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An Efficient Plasmonic Back Reflector for Thin-film Silicon Solar Cell Application

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***Abstract*—**A plasmonic back reflector based on gold nanoparticles were numerically investigated for thin-film solar cell application. A cluster of 21 gold nanoparticles was placed at the bottom layer of the cell with the objective to enhance the absorption of incident solar radiations. Different parameters of the proposed design are changed due to which maximum absorption is obtained. Furthermore, the influence of shape and material are also varied, which also affect and enhance the absorption characteristics of the solar cell.

***Keywords*—** Perfect absorber, back reflectors, broadband, polarization-sensitive, solar energy harvesting.

I. INTRODUCTION

To attain a high broad band absorption of electromagnetic waves from incoming light by a thin film solar cells is one of the most inspiring job, which is not easy for ordinary absorbers. Because the thickness of thin film solar cells are very small compared to traditional solar cells, so some rate of short wavelength light is trap inside the absorbing layer but most high wavelength light penetrate through it which takes no part in absorption. Generally, light trapping falls into two types i.e. one is to reduce the reflection losses from the top surface and allow more low and high wavelength light into the cells. By reducing reflection losses, anti-reflection layers are used. The second type is to increase the optical path length of the photons inside the absorbing layers. In this type, back surface of solar cells are textured in order to permits scattering and diffraction of longer wavelengths back into absorbing layer. The traditional back reflectors are not suitable for thin film solar cells due to its thickness smaller than the back textured surface which increases surface area and give rise to minority recombination losses [1].

By introducing an artificial absorber for thin film solar cells, also called plasmonic perfect absorber, composed of subwavelength size have received great attention [2-4]. These absorbers are based on plasmonic nanoparticles which are being made for different frequencies such as, infrared [5-7] and visible range [8-10]. The plasmonic nanoparticles can be used for applications, such as solar cells [11-13], slow light [14-17], sensors [18-20], and negative refractive index [21-25]. Plasmonic nanoparticles have been spectrally designed for both narrow and broadband perfect absorptions that can absorb large volume of incident light than old-fashioned absorbers, for both transverse electric and transverse magnetic polarizations [26-29].

Several researches have designed back reflectors to obtained maximum optical path length for solar cells. C. D Hungerford et al., suggested an efficient plasmonic back reflector structure for solar cells. They used a hemispherical nanoparticle at the back surface where they achieved 72% absorption with spectral range 400-600nm but still they didn’t cover the entire visible range in solar spectrum [30]. L. J. Crudgington et al., proposed a plasmonic back reflector structure for thin film solar cells, where they used an array of silver nanoparticle at the top surface of back reflector layer. They obtained about 80% absorption with 140nm spectral width. However, their results still lack some requirements, which an ideal solar cell needs [31]. C. Sun et al., suggested a new design for back surface of thin film solar cells, where they used array of silver nanoparticles in the bottom surface of silicon layer. They minimized transmission losses below than 50% from 800-1200nm in solar spectrum. But still half of the visible range suffers from transmission losses [32]. C. Sun proposed another design for back reflectors, where they textured the back surface with blazed grating for thin film solar cells. They minimized the transmission losses at the back surface but this structure is not suitable for thin film solar cells because texturing in thin film solar cells give rise to recombination losses and badly effect the overall efficiency [33].

The earth receives about 48% of visible and 43% of near infrared radiations [34]. Thus, for solar energy harvesting, our focus should be on visible and near infrared region in the solar spectrum. In order to absorb most of the solar radiations, the thin film solar cell can be carefully designed such that the top surface reduces the reflection losses and the bottom layer reduces the transmission losses. Due to small thickness of the thin film solar cells, most of the light penetrate through it without being absorbed and take no part in the formation of current. The existing plasmonic reflectors do not cover completely the visible range of electromagnetic spectrum. Also, some of the structures support single or multiple absorption modes with narrow wavelengths, which is not appropriate for solar energy harvesting applications. To overcome this issue, we designed a back reflector based

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on plasmonic nanoparticles for thin film solar cells, which increases the absorption of light in large amount.

II. Simulation Model

The suggested structure of back reflector is shown in figure 1(a), which is made of three layers: (i) the top layer is an anti-reflection coating (ARC) made of silicon dioxide used to minimize reflection losses and also provide good surface passivation, (ii) a middle layer made of silicon, used to trap light, and (iii) the bottom layer made of silicon dioxide. An array of gold spherical nanoparticles are inserted at the bottom of silicon layer in order to push back maximum light into silicon layer. The unit cell of the structure is shown in figure 1(b), where the period along x is, Lx= 420nm and the period along y is, Ly= 230nm. Periodic boundary conditions are used for the duplication of unit cell in x and y directions. The geometric parameters of the structure are: radius, r = 10nm, and particle separation, s= 20nm. The thickness of the bottom layer is, tb= 100nm, thickness of the dielectric layer is, tm = 150nm and thickness of ARC layer is, ta=80nm. The relative permittivity of silicon and SiO2 layer is 11.7 and 3.9, respectively. The electromagnetic waves is incident upon the structure in z-direction. The environment of the entire simulation is chosen air and all the simulations are conducted in COMSOL Multiphysics software.

