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Si Nanofilm Efficient UV Solar Absorber

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Abstract

We report on optical properties of Si on insulator (SOI) and layered Si/SiO$_2$ structure displaying high ultraviolet (UV) light absorption predominantly in the top ultrathin Si layer. We show that such structures can be used for construction of solar cells efficiently absorbing UV light. Si/SiO$_2$ layered structure on SiO$_2$ substrate showing high transparency in the visible spectral range can be used as a transparent solar cell in windows of buildings and spaceships. Such solar cells require negligible amount of Si

1. Introduction

Usually crystalline Si solar cells and their anti-reflection coatings are designed for absorption of visible and near infrared light. However, ultraviolet (UV) part of solar radiation ranging from ~3 eV to ~4 eV at the sea level of the Earth and from ~3 eV to ~4.5 eV in space is also important since it contains ~20% of total sunlight energy. Further, if we take into account the absorption spectrum of Si (Fig.1), then we realize that the efficiency of the solar-to-electric energy conversion per unit weight of a solar cell can be significantly improved in Si solar cells that are able to effectively convert UV light into electricity. Moreover, such solar cells can be transparent for visible light and, therefore can be used in windows like transparent polymer solar cells demonstrated in Ref. [1].

In our recent work [2], we showed that ultrathin Si on insulator (SOI) at certain thicknesses of buried oxide layer displays Raman enhancement at 364 nm wavelength excitation due to constructive interference in the oxide layer enhancing electric field in SOI. In the present work, we show that this effect can be used for design of layered Si/SiO$_2$ structure effectively absorbing UV light while transmitting ~50% of visible light.

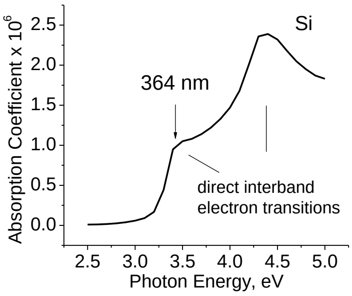

Fig. 1. Absorption spectrum of silicon.

2. Theoretical and Experimental Methods

Theoretically, we considered reflection, absorption and transmission of normally incident light on layered Si/SiO$_2$ structures of two types shown in Fig. 2, namely, traditional SOI structure and Si/SiO$_2$/Si structure on SiO$_2$ substrate. Optical constants of bulk materials were used.

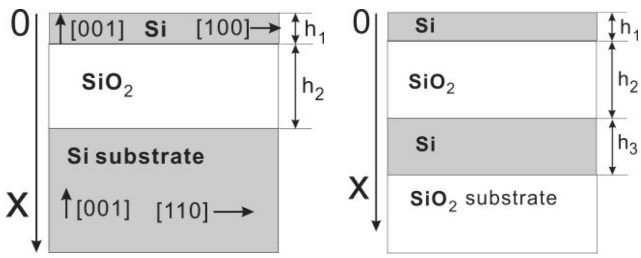

Fig. 2. Traditional Si on insulator structure on Si substrate (left) and Si/SiO$_2$/Si structure on SiO$_2$ substrate (right).

Commercially available initial SOI structures were received from SOITEC. [001]-oriented SOI were located on the top of a 145 nm BOX (h_2= 145 nm) covering a Si substrate. Initial thickness of top Si layer (h_1) was 70 nm. Then h_1 was decreased using thermal oxidation with the subsequent etching in HF. h_1 was controlled by the electron microscopy, ellipsometry and optical reflection spectroscopy. Fig. 3 shows TEM image of cross-sections of SOI with h_1 = 2.5 nm. Optical reflection spectra were measured using CRAIC micro-spectroreflectometer.

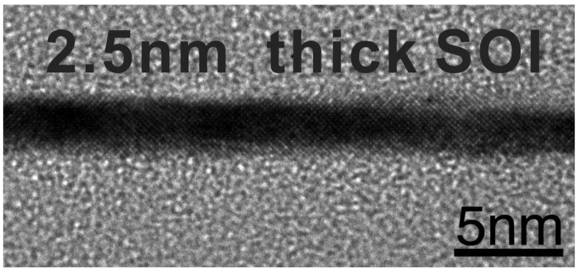

Fig. 3. TEM image of cross-section of SOI with h_1 ~2.5 nm

Results

Figure 4 shows experimental and theoretical reflection spectra of 2.5 nm thick SOI. Insignificant discrepancy between experiment and theory can be explained by size effect on Si optical constants that was not taken into account in calculations. SOI reflectance in UV is significantly lower than that of bulk Si. This is due to tiny thickness of SOI and interference in the buried oxide layer, nearly 80% of the UV light being absorbed by the 2.5 nm thick SOI nanofilm (Fig.5).

