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# Enhanced Efficiency of Thin Film GaAs Solar Cells with Plasmonic Metal Nanoparticles

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**ABSTRACT:** Global climate change, limited fossil fuels resources and their high prices have driven towards the use of clean, renewable and environment friendly solar energy. Solar cells (SC) can convert incoming sunlight directly into usable electrical energy. Although exhibiting high conversion efficiency, commercialization and utilization of conventional solar cells is still hampered by their high cost. Though, thin film solar cells promise a viable solution to the challenges faced by conventional solar cells but thin film solar cells do have limitation of poor absorption of sunlight as compared to wafer based solar cells. Hence, efficient light absorption mechanisms have to be applied for better performance of thin film solar cells. To date, various light absorption mechanisms have been examined but promising mechanism is developed by using the metal nanoparticle plasmons. Metal nanoparticles used at front side as light scattering agents in SC can be used to reduce the reflection and increase the short circuit current density. Therefore, we have simulated the structure of thin film GaAs solar cells with metal nanoparticles assembled on its front surface and aluminum layer on the backside (acting as back reflector).

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

## I. INTRODUCTION

The world is facing major challenges of burgeoning global population, water scarcity, ever increasing energy demand and climate change [1]. These issues can even become more forceful with further increase in global population. One of the greatest challenges facing the world today is to generate power that can meet the daily energy needs of increasing population. The power generation plants based on the sources of fossil fuels such as coal, petroleum and natural gas have been established to meet the energy demands. But, the intense use of these fossil fuels from mid to late 20th century onwards has resulted in the increased level of carbon dioxide emission, which is mainly responsible for presently observed global climate change with its worst yet to come [2]. The adverse effects of the climate change on human and animal life have been established in environmental studies [Natural Environment Research Council, 2014; McGuire, 2003]. An alternative to fossil fuel sources is to use renewable energy sources, which include solar energy, wind, biomass, biofuel and hydropower. The solar energy can be used to generate electric power because it has potential to meet the rising energy demands, since, the amount of solar radiations shining on the earth is  $\sim 1.76 \times 10^5$  terawatts (TW) and the usage of energy across the globe is estimated to be 15-20 TW [3].

The conventional power generation plants however still remain the main source of energy generation because the cost of renewable energy continues to be high. But, due to the limited stock of fossil fuels, it is predicted that in near future these stocks will be depleted. Therefore, researchers from all across the world are now focusing on renewable energy sources for producing electric power. In recent years, researchers also succeeded in reducing some cost of renewable sources. Further, to promote these sources, government is also providing subsidy which also decreases their cost of implementation. The Ministry of New and Renewable energy (MNRE), India is now focusing on generating 40% of its total energy from renewable energy sources by 2030 [4]. To accomplish this target i.e., for large scale utilization of renewable energy sources, the cost of electric power generated from these sources should be in competition with the cost of power generated from fossil fuels. The use of eco-friendly energy sources will solve the crisis that the society is facing today and will provide a safe and healthy life for humans in future. In photovoltaics, GaAs solar cells have become more popular in recent years due to high absorption coefficient and electron mobility in comparison to other semiconductor materials [5]. Although, GaAs is efficient material for single junction solar cells but still needs more development and optimization for higher conversion efficiency.



Further, GaAs solar cells are too expensive for terrestrial large-area applications because of the high device manufacturing cost and the availability of GaAs. In order to make GaAs-based solar cells be widely used, the direct ways to solve this problem are to improve the efficiency of solar cells and reduce the manufacturing cost. By making thin film solar cells is a pathway to decrease the use of material, thus, the cost and weight of solar cell. But, thin film solar cells have major problem of light absorption due to small thickness of substrate. Hence, to increase the absorption in thin film GaAs solar cells plasmonic nanoparticles are integrated at different locations in the solar cells. The nanoparticles enhance the absorption in GaAs layer by plasmonic scattering, near field enhancement and propagation of waveguide modes. GaAs solar cells have typically a multi-layered structure with total thickness in the range of the few microns which makes solar cells very expensive. Further, there are a number of important factors involved in the design of multi-layered solar cells e.g. band gaps, lattice constant, current matching and layer thickness calculation [Burnett, 2002]. Research at the National Renewable Energy Laboratory (NREL) showed that a lattice mismatch as small as 0.01% significantly decreases the current produced by the solar cells [6]. The restriction of each semiconductor material having the same lattice constant significantly decreases the number of materials that may be used. Therefore, it is desirable to develop single layer GaAs solar cells in which deep insight on the efficiency enhancement by plasmonic nanostructures is required.

