IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 11, Issue 3, March 2022

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.282

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 11, Issue 3, March 2022 ||

DOI:10.15662/IJAREEIE.2022.1103012

Spectral Response of Thin Film GaAs Solar Cells through Al Nanoparticle Plasmon Excitation

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ABSTRACT:-The key role of solar cell technology is to supply sustainable energy and is one of the important approaches for solving future energy problems. Presently, due to increasing environmental crisis, it has been given more attention to make use of clean and eco-friendly energy available freely from Sun. But, major limitation of solar cell technology is its cost, which needs to be reduced in order to make the vast use of the technology. One of the best ways to reduce the cost is thin film solar cell technology. This method offers the possibility to reduce the cost and weight of the cell as compared to conventional ones but usually at the expense of optical absorption, which reduce the efficiency of solar cell.It is found that in comparison to other metallic nanoparticles, Al nanoparticles have strong plasmonic scattering effect. Further, at optimal period and radius of Al nanoparticles, the current density comes out to be 26.24mA/cm2, which is 31% more as compared to bare. This enhancement in current density is mainly attributed to antireflection effects induced by Al nanoparticles placed on the top of thin film GaAs solar cells.

KEYWORDS:-Solar cells, Nanoparticles, Metal, GaAs Solar Cells

I. INTRODUCTION

In order to improve the efficiency of thin film GaAs solar cells, the major loss of light due to reflection from the surface must be reduced. To reduce this reflection dielectric coating of single layer, multilayer and nano structures like moth eye on the surface of photoactive materials were widely studied [1, 2]. Although, multilayer coating has better antireflection in broader band of solar spectrum but from practical aspect designing the cell with a specified refractive index matching is always a problem. It is reported that Ta_2O_5 is the best material for the antireflection activity on GaAs surface instead of Al_2O_3, Si_3N_4, and ZnS. Next, although metal nanoparticles can potentially enhance light absorption in bare surface solar cells, applying a metal nanostructures coating on antireflection coated cell may not necessarily enhance the photon injection and may sometimes degrade the overall photon injection [3, 4]. It is also found that a smaller sized (about 50–70 nm radius) dielectric nanoparticles array with optimized surface coverage placed on the top of bare or standard anti reflection coated solar cells as a combined optical system substantially improves the photon transmission but does not produce the large angular scattering which is necessary for light trapping [5, 6]. On the other hand, larger sized dielectric nanoparticles on the front surface do produce large scattering due to the excitation of higher order modes, but coupling to the underlying substrate is low [7]. To address such issues, it is very important to understand efficiency of single layer antireflection coated solar cells with metal nanoparticle scatters at different locations.

II. LITERATURE REVIEW

Rokeya Jahan Mukti et al. [1], Front surface light trapping rate is significantly enhanced here by incorporating the Aluminium (Al) nanoparticle arrays into silicon nitride anti-reflection layer. The outcome indicates that the structural parameters associated with the aluminium nanoparticle arrays like particle radii and separations between adjacent particles, play vital roles in designing the solar cell to achieve better light trapping efficiency. A detailed comparative analysis has justified the effectiveness of this approach while contrasting the results found with commonly used silver nanoparticle arrays at the front surface of the cell.

ZhiqiangDuan et al. [2], Silver nanoparticle (NP) arrays are used as antireflection coating to enhance light trapping capability of thinfilm silicon solar cells. In this paper, we theoretically investigate the differences of light absorption

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distribution between the silver NP (spherical and hemispherical) array layer and the crystalline silicon (CS) substrate. the optimum ratio of lateral (NP diameter divided by the array periodicity) and longitudinal (NP height divided by diameter) are 0.86 and 0.22, respectively.

