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REGULAR ARTICLE

Transmission and Absorption of Bilateral Porous Silicon with Macropores or Nanowires

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The transmission and absorption spectra of bilateral macroporous silicon and nanowires were calculated. The transmission and reflection of the interfaces between the monocrystalline substrate and the layers of macroporous silicon is taken into account. The absorption of bilateral macroporous silicon when one or the other layer of macroporous silicon is illuminated is considered. The transmission of the lateral interfaces between bilateral macroporous silicon and air is calculated. The transmission of the lateral interfaces of bilateral macroporous silicon depends on the reflection coefficients of the interfaces between the monocrystalline substrate and the layers of macroporous silicon and the volume fraction of pores. The incidence of light on the lateral interface between bilateral macroporous silicon and air at different angles and the effect of total internal reflection are taken into account. The dependence of the transmission and absorption spectra of bilateral macroporous silicon and nanowires on the reflection and transmission of the interface between the frontal layer of macroporous silicon and the monocrystalline substrate and the volume fraction of pores is considered. The increase in absorption and transmittance of bilateral macroporous silicon with an increase in the volume fraction of pores to a certain value and a decrease in absorption and transmittance due to an increase in the reflection of the interface between the frontal layer of macroporous silicon and the monocrystalline substrate are shown.

Keywords: Transmission, Absorption, Nanowires, Bilateral macroporous silicon.

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1. INTRODUCTION

Macroporous A layer of macroporous silicon is obtained electrochemically using illumination from the opposite side of monocrystalline silicon. The reflection coefficient of the surface of macroporous silicon is equal to 1 % and lower in the visible region of the spectrum. By changing the conditions of electrochemical etching, the porosity and thickness of the layer is regulated. Low reflectivity is observed at different angles of incidence [1]. Macroporous silicon is investigated directly in electrochemical cells under simulated solar illumination of AM 1.5. The concept of interpenetrating networks is being developed. Macroporous silicon is used as a model for solar cells with a surface structured by monocrystalline silicon wires [2]. The reflection of nanowires and macroporous silicon is studied and analyzed using the derived formula. The formula takes into account the reflection of the interface between the layer of macroporous silicon and the monocrystalline substrate, the angular distribution of scattered light and the complex index of refraction. The reflectance of macroporous silicon and arrays of single-crystal silicon nanowires increases with a decrease in the volume fraction of pores [3]. The reflectivity of black silicon solar cells is calculated using rigorous coupled wave analysis. The calculation of the angular distribution of light intensity after passing through the structured frontal surface indicates that 70 % of the light is completely reflected due to internal reflection [4]. The influence of the pore volume fraction and pore depth on the absorption and transmission of macroporous silicon and nanowires is calculated. The absorption of macroporous silicon and nanowires increases due to the decrease in the effective refractive index of the macroporous silicon layer with an increase in the volume fraction of pores. Decreasing the thickness of the monocrystalline substrate and increasing the thickness of macroporous silicon increase the transmission of macroporous silicon [5]. Light trapping by solar cells with a surface structured by cylinders, cones, inverted pyramids, and inverted hemispheres are compared. Modeling the 20 μm-thick solar cell optimizes the surface geometry of each structured surface to improve light trapping. Modeling of the efficiency of the solar cell is carried out for light falling at different angles [6]. The ratio between light trapping by the solar cell and the increase in the surface recombination rate with an increase in the surface area is optimized [7]. Light trapping by a solar cell structured by randomly positioned real pyramids is compared to a similar structure with a pyramid base angle of 54.7 ° (ideal pyramids) and Lambertian scatterers. Calculations are performed using ray tracing simulation. The angular distribution of light intensity is calculated for each reflection from the front and back surfaces [8]. Macroporous silicon with through

