Optical Absorption Enhancement in Plasmonic Nanowire Solar Cell by Increasing the Plasmonic Metal Nanoparticle (Au) layer inside the C-Si Nanowire.

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Abstract — **Integration of plasmonic metal nanoparticles in the form of gold or silver as the core of conventional nanowire solar cells has proved to enhance their overall absorption and efficiency. In this paper, we proposed a simple model where using gold as the core of crystalline silicon plasmonic nanowire and for a fixed filling ratio, length and lattice constant we are able to show the relationship the inner radius of gold core has with the outer radius of crystalline silicon nanowire (NW) for improved efficiency. Results show that the lower the ratio between the inner and outer radius, the higher the light absorption and efficiency. When the ratio between the inner radius to the outer radius is 1/3rd, it is 59.08% more efficient than when the ratio is 1/12th.**

Index Terms — **conventional nanowire, crystalline silicon, fixed filling ratio, lattice constant, nanowire, plasmonic metal nanoparticles.**

I. Introduction

Cost-effective PV technologies play an important role for the deployment of large-scale photovoltaic cells. The promising way to reduce the overal costs of PV is to make it as thin as possible. However, the overall efficiency in a conventional PV is not satisfactory which is attributed to the poor absorption in the visible spectrum. In contrast, thick film PV devices have better absorption capability. Even though thick film devices show wider spectral absorbance, the overall photocurrent is reduced as the minority carrier diffusion length is several times the material thickness. Thus to collect all the photo carriers, the film thickness is required to be within smaller ranges. The application of surface Plasmon in photovoltaic devices attracted a lot of attention in recent years due to its potential light harnessing capability without increasing the overall optical thickness [1]. On the other hand, vertically aligned silicon nanostructure arrays also offers low cost alternatives to bulk silicon wafers and thin film photovoltaics for next generation photovoltaic applications due to its promising light absorption capabilities. An assemble of nanowires show improved optical characteristics, such as low reflection, strong broadband absorption, wavelength selective absorption [2,3], light trapping, resonant mode between neighboring NWs via controlling the period, filling ratio and spatial arrangement [4]. On the other hand, to achieve higher light absorption metallic nanoparticles often used to support the conduction electron as at the interfacebetween metal and dielectric produces surface Plasmon [5].

In this paper, we propose a simple plasmonic nanowire structure by using gold as the core of conventional NW structure. We verified our results through 3D electromagnetic field simulation with finite element method over the periodic structures and we were able to show the relationship the inner radius of gold core has with the outer radius of crystalline silicon NW and found that the lower the ratio between the inner and outer radius, the higher the light absorption and efficiency.

II. Proposed Model

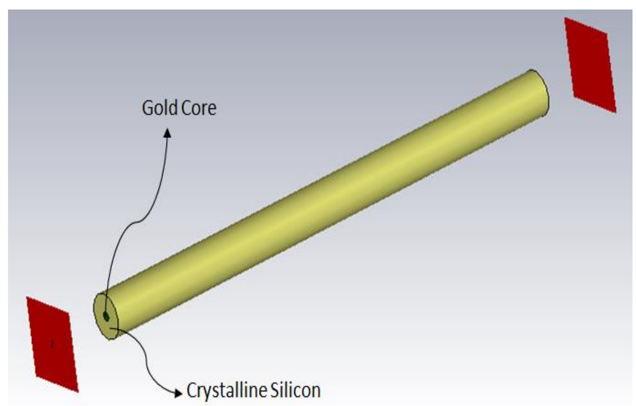

Fig 1: Side view of our model

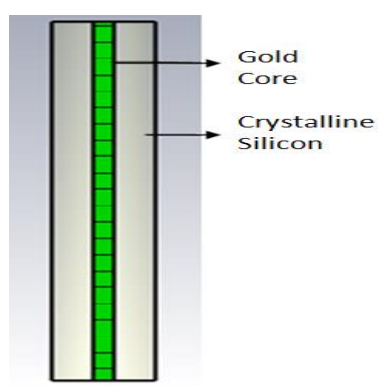

Fig 2: Internal view of our model

Fig 1 and 2 shows the side and internal view of our proposed model (PNW with gold) which yielded different results of ultimate efficiency with changes in ratio of inner radius (Au) to outer radius (C-Si) and it is shown in the next section.

III. Results

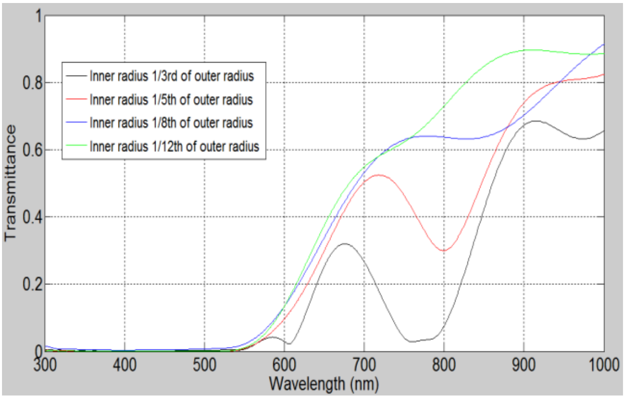

Fig 3: Transmittance for different outer and inner radius relationship of Crystalline Silicon PNW

