Plasmonic Scattering Structures For Improved Performance of Thin Film Solar Cells

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Abstract

Solar Photovoltaics is an alternate green energy source compared to the depleting fossil fuel technologies. The cost of solar energy need to be reduced significantly for competitiveness and proliferation in residential solar. Thin film photovoltaics is a promising technology for the growth of solar industry. In this paper, novel multilevel scattering element is investigated to increase the solar absorbance. Nano plasmonic scattering structures embedded in a dielectric medium is modelled leveraging COMSOL 2D Electromagnetic wave propagation in the frequency domain with periodic boundary conditions. The computational electromagnetic simulation model is set to sweep across the incident wave frequency range from 400 nm to 800 nm and to measure reflection, transmissions and absorption coefficients.

Four type of circular and corrugated circular shaped plasmonic structural configuration is considered. Plasmonic structures shows good potential in narrow frequency band. However, for practical use, broad band response is desired, which is a critical challenge in plasmonic structures. The effectiveness of these structures for enhancing the absorbance and broad band response is investigated. The results show the increase in absorbance coefficient for multilevel corrugated circular structures. The frequency sweep results also highlight the improved broadband response of the corrugated circular structures. This type of study can fuel the solar Photovoltaics industry growth and proliferation of low-cost thin film solar cells.

Keywords: Residential solar, solar spectrum, solar products,solar components cost, effective ideas, Plasmonic solar cells, solar inverter, inverter efficiency, DC solar appliances, DC power house, printed solar cells, residential solar panel cost, residential solar energy, COMSOL Multiphysics.

1. Introduction

Array of photovoltaic cells are used to collect energy from the sun and convert it into electricity. The collection and conversion efficiency for most of the solar cells employed in the field is low. The solar energy cost need to be reduced significantly for competitiveness and proliferation in residential solar. Thin film photovoltaics is a promising technology for the growth of solar industry. Plasmonic Solar Cells (PSCs) have great potential to cut down the cost of solar energy. Plasmonic cells shows potential to improve absorption by scattering light using metal nanoparticles excited at their surface plasmon resonance [3]. Plasmonic structures shows good potential in narrow frequency band. However, for practical use, broad band response is desired, which is a critical challenge in plasmonic structures.

A brief introduction to plasmonic solar cells is given. In this paper, nanoscale plasmonic structures are explored for performance improvement. These structures provide novel ways to guide, concentrate and trap light within thin film solar cells for enhancing absorbance and the overall performance. Nano plasmonic scattering structures embedded in a dielectric medium is modelled leveraging COMSOL 2D Electromagnetic wave propagation in the frequency domain with periodic boundary conditions. Four type of circular and corrugated circular shaped plasmonic structural configuration is considered. The effectiveness of these structures for enhancing the absorbance and broad band response is investigated.

2. Plasmonic solar cells

Plasmonic solar cells are photovoltaic devices that convert light into electricity with the usage of plasmons. Plasmons, waves of electrons are created when light hits a metal under specific circumstances.

Around 40% of the cost of a solar module made from crystalline silicon is the cost of the silicon wafers [2]. Plasmonic solar cells can be replace crystalline silicon in order to cut the cost of solar energy. Trapping of light is crucial for thin film Solar Cells. Plasmonic nanoparticles can be used to increase the efficiency of thin film solar cells. The scattered light from plasmonic nanoparticles make them efficient. The design of a plasmonic solar cells varies depending on the method being used to trap light through the material.

Scattering and absorption of light is the basic principle of plasmonic solar cells performance enhancement. A thin silicon sheet does not absorb light very efficiently. So, light needs to be scattered across the surface in order to increase the absorption to convert it into electrical energy. It has been found that metal nanoparticles help to scatter the incoming light across the surface of the Si substrate at resonance wavelengths [3]. In this paper, novel multilevel plasmonic scattering structures are investigated for broadband performance improvement of solar cells.