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pores is considered as an effective medium. Its structured surface diffuses light. The transmittance and absorption of macroporous silicon with through-pores increase due to the decrease in its reflectance with an increase in the volume fraction of pores [9]. Absorption of solar cells with textured frontal and rear surfaces with different cell sizes is calculated using the formalism of the optical properties of textured optical sheets. Solar cells with a frontal surface structured by pyramids and diffraction gratings on the rear surface show absorption close to the Yablonovich limit [10]. The optimization of a solar cell with an arbitrary surface texture is simulated. The surface is structured by a layer of spheres with a certain distribution of sphere sizes to improve light absorption in a wide range of wavelengths [11]. The excess minor carrier concentration and photoconductivity in bilateral macroporous silicon are calculated depending on the bulk lifetime of minor charge carriers and the pore depth. The photoconductivity of bilateral macroporous silicon decreases if the bulk lifetime decreases and the pore depth increases [12]. The photodiode based on porous silicon has a quantum efficiency of 96 %. The efficiency of light trapping is increased by reducing the reflection of the surface of black silicon. Passivation of the photodiode surface reduces recombination. Charge carriers are efficiently collected by negatively charged aluminum oxide, which forms an inversion layer [13]. Kinetics of photoconductivity of bilateral macroporous silicon was calculated by the finite difference method. The diffusion equation of excess minor charge carriers, initial and boundary conditions were used to calculate the kinetics of photoconductivity [14]. An optical analysis of a solar cell with periodically located pyramids was carried out. The pyramids are located on the frontal surface. The reflection and absorption coefficient of a solar cell with periodically arranged pyramids is studied depending on the size of the pyramids. The reflection coefficient from the back side of the solar cell does not depend on the size of the pyramids, if their size is more than 0.6 µm [15].

2. TRANSMISSION AND ABSORPTION OF BILATERAL POROUS SILICON WITH MACROPORES OR NANOWIRES

The light transmission of bilateral macroporous silicon includes the transmission of the frontal layer of macroporous silicon, the transmission of the monocrystalline substrate and the transmission of the rear layer of macroporous silicon. The transmission of the monocrystalline substrate is considered. The normalized intensity of scattered light at the interface between the monocrystalline substrate and the rear layer of macroporous silicon after passing at an angle β from the interface between the monocrystalline substrate and the frontal layer of macroporous silicon to this interface will be written as follows:

$$I_b(h_m,\beta)=\sin(\beta)\cos(\beta)\exp\left(-\frac{\alpha h_m}{\cos(\beta)}\right). \quad (2.1)$$

The normalized distribution of light intensity at the interface, after the propagation of light from one interface to another (distribution of scattered light intensity), will be written as follows:

$$\begin{aligned}I_b(h_m,y)&=\int_0^{\beta(y)}I(h_m,\beta)d\beta+\int_0^{\beta(b-y)}I(h_m,\beta)d\beta+\\&+\int_{\beta(y)}^{\frac{\pi}{2}}R(\beta)I(h_m,\beta)d\beta+\int_{\beta(b-y)}^{\frac{\pi}{2}}R(\beta)I(h_m,\beta)d\beta\end{aligned},(2.2)$$

where $\beta(y)=\arctan(y/h_m)$, if $\arctan(y/h_m)<\pi/2-\beta_c$, otherwise $\beta(y)=\pi/2-\beta_c$, where $\beta_c=\arcsin(1/n_{Si})$ is the critical angle of total internal reflection. The average value of the normalized distribution of light intensity at the interface, after the propagation of light from one interface to another (average intensity of scattered light), is written as follows:

$$I_b(h_m)=\frac{1}{b}\int_0^b I_b(h_m,y)dy\ . \quad (2.3)$$

The expression (2.2) is multiplied by the transmission coefficient of the interface between the frontal layer of macroporous silicon and the monocrystalline substrate and the transmission coefficient of the interface between the monocrystalline substrate and the rear layer of macroporous silicon $(1-R_{s2*})(1-R_{s3})$. The reflection coefficient of the interface between the frontal layer of macroporous silicon and the monocrystalline substrate is marked R_{s2*}. The reflection coefficient of the interface between the monocrystalline substrate and the back layer of macroporous silicon is marked R_{s3}. The first term of the distribution of the transmission coefficient of the monocrystalline substrate that has interfaces with layers of macroporous silicon:

