Characteristics of nanocomposite sol-gel films on black silicon surface

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Abstract
The structural and photoelectric characteristics of thin sol-gel ZnO, TiO_2, and SiO_2 films on the black silicon (b-Si) surface have been studied. It has been shown that it is preferable to use ZnO and TiO_2 films as passivating and protective films of solar cells based on b-Si, which have stable structural and optical properties and, at least, do not worsen the reflection of b-Si in the near infrared and visible regions of the solar radiation.

Introduction
Black silicon (b-Si) is a needle-like surface nanostructure [1, 2]. These needles increase the amount of light that is captured rather than reflected back from the surface. The combination of low reflectivity and the semi-conductive properties of Si found in b-Si make it a prime candidate for application in solar cells as an antireflection surface. The large surface area of

b-Si leads to a high surface recombination velocity and, therefore, efficient surface passivation by thin films is of utmost importance in employing b-Si in solar cells.

A wide variety of techniques for the deposit method of high quality ZnO, TiO_2, and SiO_2 passivating films on planar (without b-Si) Si surface have been reported, such as chemical vapor deposition, atomic layer deposition, pulsed laser deposition, sol-gel, sputtering and electrochemical deposition [3]. The general advantage of the sol-gel method is that it can be used for large area deposition and processed at a low temperature [4]. In addition, this method is easy in its composition control, it has a low cost and provides uniformity of the film's thickness.

This work presents the results of studying the structural and photoelectric (current-voltage and capacitance-voltage) characteristics of thin sol-gel ZnO, TiO_2, and SiO_2 passivating films on the b-Si surface.

Experimental

The b-Si on the front surfaces of Si wafers was fabricated by reactive ion etching method in a gas mixture of sulfur hexafluoride (SF_6) and O_2. The process pressure was 55mTorr and gas flow rates were 75 cm^3/min and 40 cm^3/min for SF_6 and O_2, respectively. Samples were placed on the water-cooled bottom electrode that was powered by a 13.56 MHz RF generator [2]. Etching of 10 min leads to a random nanostructure with an average needle height of 1.0 μm and width of 110 nm. The precipitation of ZnO, TiO_2, and SiO_2 nanocomposite films was performed by depositing a sol by centrifugal separation (the spin-coating procedure) [4, 5]. The thickness of the films was about 300 nm.

The cross-section and top-view morphology of the b-Si and thin films were observed by a scanning electron microscope (SEM) and Atomic Force Microscopy (AFM). Measurement of photoelectric characteristics (current-voltage and capacitance-voltage) was carried out under the influence of laser and UV radiation of different wavelengths. The optical reflectance of the samples was detected using a spectrophotometer T70 UV-VIS with an integrating sphere.

Results and discussion

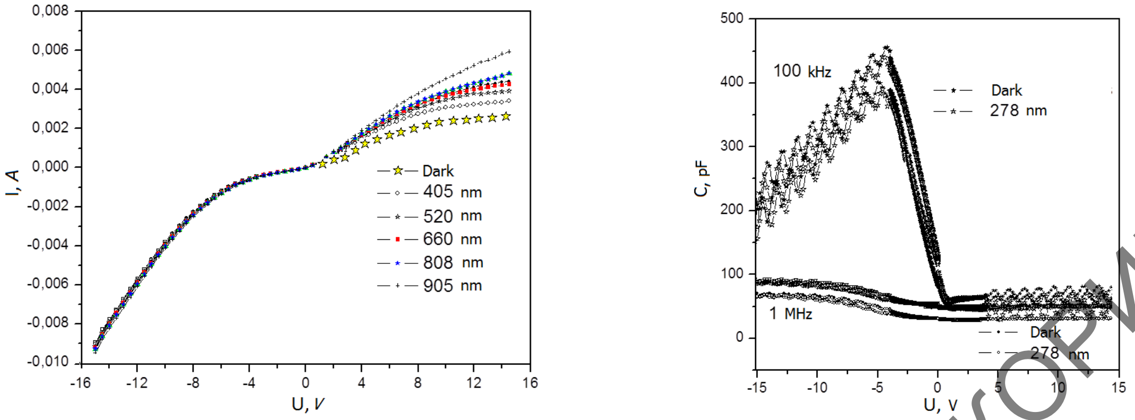
SEM and AFM studies have shown that sol-gel films precisely reproduce the morphology of the b-Si surface without any voids or inclusions. Thus, these films can be concluded to be rather conformal, which is essential for efficient surface passivation.

Studies of the reflection spectrum of ZnO, TiO_2, and SiO_2 films on the b-Si surface showed that ZnO and TiO_2 films, especially in the long-wavelength visible region of the solar radiation, have the lowest optical reflectance, which is most likely due to the large number and small size of their grains. Therefore, it is preferable to use ZnO and TiO_2 sol-gel films as passivating and protective coatings in solar cells based on b-Si. These films not only retain low reflection of b-Si in the near infrared and visible regions of solar radiation, but also extend it to the short wavelength region of the spectrum.

Fig. 1 shows the current-voltage and capacitance-voltage characteristics of b-Si samples with TiO_2 films. The absolute values of the photocurrent in the b-Si / TiO_2 structures are insufficient for converting solar energy in practice (Fig. 1,a). However, the combined use of TiO_2 films and solar cells based on b-Si can facilitate the efficient use of the solar spectrum, for example, in tandem solar cells based on materials with different band gap. At negative bias voltages from -15 V to 0 V at a signal frequency of 1 MHz, the capacity of the b-Si / TiO_2 structure slightly decreases due to the rearrangement of metastable defects (Fig. 1,b). The extended slope of the experimental curves in the middle part of the capacitance-voltage characteristics is due to the presence of a significant density of surface states at the interface.

Conclusion

It is shown that the ZnO and TiO_2 films have stable structural properties and do not worsen the reflection of b-Si in a wide range of solar radiation. Only samples with a TiO_2 film have a noticeable photosensitivity. The functional possibilities of using b-Si/oxide film structures in semiconductor devices for different applications are analyzed. It is preferable to use ZnO and TiO_2 sol-gel films as passivation and protective coatings in solar cells based on b-Si.



a *b*

Fig. 1. Current-voltage (a) and capacitance-voltage (b) characteristics of b-Si samples with TiO_2 films

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