Bo Shi et al. [3], Light trapping structures are a promising method of improving the efficiency of solar cells. We focused on the plasmonic thin-film solar cell. A structure is proposed consisting of an indium tin oxide layer with embedded metal nanoparticles, a hydrogenated amorphous silicon (a-Si:H) layer, and an aluminum (Al) layer. By arranging the material, size, and locations of metal nanoparticles to maximize the scattering and minimize absorption of nanoparticles themselves, the optical absorption in the solar cell is significantly enhanced.

Narottam Das et al. [4], the design and analysis of nano-structured gratings to improve the conversion efficiency in GaAs solar cells by reducing the light reflection losses. The subwavelength grating (SWG) structures perform as an excellent alternative antireflective (AR) coating due to their capacity to reduce the reflection losses in GaAs solar cells. It allows the gradual change in the refractive index that confirms an excellent AR and the light trapping properties, when compared with the planar thin film structures.

III. METHODOLOGY

In simulations, proposed structure consists of Al nanoparticle array of 3×3, antireflection layer of Ta2O5, GaAs substrate of thickness 500nm and Al back reflector of thickness 70nm as shown in Figure 1. The x-axis and y-axis boundary conditions are periodic and z-axis boundaries are defined by perfectly matched layers (PML). Metal nanoparticle array is placed in x-y plane and a plane wave of light with wavelength range of 300-870nm is normally incident along z-axis. The mesh size is always kept smaller than 1/10 of the shortest wavelength used (Courant stability criterion) to avoid artifacts induced by FDTD simulations. The distance (d) between adjacent nanoparticles of array was fixed at 40nm. The radius of nanoparticles was varied from 15nm to 35nm in the step of 5nm. The dielectric constants (real and imaginary parts) as a function of energy used in the present simulation are taken from literature [8, 9].

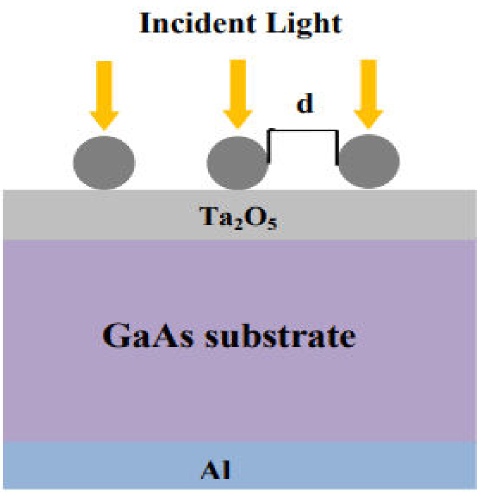

Figure 1: Schematic diagram of thin film GaAs solar cells with Al nanoparticle array on the top of antireflection layer of Ta_2O_5.

First, we optimized the radius of Al nanoparticle array advocated on the top of Ta_2O_5 coated GaAs layer. Afterwards, optimal Al nanoparticle array is placed at three different locations i.e. on the top surface, rear surface and embedded within the layer. Further, optimal depth of Al nanoparticle array in GaAs layer is obtained. Results demonstrated that location of Al nanoparticle array has strong influence on optical absorption and current density of thin film GaAs solar cells.

IV. RESULTS

It is well known that the light transmitted to the photoactive layer of GaAs solar cell can be quickly absorbed by direct band gap GaAs semiconductor but the major loss of light is the reflection from the bare surface. In order to reduce this

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surface reflection, GaAs solar cell is coated with an antireflection layer. The schematic of thin film GaAs solar cells with antireflection layer of Ta2O5 is shown in Figure 2. The scattering cross section of Al nanoparticle array has been calculated for its radius range from 15nm to 35nm and plotted in Figure 3. It is noticed that the surface plasmon resonance (SPR) spectra get broaden and its peak position shifts toward higher wavelength regime with increase in Al nanoparticles radii. Another noticeable point is that the scattering cross section also increases as the size of the nanoparticles increases. To consider the full advantage of these Al nanoparticle array, we have advocated this array of different radii on antireflection layer, which fulfills the requirement of quarter wavelength limit corresponding to the calculated SPR wavelength. This optimized antireflection layer thickness corresponding to quarter wavelength limit for each radius are calculated and presented in Table 1. The effect of quarter wavelength antireflection layer on absorption is examined in comparison to the bare GaAs solar cell andis shown in Figure 4. It is evident from Figure that the optical absorption is significantly enhanced over the whole electromagnetic spectrum by incorporating antireflection layer that might be helpful for effective performance of thin film solar cells. Therefore, antireflection layer is used in the following design of thin film GaAs solar cells with Al nanoparticle array.

