency (UHF) devices, chemical sensors, as well as for the creation of sensors and information security. The study of its structural and optical properties is important for several reasons. Knowing the structure of porous silicon helps us understand how its physical properties depend on the morphology of the material, such as the size and shape of the pores. Studying the structure can help develop efficient sensors that have a large specific surface area and high sensitivity to certain substances. The optical properties of porous silicon can be used to develop new devices such as photonic crystals, photonic waveguides, etc. The interaction of porous silicon with light allows us to determine its optical characteristics and their dependence on the structure.

The subject of research

In this work, multilayer samples of porous silicon with a periodic structure were studied by electrochemical etching (anodising) of single-crystal silicon wafers of orientation (100) with a resistivity of 10-20 mΩ×sm (p+-silicon) in a mixture of 48% aqueous solution of HF and C_2H_5OH in a ratio of 1:1. The samples alternated layers with different porosities (Sample 1: 166 layers, total thickness D=26 μm; Sample #2: 64 layers, total thickness D=5.3 μm), each of which was synthesised at a specific anodising current density in the range from 30 to 240 mA/sm^2.

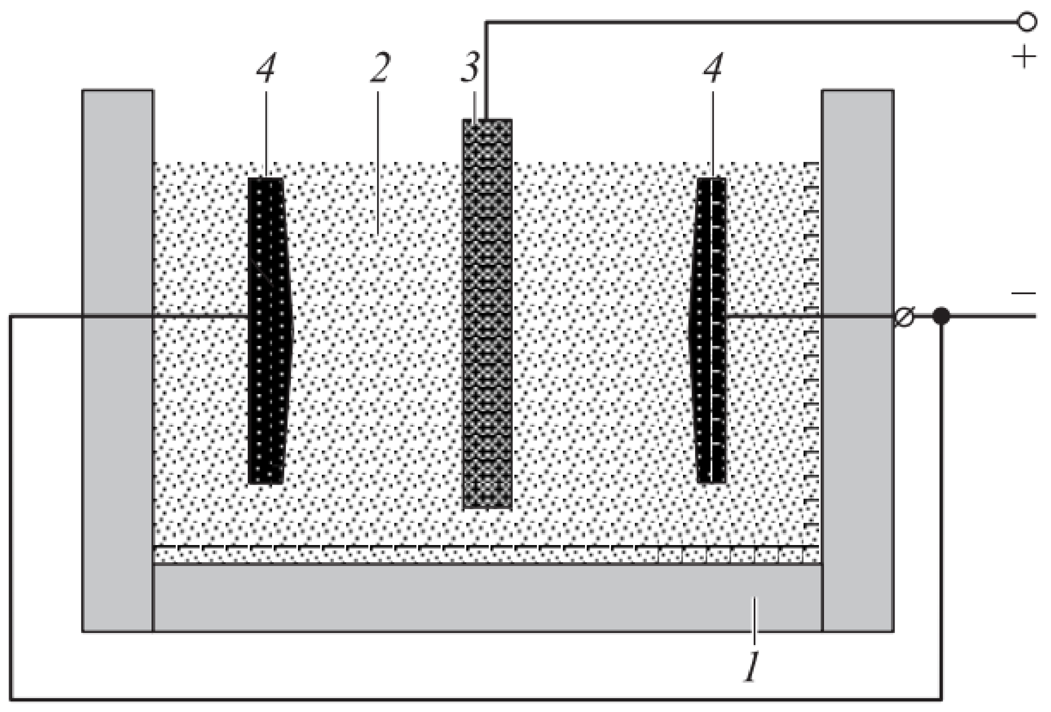

Fig. 1. Schematic of an electrochemical cell for double-sided silicon etching: 1 - fluoroplastic cup, 2 - HF-containing electrolyte solution, 3 - silicon plate, 4 - platinum electrodes

Methodology

The experimental dependences of the parameters ψ, Δ, as well as the intensities of the p- and s-components of the reflected light at different angles of incidence, on the wavelength before and after annealing, were obtained by spectroscopic ellipsometry. The samples differ in the thickness of the periodic layer and their porosity. Using the Complete EASE software, a theoretical model was created that well describes the experimental dependencies: according to the model, the sample is a single-crystal silicon substrate with n number of pairs of pitted silicon layers of different thickness and porosity, between which there is a thin transition layer.