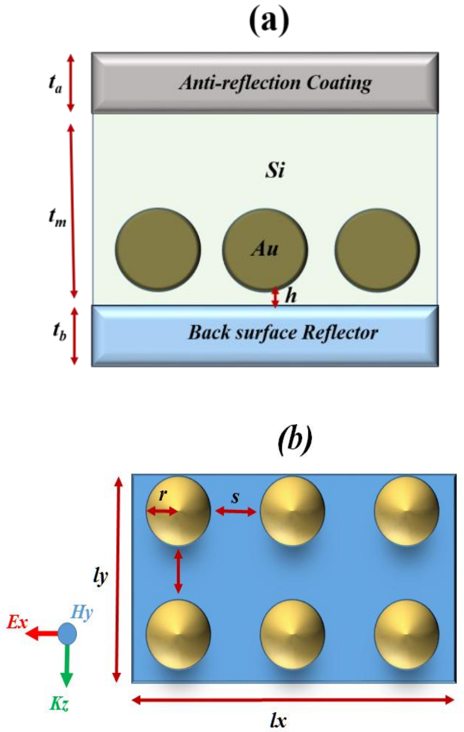

Figure 1. (a) Schematic setup of plasmonic back reflector, (b) top view of the structure

III. Results and Discussion

To achieve a best optical absorption of the proposed thin film solar cell structure, we have used an array of 21 nanoparticles at the back surface and analyzed different configurations i.e. influence of particle radius (r), influence of particle separation (s), influence of space between nanoparticles array and back surface reflectors (h), influence of different noble metals, and shapes on efficiency of absorption spectrum. We have first calculated absorption spectra of nanoparticles radius from 5nm to 25nm while keeping constant distance between nanoparticles s=20nm, which is plotted in Figure 2(a). Here, several absorption modes are observed for different radiuses and compared the results with planer gold metal sheet. We have observed that as the particle radius increases the absorption spectrum involving in optical losses and their modes are suppressing. Here, broadband absorption are obtained for r=10nm, which have 60% absorption capability and covered the entire visible and near infrared region. This clearly proves that nanoparticles can be implemented at the bottom surface of thin film solar cells to increase the optical path length.

Next we used the same number of particles having radius r=10nm and varied inter particle separation from 10nm to 50nm as shown in Fig. 2(b). Here, the absorption efficiency is almost remain unchanged by varying s. Therefore, it means that the absorption efficiency is independent of s.

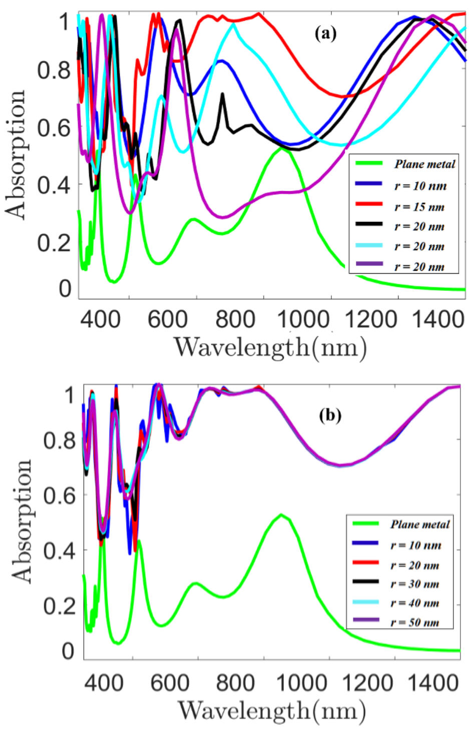

Figure 2. Influence of absorption efficiency on (a) radius and (b) inter particle separation

Next variation in absorption efficiency is investigated by changing space (*h*) between gold nanoparticle array and back reflector. The parameter *h* is varied from 20nm to 80nm while keeping the particle separation constant at *s*=20nm, radius of nanoparticles at *r*=10nm, and used array of 21 nanoparticles, see figure 3. For wavelength higher than 600nm, a slight enhancement in absorption efficiency is experienced but when the array of nanoparticles are moving up i.e. getting close to the surface of silicon substrate then maximum absorption is observed in the wavelength ranges from 400nm to 600nm at *h*=80nm. So here we have reached to a point that overall absorption can be improve by inserting array of nanoparticles close to the surface of silicon layer.

