JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 16 No 1, 01007(6pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 16 № 1, 01007(6cc) (2024)

OPEN ACCESS

REGULAR ARTICLE

Absorption and Transmission of Macroporous Silicon and Nanowires

V.F. Onyshchenko * ✉, L.A. Karachevtseva, K.V. Andrieieva, N.V. Dmytruk, A.Z. Evmenova

V.Ye. Lashkaryov Institute of Semiconductor Physics of National Academy of Sciences of Ukraine, 03028 Kyiv, Ukraine

(Received 15 December 2023; revised manuscript received 17 February 2024; published online 28 February 2024)

Absorption and transmittance of macroporous silicon and nanowires are calculated using the proposed analytical model. The analytical model takes into account the absorption and transmission of the macroporous layer and the monocrystalline substrate. The influence of the pore volume fraction and pore depth on the absorption and transmittance of macroporous silicon is calculated. The macroporous layer and the nanowire layer are considered as an effective medium. The structured surfaces of the macroporous layer are considered as Lambert surfaces. Absorption and transmittance of macroporous silicon and silicon nanowires are calculated according to formulas found analytically. Reflection from the surfaces of macroporous silicon affects the absorption, transmission, and trapping of light by the macroporous silicon. The absorption of macroporous silicon increases with an increase in the volume fraction of pores, due to a decrease in the effective refractive index of the macroporous silicon layer. The absorption of macroporous silicon begins to decrease at high pore volume fraction due to the increase in reflection from the boundary of the layer of macroporous silicon with a monocrystalline substrate. The absorption spectrum of macroporous silicon does not depend on the pore depth when the pore volume fraction is less than 0.25. The transmittance of macroporous silicon increases with an increase in the volume fraction of pores in relation to single crystal silicon. An increase in the thickness of the macroporous silicon and a decrease in the thickness of the monocristalline substrate lead to an increase in the transmittance of macroporous silicon.

Keywords: Macroporous silicon, Nanowires, Absorption, Transmission.

DOI: 10.21272/jnep.16(1).01007 PACS number: 78.20. – e

1. INTRODUCTION

Macroporous silicon is made by electrochemical etching and has micron-sized pores. Samples of macroporous silicon emit light with an external quantum efficiency of 15–20 %. Nanowires located on the surface of macropores demonstrate luminescence. X-ray diffraction shows the presence of quantum-sized strained nanowires [1]. The dependence of the effective life time of minor charge carriers in the structure of bilateral macroporous silicon on the depth of macropores was calculated using the derived equations. The equations are found from the solution of the diffusion equation of minor charge carriers and the boundary conditions. The accuracy of the analytical calculation is checked by the numerical method [2]. Macroporous silicon with a periodic arrangement of macropores is created by the method of anisotropic etching with the help of metal and lithography. Photoelectric characteristics of macroporous silicon show sufficient efficiency for solar cells to convert solar energy into electricity [3]. The dependence of the photoconductivity of bilateral macroporous silicon on the pore depth and the bulk lifetime of minority charge carriers is calculated by the finite difference method. The excess minority carrier concentration has two maxima [4]. A solar cell based on ordered macroporous silicon shows an efficiency of 15% due to good surface passivation and optimization of light capture [5]. Solar cells made of macroporous polycrystalline silicon demonstrate an efficiency of more than 13.5 %. The reflection coefficient of the surface of macroporous polycrystalline silicon is less than 9 %. Improved characteristics were achieved due to a new surface etching method [6]. Solar cells have a metal reflector that is placed on the back side. The structured surface diffuses the light and increases the optical path of the light. The passage of light from the Lambert surface to the opposite surface is analyzed using the angular intensity distribution. The distribution of light in the middle of the solar cell is described by a hemispherical flux. A structured surface can scatter light both in one direction and in two, then a one-dimensional or two-dimensional case is considered [7]. A comprehensive analysis of management and control systems for the energy efficiency of solar batteries was developed and the principles of their construction were proposed. The maximum power is determined for control. The projected energy is generated by solar batteries [8]. The reflection spectra of macroporous silicon and nanowires are calculated according to the proposed formulas. A layer of macroporous silicon is considered an effective medium. The reflection coefficient takes into account the complex index of refraction of silicon. The reflection of the structure of macroporous silicon and nanowires increases when the volume fraction of pores decreases [9]. The emission spectrum of light-emitting diodes is simulated for systems with the possibility of changing parameters.