## II. LITERATURE REVIEW

**Green et al. (2019)**, in spite of the fact that Si is the most famous material for dainty film sun oriented cells however Gallium Arsenide (GaAs) presently additionally drawing in generous fixation as a photovoltaic material in light of its extraordinary qualities like high electron portability, high photon ingestion, low surface recombination and longer dissemination lengths. Attributable to these qualities, single intersection slender film GaAs sun oriented cells have recorded a most elevated proficiency of around 29% while for Si sun powered cells, it stays at 27%. In addition, GaAs has turned into a decent decision to be utilized as meager film sun oriented cells because of its high retention coefficient as a layer of not many microns can assimilate ~95% of approaching photons. It is notable that the light communicated to the photoactive layer of GaAs sun powered cells can be immediately consumed by direct band hole GaAs semiconductor however the significant loss of light is the reflection from the uncovered surface. To lessen this reflection, we have joined Al, Ag, Au and Cu nanoparticles with different plans as talked about in Chapter 1. Besides, the utilization of metal nanoparticles permits one to lessen the thickness of semiconductor material without compromising with the productivity of sunlight based cells. Hence, the convergence of plasmonics and photovoltaics offers new choices for photovoltaic plans.

**Ranjan et al. (2019)**, perovskite-based sun powered cells (PSCs) have arisen as an extremely encouraging sun oriented photovoltaic innovation with fivefold increment saw in the gadget productivity inside under 10 years of its origin. The effectiveness of these sun powered cells is emphatically impacted by the nature of perovskite layer surface inclusion and its grain size. Despite the fact that utilization of antisolvents, for example, chlorobenzene has been utilized to treat methylammonium lead iodide (CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>) bringing about grain size of ca. 200–300 nm, one actually needs to limit the grain limits to diminish their effect on recombination. In this review, we have effectively consolidated [6, 6]-phenyl-C70-butyric corrosive methyl ester (PC70BM) acceptor as an added substance in the perovskite layer of the mesoscopic sun oriented cell gadgets, which not just prompts the arrangement of bigger grains with less grain limits bringing about diminished charge transporters recombination, the band arrangement somewhere in the range of CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> and TiO<sub>2</sub> was likewise found to improve. The gadget having the ideal PC70BM focus in perovskite showed upgraded power transformation proficiency (PCE) because of progress in current thickness (JSC) and fill-factor (FF), connected to the reduction in control move obstruction (RCT). The gadgets involving PC70BM added substance display more than 15% improvement in the power transformation effectiveness or PCE (15.5% for PC70BM containing gadget and 13.3% PCE for the reference gadget with no acceptor added substance). All the more critically, the gadget containing PC70BM acceptor added substance, held ca. 75% of the first PCE for 250 h when kept at 85 °C without embodiment in an encompassing at 20% RH.

**Khrypunov et al. (2019)**, by the strategy for nonreactive high-recurrence magnetron faltering on Upilex polyimide films, straightforward and conductive layers of ITO were acquired. These layers, later high-temperature toughening, at temperatures normal for the sun oriented cell development, had an obstruction of 11 ohm/and a conveyance of up to 72%. The utilization of such an ITO layer with the expansion of a 100 nm thick layer of undoped zinc oxide, as the front contact, and Cu/ITO structure, as the back contact, made it conceivable to acquire an adaptable sun based cell polyimide/ITO/CdS/CdTe/Cu/ITO with a proficiency of 10.4%. With a thickness of the base layer of cadmium telluride 2.5 μm, the normal conveyance of the SC in the 850-1100 nm frequency range is 46.8%. The created plan of an adaptable sun powered cell dependent on cadmium telluride because of the utilization of a straightforward back contact



with a brush metal terminal is effectively interacted with existing plans of adaptable sun oriented cells dependent on copper and indium diselenide, which permit the development of adaptable couple photoelectric converters CdTe/CuInSe<sub>2</sub>.

