Optical Characterization of Silicon Nanowire Array

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Abstract: In this paper characterization on optical properties of silicon nanowire arrays has been made. Nanowire array has potential applications in solar cells. The effects of wire length and wavelength on the Transmission and reflection properties of nanowire arrays have been simulated. The analysis of simulated resulted has also been presented.

Keywords: **Absorption Nanowire, Photonics, Photovoltaic, Solar Cell, Transmission.**

I. INTRODUCTION

Photonics is the technology associated with signal generation, processing, transmission, and detection where the signal is carried by photons. Photonics is a rapidly expanding technology with applications in a large number of areas. One hitherto dominating sector has been telecommunication, but photonics is much broader than that. Nowadays, besides telecommunication, applications of photonics include consumption equipment, medicine, industrial manufacturing, construction, aviation, military, entertainment, metrology, photonic computing, etc. However, as compared to electronics, photonics is about several tens of years behind in maturity. In order to compete with electronics in our modern life, photonics has to follow the same development dynamics as electronics.

Photonics has its very important application in the development of low cost, high performance photovoltaic nano-devices. In order to ensure the widespread use of photovoltaic (PV) technology for terrestrial applications, the cost per watt must be significantly. In 2008 the average cost of industrial Si solar cell with conversion efficiency of 14.5 % was very high [4]. At that cost level, the PV electricity still remains more expensive comparing with traditional nuclear or thermal power engineering.

Nanowire solar cells demonstrated to have high conversion efficiency with low cost. Huynh *et al*. utilized CdSe nanorods as the electron-conducting layer of a hole conducting polymer matrix solar cell and produced an efficiency of 1.7 % for AM 1.5 irradiation [2]. Similar structures have been demonstrated for dye-sensitized solar cells using titania or ZnO nanowires, with efficiencies ranging from 0.5 % to 1.5 % [3]. These results show the benefits of using nanowires for enhanced charge transport in nanostructured solar cells compared to other nanostructured architectures. The Si nanowires solar cells have a potential to provide the equal or better performance to crystalline Si solar cells with processing methods similar to thin film solar cells [1], [5], [7].

II. OPTICAL PROPERTIES OF Si NANOWIRES

A variety of the optical techniques have shown that the properties of nanowires are different to those of their bulk counterparts; however the interpretation of these measurements is not always straightforward. The wavelength of light used to probe the sample is usually smaller than the wire length, but larger than the wire diameter. Hence, the probe light used in the optical measurement cannot be focused solely onto the nanowire and the wire and the substrate on which the wire rests are probed simultaneously. For example, for measurements such as photoluminescence, if the substrate does not luminescence or absorb in the frequency range of the measurements, PL measures the luminescence of the nanowire directly and the substrate can be ignored. In reflection and transmission measurements, even a non-absorbing substrate can modify the measured spectra of nanowires. However, despite these technical difficulties it was experimentally proved that Si nanowire materials have exhibited properties such as ultrahigh surface area ratio, low reflection, absorption of wideband light, and tunable bandgap.

SiNW PV devices show improved optical characteristics compared to planar devices. Fig. 29 (a) shows typical optical reflectance spectra of Si nanowire film as compared to solid Si film of the same thickness [6]. As one can see, the reflectance of the nanowire film is less than 5% over the majority of the spectrum from the UV to the near IR and begins to increase at ~700°nm to a values of ~41% at the Si band edge (1100 nm), similar to the bulk Si. It is clear that the nanowires impart a significant reduction of the reflectance compared to the solid film. More striking is the fact that the transmission of the nanowire samples is also significantly reduced for wavelength greater than ~700°nm. This residual absorption is attributed to strong IR light trapping4 coupled with the presence of the surface states on the nanowires that absorb below bandgap light. However, the level of optical absorption does not change with passivation, which further indicates that light trapping plays a dominant role in the enhanced absorption of the structures at all wavelength. It should be also noted that the absorption edge of a nanowire film shifts to longer wavelength and approaches the bulk value as the nanowire density is increased. Essentially, the Si nanowire arrays act as sub-wavelength cylindrical scattering elements, with the mactroscopic optical properties being dependent on nanowire pitch, length, and diameter.

