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Novel Light Trapping in Thin Film Solar Cells with Nano Particles and Integrated Diffraction Grating

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***Abstract*—** To over come the lower absorption of solar radiation in thin film solar cell a novel technique of combining metallic grating and metallic nano particle is presented. The increase in absorption is associated with localized surface Plasmon's resonance that depends on many factors ranging from the size of nano particle to its shape, material of nano particle, polarization of light and the medium of enviroment in which the solar cell is placed. The solar cell is designed in COMSOL Multiphysics environment which uses the numerical finite element method (FEM). The enhancement of absorption of spectral density in the solar radiation is demonstrated, theoretically. The collective oscillaton of the metallic nano particles and metallic grating produces individual electric field thus interacting with each other to produce higher modes of excitation. This collective mode supports the dark modes of nano partiles which is very useful for harnessing the long range of radiation. To reduce reflection from the top of solar cell, anti reflection coating is provided at the top whereas the back of solar cell is made of metallic reflector aluminium. The different simulations reveals that the antireflection coating has negligent effect on the absorption of solar cell by using the integrated structure of metallic grating and nano particles. Moreover, this approach is suited for thin film solar cell which will absorb more radiations due to the multiple peaks in the spectrum of the aforementioned proposed structure.

***Keywords*—** Thin Film Solar Cells, Light Trapping, Anti Reflective Coating, Localized Surface Plasmon Resonance, Nano Particles, Grating.

I. INTRODUCTION

Photovoltaic (PV) is the process of converting light into electricity by utilizing solar cells. When light strikes a semiconductor material, photons are absorbed inside the semiconductor and create electron-hole (e-h) pairs which are directed to negative and positive terminals of the cell. Photovoltaic impact was first discovered by a French physicist, Becquerel, in 1839, while conducting various experiments using metal cathodes in an electrolyte. In 1877, Adams and Day concluded that the emanated selenium anodes produced electricity. In 1904, Albert Einstein clarified the hypothesis of the marvel behind PV impact, which was tentatively demonstrated by Robert Millikan in 1916. Decades after revelation of Jan Czochralski's technique to develop mono crystalline silicon, in 1954, Bells' research center designed designing the first crystalline silicon solar cell with 6% efficiency. In early days, solar cell efficiency was very low because of a lesser amount of absorption of light and amount of reflected light from the solar cell. To overcome these problems antireflection coating (ARC) was used, but it also contained many shortcomings. The concept of surface texturing was bobbed up as a result, which further enhanced the efficiency of solar cells.

In the last decade, many ligh-trapping strategies have been explored, among which a run of the mill case is utilizing a pyramidal surface texture [1]. But, such technique is feasible for solar cells which have thicker light absorber layer than the spectrum of visible light. The enhanced light catching is adjusted by the surface roughness. It is almost an indistinguishable request from the film width and by the enhanced surface recombination, because of the bigger surface area. Lately, much consideration has been given to light coupling in solar cells with the plan of improving absorption and henceforth photogeneration inside the cell [2,3]. Empowering light catching into the light absorbing layer solar cell having less width and has reliably drawn an expanding measure of consideration. Nanostructures made of metals, which support surface plasmons are employed nowadays [4]. Electron motions which proliferate along the border amid a metal and a semiconductor or dielectric material, is known as surface plasmons. In addition, electromagnetic field is unequivocally bound at the metal/dielectric or semiconductor edge, with their power having an exponential reliance on the separation far from the interface by surface plasmons. In this manner, through excitation of SPs, near-field electromagnetic field boosting and the upgraded scattering cross area (SCS) can be attained [14-21]. Larger electrical field will lead to more absorption and a bigger SCS will divert the falling sunlight amount into the retaining layer. These two things will bring about a substantially more light retention in a considerably more slender semiconductor layer. Thus, both restricted or localized surface plasmons (LSPs) are [5] energized in metallic nanoparticles and surface plasmon polarizations (SPPs) [6] proliferating at the occasional metal/semiconductor boundaries have been so far generally examined with zealous interests in making high efficient thin film solar cells [7-10] Due to less consumption of the absorber material the thin film solar cell can overcome the high cost of solar cells. Thus it can be considerd as a cheaper renewable energy resource which can contribute significantly to the energy mix of the world [11,12, 13,22].