**Hao et al. (2018)**, in this commitment, the efficiencies of perovskite sun powered cells have been additionally upgraded, in light of optical advancement review. The photovoltaic gadgets with finished perovskite film can be gotten and a power change effectiveness (PCE) of the finished fluorine-doped tin oxide (FTO)/Ag nanoparticles (NPs) inserted in c-TiO<sub>2</sub>/m-TiO<sub>2</sub>/CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>/Spiro-OMeTAD/Au showed 33.7% improvement, and a limit of up to 14.01% was accomplished. The effectiveness improvement can be ascribed to the light catching impact brought about by the finished FTO and the consolidated Ag NPs, which can upgrade dispersing to expand the optical pathway in the photoactive layer of the sun oriented cell. Strangely, beside upgraded light ingestion, the charge transport attributes of the gadgets can be improved by advancing Ag NPs stacking levels, which is because of the limited surface plasmon reverberation (LSPR) from the joined Ag NPs. This light catching technique assists with giving an appropriated administration to optical enhancement of perovskite sunlight based cells.

**Shi et al. (2017)**, light catching designs are a promising technique for working on the proficiency of sun oriented cells. We zeroed in on the plasmonic slender film sun based cell. A construction is proposed comprising of an indium tin oxide layer with implanted metal nanoparticles, a hydrogenated formless silicon (a-Si:H) layer, and an aluminum (Al) layer. The limited contrast time-area (FDTD) strategy was utilized to ascertain the retention qualities of the a-Si:H slender film sun oriented cells containing nanoparticles. By organizing the material, size, and areas of metal nanoparticles to amplify the dispersing and limit retention of nanoparticles themselves, the optical assimilation in the sunlight based cell is essentially upgraded.

**Medhat et al. (2016)**, antireflection covering on silicon, a high refractive index substrate, was hypothetically examined. The impacts of antireflection covering on electrical boundaries like the short out flow, open circuit voltage, greatest flow thickness, most extreme voltage, most extreme power, power thickness, and change productivity of the sun based cell were mimicked. Different past works in which sun powered cell efficiencies were explored subsequent to applying twofold layer antireflection covering (DLARC) were checked on. Ti<sub>2</sub>O<sub>3</sub> and MgF<sub>2</sub> were then applied in a DLARC configuration, thinking about the refractive index scattering of the two materials. The outcomes were contrasted and different works in the sun powered phantom reach (400-1200 nm). Because of reproduction, the reactance on a superficial level was decreased from 30.2% to 2.37%. In addition, around 22% change proficiency and 38.6 mA/cm<sup>2</sup> short out current thickness were accomplished for a silicon cell with DLARC. These outcomes were contrasted and the boundaries of a cell without covering, one with single layer covering, and one with no reactance on the front surface.

**Atalla et al. (2015)**, the impact of differing the n-layer on the penchant of directing surface-plasmon-polariton (SPP) waves by the back-contact of a p-I-n sunlight based cell was concentrated hypothetically. The I-layer was accepted to comprise of a-Si<sub>1-x</sub>Gex:H homogeneous layer of bandgap energy 1.3 eV. To decide the SPP waves that can spread at the metal/multi-facet material point of interaction, a standard limit esteem issue involving occasionally rehashed p-I-n semiconductor layers collaborating a homogeneous metal was settled for four unique n-layers. The sanctioned issue was detailed to foresee both of the TM-and TE-surface SPP waves that can be directed by the point of interaction. It was observed that the designs that have a shapeless silicon layer cooperating the metal have comparable inclination for directing TM-and TE-enraptured SPP waves by the planar metal/multi-facet material point of interaction, despite the fact that their stage speeds, e-collapsing distances, and limitation are somewhat adjusted. Then again, the arrangement that has an aluminum zinc oxide joining forces the metal has fundamentally diminished affinity for directing TE-captivated SPP waves. To look at the sensitivity of the SPP waves anticipated from the sanctioned issue, one of the considered arrangements is joined in a viable grinding coupled setup. Diagonal occurrence was accepted, and numerous SPP waves were effectively invigorated. The all out absorptance of the p-I-n sun based cell shows improvement at the SPP wave excitation frequencies.