3. COMSOL multiphysics Formulation and Simulations

Nano plasmonic scattering structures embedded in a dielectric medium is modelled as electromagnetic wave propagation in the frequency domain with periodic boundary conditions using COMSOL AC/DC module.
Time-harmonic wave equations in the electric field *E* and the magnetic field *H*:

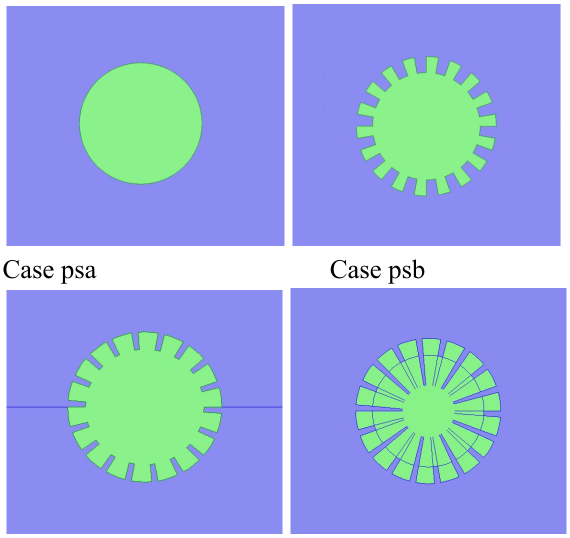
$$\nabla \times \nabla \times \vec{E} - n^2 k_0^2 \vec{E} = 0$$

$$\nabla \times \left(\frac{1}{n^2} \nabla \times \vec{H}\right) - k_0^2 \vec{H} = 0$$

Where, n , complex refractive index
k_0 , magnitude of the free-space wave

A 2D model with periodic boundary conditions is considered. Appropriate dielectric and metal material properties are specified for the simulations. The input and output boundary conditions are specified for incident solar radiation from 400 nm to 800 nm and for reflection, transmissions and absorption output, respectively.

The performance of the plasmonic structures depends on the polarization of the incident wave, hence, both transverse electric and transverse magnetic simulations are considered. The model is set to sweep across the incident wave frequency range in the visible spectrum from 400 nm to 800 nm and to measure reflection, transmissions and absorption coefficients. Four cases of circular and corrugated circular shaped plasmonic structural configuration is considered as shown in Figure 1. Case psa, is the simple circular shape and the remaining multilevel scattering elements are modelled around the circular shape for increasing the plasmonic absorbance. The effectiveness of these structures for enhancing the absorbance and broadband response is investigated.



Case psa

Case psb

Case psc

Case psd

Figure 1: (case psa,case psb, case psc, case psd) circular and multi level corrugated circular shaped plasmonic structures

4. Results and Discussion

The simulation results are detailed in this section for all the four shapes. The electrical field normal at 550 nm , and 800 nm are reported. The reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm is reported. The average absorption coefficient is also calculated for comparison.

Figure 2a and 2b shows the contour plots of electrical field normal for circular shape, case psa at at 550 nm , and 800 nm , respectively.

Figure 3, shows the reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm for case psa.