The longer wavelength radiations require more diffusion depth in order to be absorbed in the solar cell. Thin film has less absorber material and thus it has small diffusion length. So,the longer wave length radiations are transmitted therein rather than absorption which leads to absorption loss of the radiations. To overcome the smaller diffusion length of thin film solar cell, light trapping techniques and light management are highly encouraged. Conventional technique like texturing is not suitable for thin film solar cell because the thickness of the thin film solar cell is few microns. However, texturing also require the removal of few micron materials which will be horrible scenario for TFSC and will lead to the stability issues of the solar cells [23]. The anti reflection coating (ARC) can be replaced by novel nano materials which can further enhance the absorption of solar cell by local surface plasmon resonance leading to the broad band spectrum of the solar cell [24-26]. Owing to uni-sepctral property of ARC, it can not completely prevent the reflection and transmission through the absorber layer of solar cell, which is very thin in case of thin film solar cell. The operational band of TFSC can be tuned using surface Plasmon resonance (LSPR). Moreover, the LSPR depends on the following properties of the nano material.

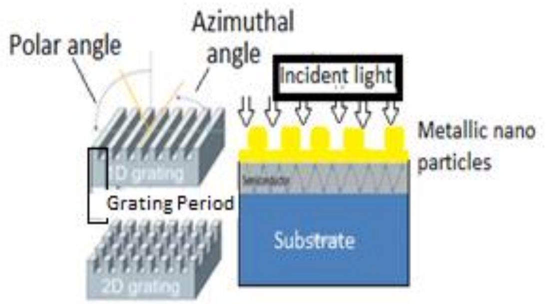

Figure 1. Left side Grating and right side metallic nano particles on top of solar cell

- Size, shape and number of the nano particles
- Distance between nano particles
- Refractive idex of environment around the solar cell
- Material of absorber layer in the solar cell
- Polarization of incident radiation

The grating period and the thickness of the grating material also influence the absorption of radiation in solar cell. The grating period and nano particles on the top of solar cell is shown in Figure 1. In this paper, we used the approach of combing metallic nano particles and metallic grating to enhance the absorption of silicon solar cell. There are many parameters which govern the tuning of the surface plasmon resonance to the operational bandwidth of thin film solar cell. The individual dimensions of the metallic nano structure have been considered herewith. Also, the individual grating period of the metallic grating and the grating structure dimension are stated. After that, the optimized structure, metallic nanostructure and grating are selected. Lastly, the grating and nanoparticles are coupled."