**Garg et al. (2015)**, report on the utilization and strength of arrangement handled molybdenum oxide (sMoOx) flimsy movies as anode-altering layers to supplant expectedly utilized poly(3,4-ethyldioxythiophene)/poly(styrenesulfonate) (PEDOT/PSS) layers in poly(3-hexylthiophene):[6,6]-phenyl C61 butyric corrosive methyl ester (P3HT/PC61BM) mass heterojunction natural sunlight based cells. Our results show that while as pre-arranged gadgets utilizing the two anode-altering layers have comparative exhibitions, the sMoOx gadgets display an amazing 20-fold soundness improvement in its presentation half-life contrasted and PEDOT/PSS gadgets, ~3400 h versus ~150 h, individually.

### III. METHODOLOGY

The proposed structure, as shown in Figure 1, consists of 1000nm thick GaAs layer and 70nm thick Al layer on backside. In simulations, 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 dielectric constants (real and imaginary parts) as a function of energy used in the present simulation are taken from literature.

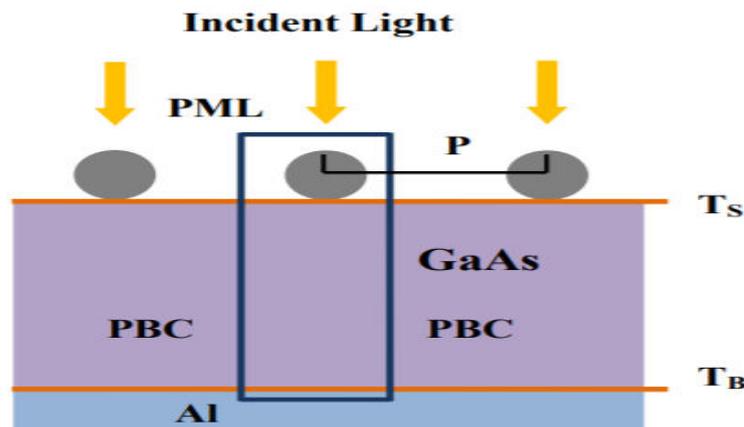


Fig. 1: Schematic diagram of FDTD simulation with Al as back reflector

#### GaAs SOLAR CELLS BY Al NANOPARTICLE ARRAY

Plasmonic nanostructures can be integrated with thin film solar cells in three ways:

- 1) they are advocated on the top of the cell
- 2) they can be entrenched within the absorption layer in order to maximize plasmonic coupling and trap the light
- 3) they can be placed at the rear surface of the cell, then they excite surface plasmon polaritons at substrate/metal interface and can enhance the absorption within cell through the coupling of light into waveguide modes.

However, the general way to enhance the optical absorption within solar cell is through the optimization of size and period of metal nanoparticle array. Although, there has been many attempts to enhance the optical absorption of thin film solar cells by using different radii, period and location of nanoparticles but finding the optimal parameters to enable surface plasmon enhancement for different structures of solar cells is still challenging. Therefore, a systematic study to optimize solar cell parameters for better optical response is greatly needed.