* Correspondence e-mail: onyshchenkovf@isp.kiev.ua

Cite this article as: V.F. Onyshchenko et al., *J. Nano- Electron. Phys.* 16 No 1, 01007 (2024) https://doi.org/10.21272/jnep.16(1).01007

Optimum spectral parameters provide regulation of the correlated color temperature [10, 11]. The effective medium theory was used to model and calculate the reflection coefficient of a porous layer on a monocrystalline substrate. The theory takes into account light scattering by a porous surface and calculates the reflection coefficient of the porous layer at different angles [12]. The temperature dependence of photoconductivity relaxation in macroporous silicon was measured experimentally. The temperature dependence of photoconductivity relaxation is determined by the current transfer mechanism in the depletion region [13]. The kinetics of photoconductivity in bilateral macroporous silicon was calculated by the finite difference method. The numerical model contains charge carrier diffusion equations, initial and boundary conditions. Calculations were performed for samples with a thickness of 500 μm [14]. Light can be captured using a photonic crystal. The structure consists of two-layer porous silicon. The upper layer has pores of a smaller diameter than the lower one. Light absorption by a solar cell with two-layer porous silicon increases 8 times compared to a solar cell with a flat surface of the same thickness [15].

2. ABSORPTION AND TRANSMISSION OF MACROPOROUS SILICON AND NANOWIRES

Consider porous silicon. The porous layer can consist of macropores or nanowires. Let the thickness of the porous silicon layer be h_1, and the thickness of the monocrystalline substrate h_2. The light that entered the middle of the porous silicon is reflected many times from the surfaces of the porous silicon. The reflection coefficient of macroporous silicon and nanowires is considered in [9]. The transmission and absorption coefficients of macroporous silicon and nanowires are considered in this work. First, consider the transmission coefficient through a monocrystalline substrate. The transmission coefficient through a monocrystalline substrate is calculated as the sum of the coefficients formed due to reflection inside the monocrystalline substrate. The first term of the transmission coefficient through a monocrystalline substrate will be written as follows:

$$T_{m1}(y) = (1 - R_{s2^*}) I_{ST3}(h_2, y) , \tag{2.1}$$

where R_{s2^*} is the reflection coefficient from the boundary of macroporous silicon with a single crystal substrate. The intensity of the light that passed through the monocrystalline substrate and the flat third surface will be written as follows:

$$I_{ST3}(h_2, y) = \frac{1}{2}\left(\int_0^{\beta 1(y)} I_{ST3}(h_2, \beta) d\beta + \int_0^{\beta 1(b-y)} I_{ST3}(h_2, \beta) d\beta \right), \tag{2.2}$$

where $I_{ST3}(h_2, \beta) = (1 - Rs_{3^*}(\beta)) I_S(h_2, \beta)$, $I_S(h_2, \beta) = \sin(\beta)\cos(\beta)\exp(-\alpha h_2/\cos(\beta))$. Let β_c be the angle of total internal reflection. The angle of incidence $\beta_1(y) = \beta_c$ if $\beta_c < \arctan(y/h_2)$), and otherwise $\beta_1(y) = \arctan(y/h_2)$ [9]. The first term of the transmittance through the monocrystalline substrate shows that the light has passed through the interface of macroporous silicon with the monocrystalline substrate $(1 - R_{s2^*}(\beta))$, the monocrystalline substrate, and the third boundary $I_{ST3}(h_2, \beta)$. The intensities of the light that passed through the monocrystalline substrate and reflected from the third flat surface and passed through the monocrystalline substrate will be written as follows:

$$\begin{aligned}\bar{I}_{SR3}(2h_2, y) = \frac{1}{2b}\Bigg(& \int_0^{\beta 1(y)} I_{SR3}(2h_2, \beta) d\beta + \\ & + \int_0^{\beta 1(b-y)} I_{SR3}(2h_2, \beta) d\beta + \int_{\beta 1(y)}^{\beta 2(y)} I_S(2h_2, \beta) d\beta + \\ & + \int_{\beta 1(b-y)}^{\beta 2(b-y)} I_S(2h_2, \beta) d\beta + \int_{\beta 2(y)}^{\pi/2} I_{SR3}(2h_2, \beta) d\beta + \\ & + \int_{\beta 2(b-y)}^{\pi/2} I_{SR3}(2h_2, \beta) d\beta \Bigg) dx\end{aligned} , \tag{2.3}$$

where $I_{SR3}(h_2, \beta) = (R_{s3^*}(\beta) I_S(h_2, \beta)$, the incidence angle $\beta_2(y) = \pi/2 - \beta_c$, if $\pi/2 - \beta_c < \arctan(y/h_2)$, and in otherwise, $\beta_2(y) = \arctan(y/h_2)$ [9]. The sum of the first and second terms of the transmission coefficient through a monocrystalline substrate will be written as follows:

$$T_{m12}(y) = (1 - R_{s2^*})(1 + R_{s2}\bar{I}_{SR3}(2h_2)) I_{ST3}(h_2, y) , \tag{2.4}$$

where R_{s2} is the reflection coefficient from the boundary of a monocrystalline substrate with macroporous silicon. The first multiplier of expression (2.4) shows the passage of light through the structured boundary of macroporous silicon with a monocrystalline substrate. The third multiplier shows the distribution of light that passed through the third flat surface. The second multiplier shows that the intensity of light that passed through the third flat surface for the second time is equal to the previous intensity multiplied by the multiplier $R_{s3} I_{SR3}(2h_2)$. This happens every time light passes through a third flat surface. Using expression (2.4) and the above, we write down the distribution of the transmission coefficient through a monocrystalline substrate:

$$T_m(y) = (1 - R_{s2^*}) \sum_{n=1}^{\infty} ((R_{s2}\bar{I}_{SR3}(2h_2)^{n-1}) I_{ST3}(h_2, y)) . \tag{2.5}$$

The sum in expression (2.5) goes to the fraction, therefore, the distribution of the transmission coefficient through the monocrystalline substrate will be written as follows:

$$T_m(y) = \frac{1 - R_{s2^*}}{1 - R_{s2}\bar{I}_{SR3}(2h_2)} I_{ST}(h_2, y) . \tag{2.6}$$

The average value of the transmission coefficient through a monocrystalline substrate will be written as follows:

$$\bar{T}_m = \frac{1}{b}\int_0^b T_m(y) dy = \frac{(1 - R_{s2^*})\bar{I}_{ST3}(h_2)}{1 - R_{s2}\bar{I}_{SR3}(2h_2)} , \tag{2.7}$$

where

$$\bar{I}_{ST3}(h_2) = \frac{1}{b}\int_0^b I_{ST3}(h_2, y) dy . \tag{2.8}$$

Consider a porous layer. Scattering by structured surfaces is described by the effective scattering angle θ_{eff}. The passage of light in macroporous silicon is similar to that of a monocrystalline substrate, but with the use of an effective angle of incidence. The transmission coefficient through a layer of macroporous silicon will be written as follows:

$$T_{12}=\frac{(1-R_{s1*})(1-R_{s2*})\exp(\frac{-\alpha h_1}{\cos(\theta_{eff})})}{1-R_{s1}R_{s2*}\exp(\frac{-2\alpha h_1}{\cos(\theta_{eff})})}\,. \qquad (2.9)$$

Light, passing through a layer of macroporous silicon, will reduce its intensity by T_{12}. Light, passing through a monocrystalline substrate, will reduce its intensity by T_m, so the transmission coefficient through macroporous silicon is equal to $T_{PSi} = T_{12}T_m$. The transmission coefficient through macroporous silicon will be written as follows:

$$T_{PSi}=\frac{(1-R_{s1*})(1-R_{s2*})(1-R_{s3*})\bar{I}_{ST3}(h_2)\exp(\frac{-\alpha h_1}{\cos(\theta_{eff})})}{(1-R_{s1}R_{s2*}\exp(\frac{-2\alpha h_1}{\cos(\theta_{eff})}))(1-R_{s2}\bar{I}_{SR3}(2h_2))}\,.(2.10)$$