II. Literature Review

Solar power is free and clean wellspring of endless power that can be collected to help the energy shortage on planet earth. Solar cells have lower efficiency, which is a major obstacle in its way. An extensive research is conducted in this field to expand the proficiency of Solar PV modules to its hypothetical cut-off, given by Shockley-Quiesser. When sunlight interact with PV module, the first loss occurs at the front glass surface, that is reflection which is around 8-9% of the total light, which implies that even 8-9% of the light does not enter the PV panel. To limit reflection losses, diverse arrangements were proposed by various analysts. Reflection from glass Surface of PV panel can be limited by either surface texturing that creates roughness in the surface, which helps in the trapping of light, or by utilizing antireflective coatings [27]. Needle-like structures on melded silica substrate were made by Park et al [28] that showed a wide antireflective impact with a normal transmittance of 98.5%. Similarly, a surface was made by texturing and accomplished a normal transmittance of 94.4% by Son et al [29]. However, these procedures include various advances, are costly, and don't promptly scale to substantial substrates. Different size layers of silica particles on top were kept individually on double layer TiO2 and SiO2 antireflection coating (ARC) by Watanabe et al [30]. These layers were of 100nm, 200nm and 300nm. The small layer molecule covering that is 100nm demonstrated increase in efficiency of 7.1 % as compared to double covering alone. Composite films of zinc sulfide and magnesium fluoride were sputtered by Jung et al [31] on three layer anti reflection coating of gallium arsenide substrate and the improvement in efficiency was achieved. Lesser absorption of light is a major drawback in thin film solar. This problem is encountered especially at larger wavelengths and henceforth, effective light trapping designing is required [32]. The other approach for light absorption upgrade is to limit the reflection from the top surface that can be accomplished by progressive difference in refractive index, called reflectivity. Total internal reflection (TIR) can confine light inside the solar cell. On the off chance, that light is totally randomized into the solar cell, the mean path length of light within the cell material an be improved by a factor of 4n2, where n represents the refractive index of the medium in which light is trapped [33]. To start with thoughts to utilize the diffractive properties of gratings for light trapping in solar cells were planned by Sheng [34]. Plasmonics was intended for collective oscillation of the free electrons gas density by David Pines in 1956 [35]. In plasmonics, interaction of light and nano size metals particles are studied. During last five years or in the previous couple of years, plasmonics has been shown widely in solar cell applications; in any case, the idea of light absorption boost because of the scattering properties of little metal nanoparticles (MNPs) supporting surface plasmons was just presented with the 1998 spearheading work of Stuart [36]. Thin film solar cell perfomance can be enhanced by light trapping prompting decrease of the material utilization took after by the cost of green power generation [37,38]. Thin film plasmonic solar cells (TFSC) has three advantages due to three independent impacts: expanded semiconductor assimilation (enhanced Jsc), diminished non-raditative recombination (enhanced Voc), and diminished sheet resistance (enhanced FF) [39]. By introducing metallic resonators in solar cells higher excitation modes can be obtained which can also increase the bandwidth capacity of the MPAs. The response of every resonator is specific for a specific frequency and does not depend on the response of other resonators [40,41]. To keep away from expanded manufacture costs, straightforward templating strategies and less expensive metals like copper and Aluminium ought to be considered for substantial scale selection of these ideas. Localized surface plasmon resonance is caused by the metallic grating structure because it is energized when strike by photons. The optical path length of photons in the absorbing layer is delayed which leads to greater absorption [42-45]. Another type of solar cell based on Gallium arsenide by fusing a nanoparticles of silver in a periodical way was designed by Hong et al [46] wherein they observed improved light absorption because of the surface plasmon actuated by metal nanoparticles. As compared to planar solar cells, gallium arsenide based solar cells can bring about 31 % change in short-circuit current. By plasmonic back grating, more than 80% of the incident radiation above bandgap of GaAs using layer of just 200 nm can be achieved. The change in the open circuit voltage is obtained by decreasing the bulk recombination current when the solar cell becomes very thin. Providing the condition that open circuit voltage ramps more quickly than the short circuit current falls so thinner layers will deliver more productive cells. The fill factor is enhanced by the consolidation of metallic scatters which diminish the sheet resistance of a top surface-passivating layer [47].

A. Photonics

Photonics is the branch of physics which deals with the interaction of light and matter, while, plasomonic is the interaction of electromagnetic wave with metallic nano particles. In this research paper, effect of surface plasmon resonance on the absorption of light in solar cell is observed. Surface plasmon resonance (SPR) is observed due to the interaction of light and metallic nano particles. Noble elements like gold (Au), silver (Ag), copper (Cu), aluminium(Al) can generate surface plasmon resonance and can absorb more light in solar cell by scattering and absorbing more light [48]. Surface plasmon resonance depends on the geometry of nano particles, the medium surrounding the solar cell and the nano particle and the polarization of the incoming radiation. The plasmon resonance also depends on the number of electrons present in the nano particle. So, the electronic densities of different elements are different. Therefore, aluminium, silver, gold and copper will have different shape of surface and amplitude of surface plasmon resonance. Gold (Au) nano particles are suitable for the visible range of spectrum, aluminium and silver nano particles are suitable for the ultra-violet region while copper support surface plasmon resonance in the visible range [49]. If LSPR is shifted towards the blue region of spectrum, then the absorption of light in solar cell is significantly ameliorated [50].

B. Higher-Order Modes Excitation for Enhanced Absorption

The energy of photons can also be trapped in the absorber layer of solar cell by exciting darker modes of the nano particles which are placed at the solar cell. This can be achieved either by symmetry breaking of the nano particle or placing the nano particles in the form of cluster. There are two modes of the interaction of light with different materials. The one is the bright mode and the other is darker mode. So each nano particle and the material of solar cell will have different modes of bright and dark modes. The interaction of bright mode of the nano particle with the dark mode of solar cell material will excite the dark mode of solar cell material. Thus, this process can excite the higher modes that will lead to field enhancement of the nano particle and hence absorption of the solar cell will be improved that will result into the better current density of the solar cell [51,52]. By placing nano particles in cluster or in array form on the solar cell will lead to more Raman scattering that will also excite the dark modes resulting into higher absorption of photons [53,54].