It is shown in previous model that Al nanoparticles decorated on the top of thin film GaAs solar cells perform better in comparison to Ag, Au and Cu nanoparticles. Therefore, we demonstrated a structure of thin film GaAs solar cell based on Al nanoparticle array placed on the top and rear surface of cell with SiO<sub>2</sub> of thickness 100nm as back reflector (Fig. 4.2). In this study, we also reduced the thickness of GaAs layer to 500nm in comparison to 1000nm (as in previous model) towards cost effective solar cells. Al nanoparticles are placed on the top of cell in order to reduce the top surface reflection while nanoparticles placed at rear surface reduce the light that is escaping from the rear of the cell. Before the execution of Al nanoparticle array on the top of the cell, we first optimized the structure of rear surface array in response to absorption enhancement factor. Afterwards, we optimized the period and radius of nanoparticle array placed on the top of solar cell having optimized rear array. We then studied the absorption, spectral absorption rate (SAR) and current density profiles for the proposed optimized structure of thin film GaAs solar cells. Using this structure, we demonstrated that the optical absorption and current density is greatly enhanced as compared to non plasmonic case.

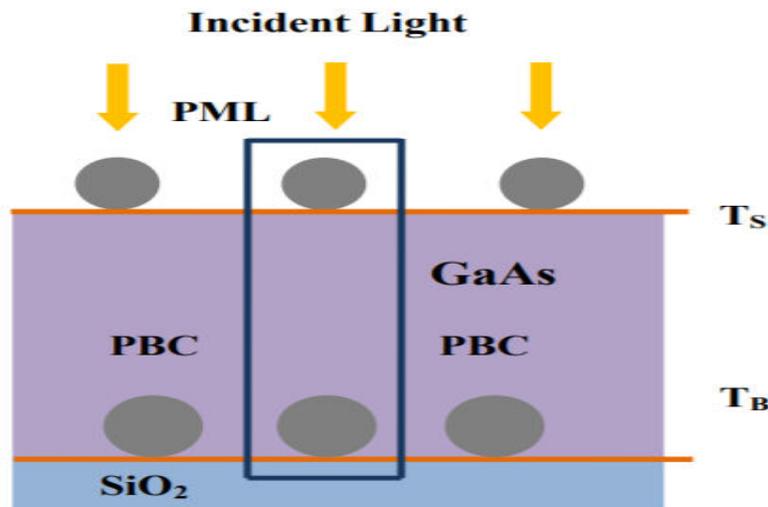


Fig. 2: Schematic diagram of thin film GaAs solar cells having Al nanoparticle array placed both on top and rear surface.

#### IV. RESULTS

##### Absorption Enhancement Factor (G)

To find optimal nanoparticle parameters towards efficient plasmonic solar cells, absorption enhancement factor (G) as a function of period (P) has been investigated for Ag, Al, Au and Cu nanoparticles, respectively and results are shown in Figure 3.