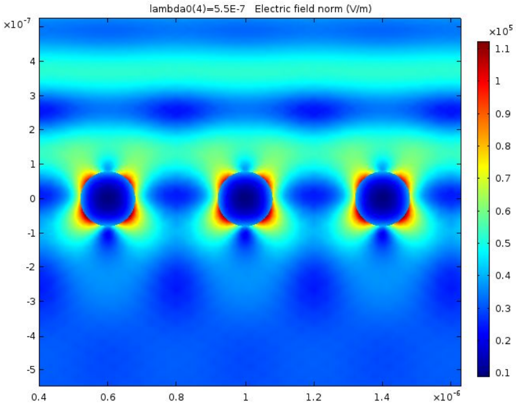


Figure 2a.: Contour plot of electrical field normals at 550nm of case psa

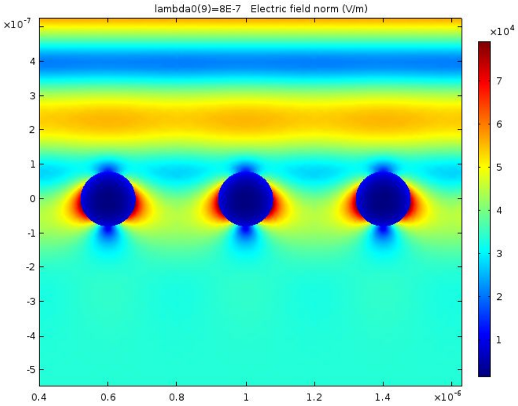


Figure 2b.: Contour plot of electrical field normals at 800nm of case psa

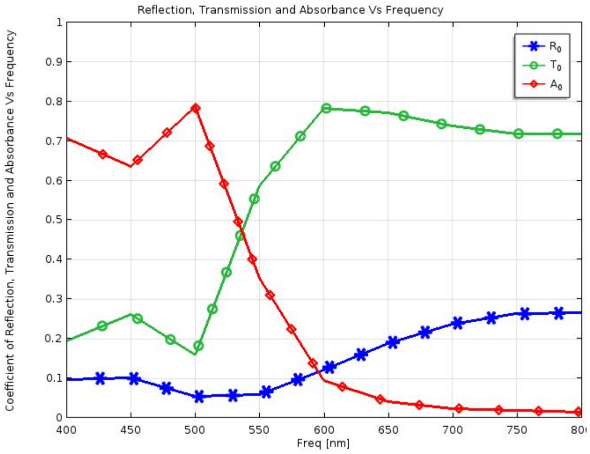


Figure 3.: reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm of case psa

Figure 4a and 4b shows the contour plots of electrical field normal for circular shape, case psb at at 550 nm , and 800 nm , respectively. Figure 5, shows the reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm for case psb

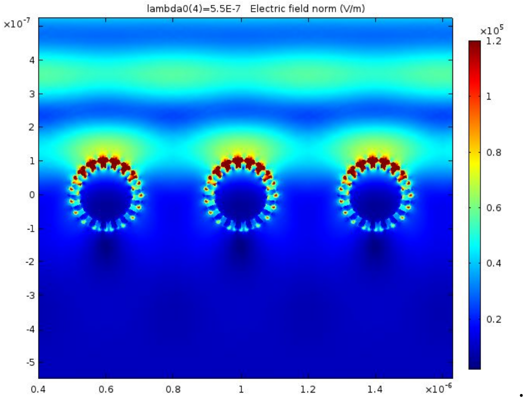


Figure 4a.: Contour plot of electrical field normals at 550nm of case psb

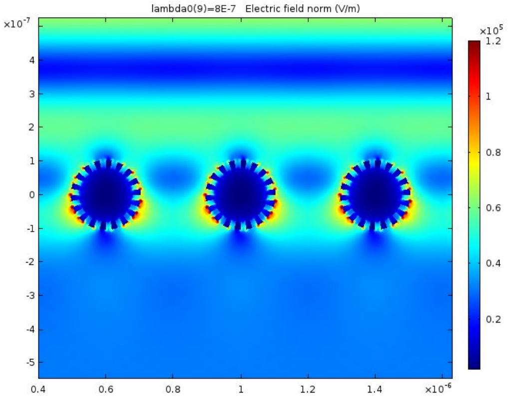


Figure 4b.: Contour plot of electrical field normals at 800nm of case psb

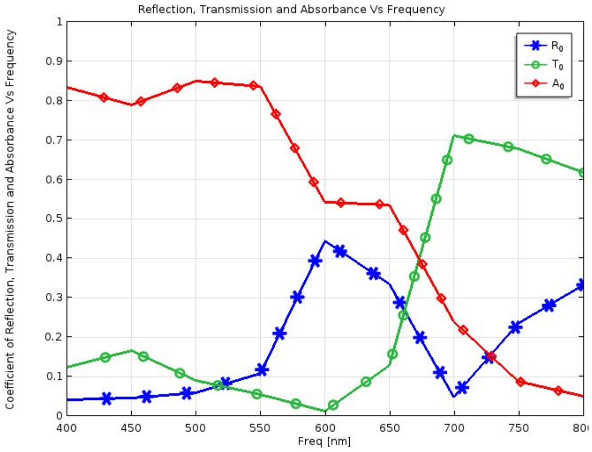


Figure 5.: reflection, transmissions and absorption coefficients as function of frequency from 400 to 800nm of case psb

Figure 6a and 6b shows the contour plots of electrical field normal for circular shape, case psc at at 550 nm , and 800 nm , respectively. Figure 7, shows the reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm for case psc.