Symmetry breking of the nano particle and the absorber layer can also excite the dark modes. The electron distribution of nano particle is disturbed, when the symmetry of nano particles is broken. Therefore, the interaction of the resulted nano particle with light will be different. Surface plasmon resonance in the desired range of spectrum can be achieved by manipulating the symmetry of nano particle [55].

III. Simulation Model

A silicon solar cell is made silicon solar cell having thickness of absorber layer 300 nm, silicion dioxide layer 40 nm and gold reflector 40 nm respectively. After this simple block shape metallic grating and metallic nano particle of spherical shape are introduced separately in the solar cell. The effect of these structures for different dimensions of metallic grating and nano particles is investigated individually. In the last simulation, the effect of both metallic gratting and metallic nano structure on absorption enhancement is explored. The different size of grating and nano particle is selected such that one can easily calculate the best case scenario for both structures. The enhanced absorption is given by

$$\mathbf{\bar{A}\ (\lambda) = P_{ABS\text{-}Silicon}(\lambda) \ / \ P_{Source}(\lambda)} \qquad (1)$$

Where,

$P_{Source}(\lambda)$ = Incident power from the sun source of photon flux having air mass (AM) 1.5G,

$P_{ABS\text{-}Silicon}$ (λ) = Power absorbed in the silicon solar cell while λ is the wavelength of the surrounding medium of the solar cell's environment.

The above equation tells about how much the additional structure introduced in the solar cell has scattered the light and how much light is absorbed in the active region. For finding the power which is absorbed in the bulk region of the absorber layer with improved matching between thin film of silicon and air the equation (I) takes the form

$$\bar{\mathbf{A}}_{\mathbf{Silicon}}(\lambda) = \mathbf{P}_{\mathbf{Trans\text{-}silicon}}(\lambda) \,/\, \mathbf{P}_{\mathbf{Source}}(\lambda) \qquad (2)$$

Where,

$\mathbf{P}_{\mathbf{Trans\text{-}silicon}}(\lambda)$ = Power that passes from the geometry of nanostructures placed at the top of solar

and $\mathbf{P}_{\mathbf{Source}}(\lambda)$ = Incident power from the sun source of photon flux having air mass(AM) 1.5G,

IV. Results and Discussion

The model we suggested has a back reflector made of gold which help the solar cell to over come the transmission losses and improve the absorption efficiency of solar cell.

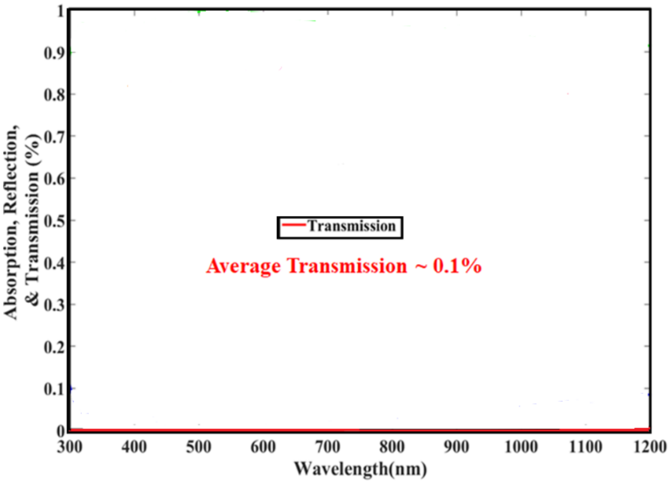

Figure 2. Approximately zero transmission due to Gold reflector

The diferent size of spherical nano particles when palced at the top of solar cell has different absorption efficiencies. The larger the size of nano particle, more will be the efficiency of absorpting solar radiation. When more than one nano particle is placed at the top of solar cell then there will be more absorption of light. The absorption is further improved when the distance between nano particles is reduced which is due to the fact that there will be the interaction of fields of the light absorbing nano particles and hence will lead to near field enhancement. The spherical shape of nano particle is taken because of its ability of not depending or very less dependence on the polarization of electro-magnetic radiation.