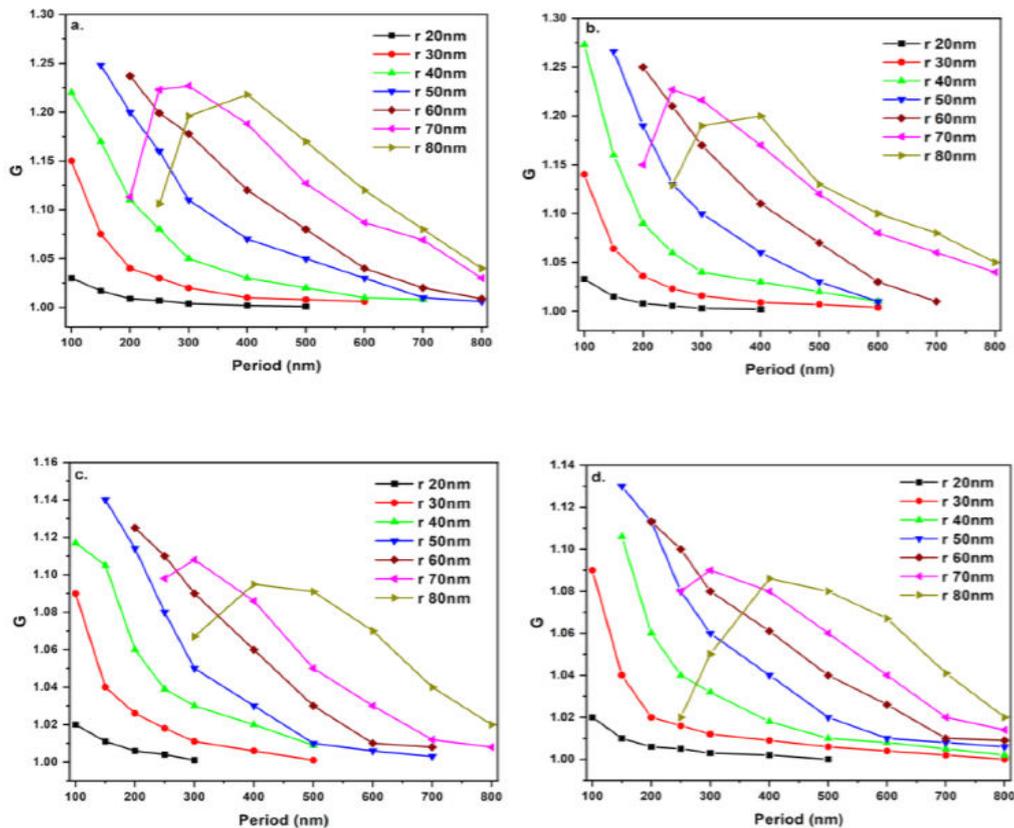


Fig. 3: Variation of absorption enhancement factor (G) with period for a) Ag b) Al c) Au, and d) Cu nanoparticles of different radii



It is observed that the material, period and radius have a significant impact on G of thin film GaAs solar cells. Further, Al nanoparticle array shows maximum G value of about 1.273 (when  $P = 100\text{nm}$  and  $r = 40\text{nm}$ ), while for Ag it is about 1.248, for Au about 1.14 and for Cu about 1.13 (when  $P = 150\text{nm}$  and  $r = 50\text{nm}$  for all metals except Al), respectively. This shows that maximum enhancement factor is observed for small nanoparticle radii with closed period for each metallic nanoparticle array. It is also observed that for small nanoparticle radii, absorption enhancement factor decreases with increasing period and tends to one (means no enhancement) for large periods which implies that incoming light is not absorbed by the solar cells but gets absorbed or reflected by metallic nanoparticle array. For radii above 60nm, the absorption enhancement factor first increases then decreases, indicating that enhancement factor for closed periods get minimized due to interparticle coupling effects for large nanoparticle radii.

**Total Power Absorbed**

The absorption characteristics of thin film GaAs plasmonic solar cells with optimum structure parameters for Ag, Al, Au and Cu nanoparticles are shown in Figure 4 (a) with bare GaAs cell as a reference. It is observed that absorption increases significantly for all materials and both the absorption value and peak position changes compared to bare. This can be attributed to the antireflection effects exhibited by metal nanoparticles in the visible region due to forward scattering of incident light. Whereas, the absorption for Ag, Au and Cu nanoparticles in short wavelength regime significantly get reduced in comparison to bare GaAs solar cell. This may be due to the strong parasitic absorption of light near surface plasmon resonance wavelength, where sufficient amount of incident light is dissipated as shown in Figure 4 (b).