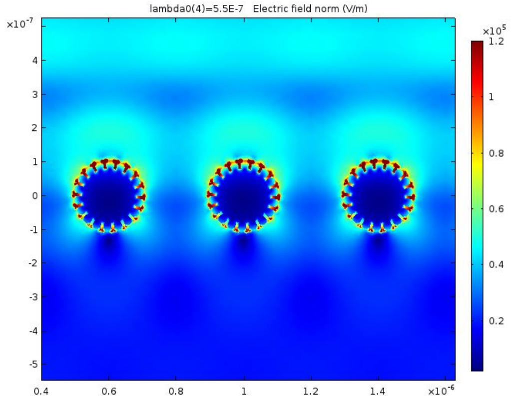


Figure 6a.: Contour plot of electrical field normals at 550nm of case psc

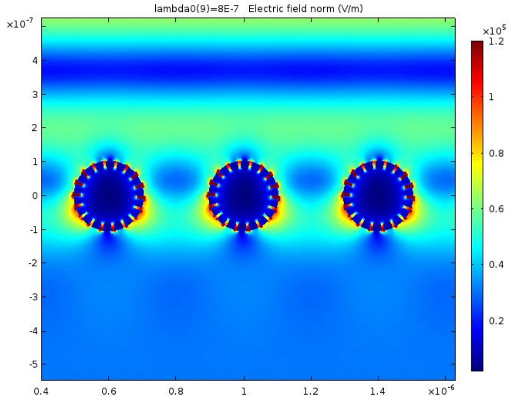


Figure 6b.: Contour plot of electrical field normals at 800nm of case psc

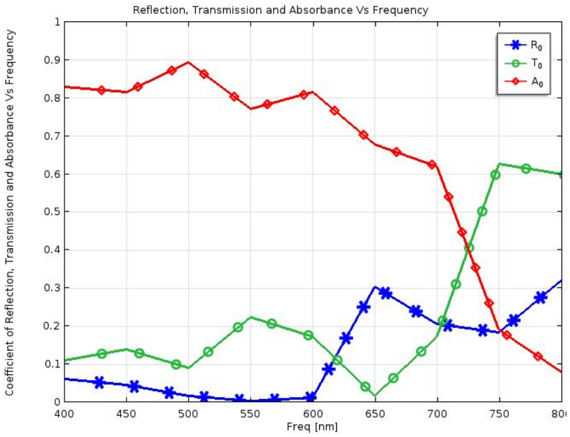


Figure 7.: reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm of case psc

Figure 8a and 8b shows the contour plots of electrical field normal for circular shape, case psd at at 550 nm , and 800 nm , respectively. Figure 9, shows the reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm for case psd.