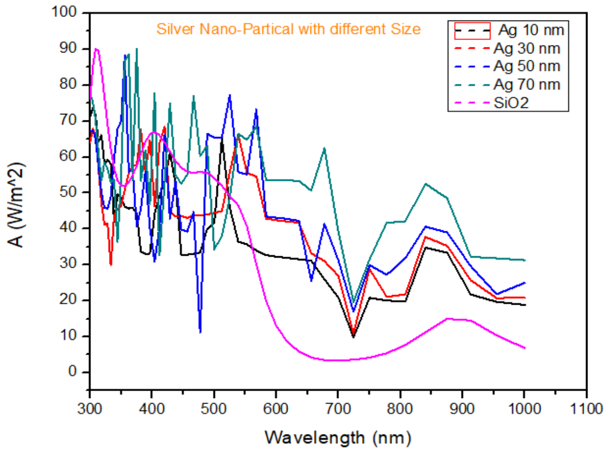

Figure 3. Silver nano particles of different raddi

Materials for nano particles having spherical shape of silver and gold has separately tested in the simulations. Both materials show higher absorption than the solar cell that has only anti reflective coating of silicon dioxide. When the size of the silver nano particle is increased then the absorbtion is also increased which can be noted from figure 3.

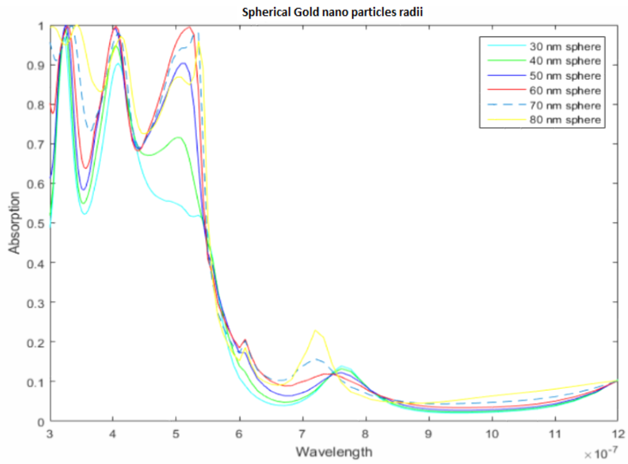

Figure 4. Gold nano particles of different raddi

The size of gold nano particle relation versus absorption is shown in Figure 2. Both Figure 3 and Figure 4 shows the dependence of absorption of electromagnetic waves on the size of nano particle.When both nano particles and grating are introduced at the top of solar cell then the absorption is surpassed than that of the individual nano particles imparted in the solar cell and the grating applied at the top of solar cell which is shown in Figure 5.

By reducing the distance between nano particles and the grating structures the absorption is further improved. Grating and nano particle made of gold lead to more absorption than that of aluminnium grating and nano particles. Also, in the Figure 5, it is shown that the more nano particles integrated with the grating will lead to further enhance absorption. The sky blue line is of grating and 2 spherical nano particles which are all made of gold shows less absorption than the dark blue grating and 6 spherical nano particles that are all made of gold. Furthermore, grating and 6 spherical nano particles made of aluminium also shows more enhanced absorbtion than that of separate nano particles.

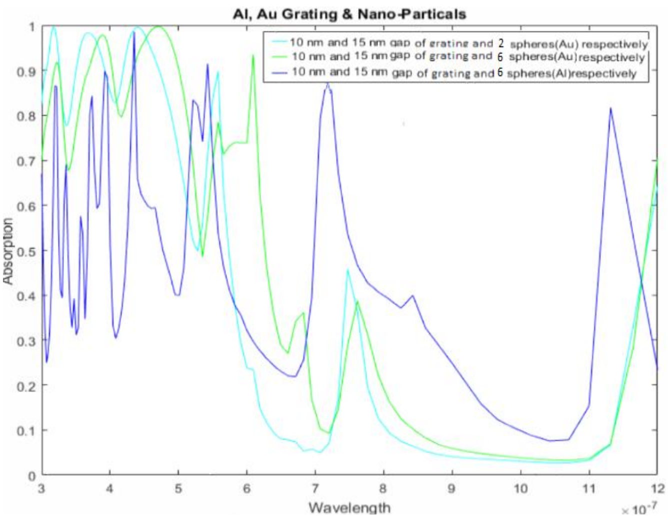

Figure 5. Integrated Grating and Spherical nano particles

CONCUSLION

The novel idea of integrating nano particles and metallic grating in solar cell provides better absorbtion of light than solar cells which have only nano particles or grating in them for light absorption. By changing the materials of nano particles, the spacing between them and size of each individual nano particle we can excite the spectrum of our interest in solar cell that will lead to better absorption of light.

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