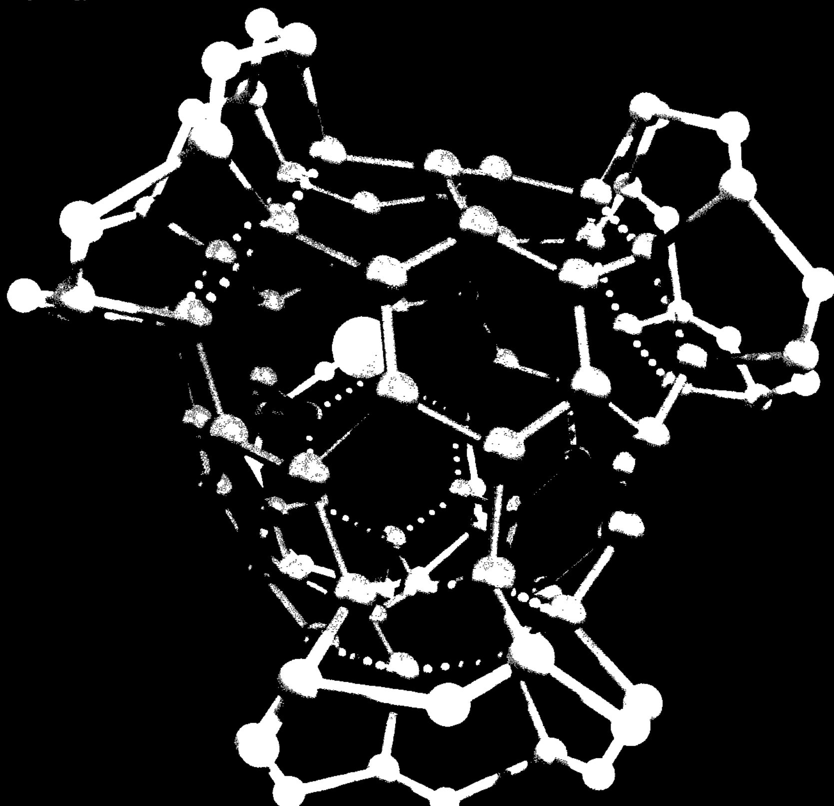
Editors
V. E. Borisenko
S. V. Gaponenko
V. S. Gurin
C. H. Kam



PROCEEDINGS OF INTERNATIONAL CONFERENCE
NANOMEETING – 2015

REVIEWS AND SHORT NOTES

PHYSICS, CHEMISTRY AND APPLICATIONS OF NANOSTRUCTURES

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PHYSICS, CHEMISTRY AND APPLICATIONS OF NANOSTRUCTURES

REVIEWS AND SHORT NOTES

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editors

V E Borisenko

Belarusian State University of Informatics and Radioelectronics, Belarus

S V Gaponenko

B I Stepanov Institute of Physics,
National Academy of Sciences of Belarus, Belarus

V S Gurin

Belarusian State University, Belarus

C H Kam

Nanyang Technological University, Singapore

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PHYSICS, CHEMISTRY AND APPLICATION OF NANOSTRUCTURES, 2015

STRONG SCATTERING OF LIGHT IN SILICON NANOWIRES FORMED BY METAL-ASSISTED CHEMICAL ETCHING

A. EFIMOVA, A. TKACHEV, A. ELISEEV, D. PRESNOV, V. TIMOSHENKO
Lomonosov Moscow State University, Leninskie Gory 1, 119991 Moscow, Russia
efimova@vega.phys.msu.ru

T. NYCHYPORUK
Institut des Nanotechnologies de Lyon, INL-UMR5270, INSA de Lyon
University of Lyon, F-69621 Villeurbanne, France

Yu. RYABCHIKOV
Aix-Marseille University, CNRS, LP3 UMR 7341, Campus de Luminy
Case 917, Cedex 9, 13288 Marseille, France

Layers of silicon nanowires (SiNWs) formed by metal-assisted chemical etching of low boron doped monocrystalline silicon (c-Si) substrates were investigated by means of the optical spectroscopy of reflection/absorption in visible and near-infrared regions. The total reflection of SiNW layers with thickness above 1 μm was significantly lower than that of c-Si wafer for the spectral region above the band gap of c-Si, while it was comparable or even higher than the c-Si reflection in the near-infrared range below the band gap. An approximation of the diffusive propagation of light was found to be applicable to explain the near-infrared spectra of SiNWs.

1. Introduction

Recently, metal-assisted chemical etching (MACE) of c-Si has been used to fabricate SiNW layers with different morphology, *i.e.* SiNWs perpendicular or tilted to the substrate, straight or zigzagged [1]. So-called "black silicon" with high absorption and low reflection in visible spectral region can be easily produced by MACE and it is assumed to be promising for solar cell applications [2]. Surface roughness of individual nanowires was found to be responsible for the visible photoluminescence of SiNW arrays and their possible applications in novel light-emitting devices [3].

There are a lot of works on the optical and electrophysical properties of low-reflective SiNW ensembles made by MACE, though the theory of light propagation in such optically dense media with anisotropic absorbing elements is originate yet. In the present work, we study the optical properties of SiNW with different thickness formed by MACE in order to reveal features of scattering below and above the band gap of c-Si.