III. OPTICAL CHARACTERIZATION OF NANOWIRE ARRAY

Silicon nanowire solar cell consists of arrays of p-n junction nanowires as shown in Fg.1.

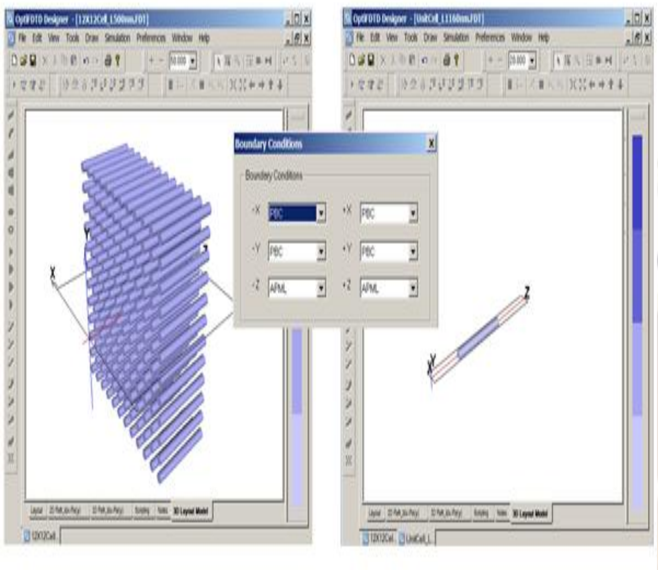

Fig. 1 Screenshot of Silicon Nanowire Array

Each individual nanowire in the array has a p-n junction and acts as a tiny photovoltaic cell. Silicon solar cells based on nanowires have much shorter p-n junctions that thin film solar cells.

The simulation has been simplified by using PBC boundary conditions in transverse direction. OptiFDTD software has been used, which simulates each array with the normal plane wave incident. The Si has been modeled using Drude-Lorentz model, which in frequency domain can be expressed as

$$\epsilon_r(\omega) = \epsilon_{r,\infty} + \sum_{m=0}^{M} \frac{G_m \Omega^2_m}{\omega^2_m - \omega^2 + j\omega\Gamma_m} \tag{1}$$

By using polarization and Fourier transform, Drude-Lorentz model can be expressed in terms of Maxwell's equations as equations 2 and 3.

$$\epsilon_{r,\infty}\epsilon_0 \frac{\partial \vec{E}}{\partial t} + \sum_{m=0}^{M} \frac{\partial P_m}{\partial t} = -\nabla \times \vec{H} \tag{2}$$

$$\frac{\partial^2 \vec{P}_m}{\partial t^2} + \Gamma_m \frac{\partial \vec{P}_m}{\partial t} + \omega^2_m \vec{P}_m = \epsilon_0 G_m \Omega^{2_m} \vec{E} \tag{3}$$

The Drude-Lorentz model used in our simulations has been shown in Fig. 2.

