Silicon Nanowires Based Photodetectors

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Abstract: We propose a silicon-nanowire (SiNW)-based photodetector with a radial metal junction that is predicted to exhibit a significantly reduced response time. The width of the radial depletion layer across the nanowire can be controlled by adjusting the doping concentration of the silicon nanowire. We calculated depletion region widths for silicon nanowires of various diameters and doping concentrations, and then calculated the photogenerated carrier transit time, the RC time constant, and the diffusion time in the nanowire structure. We also simulated photon absorption on nanowire arrays coated with metal to determine the effect of array and nanowire diameter size to the absorption efficiency using finite element method, We found that by using the radial junction configuration we could significantly improve the response time to 81 ps. We also found that the diffusion time for the photogenerated carriers depends strongly on the nanowire length and doping concentration. At the 850 nm wavelenght, SiNW with the smallest fill factor has the highest responsivity.

Keywords: Silicon nanowires, photon absorption, response time, nanowire arrays.

INTRODUCTION

We propose a SiNW structure with a radial junction induced by a Schottky metal contact across the nanowire surface. A Radial n-p core-shell nanowire for use in solar cells has been reported by Garnet and Yang (7). By adjusting the SiNW doping concentration, we can control the depletion layer width. Photogenerated carriers in the depletion layer will be collected radially toward the outer electrode and the inner conducting Si channel, promoting shorter transit times. We also investigate optical absorption characteristic of SiNW arrays coated with an ultra-thin metal film. Metal coating over SiNWs surface will serve as a passivation layer and radial Schottky junction to induce radial depletion layer. For this calculation, we used COMSOL Multiphysics to calculate the responsivity of the SiNW array at 850 nm wavelength.

MATERIALS AND METHODS

To evaluate photonic absorption for periodic nanostructures, we used Transfer Matrix Method (TMM) (7-9) which are commonly used to evaluate the structure optical absorption. The absorption of the structure is given by energy balance in form of $A(w) = 1 - (T(w)+R(w))$ where w is the angular frequency, A, T, and R, are absorptance, transmittance, and reflectance of the structure. In our study about optical absorption in a metal coated SiNW, we use power absorption per unit volume (Pabs) method with material spatial index filter to differentiate the absorptance in silicon and metal. Pabs can be calculated from the divergence of the Poynting vector.

RESULTS AND DISCUSSION

Fig. 1 (a) shows the dependence of the depletion region width and of the carrier transit time on the doping concentration for different nanowire diameters. Fig. 1 (b) shows that the transit time of photogenerated carriers for a radial junction is much shorter than that for a naturally fully depleted undoped nanowire (~141 ns). In the fully depleted mode, radial charge separation cannot occur, and photogenerated carriers must traverse the nanowire length in order to reach the electrodes at the ends.

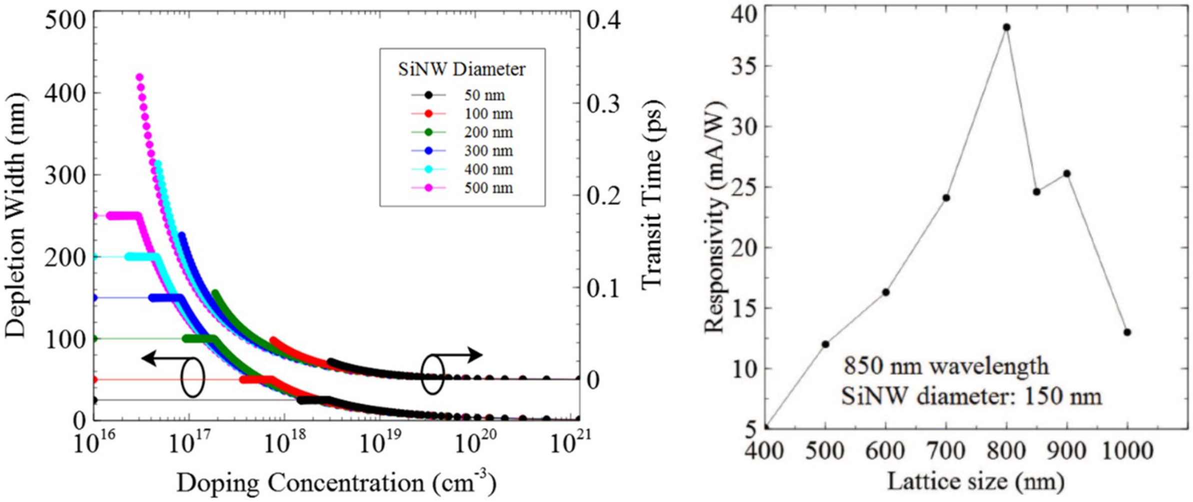

Fig. 1. (a) Calculated depletion layer width and photogenerated carrier transit time (t_{tr}). (b) **The responsivity of SiNW array coated with 20 nm ITO for SiNW with an overall diameter of 150 nm. Peak responsivity observed around 800 nm lattice size.**

We can see from Fig. 1 (b), by using SiNW with an overall diameter of 150 nm, we could achieve peak responsivity around 38.2 mA/W when the lattice size is 800 nm. Electric field intensity in the SiNW arrays depends on the lattice size. As the lattice size are close to the application wavelength, the electric field intensity increases and starting to decrease as the lattice size is greater than the application wavelength.

CONCLUSIONS

We propose a SiNW with a radial junction to promote a faster photogenerated carrier collection and an improved response time. By using a moderately doped SiNW with a radial metal junction, a response time of 81 ps can be achieved for a 500-nm-diameter SiNW. We can also shorten the response time to 6 ps by shortening the SiNW length to reduce the diffusion time. We also simulated SiNW in hexagonal arrays coated with 20 nm ITO and shown responsivity of 38.2 mA/W by using 150 diameters SiNW with 300 nm length without the usage of backside reflector. By changing the array lattice size we found the optimum lattice size at 800 nm. This novel design is a good candidate for optical communication photodetector with fast response time in which the radial Schottky junction provide fast photo-generated carrier separations and the unique properties of SiNW which allows more light absorption due to waveguiding effect.

REFERENCES

[1]. C. Thelander, P. Agarwal, S. Brongersma, J. Eymery, L. F. Feiner, A. Forchel, M. Scheffler, W. Riess, B. J. Ohlsson, U. Gosele and L. Samuelson, *Mater. Today* 9, **28** (2006).
[2]. A. Taflove, and S.C. Hagnes, Computational Electrodynamics: The Finite-Difference Time-Domain method (Artech, Norwood, MA, 2000).
[3]. J. B. Pendry, *J. Mod. Opt* **41**(2), 209-229 (1994).