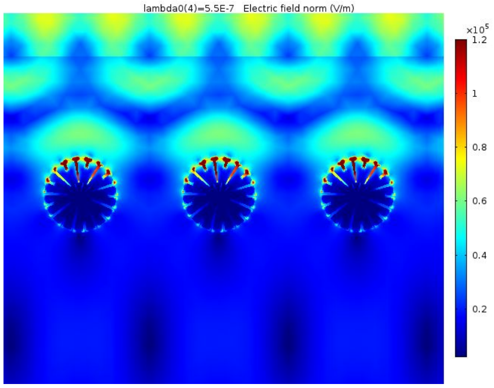


Figure 8a.: Contour plot of electrical field normals at 550nm of case psd

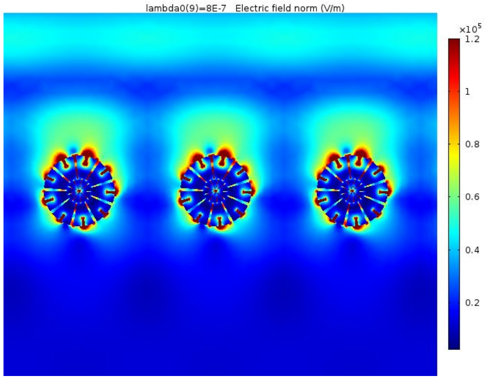


Figure 8b.: Contour plot of electrical field normals at 800nm of case psd

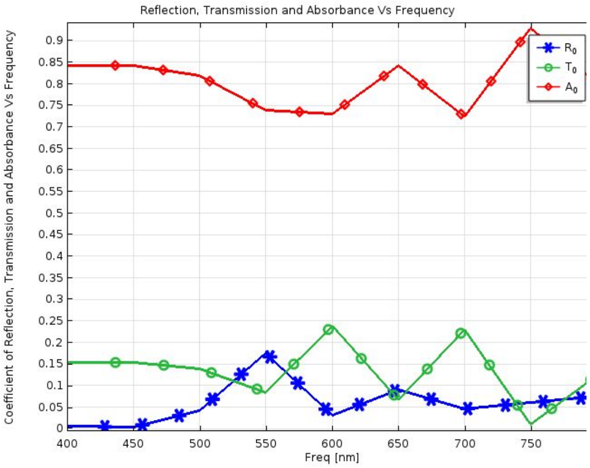


Figure 9.: reflection, transmissions and absorption coefficients as function of frequency from 400 to 800 nm of case psd

Figure 10, shows the comparison of absorption coefficients as function of frequency from 400 to 800 nm for case psa, psb, psc and psd. Table 1 shows the summary of results, average absorption coefficients across the visible spectrum.

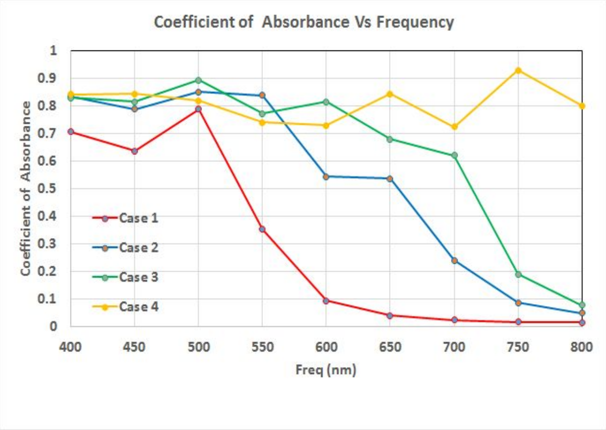


Figure 10.: comparison of absorption coefficient for all case psa,psb,psc and psd.

The results show the increase in absorbance coefficient of multilevel circular structures. The frequency sweep results also highlight the improved broadband response of the corrugated circular structures, absorbance coefficient from 0.30 to 0.83. Case psb is 78% better than case psa in absorbance. Case psc is 112 % better than case psa in absorbance. Case psd is 172 % better than case psa in absorbance. The overall broadband response improvement across the frequency spectrum is evident from figure 10. Thus computational electromagnetic simulations of multi level plasmonic structures demonstrated broadband response and significant increase in absorbance coefficient.

5. Conclusions

A brief introduction to plasmonic solar cells was given. Nanoscale plasmonic structures were explored for performance improvement.

The simulation details of Nano plasmonic scattering structures embedded in a dielectric medium as modelled in COMSOL 2D Electromagnetic wave propagation in the frequency domain with periodic boundary conditions is given.

Four type of circular and corrugated circular shaped plasmonic structural configuration was considered. The effectiveness of these structures for enhancing the absorbance and broad band response was investigated. Multi-level plasmonic scattering elements showed performance improvement of as high as 172% in absorbance coefficient as compared circular plasmonic scattering elements. Multi-level plasmonic scattering elements are also shown broadband response from 400 to 800 nm.

Computational electromagnetic investigation demonstrated the potential for increasing the solar absorbance and broadband response of thin film solar cells by multi-level plasmonic scattering elements. Highly efficient plasmonic structures can fuel the solar Photovoltaics industry growth and proliferation of low-cost thin film solar cells.

6. References

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