The reflection coefficient of macroporous silicon will be written as [9]:

$$\bar{R}_{PS}=R_{s1*}+\frac{(1-R_{s1*})(1-R_{s1})\exp(\frac{-2\alpha h_1}{\cos(\theta_{eff})})}{1-R_{s1}R_{s2*}\exp(\frac{-2\alpha h_1}{\cos(\theta_{eff})})}\times$$
$$\times\left(R_{s2*}+\frac{(1-R_{s2*})(1-R_{s2})\bar{I}_{SR3}(2h_2)}{1-R_{s2}\bar{I}_{SR3}(2h_2)}\right) .(2.11)$$

Let's find the distribution of the transmission coefficient through the side surface of macroporous silicon. Let's choose a point on the side surface with coordinate x, coordinate $y = 0$. Light falling at an angle smaller than the critical angle of total internal reflection will pass through the side surface according to Fresnel's law. The critical angle of total internal reflection is calculated from the perpendicular to the flat side surface. At other angles of incidence, it will be completely reflected. Part of the light will fall on the side surface from the second structured surface, and part from the first structured surface. Note that the light will be completely reflected from the side surface if it is reflected from the third surface at an angle smaller than the angle of total internal reflection. The light that is completely reflected from the third surface will partially pass through the side surface, so there will be no reflection coefficient from the third surface. The first term of the transmission coefficient distribution through the side surface of a monocrystalline substrate:

$$T_{ml1}(x)=(1-R_{s2*})(I_{lT}(x)+I_{lT}(2h_2-x))\,. \qquad (2.12)$$

where

$$I_{lT}(x)=\int_{\pi/2-\beta c}^{\pi/2}(1-R(\beta))\sin(\beta)\times ,$$
$$\times\cos(\beta)\exp(-\frac{\alpha x}{\cos(\beta)})d\beta\,, \qquad (2.13)$$

where $R(\beta)$ is the reflection coefficient calculated according to Fresnel's law. The second term of the transmission coefficient distribution through the side surface of the monocrystalline substrate is equal to expression (2.13) multiplied by the product. The third term is equal to the second term multiplied by the product, and so on. The distribution of the transmission coefficient through the side surface of the monocrystalline substrate will be written as follows:

$$T_{ml}(x)=(1-R_{s2*})\sum_{n=1}^{\infty}\left((R_s\bar{I}_{SR3}(2h))^{n-1}\right)\times$$
$$\times\left(I_{lT}(x)+I_{lT}(2h_2-x)\right) . \qquad (2.14)$$

An infinite sum leads to a fraction, so the distribution of the transmission coefficient through the side surface of a monocrystalline substrate will be written as:

$$T_{BSl}(x)=\frac{1-R_{s2*}}{1-R_{s2}\bar{I}_{SR3}(2h)}\left(I_{lT}(x)+I_{lT}(2h_2-x)\right). \ (2.15)$$

Transmittance coefficient through the entire side surface of the monocrystalline substrate:

$$T_{ml}=\frac{1-R_{s2*}}{h_2(1-R_{s2}\bar{I}_{SR3}(2h_2))}\int_{\pi/2-\beta c}^{\pi/2}\left(\sin(\beta)\cos(\beta)(1-R(\beta))\times\right.$$
$$\left.\times\left[\int_0^{h2}\exp(-\frac{\alpha x}{\cos(\beta)})dx+\int_0^{h2}\exp(-\frac{\alpha(2h_2-x)}{\cos(\beta)})dx\right]\right)d\beta \,.(2.16)$$

Let's find the second integral over x in expression (2.16):

$$\int_0^{h2}\exp(-\frac{\alpha(2h_2-x)}{\cos(\beta)})dx=$$
$$=\frac{\cos(\beta)}{\alpha}\left(\exp(-\frac{\alpha h_2}{\cos(\beta)})-\exp(-\frac{2\alpha h_2}{\cos(\beta)})\right) . \qquad (2.17)$$