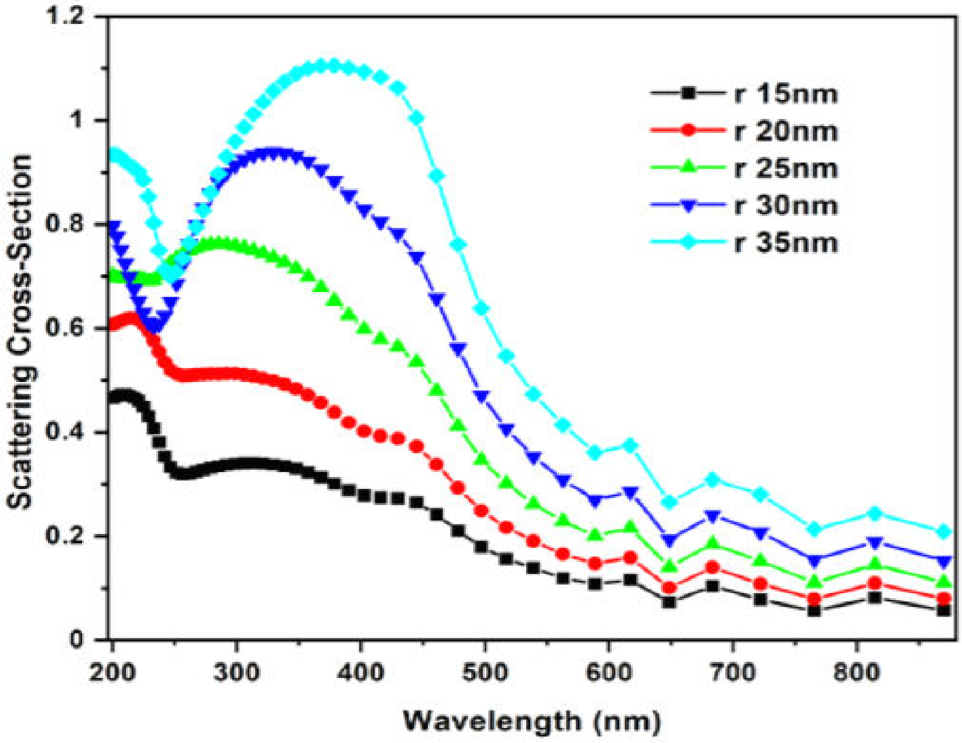

Figure 2: Scattering cross section of Al nanoparticle array of various radii.

The effect of quarter wavelength antireflection layer on absorption is examined in comparison to the bare GaAs solar cell and is shown in Figure 3. It is evident from

Table 1: Scattering Cross-Section

	200	300	400	500	600	700	800
r 15nm	0.48	0.33	0.24	0.19	0.16	0.13	0.11
r 20nm	0.6	0.52	0.48	0.38	0.32	0.22	0.17
r 25nm	0.7	0.74	0.76	0.49	0.39	0.29	0.19
r 30nm	0.8	0.85	0.91	0.58	0.44	0.32	0.22
r 35nm	0.92	0.98	1.1	0.63	0.47	0.36	0.24