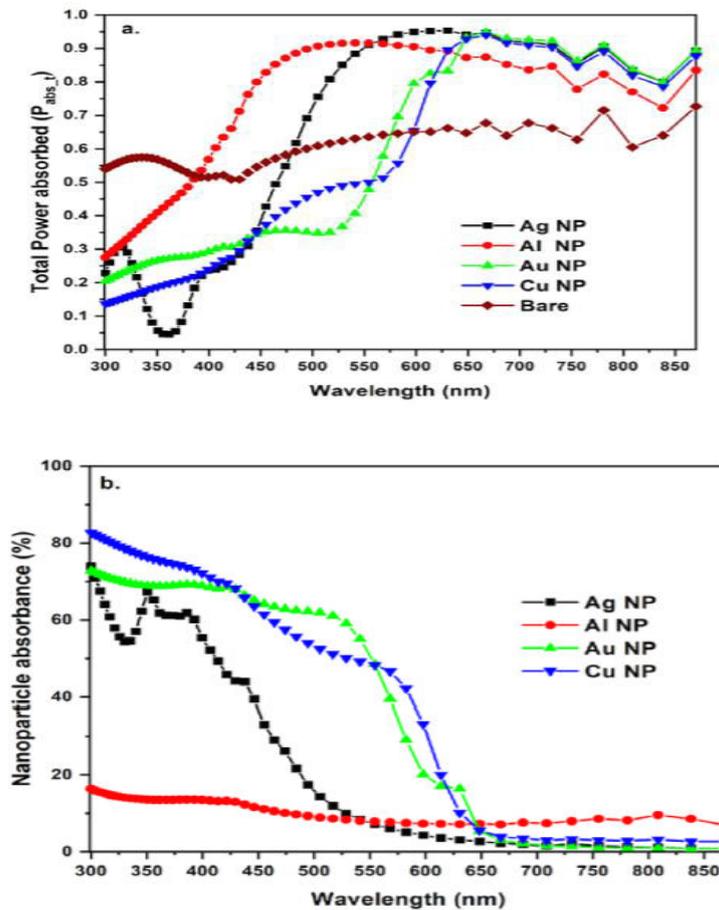


Fig. 4: a) Total power absorbed in thin film GaAs solar cells with Ag, Al, Au and Cu nanoparticles (For Al, with  $P = 100\text{nm}$  and  $r = 40\text{nm}$ , for Ag, Au and Cu, with  $P = 150\text{nm}$  and  $r = 50\text{nm}$ , respectively). b) Spectral characteristics of nanoparticle absorption of the optimized Ag, Al, Au and Cu nanoparticles placed on thin film GaAs solar cells.



In contrast, Al nanoparticles show broadband light absorption enhancement over the whole solar spectrum. This is due to the much smaller parasitic absorption of incident light in short wavelength region since the surface plasmon resonance of Al nanoparticles lies in the ultraviolet region, where the intensity of solar irradiance is negligible. From Table 1, it is evident that Al nanoparticle array deposited on top of thin film GaAs solar cells has a large impact on the spectral absorption rate (SAR) as compared to other metallic nanoparticle array. The SAR enhancement shows little influence of Au and Cu nanoparticle array while the enhanced SAR reaches maximum to 31.33% with Al nanoparticle array. Hence, it can be concluded that the deposition of Al nanoparticle array with optimum structure parameters on the top of thin film GaAs solar cells can effectively improve the absorption as compared to other materials in consideration.

Table 1: Spectral Absorption Rate (SAR) and enhanced ratio of SAR of thin film GaAs solar cells with Ag, Al, Au and Cu nanoparticle array (For Al, with  $P = 100\text{nm}$  and  $r = 40\text{nm}$ , for Ag, Au and Cu, with  $P = 150\text{nm}$  and  $r = 50\text{nm}$ , respectively).

Nanoparticle Material	Spectral Absorption Rate (SAR)	Enhanced Ratio of SAR (%)
Without NP	0.6203	---
Ag	0.7450	20.10
Al	0.8147	31.33
Au	0.6365	2.61
Cu	0.6339	2.19

## V. CONCLUSION

The present study optimized the structural parameters of different metallic nanoparticles assembled on the top of thin film GaAs solar cells with Al back reflector. The results demonstrate that Al nanoparticles were found to be superior to Ag, Au and Cu nanoparticles in terms of photons absorption due to broadband light absorption enhancement over solar spectrum. Further, Al nanoparticle array decorated on top of GaAs solar cells shows maximum absorption enhancement factor of about 1.273 at period 100nm and radius 40nm. Also, optimized Al nanoparticle array enhance current density with an increase of 31% as compared to non-plasmonic case. Hence, these findings could lead towards low cost and highly efficient thin film GaAs plasmonic solar cells.

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