Transmission coefficient through the side surface of a monocrystalline substrate:

$$T_{ml}=\frac{1-R_{s2*}}{\alpha h_2(1-R_{s2}\bar{I}_{SR3}(2h_2))}\int_{\pi/2-\beta c}^{\pi/2}\left(\sin(\beta)\cos(\beta)^2\times\right.$$
$$\left.\times(1-R(\beta))(1-\exp(-\frac{2\alpha h_2}{\cos(\beta)})\right)d\beta \,.(2.18)$$

Taking into account expression (2.13), expression (2.18) can be written as:

$$T_{ml}=\frac{I_{lT}(2h_2)(1-R_{s2*})}{1-R_{s2}\bar{I}_{SR3}(2h_2)}\,. \qquad (2.19)$$

We neglect the transmission coefficient through the side surface of the macroporous silicon layer. The absorption coefficient in macroporous silicon will be written as follows:

$$A_{PSi}=1-(R_{PSi}+T_{PSi}+2T_{ml})\,, \qquad (2.20)$$

3. RESULTS AND DISCUSSION

Fig. 1 shows the absorption spectrum of macroporous silicon with different volume fraction of pores. The thickness of the macroporous silicon sample is 500 µm, the pore depth is 100 µm. Curve 1 shows the absorption of single crystal silicon. Absorption coefficient, refractive index and fundamental absorption of light affect the absorption of single crystal silicon. For wavelengths of light longer than 0.95 μm, the thickness of the silicon single crystal is less than the depth of light penetration into the silicon single crystal, so part of the light leaves the single crystal and is not absorbed.

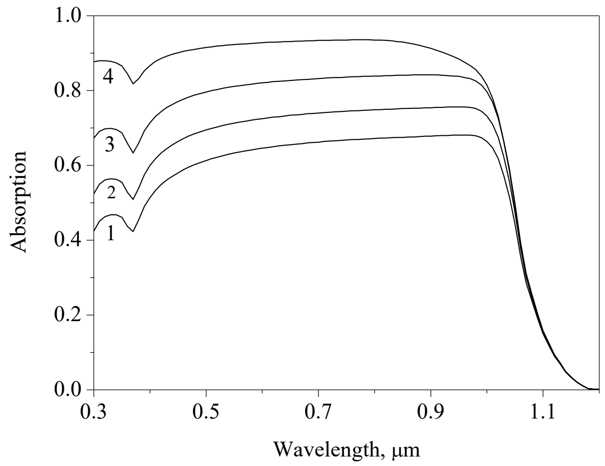

Fig. 1 – Absorption spectrum of macroporous silicon or arrays of nanowires on a monocrystalline substrate with a volume fraction of pores: 1 – 0; 2 – 0.25; 3 – 0.5; 4 – 0.75

The absorption of macroporous silicon consists of the absorption of the macroporous silicon layer and the absorption of the monocrystalline substrate. Reflection from the surfaces of the macroporous silicon sample affects the trapping and absorption of light by the macroporous silicon. Reflections from the interface of air with a macroporous layer change as the volume fraction of pores decreases. Curve 2 (see Fig. 1) shows the absorption of macroporous silicon with a volume fraction of pores of 0.25 μm. The reflection of macroporous silicon increased on 0.1 in relation to single crystal silicon. The increase in absorption occurred over the entire spectrum from 0.3 μm to 1.2 μm. Curve 3 shows the absorption of macroporous silicon with a volume fraction of pores of 0.5. The absorption spectrum of macroporous silicon increased on 0.15 in relation to macroporous silicon with a volume fraction of pores of 0.25. The absorption spectrum of macroporous silicon with a volume fraction of pores of 0.75 increased by 0.2 in relation to macroporous silicon with a volume fraction of pores of 0.25. Thus, the absorption spectrum of macroporous silicon grows unevenly with the increase in the volume fraction of pores. The absorption of macroporous silicon increases each time by a larger amount with an increase in the volume fraction of pores. Curve 4 (see Fig. 1) shows that the absorption of macroporous silicon begins to decrease starting from 8 μm. This is due to the increase in reflectance of the illuminated surface of the macroporous silicon sample at a volume fraction of pores of 0.75 [9].