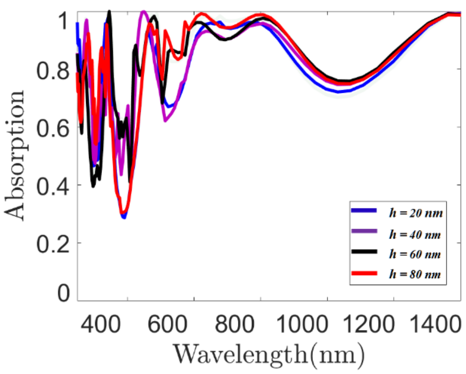

Figure 3. Influence of absorption efficiency on space between nanoparticles array and back surface reflector

Eventually, we investigate the influence of shape of nanoparticles on the absorption efficiency of solar cells. We took some shapes, which includes sphere, pyramid, disk, and square and calculated their influences on the optical absorption. The result is plotted in figure 4(a), where number of particles are same i.e. 21, having radius r=10nm, particle separation as s=20nm and inserted array at the bottom of silicon with h=0nm. We have achieved best absorption spectra for almost all individual shapes and covered the entire spectrum with 70% amplitude. However, the sphere and disk array generates better absorption performance than the other two shapes where improves absorption from 70% to 80% in wavelength from 420nm to 560nm. Now in the final investigation we used different materials for array of nanoparticles and calculated its influence on absorption spectrum, see figure 4(b). In this case, we only considered spherical shape and the radius of nanoparticles were selected as r=10nm, particle separation, s=20nm and space between array of nanoparticle and back surface reflectors as h=0nm. Here, we observed good result for all different materials with 60% absorption capability. The results of this work can be used to optimize other different thin film solar cells with gold nanoparticle arrays.

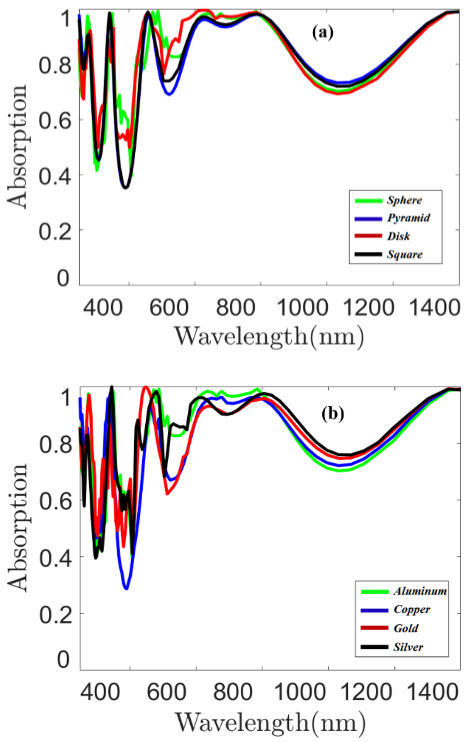

Figure 4. Influence of absorption efficiency on various (a) shapes and (b) materials.

CONCLUSION

We present a plasmonic back reflector based on gold nanospheres inserted at the bottom surface of silicon layer. The structure is composed of three functional layers i.e. an anti-reflection coating is placed at the top surface and bottom layer is made of SiO2 and middle layer is made of dielectric. Different geometric parameters are studied in order to get high absorption efficiency. It is found that nanospheres with 10nm radius, 20nm particle separation can reduce transmission losses with wide spectrum, which also provide best absorption efficiency with spectral bandwidth of 985nm. These results show that the proposed back reflector may be a better choice for thin film and solar energy harvesting applications.

REFERENCES

[1] Tang, Z., W. Tress, and O. Inganäs, Light trapping in thin film organic solar cells. Materials today, 2014. 17(8): p. 389-396.

[2] Landy, N.I., et al., Perfect metamaterial absorber. Physical review letters, 2008. 100(20): p. 207402.

[3] Khan, A.D. and M. Amin, Tunable salisbury screen absorber using square lattice of plasmonic nanodisk. Plasmonics, 2017. 12(2): p. 257-262.

[4] Ullah, H., et al., Novel multi-broadband plasmonic absorber based on a metal-dielectric-metal square ring array. Plasmonics, 2017: p. 1-7.

[5] Liu, X., et al., Infrared spatial and frequency selective metamaterial with near-unity absorbance. Physical review letters, 2010. 104(20): p. 207403.

[6] Khan, A.D., et al., Multiple higher-order Fano resonances in plasmonic hollow cylindrical nanodimer. Applied Physics A, 2015. 120(2): p. 641-649.

[7] Muhammad, N. and A.D. Khan, Tunable Fano resonances and electromagnetically induced transparency in all-dielectric holey block. Plasmonics, 2015. 10(6): p. 1687-1693.

[8] Zhang, S., et al., Experimental demonstration of near-infrared negative-index metamaterials. Physical review letters, 2005. 95(13): p. 137404.