$$T_{m1}(h_m,y,\gamma)=(1-R_{s2*})(1-R_{s3})I_b(h_m,y)\cos(\gamma)\ .(2.4)$$

A Lambertian surface scatters light, so $\cos(\gamma)$ is added. From the expression (2.4), it can be seen that the light partially passed through the interface between the frontal layer of macroporous silicon and the monocrystalline substrate, which is shown by the expression $1-R_{s2*}$. The light passed through the monocrystalline substrate with thickness of h_m, which is shown by the distribution of the intensity of scattered light at the interface between the monocrystalline substrate and the rear layer of macroporous silicon, expression (2.2). Expression $1-R_{s3}$ shows that the light passed through the interface between the monocrystalline substrate and the rear layer of macroporous silicon. Light passes the interface between the monocrystalline substrate and the rear layer of macroporous silicon a second time when it propagates to the interface between the monocrystalline substrate and the frontal layer of macroporous silicon, is reflected from it, propagates to the interface between the monocrystalline substrate and the rear layer of macroporous silicon, and partially passes through it. The intensity of light reflected from two interfaces of the monocrystalline substrate is equal to the expression (2.4) multiplied by the product of the reflection coefficients of the interfaces of the monocrystalline substrate by the average intensity of scattered light, expression (2.3). The second term of the distribution of the transmission coefficient of monocrystalline substrate that has interfaces with layers of macroporous silicon:

$$\begin{aligned}T_{m2}(h_m,y,\gamma)&=(1-R_{s2*})(1-R_{s3})\times\\&\times R_{s2}R_{s3}I_b^2(h_m)I_b(h_m y)\cos(\gamma)\end{aligned}, \quad (2.5)$$

where R_{s2} is the reflection coefficient of the interface between the monocrystalline substrate and the frontal layer of macroporous silicon. Expressions (2.4) and (2.5) differ by the product of the reflection coefficients of the interfaces of the monocrystalline substrate and the square of the average intensity of the scattered light. The third term of the transmission coefficient of monocrystalline substrate is obtained by multiplying the second term by the product of the reflection coefficients of the interfaces of the monocrystalline substrate and the square of the average intensity of the scattered light. Each time, two more reflections from the interfaces of the monocrystalline substrate are added. Distribution of the transmission coefficient of monocrystalline substrate that has interfaces with layers of macroporous silicon:

$$T_m(h_m,y,\gamma)=\cos(\gamma)(1-R_{s2^*})(1-R_{s3})\times \times I_b(h_m,y)\sum_{n=1}^{\infty}\left((R_{s2}R_{s3})^{n-1}I_m^{2n-2}(h_m)\right) . \quad (2.6)$$

The infinite sum in expression (2.6) tends to a fraction. The distribution of the transmission coefficient of the monocrystalline substrate, which has an interface with layers of macroporous silicon, can be written as:

$$T_m(h_m,y,\gamma)=\frac{(1-R_{s2^*})(1-R_{s3})}{1-R_{s2}R_{s3}I_b^2(h_m)}I_b(h_m,y)\cos(\gamma) . \quad (2.7)$$

The transmittance coefficient (average) of the monocrystalline substrate that has interfaces with layers of macroporous silicon is as follows:

$$T_m=\frac{1}{b}\int_0^b\int_0^{\pi/2}T_m(h_m,y,\gamma)d\gamma dy=\frac{(1-R_{s2^*})(1-R_{s3})}{1-R_{s2}R_{s3}I_b^2(h_m)}\times \times\frac{1}{b}\int_0^b I_b(h_m,y)dy\int_0^{\pi/2}\cos(\gamma)d\gamma , \quad (2.8)$$

or:

$$T_m=\frac{(1-R_{s2^*})(1-R_{s3})I_b(h_m)}{1-R_{s2}R_{s3}I_b^2(h_m)} . \quad (2.9)$$

The transmission of the effective medium of macroporous layers is similar to the transmission of the monocrystalline substrate with two Lambert surfaces. The transmission coefficient through bilateral macroporous silicon will be written as follows:

$$T_{BMS}=\frac{(1-R_{s1^*})(1-R_{s2^*})(1-R_{s3})(1-R_{s4^*})}{(1-R_{s1}R_{s2^*}I_{b1}^2(h_1))(1-R_{s2}R_{s3}I_b^2(h_m))}\times \times\frac{I_{b1}(h_1)I_b(h_m)I_{b2}(h_2)}{(1-R_{s3}R_{s4^*}I_{b2}^2(h_2)))} , \quad (2.10)$$