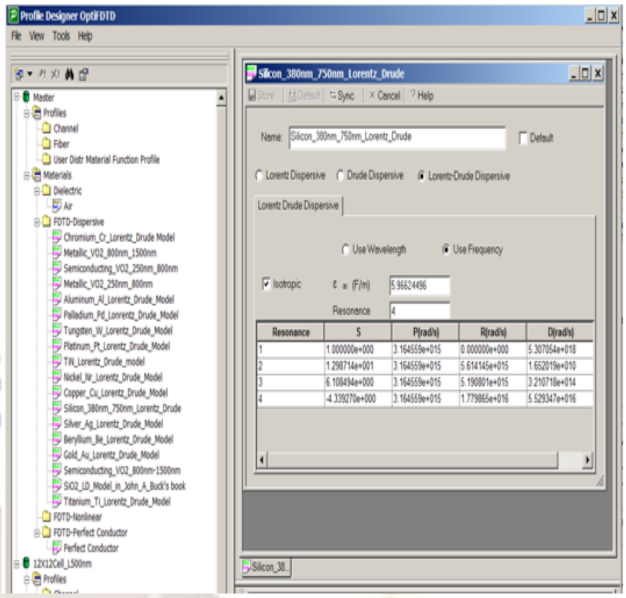

Fig.2 Screenshot of Drude-Lorentz model used in our simulations

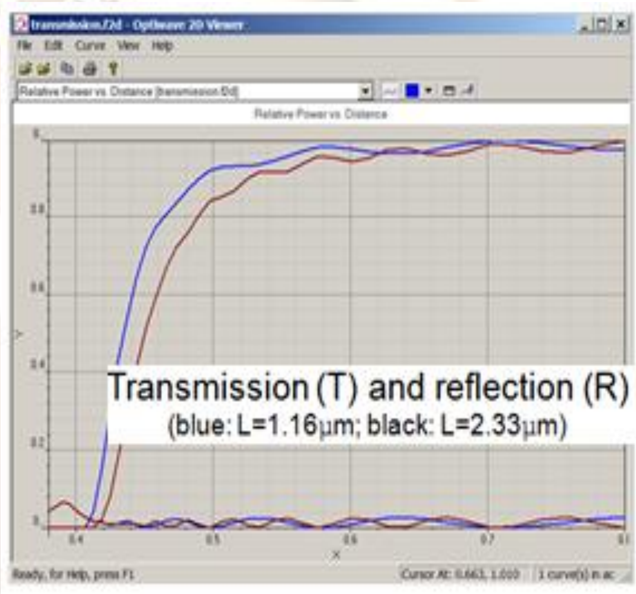

Fig. 3 Transmission and Reflection plot of nanowires with L = 1.16 and 2.33 6μm.

The effect of wire length on transmission and reflection properties has been investigated. Fig. 3 shows the optical transmission and reflection of an array of silicon nanowires with lengths, 1.16 and 2.33μm. The light is incident the top of the nanowire structure in the normal direction along the wire axis.

Fig. 4 shows the absorptance of nanowire structures with different wavelengths. From results it hs been concluded that as the wavelength increases, the value of absorptance goes on decreasing. Also for smaller length of nanowire, the absorptance decreases sharply.

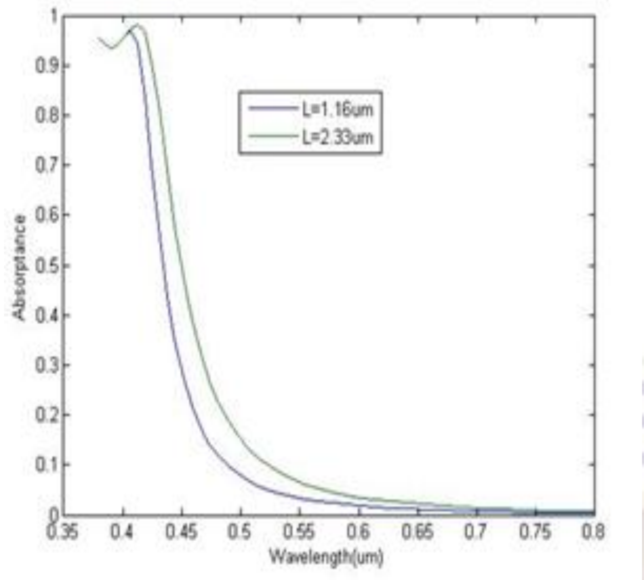

Fig. 4 Reflectance of nanowire structures for various wavelengths.

IV. CONCLUSIONS

We have demonstrates the optical properties of nanowire arrays. The variation of transmission and reflection for various lengths of nanowires has been studied. Also absorptance of nanowire structures with different wavelengths and for different lengths has been studies. The present study could help in the design of low cost, high efficient solar cells.

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