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Table 2: Thickness of quarter wavelength antireflection layer of Ta_2O_5 corresponding to predetermined surface plasmon resonance wavelength of spherical aluminum nanoparticle array with different nanoparticle radii

r (nm)	15	20	25	30	35
Ta_2O_5 (nm)	25	27	35	40	44

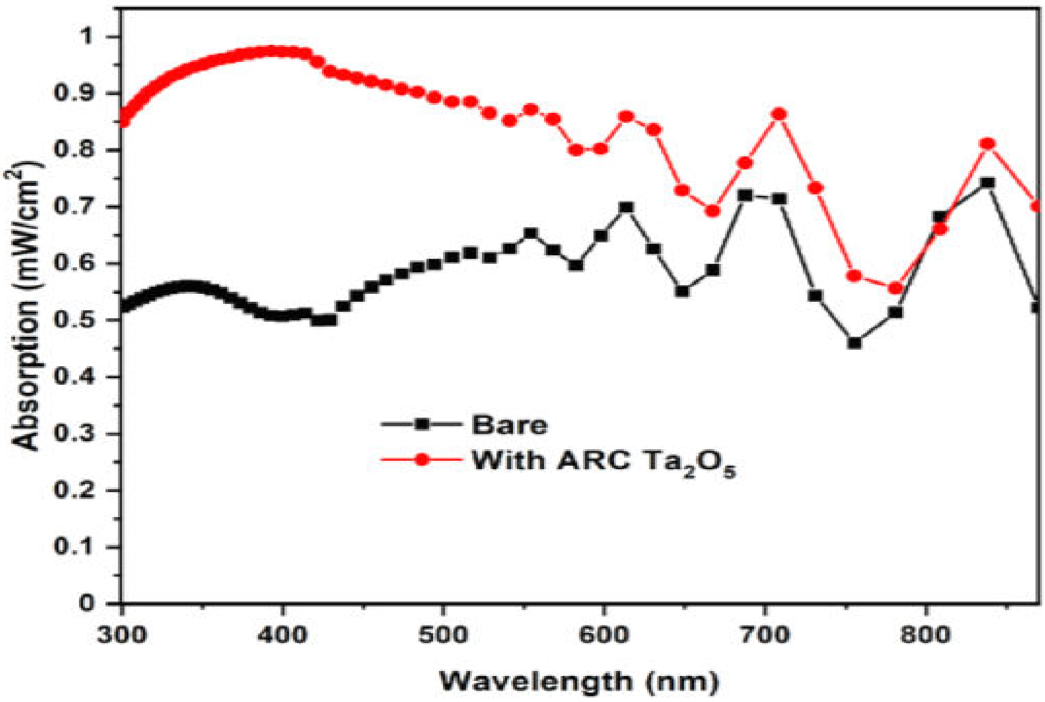

Figure 3: Wavelength dependent spectral absorption profiles with and without quarter wavelength antireflection layer of Ta_2O_5 (thickness 40nm)

Figure 3, that the optical absorption is significantly enhanced over the whole electromagnetic spectrum by incorporating antireflection layer that might be helpful for effective performance of thin film solar cells. Therefore, antireflection layer is used in the following design of thin film GaAs solar cells with Al nanoparticle array.

Table 3: Absorption (mW/cm^2)

	300	400	500	600	700	800	900
Bare	0.51	0.48	0.61	0.70	0.72	0.74	0.52
With ARC TA_2O_5	0.82	0.94	0.91	0.83	0.79	0.73	0.69

V. CONCLUSION

The optical absorption and current density in thin film GaAs solar cells is found to be significantly enhanced due to surface plasmons and surface plasmonpolaritons induced by Al nanoparticles. It is found that nanoparticles of radii 30nm have strong effect on optical absorption and current density in contrast to other radii considered in study. Further, Al nanoparticle array of radius 30nm embedded in GaAs at a depth of 10nm below the antireflection layer has significant impact on optical absorption profiles as compared to nanoparticles placed at different embedding depths as well as their top and bottom locations. In above optimized design, enhancement in current density of about 11.17% is

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obtained. Hence, efficiency of thin film GaAs solar cells may be significantly improved by optimizing the radius, depth and location of Al nanoparticle array.