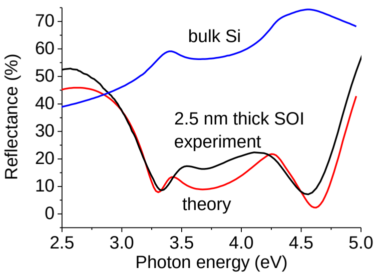

Fig. 4. Experimental (black) and calculated (red) reflection spectra of thick SOI structure with h_1 =2.5 nm and h_2 ~145 nm.

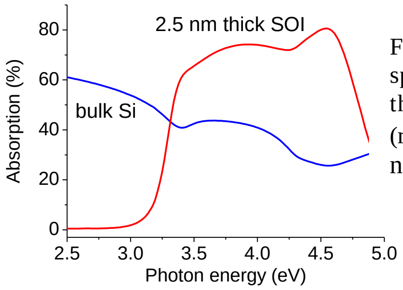

Fig. 5. Absorption spectra of 2.5 nm thick SOI nanofilm (red) with h_2 = 145 nm and bulk Si (blue).

For application in photovoltaics, in addition to the efficient solar light absorption, SOI structure should allow charge separation. Figure 6 shows a way of charge separation. According to this idea, SOI nanofilm consists of n- and p-doped ~1 μm wide stripes allowing voltage harvesting.

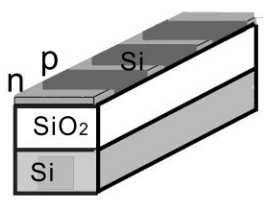

Fig. 6. SOI consisting of n- and p-doped stripes for photovoltaic application.

Let us consider optical properties of Si/SiO_2 layered structure on the oxide substrate (Fig. 2, right). Figure 7 shows calculated total transmission and each Si layer absorption spectra of the structure with h_1 = 2.5 nm, h_2 = 155 nm and h_3 = 65 nm. Average transmission in visible spectral range is about 50 % with ~80 % peak at ~2.3 eV. Top 2.5 nm thick Si layer shows > 70 % absorption in the range from ~3.3 eV to 4.5 eV while the 65 nm thick Si layer displays a sharp absorption peak at ~3.2 eV. Total absorption of both Si layers in the range 3 – 4.5 eV is ~90%. For application in photovoltaics, both layers can be made of n- and p-doped stripes like in Fig. 6.

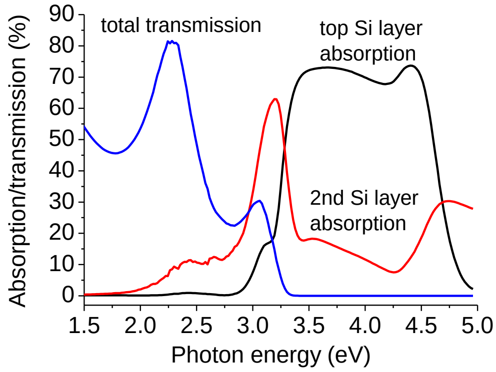

Fig. 7. Calculated total transmission (blue) and absorption in top Si layer (black) and 2nd Si layer (red) in the Si/SiO_2 structure on SiO_2 substrate with h_1 = 2.5 nm, h_2 = 155 nm and h_3= 65 nm.

3. Conclusions

We demonstrated high UV absorption of ultrathin Si nanofilm in traditional SOI structure as well as in layered Si/SiO_2 structure on SiO_2 substrate. This can be used in solar cells with extremely low Si material consumption. Layered Si/SiO_2 structure, transparent for visible light, is suitable for construction of transparent solar cells for windows of buildings and spaceships. Moreover, such structure can be used in hybrid silicon-organic solar cells since it absorbs UV radiation and, therefore, protects visible-light organic solar cells from the UV-radiation-induced aging.

Acknowledgements

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References

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