where R_{s1} is the reflection coefficient of the interface between air and the frontal layer of macroporous silicon, R_{s1^*} is the reflection coefficient of the interface between the frontal layer of macroporous silicon and air, R_{s3^*}, R_{s4^*} are the reflection coefficients of the interfaces of the rear layer of macroporous silicon with the monocrystalline substrate and air, respectively. Light also partially falls on the side boundaries of the monocrystalline substrate and air. A point with coordinate x is selected on the lateral interface between the monocrystalline substrate and air. Coordinate $y = 0$. Light will be completely reflected if it propagates to this point at angles greater than the critical angle of total internal reflection with respect to the lateral interface between the monocrystalline substrate and air. The lateral interface between the monocrystalline substrate and air will partially transmit light incident at angles smaller than the critical angle of total internal reflection with respect to the lateral interface. The light reflected by the lateral interface between the monocrystalline substrate and air will be reflected many times inside the monocrystalline substrate from its interfaces, so the distribution of the transmittance of the lateral interface between the monocrystalline substrate and air consists of the sum. The first component of the first term of the distribution of the transmission coefficient of the lateral interface between the monocrystalline substrate and air is written in the form:

$$T_{ml11}(x,\beta)=(1-R_{s2^*})(1-R(\beta))\times \times\sin(\beta)\cos(\beta)\exp\left(-\frac{\alpha x}{\cos(\beta)}\right) . \quad (2.11)$$

The first component of the first term is called so because the light at the point with coordinates x, $y = 0$ comes only from the interface between the monocrystalline substrate and the frontal layer of macroporous silicon. The transmission coefficient of the lateral interface between the monocrystalline substrate and air at point x is found by integrating the expression (2.11) at angles smaller than the critical angle of total internal reflection, calculated from the perpendicular to the lateral interface. The first component of the first term of the distribution of the transmission coefficient of the lateral interface between the monocrystalline substrate and air is written in the form:

$$T_{ml11}(x)=(1-R_{s2^*})I_{lT^*}(x) . \quad (2.12)$$

where

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

The light propagates to the point x, which is located on the lateral interface, from the interface between the monocrystalline substrate and the frontal layer of macroporous silicon at angles from $\pi/2-\beta_c$ to $\pi/2$. Expression (2.13) is the normalized intensity of light refracted by the lateral interface between the monocrystalline substrate and air, or simply the intensity of light refracted by the lateral interface. The second component of the first term of the distribution of the transmission coefficient of the lateral interface between the monocrystalline substrate and air:

$$T_{ml21}(x)=(1-R_{s2^*})R_{s3}I_b(h_m)I_{lT^*}(h_m-x) . \quad (2.14)$$

The light propagates to the point x, which is located on the lateral interface, from the interface between the monocrystalline substrate and the rear layer of macroporous silicon at angles from $\pi/2-\beta_c$ to $\pi/2$. The first and second components of the second term of the transmission coefficient of the lateral interface between the monocrystalline substrate and air are obtained from expressions (2.12) and (2.14) by multiplying by the product of the reflection coefficients from the interfaces of the monocrystalline substrate with the frontal and rear layers of macroporous silicon and by the average intensity diffused light, expression (2.3). All other first and second components of the nth term are obtained from the previous first and second components of the $n-1$th terms by multiplying them by the product of the reflection coefficients from the interfaces of the monocrystalline substrate with the front and back layers of macroporous silicon and by the average intensity of scattered light, the expression (2.3). The distribution of the transmission coefficient of the lateral interface between the monocrystalline substrate and air is found by adding the first and second components of the nth term:

$$T_{ml}(x)=(1-R_{s2*})\left(I_{lT*}(x)+R_{s3}I_b(h_m)I_{lT*}(h_m-x)\right)\times \times\sum_{n=1}^{\infty}(R_{s2}R_{s3}I_b^2(h_m))^{n-1} \quad (2.15)$$

The infinite sum in expression (2.15) tends to a fraction, so the distribution of the transmission coefficient of the lateral interface between the monocrystalline substrate and air is written as follows:

$$T_{ml}(x)=\frac{1-R_{s2*}}{1-R_{s2}R_{s3}I_b^2(h_m)}\times \times\left(I_{lT*}(x)+R_{s3}I_b(h_m)I_{lT*}(h_m-x)\right) \quad (2.16)$$