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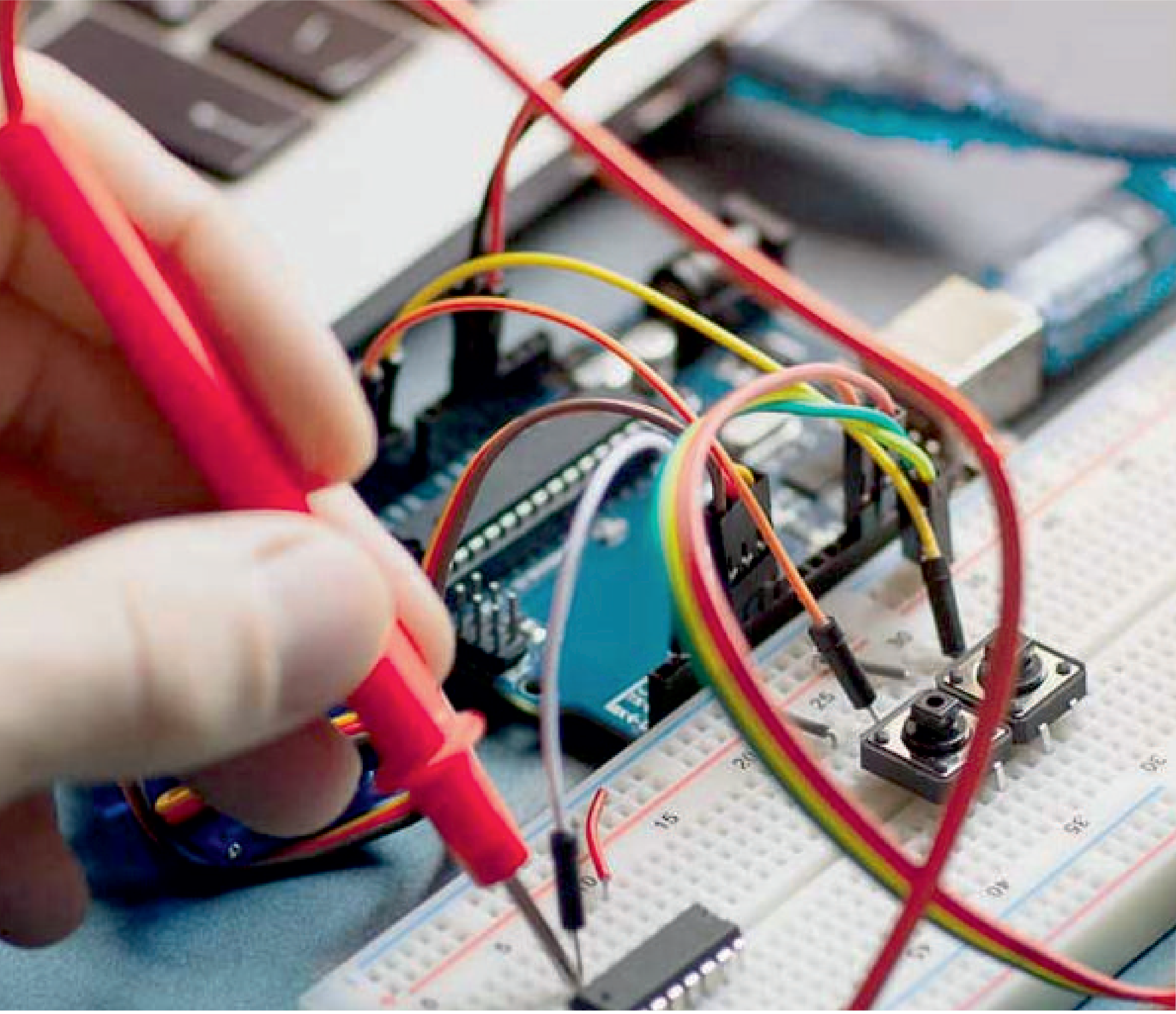

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