Hybrid Core Semiconductor Nanowires for Solar Cell Applications

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Abstract –

In this study, novel design of semiconductor nano-wires in decagonal lattice with hybrid core is proposed and simulated using 3D finite difference time domain method. The hybrid core has godl/silicon combination to increase the light absorption and hence the ultimate efficiency. The reported NWs solar cell achieves broadband absorption in long wavelength region with excellent absorption (>95%) in short wavelength regime. The proposed structure with hybrid core shows an ultimate efficiency of 32.62 % which is higher than that of silicon core design by 19.7%.

I. Introduction

Over the last decade, a variety of nanostructures has been actively researched and fabricated for utilizing advanced photon management to increase the absorption in thin film silicon solar cell [1-3]such as grating couplers [2], photonic crystals [2], random surface textures [2], Nanowire [3,4] and plasmonic [3]. One dimensional (1D) Si nanostructures shows unique electrical and optical characteristics relative to their thin film or bulk counter parts, such as: large junction area[2,5,6], enhanced light absorption[2,5,6], low reflection, efficient charge separation and collection and reduced cost by using low grade raw materials [1-3, 5-6].

Metallic nanostructures (gold and silver) attract appreciable attention because of the substantial plasmonic effect on the near–field enhancement as well as to achieve light trapping in thin film solar cell [2,7]. These nanostructures provide optical modes with strong dependence on size and geometry. Inevitably this could support multiple optical resonances critical for the broadband absorption; leading to low cost high efficiency solar conversion devices [7]**.** However, simulation studies on the optical characteristic of designing combining metal /semiconductor nanowire (SiNW) for solar cell applications are lacking in literature.

The previous work in SiNWs has been restricted to increase the ultimate efficiency through changing the radius [8] lattice constant [8] and the NWs height [9]. However, this can decrease the light absorption in higher energy region and shift the peak toward lower energy region. The ultimate efficiency of 30.5 % is obtained by vertical SiNW at radius 240 nm with periodicity p= 300nm and height 2.33 μm [8].

In this work, a novel design of decagonal metal/ semiconductor nanowire solar cell is introduced and analyzed in the aim of increasing the ultimate efficiency. The finite difference time domain method (FDTD) is used to investigate the semiconductor absorption of the proposed structure. The light absorption is dramatically improved due to the hybrid core which supports the Fabry-Berot modes, plasmonic modes, and hybrid modes. It is found that the proposed NWs solar cell achieves broadband absorption in long wavelength regime with excellent absorption (>95%) in short wavelength regime. The reported structure with hybrid core has an ultimate efficiency of 32.62 % which is higher than that of silicon core design by 19.7%.

II. Design Considerations

Figure 1 shows a schematic diagram of the suggested decagonal semiconductor NWs with central hybrid core. In addition, three different configurations of the hybrid core are shown in Fig. 1 (c). The gold/silicon core of diameter 120 nm is used to increase the ultimate efficiency of the proposed solar cell. The cladding NWs are arranged in a decagonal shape with diameter 50 nm and height h=2.33μm. The distance between two neighboring NWs in the same ring is equal to d_1=90 nm, while the distance between two neighboring NWs in two neighboring rings is d_2 = 45 nm. It should be noted that the height of the metal layer of the core is lower than that of the Si layer by 250 nm.

III. Simulation Methodology

The 3D FDTD is applied by using lumerical FDTD solution packages to study and analyze the semiconductor absorption of the proposed structure. The proposed structure is excited from the top by a plane wave in the range from 300 nm to 1100 nm, which covers the main part of the solar spectrum AM 1.5 [10]. The refractive index of Silicon and Gold are taken from the literature [11]. The ultimate efficiency ( ) is used to quantify the light absorption ability of the SiNW which can be calculated from

$$\eta_{Abs}^{S_i} = \frac{\int \lambda I(\lambda) A(\lambda) d\lambda}{\int I(\lambda) d\lambda} \qquad (1)$$

where $I(\lambda)$ is the photon flux density in the AM1.5G solar cell spectrum [10]. The integrated waveband region in (1) is set

from 300nm to 1100 nm. In addition, $A(\lambda)$ is the optical absorption of the active material Si.

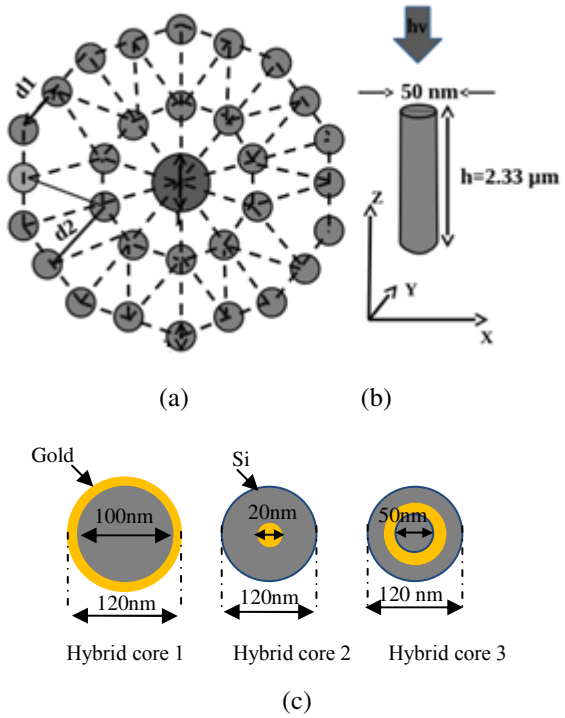

Figure1. Schematic of decagonal SiNW with central metal NW (a) Top View

V- Results and Discussion

Figure 2 shows the semiconductor absorption spectra for the proposed structure with solid Si core, hybrid core 1, hybrid core 2, and hybrid core 3, respectively. The ultimate efficiencies of the reported structure with solid Si core, hybrid core 1, hybrid core 2, and hybrid core 3 are equal to 19.7%, 23.97%, 19.26%, and 32.62%, respectively. It is evident from this figure that a significant broad band absorption enhancement occurs by using hybrid core 1 and hybrid core 3 compared to that with solid Si core. The higher absorption is enhanced in the long wavelength regime with excellent absorption (>95%) in short wavelength regime. The improvement of the ultimate efficiency is due to the combined effect of the Fabry-Berot modes, plasmonic modes, and hybrid modes that increase the semiconductor absorption. The obtained results pave the road to low cost and high efficient SiNW solar cell.

V- Conclusion

In summary, the FDTD method is used to study the semiconductor absorption of proposed design with hybrid core. The proposed structure improves the light absorption and reduces the reflection due to Fabry-Berot modes, plasmonic modes, and hybrid modes. The reported structure with hybrid core offers an ultimate efficiency of 32.62 % which is higher than that of silicon core design by 19.7%.

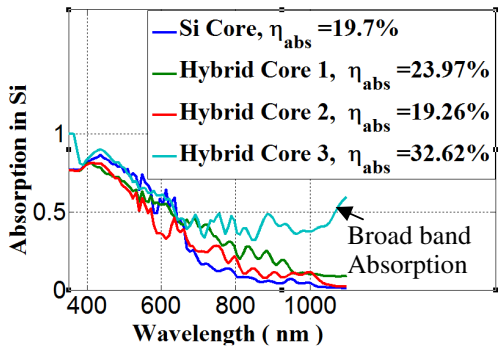

Figure2. Semiconductor absorption of the proposed designs.

VI-References

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