From the expressions (2.16) and (2.13), the (average) transmittance coefficient of the lateral interface between the monocrystalline substrate and air will be written as:

$$T_{ml}=\frac{1-R_{s2*}}{h_m(1-R_{s2}R_{s3}I_b^2(h_m))}\int_{\pi/2-\beta c}^{\pi/2}\left(\sin(\beta)\cos(\beta)\times \times(1-R(\beta))^{kr}\left[\int_0^h\exp\left(-\frac{\alpha x}{\cos(\beta)}\right)dx+ +R_{s3}I_b(h_m)\int_0^h\exp(-\frac{\alpha(h_m-x)}{\cos(\beta)})dx\right]\right)d\beta \quad (2.17)$$

Transmission coefficient through the side surface of a monocrystalline substrate:

$$\int_0^{hm}\exp(-\frac{\alpha x}{\cos(\beta)})dx=\int_0^{hm}\exp(-\frac{\alpha(h_m-x)}{\cos(\beta)})dx= =\frac{\cos(\beta)}{\alpha}\left(1-\exp\left(-\frac{\alpha h_m}{\cos(\beta)}\right)\right) \quad (2.18)$$

From the expression (2.17), the transmission coefficient of the lateral interface between the monocrystalline substrate and air can be rewritten as follows:

$$T_{ml}=\frac{(1-R_{s2*})(1+R_{s3}I_b(h_m))}{\alpha h_m(1-R_{s2}R_{s3}I_b^2(h_m))}\times \times\int_{\pi/2-\beta c}^{\pi/2}\sin(\beta)\cos^2(\beta)(1-R(\beta))(1-\exp\left(-\frac{\alpha h_m}{\cos(\beta)}\right)d\beta \quad (2.19)$$

or

$$T_{ml}=\frac{I_{lT}(h_m)(1-R_{s2*})(1+R_{s3}I_b(h_m))}{1-R_{s2}R_{s3}I_b^2(h_m)}, \quad (2.20)$$

where

$$I_{lT}(h_m)=\frac{1}{\alpha h_m}\int_{\pi/2-\beta c}^{\pi/2}\sin(\beta)\cos(\beta)^2\times \times(1-R(\beta))\left(1-\exp\left(-\frac{\alpha h_m}{\cos(\beta)}\right)\right)d\beta \quad (2.21)$$

The transmission coefficients of the lateral interface between the monocrystalline substrate and air and the lateral interface between the macroporous silicon layer and air are similar. From expression (2.20), the transmittance coefficient of the lateral interface between bilateral macroporous silicon and air is written as follows:

$$T_{BMSl}=\frac{I_{lT1}(h_1)(1-R_{s1})(1+R_{s2*}I_b(h_1))}{1-R_{s1*}R_{s2*}I_b^2(h_m)}+ +\frac{I_{lT}(h_m)(1-R_{s2*})(1+R_{s3}I_b(h_m))}{1-R_{s2}R_{s3}I_b^2(h_m)}+ +\frac{I_{lT2}(h_2)(1-R_{s3})(1+R_{s4}I_{b3}(h_2))}{1-R_{s3*}R_{s4}I_{b3}^2(h_m)}, \quad (2.22)$$

where R_{s4} is the reflection coefficient of the back layer of macroporous silicon with air, h_1, h_2 are the depths of the macropores of the front and back layers of macroporous silicon, respectively. The expression (2.21) shows the average normalized intensity of refracted light at the lateral interface between the monocrystalline substrate and air, or the average normalized intensity of light refracted by the lateral interface. The reflection coefficient of bilateral macroporous silicon R_{BMS} is found similar to expression (2.10), using the reflection coefficient from the monocrystalline substrate that has an interface with layers of macroporous silicon, found similar to transmission. The absorption coefficient of bilateral macroporous silicon will be written as:

$$A_{BMS}=1-(R_{BMS}+T_{BMS}+2T_{BMSl}). \quad (2.23)$$

3. RESULTS AND DISCUSSION

Fig. 1 shows the transmission spectrum of bilateral macroporous silicon with different volume fraction of pores of the frontal layer of macroporous silicon with a thickness of 20 µm. The volume fraction of pores of the rear layer of macroporous silicon is 0.2. Arrays of nanowires placed on both sides of the monocrystalline substrate have a similar reflection spectrum. The thickness of bilateral macroporous silicon is 500 µm. The thickness of the rear layer of macroporous silicon is 50 µm. The transmission spectrum of bilateral macroporous silicon with different volume fraction of pores of the frontal layer of macroporous silicon is calculated from the expression (2.10). The transmission of bilateral macroporous silicon increases with an increase in the volume fraction of pores from 0.1 to 0.7 (see Fig. 1, curves 1-4). The increase in transmission of bilateral macroporous silicon with an increase in the volume fraction of pores is due to an increase in the transmission of the interface between air and the frontal layer of macroporous silicon. Transmission of bilateral macroporous silicon with an increase in the volume fraction of the pores of the frontal layer of macroporous silicon begins to decrease with a volume fraction of pores greater than 0.9 (see Fig. 1, curve 5).

The transmission of bilateral macroporous silicon with an increase in the volume fraction of the pores of the frontal or rear layers of macroporous silicon is the same. This is due to the fact that light with wavelengths from 0.9 μm to 1.3 μm is weakly absorbed and passes through bilateral macroporous silicon. When passing through bilateral macroporous silicon, light crosses all interfaces. As the volume fraction of the pores of the frontal or rear layers of macroporous silicon changes, the transmittance of one of the interfaces changes, but the transmittance of bilateral macroporous silicon does not change.

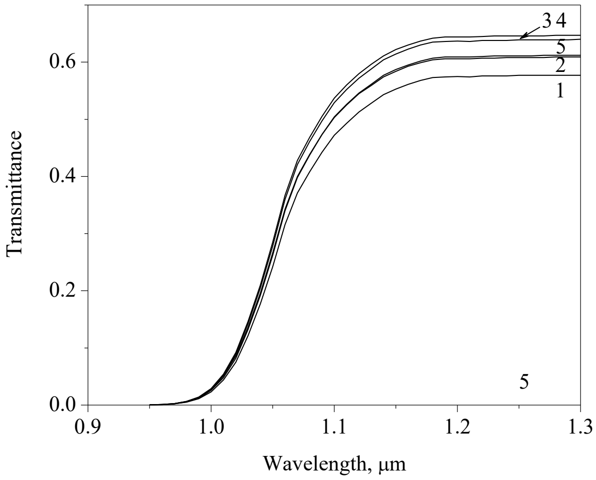

Fig. 1 – Transmission spectrum of bilateral macroporous silicon or arrays of nanowires placed on both sides of the monocrystalline substrate with a volume fraction of pores of the frontal layer of macroporous silicon: 1 – 0.1; 2 – 0.3; 3 – 0.5; 4 – 0.7, 5 – 0.9. The thickness of the frontal macroporous silicon is 20 μm, the thickness of the rear macroporous silicon is 50 μm. The volume fraction of the rear layer of macroporous silicon is 0.2

Fig. 2 shows the absorption spectrum of bilateral macroporous silicon with different volume fraction of pores of the frontal layer of macroporous silicon with a thickness of 20 μm. The volume fraction of pores of the rear layer of macroporous silicon is 0.2. Arrays of nanowires placed on both sides of the monocrystalline substrate have a similar reflection spectrum. The thickness of bilateral macroporous silicon is 500 μm. The thickness of the rear layer of macroporous silicon is 50 μm. The absorption spectrum of bilateral macroporous silicon with different volume fraction of pores of the frontal layer of macroporous silicon is calculated from the expressions (2.10), (2.22) and (2.23). The absorption of bilateral macroporous silicon determines its reflection and transmission. The absorption of bilateral macroporous silicon consists of the absorption of the frontal and rear layers of the macroporous silicon and the absorption of the monocrystalline substrate. Reflection from the interfaces of the bilateral macroporous silicon affects the trapping and absorption of light by the bilateral macroporous silicon. The absorption of bilateral macroporous silicon increases with an increase in the volume fraction of pores from 0.1 to 0.7 (see Fig. 2, curves 1-4). The absorption of bilateral macroporous silicon increases, each time by a larger amount, with an increase in the volume fraction of the pores of the frontal layer of macroporous silicon. Starting with a volume fraction of pores of the frontal layer of macroporous silicon greater than 0.7, the absorption of bilateral macroporous silicon light with wavelengths from 0.6 μm to 1.05 μm decreases due to the increase in reflectance bilateral macroporous silicon (see Fig. 2, curves 4 and 5).