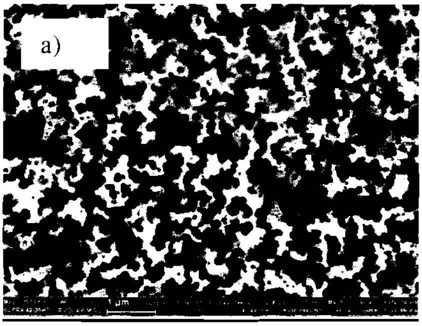
2. Experimental

SiNWs were fabricated by a two-stage MACE process. At the first step, silver nanoparticles were deposited onto polished side of p-type c-Si 12 Ohm·cm substrate via dipping it into aqueous solution of 0.02 M $AgNO_3$ and 5 M HF in the volume ratio of 1:1 for 30 s. During the second step, Ag-covered c-Si was immersed into a solution of 5 M HF and 30% H_2O_2 for time interval from 1 to 30 min. After etching the silver particles were removed by rinsing in nitric acid.

3. Results and discussion

SiNW ensembles of different thicknesses (0.7–23 μm) were investigated by means of scanning (SEM) and transmission (TEM) electron microscopy as well as the wide-range optical spectroscopy, which included the analysis of diffuse and total reflection/transmittance in the range from 400 to 2000 nm (integrating sphere measurements). Additionally, near- and mid-IR specular spectra were registered.

SEM images (Fig. 1) of thick SiNW layers demonstrated silicon prismatic structures of characteristic 0.5-3 μm transverse dimensions (and negligible part of separate wires) which were pierced by narrow channels. The surface of inner channels and outer faces is rough and contains oxidized Si nanostructures of 1-10 nm in size.



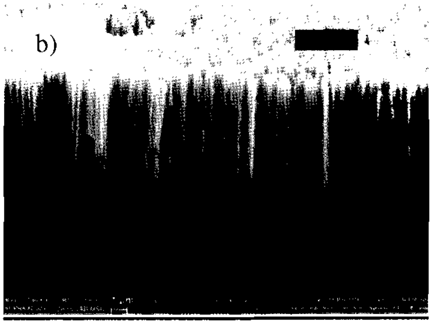
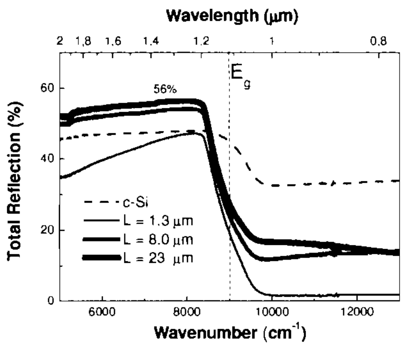


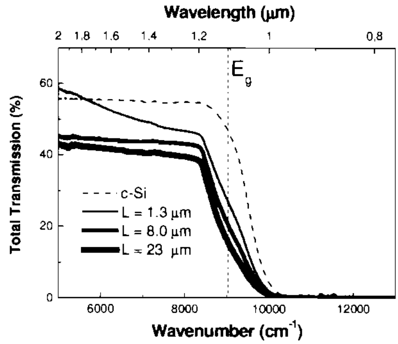
Figure 1. SEM images of a SNW layer with thickness of 9 μm: (a) top and (b) cross-sectional view.

An increase in the layer thickness from 10 to 23 μm produced similar structures with a small fracture of broken tilted wires in thicker structures. SiNW ensemble porosity grew from 51 to 60% and n_{eff} changed from 2.1 to 1.9, correspondingly.

Total reflection/transmission (integrating sphere) spectra of thin ($\leq$1 µm) layers validated the proposed low diffuse reflection above the band gap of c-Si, E_g (Fig. 2a). Thick layers exhibited considerable reflection in the c-Si absorption region. In the near-infrared range below the band gap reflection of the SiNW layers exceeded that of c-Si substrates by 10-20% (and 2.5-3 times that of effective medium of n_{eff} = 1.9-2.1).



a)



b)

Figure 2. Spectra of (a) total reflectance and (b) transmittance of SiNW layers with different thicknesses and for double side polished c-Si substrate. Vertical dashed line indicates the band gap of c-Si.

The reflection character was completely diffusive and total transmission evidenced transparent region (Fig. 2b). Removal of oxide didn't change the reflection value, while was explicitly observed in the middle-infrared and photoluminescence spectra. The corresponding absorption spectra calculated as A = 1–T–R, are shown in Fig. 3.

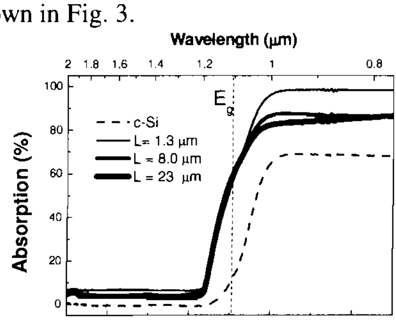


Figure 3. Absorption spectra of SiNW layers with different thickness and for double side polished c-Si substrate. Vertical dashed line indicates the band gap of c-Si.

There is an increase of the absorption of SiNWs in comparison with that of c-Si substrate in the spectral region above E_g.

Diffusive approximation was applied to explain strong reflection of SiNW arrays in the near-infrared region [4]. Proper account of inner reflection on SiNW-air and SiNW-Si interfaces and variations in scattering media and substrate adsorption (c-Si adsorption lengths ranging from 12 μm to 1000 cm) allowed us to assert the diffusive character of light propagation in the thick structures under study. The calculated transport mean free path of light ranged from 3 to 5 μm.

4. Conclusion

The optical reflection/absorption spectroscopy was used to investigate the layers of silicon nanowire arrays formed by metal-assisted chemical etching of c-Si wafers of low doping level. The obtained results are well explained in conjecture of strong light scattering, which is influenced by the absorption in the spectral range of photon energy above the band gap of c-Si. The reflection/transmittance spectra in the near-infrared range below and above the band gap is well understood by assuming the diffusive propagation of light in the silicon nanowire array. These properties of silicon nanowires can be useful in various optoelectronic and photonic applications as antireflection coatings, light trapping, random lasing, *etc*.

Acknowledgments

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