Fig. 2 shows the absorption spectrum of macroporous silicon at different pore volume fractions and pore depths. The absorption of single crystal silicon is shown for comparison with the absorption of macroporous silicon (see curve 1, Fig. 2). The absorption spectrum of macroporous silicon does not depend on the depth of pores when the volume fraction of pores is equal to 0.25 (see Fig. 2, curve 2). This is explained by the fact that the reflection from the boundary of the layer of macroporous silicon with a monocrystalline substrate does not affect the absorption. Curve 3 (see Fig 2) shows the absorption of macroporous silicon with a pore depth of 1 μm and a pore volume fraction of 0.75.

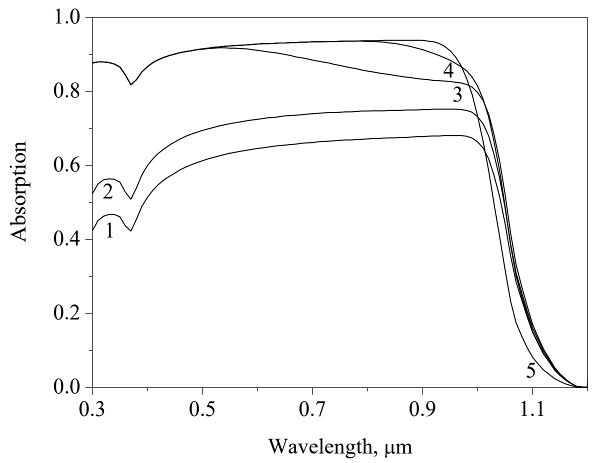

Fig. 2 – Absorption spectrum of macroporous silicon or arrays of nanowires on a monocrystalline with the volume fraction of pores: 1 – 0, 2 – 0.25, 3-5 – 0.75 and pore depth, μm: 1 – 0; 2 – 100-400, 3 – 1, 4 – 100, 5 – 400

The absorption of macroporous silicon decreases as the wavelength of light increases from 0.5 μm to 1.05 μm. The reflection from the boundary of the layer of macroporous silicon with a monocrystalline substrate increases, so the absorption of macroporous silicon decreases. Curve 4 (see Fig. 2) shows the absorption of macroporous silicon with a pore depth of 100 μm and a pore volume fraction of 0.75. Absorption of macroporous silicon is better compared to macroporous silicon with a pore depth of 0.1 μm. The macroporous layer with a thickness of 100 μm absorbs light with wavelengths from 0.3 μm to 0.85 μm reflected from the boundary of the macroporous silicon layer with a monocrystalline substrate, so the absorption of the macroporous silicon sample is improved. The absorption spectrum of macroporous silicon with a pore depth of 400 μm begins to decrease at a light wavelength of 0.95 μm (see Fig. 2, curve 5). At the same time, the absorption of other samples of macroporous silicon (curves 2-4) began to decrease at a light wavelength of 1 μm. This is due to an increase in the transparency of the sample of macroporous silicon with a pore depth of 400 μm.

Fig. 3 shows the transmission spectrum of macroporous silicon with different volume fraction of pores. The transmission of macroporous silicon increases with an increase in the volume fraction of pores (curves 2, 3) in relation to single crystal silicon (curve 1). The increase in transmission of macroporous silicon decreases (curves 2, 3) and stops (curves 3, 4). Fig. 1 shows that the absorption increases up to a light wavelength of 1 μm, so reflection is the cause. The reflection of macroporous silicon is almost unchanged in the range of wavelengths of light from 1.05 μm to 1.25 μm, when the volume fraction of pores is equal to 0.5 and 0.75 [9]. The reflection from the interface of macroporous silicon with a monocrystalline substrate increases if the volume fraction of pores changes from 0.5 to 0.75.