This is due to an increase in the reflection of the interface between the layer of macroporous silicon and the monocrystalline substrate. As the volume fraction of the pores of the macroporous silicon frontal layer increases, the reflection of the interface between the macroporous silicon layer and the monocrystalline substrate increases, due to the increase in the difference between the effective refractive index of the macroporous silicon layer and the refractive index of the monocrystalline silicon substrate. The difference between the refractive index of air and the effective refractive index of the macroporous silicon layer decreases with an increase in the volume fraction of the pores of the macroporous silicon frontal layer. For this reason, the reflection of the interface between air and the frontal layer of macroporous silicon decreases, and the reflection of the interface between the frontal layer of macroporous silicon and the monocrystalline substrate increases. This affects the absorption of bilateral macroporous silicon.

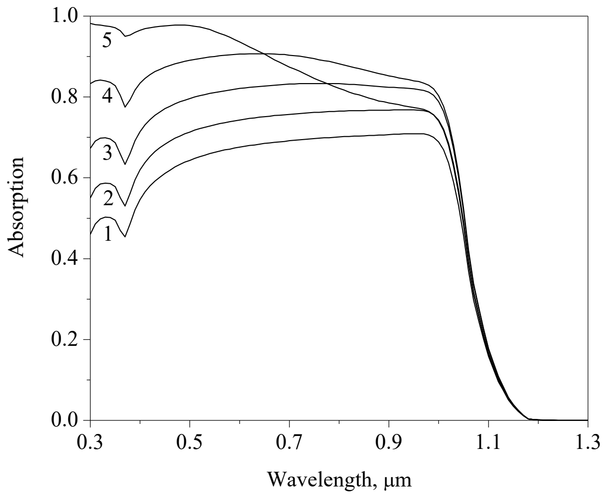

Fig. 2 – Absorption spectrum of bilateral macroporous silicon or arrays of nanowires placed on both sides of the monocrystalline substrate with a volume fraction of pores in the frontal layer of macroporous silicon: 1 – 0.1; 2 – 0.3; 3 – 0.5; 4 – 0.7, 5 – 0.9. The thickness of the frontal macroporous silicon is 20 μm, the thickness of the rear macroporous silicon is 50 μm. The volume fraction of the rear layer of macroporous silicon is 0.2

Fig. 3 shows the absorption spectrum of bilateral macroporous silicon with different volume fraction of pores of the frontal layer of macroporous silicon with a thickness of 50 μm. The volume fraction of the rear layer of macroporous silicon is 0.2. Arrays of nanowires placed on both sides of the monocrystalline substrate have a similar reflection spectrum. The thickness of bilateral macroporous silicon is 500 μm. The thickness of the rear layer of macroporous silicon is 20 μm. The absorption spectrum of bilateral macroporous silicon with different volume fraction of pores of the frontal layer of macroporous silicon is calculated from expressions (2.10), (2.22) and (2.23).