Results

According to the theoretical model, it was found that the position and shape of the main peak (Fig. 2) depends on the thickness and porosity of both layers, respectively, by selecting these parameters, it is possible to determine the thickness and porosity of the studied samples in comparison with the experimental data; periodic peaks in the right part of the graph correspond to the number of pairs of layers in the structure, selecting this parameter, it is possible to determine the total thickness of the sample.

Table. 1. Comparison of theoretically calculated structural characteristics and refractive index of samples No. 1 and No. 2 before and after annealing

Thickness of 1 layer, d_1 (nm)	Thickness of 2 layer, d_2 (nm)	Porosity of the 1st layer, p_1 (%)	Porosity of the 2nd layer, p_2 (%)	Number of pairs of layers	Refractive index, n	Total thickness of the structure, μm
Sample #1						
Before annealing						
48	87	44.5	64	35	2.52	4.72
After annealing						
33.5	109	60	75	35	2.19	4.99
Sample #2						
Before annealing						
82	100	53	71	166	2.21	30.2
After annealing						
75	99	59	79	166	2.07	28.9

Conclusions

- The total thickness, periodicity of the structure and optical characteristics of the samples before and after annealing were determined.
- It was determined that after annealing, the structure of both samples of pitted silicon changes: the porosity in both periodic layers of the structure increased and the refractive index n decreased accordingly.

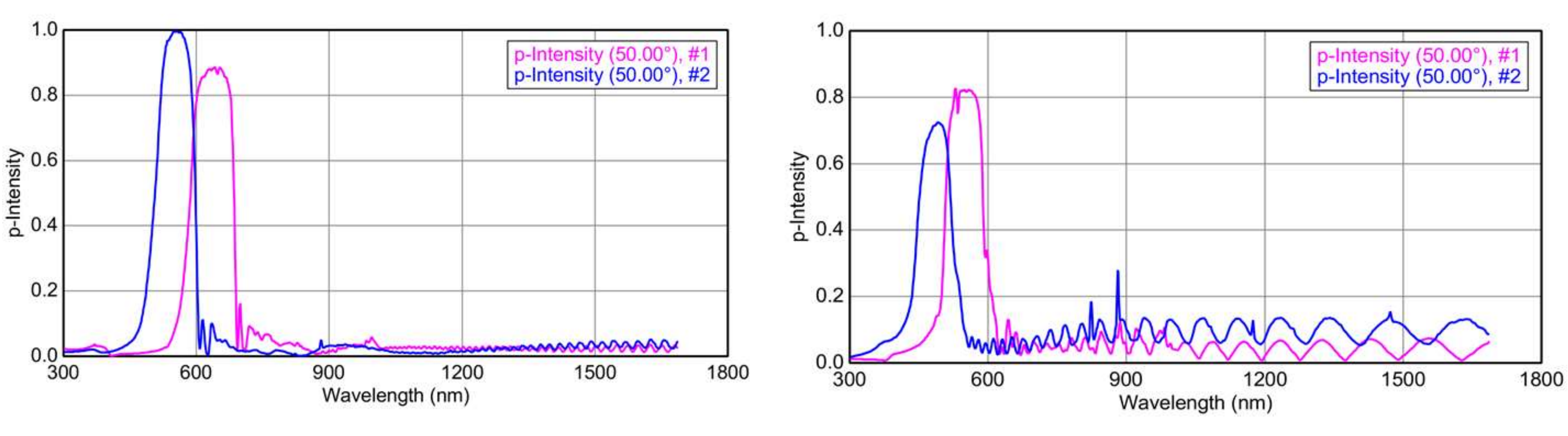

Fig. 2. Comparison of graphs of the intensity distribution of the p-component versus wavelength for samples (a) - No. 1 and (b) - No. 2, incident angle 50°. Distribution before annealing - pink line, after annealing - blue line