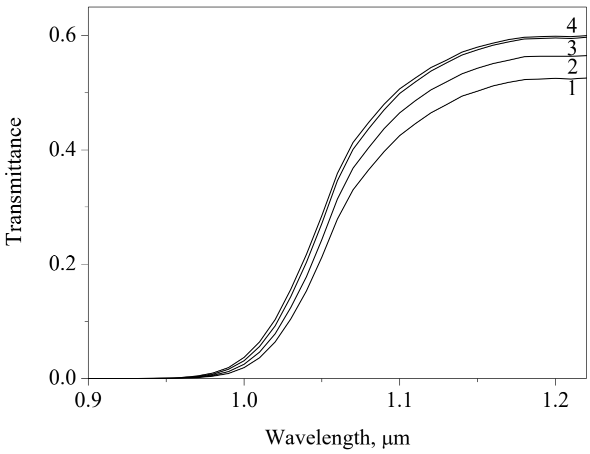

Fig. 3 – Transmission spectrum of macroporous silicon or arrays of nanowires on a monocrystalline substrate with a volume fraction of pores: 1 – 0; 2 – 0.25; 3 – 0.5; 4 – 0.75

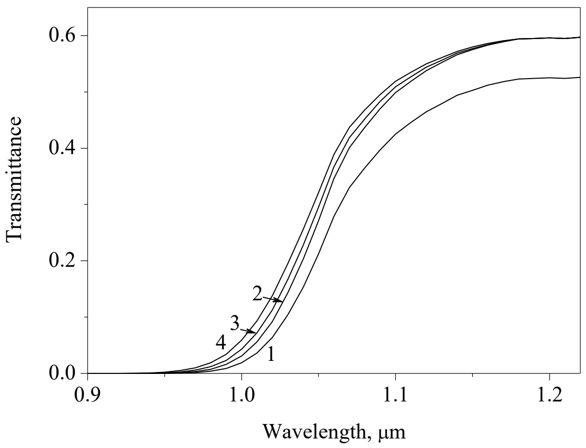

Fig. 4 – Transmission spectrum of macroporous silicon or arrays of nanowires on a monocrystalline substrate with pore depth, μm: 1 – 0; 2 – 100, 3 – 200; 4 – 300. The volume fraction of pores is 0.5

Fig. 4 shows the transmission spectrum of macroporous silicon with different pore depths when the volume fraction of pores is 0.5. The pore depth has little effect on the transmission of macroporous silicon.

The transmission spectrum of single crystal silicon (see Fig. 4, curve 1) begins to increase at a light wavelength of 0.97 μm, and the transmission spectrum of macroporous silicon increases at a light wavelength of 0.95 μm. A layer of macroporous silicon has higher transmittance than a monocrystalline substrate due to the presence of pores. An increase in the thickness of the macroporous silicon and a decrease in the thickness of the single crystal substrate lead to an increase in the transmittance of the macroporous silicon sample.

4. CONCLUSIONS

Reflection from the surfaces of the macroporous silicon sample affects the trapping and absorption of light by the macroporous silicon. Absorption of macroporous silicon increases with an increase in the volume fraction of pores, due to a decrease in the effective refractive index of macroporous silicon. A decrease in the effective refractive index leads to an increase in reflection from the boundary of macroporous silicon with a monocrystalline substrate. This leads to an increase in reflection and a decrease in absorption of macroporous silicon at a volume fraction of pores of 0.75. The absorption of macroporous silicon with a pore depth of 1 μm and a pore volume fraction of 0.75 μm decreases as the wavelength of light increases from 0.5 μm to 1.05 μm. The reflection from the boundary of the layer of macroporous silicon with a monocrystalline substrate increases, so the absorption of macroporous silicon decreases. The absorption spectrum of macroporous silicon does not depend on the pore depth when the volume fraction of pores is 0.25. The absorption of macroporous silicon with a pore depth of 400 μm begins to decrease at a light wavelength of 0.95 μm. This is due to an increase in the transparency of the sample of macroporous silicon with a pore depth of 400 μm.

The transmittance of macroporous silicon increases with an increase in the volume fraction of pores in relation to single crystal silicon. The increase in transmission of macroporous silicon stops when the volume fraction of pores is 0.75. The pore depth has little effect on the transmission of macroporous silicon. An increase in the thickness of the macroporous silicon and a decrease in the thickness of the single crystal substrate lead to an increase in the transmittance of the macroporous silicon sample.