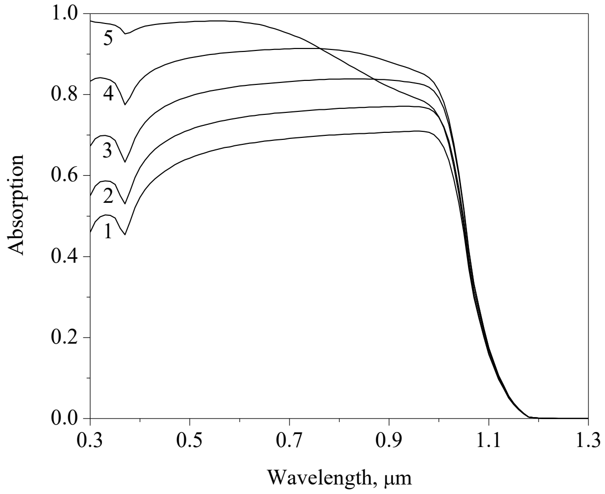

Fig. 3 – Absorption spectrum of bilateral macroporous silicon or arrays of nanowires placed on both sides of the monocrystalline substrate with a volume fraction of pores in the frontal layer of macroporous silicon: 1 – 0.1; 2 – 0.3; 3 – 0.5; 4 – 0.7, 5 – 0.9. The thickness of the frontal macroporous silicon is 50 μm, the thickness of the rear macroporous silicon is 20 μm. The volume fraction of the rear layer of macroporous silicon is 0.2

Bilateral macroporous silicon is illuminated from the other side. The frontal layer of macroporous silicon became thicker, and the rear layer became thinner. Light partially reflected from the interface between the frontal layer of macroporous silicon and the monocrystalline substrate is absorbed by the frontal layer of macroporous silicon, which has become thicker. Differences in the absorption spectra of bilateral macroporous silicon are shown in Fig. 3 and Fig. 2 due to the thickness of the frontal macroporous silicon.

4. CONCLUSIONS

The transmission of bilateral macroporous silicon increases with an increase in the volume fraction of pores from 0.1 to 0.7. The increase of the transmission of bilateral macroporous silicon is due to the increase of the transmission of the interface between air and the frontal layer of macroporous silicon with an increase in the volume fraction of pores. The transmission of bilateral macroporous silicon with an increase in the volume fraction of pores of the frontal layer of macroporous silicon begins to decrease with a volume fraction of pores greater than 0.9. The transmission of bilateral macroporous silicon with an increase in the volume fraction of pores of the frontal or rear layers of macroporous silicon is the same. When passing through bilateral macroporous silicon, light crosses all the interfaces of bilateral macroporous silicon. As the volume fraction of the pores of the frontal or rear layer of macroporous silicon changes, the transmission of one of the interface changes, but the transmission of bilateral macroporous silicon does not change.

The absorption of bilateral macroporous silicon increases with an increase in the volume fraction of pores from 0.1 to 0.7. It grows each time by a larger amount, with an increase in the volume fraction of pores of the frontal layer of macroporous silicon. Starting with a volume fraction of the pores of the frontal layer of macroporous silicon greater than 0.7, the absorption of light with wavelengths from 0.6 μm to 1.05 μm by the bilateral macroporous silicon decreases, due to the decrease in the transmission of the interface between the frontal macroporous silicon and the monocrystalline substrate. The transmittance of the interface between the macroporous silicon layer and the monocrystalline substrate decreases due to the increase in the difference between the effective refractive index of the macroporous silicon layer and the refractive index of the monocrystalline silicon substrate.

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Пропускання та поглинання двостороннього пористого кремнію з макропорами або нанодротами

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Розраховано спектри пропускання та поглинання двостороннього макропористого кремнію та нанодротин. Враховується пропускання та відбиття меж розділу між монокристалічною підкладкою та шарами макропористого кремнію. Розглянуто поглинання двостороннього макропористого кремнію при освітлені одного або іншого шару макропористого кремнію. Розраховано пропускання бічних меж розділу між двостороннім макропористим кремнієм та повітрям. Пропускання бічних меж двостороннього макропористого кремнію залежить від коефіцієнтів відбиття меж розділу монокристалічної підкладки та шарів макропористого кремнію та об'ємної частки пор. Враховано падіння світла на бічні межі розділу між двостороннім макропористим кремнієм та повітрям під різними кутами та ефект повного внутрішнього відбиття. Розглянуто залежність спектрів пропускання та поглинання двостороннього макропористого кремнію та нанодротин від відбиття та пропускання межі розділу між фронтальним шаром макропористого кремнію та монокристалічною підкладкою та об'ємної частки пор. Показано зростання поглинання та пропускання двостороннього макропористого кремнію зі збільшенням об'ємної частки пор до певної величини та зменшення поглинання та пропускання за рахунок збільшення відбиття межі розділу між фронтального шару макропористого кремнію з монокристалічною підкладкою.

Ключові слова: Пропускання, Поглинання, Нонодротини, Двосторонній макропористий кремній.