[9] Khan, A.D., Multiple Fano resonances in bimetallic layered nanostructures. International Nano Letters, 2014. 4(2): p. 110.

[10] Khan, A.D., et al., Twin dipole Fano resonances in symmetric three-layered plasmonic nanocylinder. Plasmonics, 2015. 10(4): p. 963-970.

[11] Wang, Y., et al., Metamaterial-plasmonic absorber structure for high efficiency amorphous silicon solar cells. Nano letters, 2011. 12(1): p. 440-445.

[12] Wu, C., et al., Metamaterial-based integrated plasmonic absorber/emitter for solar thermo-photovoltaic systems. Journal of Optics, 2012. 14(2): p. 024005.

[13] Rufangura, P. and C. Sabah, Dual-band perfect metamaterial absorber for solar cell applications. Vacuum, 2015. 120: p. 68-74.

[14] Khan, A. and M. Amin, Polarization Selective Multiple Fano Resonances in Coupled T-Shaped Metasurface. IEEE Photonics Technology Letters, 2017. 29(19): p. 1611-1614.

[15] Muhammad, N. and A.D. Khan, Electromagnetically Induced Transparency and Sharp Asymmetric Fano Line Shapes in All-Dielectric Nanodimer. Plasmonics, 2017. 12(5): p. 1399-1407.

[16] Amin, M. and A.D. Khan, Polarization selective electromagnetic-induced transparency in the disordered plasmonic quasicrystal structure. The Journal of Physical Chemistry C, 2015. 119(37): p. 21633-21638.

[17] Khan, A.D. and G. Miano, Investigation of plasmonic resonances in mismatched gold nanocone dimers. Plasmonics, 2014. 9(1): p. 35-45.

[18] Liu, N., et al., Infrared perfect absorber and its application as plasmonic sensor. Nano letters, 2010. 10(7): p. 2342-2348.

[19] Khan, A.D., Refractive index sensing with fano resonant L-shaped metasurface. Optical Materials, 2018. 82: p. 168-174.

[20] Khan, A.D., Enhanced plasmonic Fano-like resonances in multilayered nanoellipsoid. Applied Physics A, 2016. 122(4): p. 300.

[21] Iyer, A.K. and G.V. Eleftheriades. Negative refractive index metamaterials supporting 2-D waves. in Microwave Symposium Digest, 2002 IEEE MTT-S International. 2002. IEEE.

[22] Khan, A.D. and G. Miano, Higher order tunable Fano resonances in multilayer nanocones. Plasmonics, 2013. 8(2): p. 1023-1034.

[23] Khan, A.D. and G. Miano, Plasmonic Fano resonances in single-layer gold conical nanoshells. Plasmonics, 2013. 8(3): p. 1429-1437.

[24] Khan, A.D., et al., Generation of multiple Fano resonances in plasmonic split nanoring dimer. Plasmonics, 2014. 9(5): p. 1091-1102.

[25] Khan, A.D., et al., Excitation of multiple Fano-like resonances induced by higher order plasmon modes in three-layered bimetallic nanoshell dimer. Plasmonics, 2014. 9(2): p. 461-475.

[26] Li, Z., S. Butun, and K. Aydin, Ultranarrow band absorbers based on surface lattice resonances in nanostructured metal surfaces. ACS nano, 2014. 8(8): p. 8242-8248.

[27] Liu, Z., et al., Achieving an ultra-narrow multiband light absorption meta-surface via coupling with an optical cavity. Nanotechnology, 2015. 26(23): p. 235702.

[28] Wang, B.-X., et al., Theoretical investigation of broadband and wide-angle terahertz metamaterial absorber. IEEE Photonics Technology Letters, 2014. 26(2): p. 111-114.

[29] Ullah, H., et al. Plasmonic perfect absorber for solar cell applications. in Emerging Technologies (ICET), 2016 International Conference on. 2016. IEEE.

[30] Hungerford, C.D. and P.M. Fauchet, Design of a plasmonic back reflector using Ag nanoparticles with a mirror support for an a-Si: H solar cell. AIP Advances, 2017. 7(7): p. 075004.

[31] Crudgington, L., T. Rahman, and S. Boden, Development of amorphous silicon solar cells with plasmonic light scattering. Vacuum, 2017. 139: p. 164-172.

[32] Sun, C., J. Su, and X. Wang, A design of thin film silicon solar cells based on silver nanoparticle arrays. Plasmonics, 2015. 10(3): p. 633-641.

[33] Sun, C., et al., A surface design for enhancement of light trapping efficiencies in thin film silicon solar cells. Plasmonics, 2016. 11(4): p. 1003-1010.

[34] Solanki, C.S., Solar photovoltaics: fundamentals, technologies and applications. 2015: PHI Learning Pvt. Ltd.