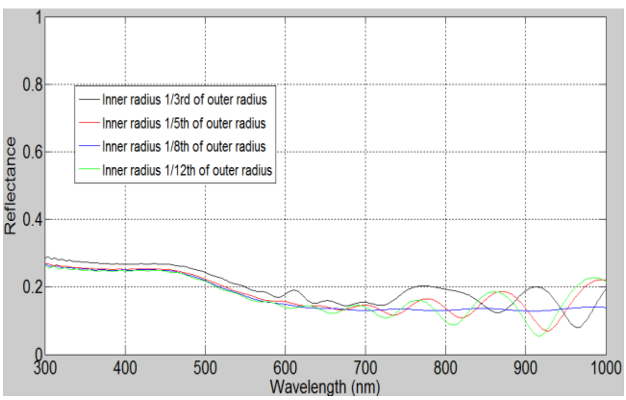

Fig 4: Reflectance for different outer and inner radius relationship of Crystalline Silicon PNW

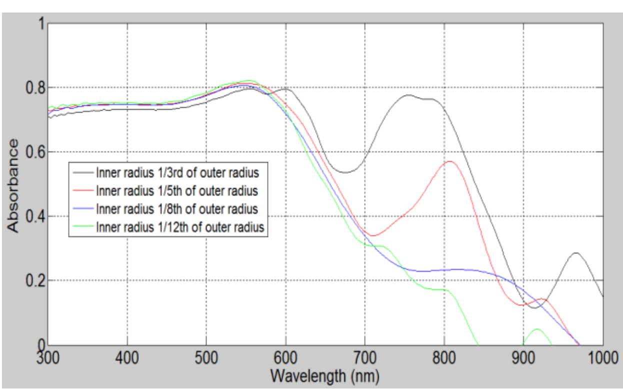

Fig 5: Absorbance for different outer and inner radius relationship of Crystalline Silicon PNW

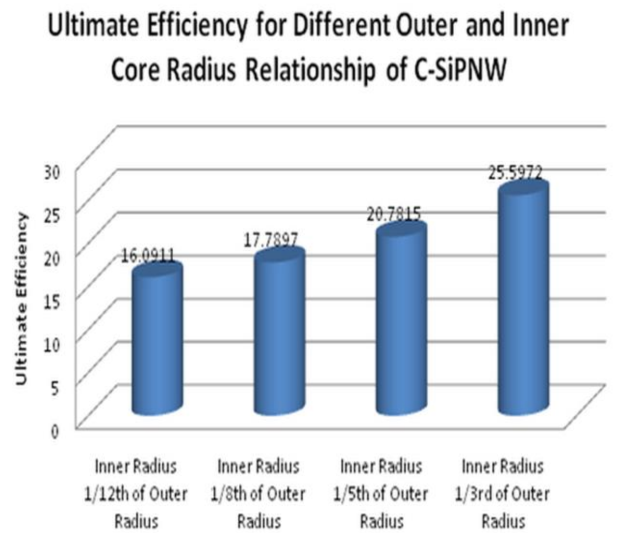

Fig 6: Ultimate efficiency for different outer and inner radius relationship of Crystalline Silicon PNW

IV. Discussion

From Fig (3-6), we can see the Transmittance, Reflectance and Absorbance of Si-PNW with different ratios of inner radius to outer radius with fixed filling ratio of 0.28, length 2.33 micrometer and lattice constant 100nm similar to [6] in order to observe overall improvement. We were able to determine the relationship between the inner core radius and outer radius of PNW for improving efficiency. The efficiency increases as the inner radius (gold core) layer increases in size. That is, as the ratio between the inner radius and outer radius decreases and comes closer to 1, the ultimate efficiency and absorption increases as shown in the above figures. From the ultimate efficiency chart in Fig 4, we can see that $1/3^{rd}$ ratio of inner radius to outer radius is 59.08% more efficient than when the ratio between the radiuses is $1/12^{th}$.

V. Summary of Work

From Fig (3-6), we can see that by introducing plasmonic nanowire in the form of gold core, we have widened the absorption bandwidth which leads to overall ultimate efficiency improvement. After measuring ultimate efficiency we have found our model has improved efficiencies particularly for $1/12^{th}$, $1/8^{th}$, $1/5^{th}$ and $1/3^{rd}$ ratio of inner radius to outer radius as shown in Fig 4. The improvement is 16.09%, 17.79%, 20.78% and 25.6% respectively.

References

[1] Li. Xiaofeng, et. al, "Bridging electromagnetic and carrier transport calculations for three-dimensional modellin g of

plasmonic solar cells," Opt. Express 19, A888-A896 (2011)
[2] J.-Y. Jung, et.al, "A strong antireflective solar cell prepared by tapering silicon NWs," Opt. Exp.18, A286-A292 (2010)
[3] L. Cao et. al., "Engineering light absorption in semiconductor NW devices", Nat. Mater. 8, 643-647 (2009).
[4] L. Hu and G.Chen "Analysis of optical absorption in silicon NW arrays for photovoltaic applications", Nano Lett. 7, 3249-3252 (2007)
[5] H. A. Atwater, and A. Polman, "Plasmonics for improved photovoltaic devices," Nat. Mater. 9, 205-213 (2010)
[6] C.Lin et. al., "Optical absorption enhancement in silicon nanowire arrays with a large lattice constant for photovoltaic applications", Opt. Exp. **17**, 19371-19381 (2009).