REFERENCES

1. B. Bulakh, N. Korsunska, L. Khomenkova, T. Stara, Ye. Venger, T. Kryshtab, A. Kryvko, *J. Mater. Sci.-Mater. El.* **20**, 226 (2009).
2. V.F. Onyshchenko, L.A. Karachevtseva, *Semiconductor Physics, Quantum Electronics and Optoelectronics* **23** No 1, 29 (2020).
3. K.-Q. Peng, X. Wang, X. Wu, S.-T. Lee, *Appl. Phys. Lett.* **95**, 143119 (2009).
4. V.F. Onyshchenko, *Ukr. J. Phys.* **67** No 12, 841 (2022).
5. J.V. Hoeymissen, V. Depauw, I. Kuzma-Filipek, K.V. Nieuwenhuysen, M.R. Payo, Y. Qiu, I. Gordon, J. Poortmans, *phys. status solidi a* **208** No 6, 1433 (2011).
6. C. Levy-Clement, S. Lust, S. Bastide, Q.N. Le, D. Sarti, *phys. status solidi a* **197** No 1, 27 (2003).
7. L.C. Andreani, A. Bozzola, P. Kowalczewski, M. Liscidini, *Sol. Energ. Mat. Sol. C.* **135**, 78 (2015).
8. V.I. Kornaga, D.V. Pekur, Yu.V. Kolomzarov, V.P. Kostylyov, V.M. Sorokin, R.M. Korkishko, Yu.E. Nikolaenko, *Semiconductor Physics, Quantum Electronics and Optoelectronics* **24** No 2, 200 (2021).
9. V.F. Onyshchenko, *J. Nano- Electron. Phys.* **15** No 3, 03026 (2023).
10. D.V. Pekur, Yu.V. Kolomzarov, V.M. Sorokin, Yu.E. Nikolaenko, *Semiconductor Physics, Quantum Electronics and Optoelectronics* **25** No 1, 97 (2022).
11. D.V. Pekur, V. M. Sorokin, Yu E. Nikolaenko, I.V. Pekur, M.A. Minyaylo, *Semiconductor Physics, Quantum Electronics and Optoelectronics* **25** No 3, 303 (2022).
12. T. Pickering, K. Shanks, S. Sundaram, *J. Opt.* **23** No 2, 025901 (2021).

13. L.A. Karachevtseva, V.F. Onyshchenko, A.V. Sachenko, *Ukr. J. Phys.* **53** No 9, 874 (2008).
14. V.F. Onyshchenko, *J. Nano- Electron. Phys.* **14** No 5, 05024 (2022).
15. S.B. Mallick, M. Agrawal, P. Peumans, *Opt. Exp.* **18**, 5691 (2010).

Поглинання та пропускання макропористого кремнію та нанодротин

В.Ф. Онищенко, Л.А. Карачевцева, К.В. Андрєєва, Н.В. Дмитрук, А.З. Євменова

Інститут фізики напівпровідників імені В.Є. Лашкарьова НАН України, 03028 Київ, Україна

Розраховується поглинання та пропускання макропористого кремнію та нанодротин за допомогою запропонованої аналітичної моделі. Аналітична модель враховує поглинання та пропускання макропористого шару та монокристалічної підкладки. Розраховується вплив об'ємної частки пор та глибини пор на поглинання та пропускання макропористого кремнію. Макропористий шар та шар нанодротин розглядаються як ефективне середовище. Структуровані поверхні макропористого шару розглядаються як Ламбертові поверхні. Поглинання та пропускання макропористого кремнію та кремнієвих нанодротин розраховані за аналітично знайденими формулами. Відбиття від поверхонь макропористого кремнію впливає на поглинання, пропускання та захоплення світла макропористим кремнієм. Поглинання макропористого кремнію зростає зі збільшенням об'ємної частки пор, завдяки зменшенню ефективного показника заломлення шару макропористого кремнію. Поглинання макропористого кремнію починає зменшуватися при високій об'ємній частці пор завдяки збільшенню відбиття від межі шару макропористого кремнію з монокристалічною підкладкою. Спектр поглинання макропористого кремнію не залежить від глибині пор, коли об'ємна частка пор менше 0,25. Пропускання макропористого кремнію зростає зі збільшенням об'ємної частки пор по відношенню до монокристалу кремнію. Зростання товщини макропористого кремнію та зменшення товщини монокристалічної підкладки приводить до збільшення пропускання макропористого кремнію.

Ключові слова: Макропористий кремній, Нонодротини, Поглинання, Пропускання.