

EFFECTS OF DIFFERENT PARAMETERS IN ENHANCING THE EFFICIENCY OF PLASMONIC THIN FILM SOLAR CELLS

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ABSTRACT

Efficiency of thin film solar cells are less comparing to thick film solar cells which can be enhanced by utilizing the metal nanoparticles near their localized Plasmon resonance. In this paper, we have reviewed the Plasmon resonance of metallic nanoparticles and its application in solar cell technology. Beside this, we have also reviewed about different parameters which dominate the nanoparticles to increase optical absorption. Thus a cost-effective model has been proposed.

KEYWORDS

Plasmonic, Thin film, Nanoparticles, Absorption, Scattering, Extinction

1. INTRODUCTION

Photovoltaics are one of the emerging fields to generate electricity. The conventional photovoltaic technology involved thick film Si solar cells with high efficiency[4] as the optical path in absorber plate was longer. But using thick film technology led to high cost of the solar cells due to scarcity of raw materials in earth[1]. To utilize the limited raw materials in the earth, thin film technology introduced in which thin film of the absorbing materials are used[2,3]. But in the thin film technology, the light absorbed is less comparing to thick film technology hence the solar cell efficiency of thin film solar cell is less[4]. To increase the solar cell efficiency, we must have to increase the optical thickness in the absorber plate.

2. Plasmonic solar cell

In the conventional thick film Si solar cells, pyramidal surface texturing were done to achieve light trapping which enhanced the effective optical path length in the cell, which is not suitable for thin film solar cells as the cell thickness is smaller than the texturing size. Plasmonics structures can be used to reduce the physical thickness while increasing the optical thickness. Two possible ways can be utilized in plasmonic thin film solar cells[5]. First, nanoparticles can be used at top surface of the absorber layer to couple and trap freely propagating plane waves from the sun [1,5]. By this way light can be trapped, scattered and folded to increase the optical path. In the second way light can be concentrated and folded in the semiconductor layer by metallic

nanostructure which support surface plasmon which is actually the excitation of conduction electrons at the interface between metal and dielectrics. In this process, a corrugated metallic film is used on the back surface of the absorber which can couple sunlight into surface plasmon polariton[1,5].

3. Effect of various parameters in plasmonics thin film solar cell

There are several parameters that plays a vital role in solar efficiency of a thin film solar cell. Among them selection of nanomaterials, size and shape of nano particles, dielectric medium etc are noticeable.

3.1 Selection of nanomaterials

Noble metal like gold, copper and silver are suitable for Plasmonic thin film solar cells because of their low resistivity and strong interactions with visible light wave. Gold is the best because of stability and reluctance to oxidation, copper is considered worst as it is oxidized easily. To prevent oxidation it needs to be overcoated. However the plasma frequency for gold and copper lie in the visible ($\sim 2.5\text{eV}$ for gold and $\sim 2.1\text{eV}$ for copper) whereas for silver the corresponding transition is outside the visible region ($\sim 4\text{eV}$) [7]. As a result, silver is a good choice for solar cell application. Also it has low absorption losses and high radiative efficiency compared to gold and copper. Absorbance of gold, silver and copper is depicted in figure-1.

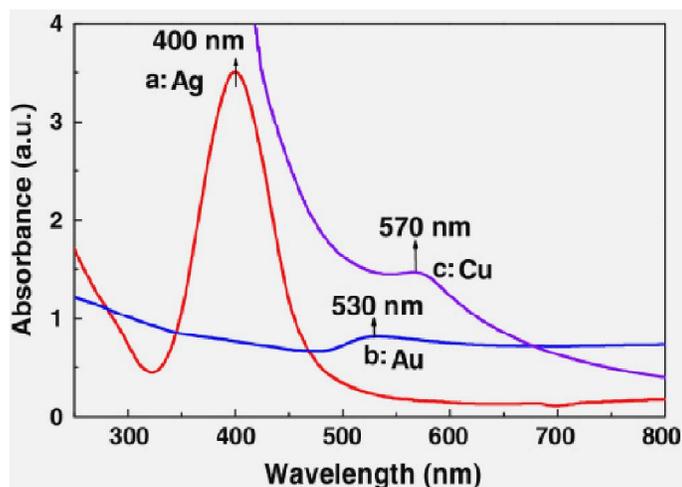


Figure-1. Absorbance of gold, silver and copper[8].

3.2 Effect of size and shape of metal nanoparticle

Both size and shape of metal nanoparticles are key factors in enhancing solar cell efficiency. According to Maxwell's equations, the intensity of absorption and scattering for metal nanoparticles is size dependant. The size of the particles should be optimized for the desired application to get strong extinction(scattering and absorption)[9]. Metallic particles that are much smaller than $\sim 20\text{nm}$ in radius, tend to absorb more and hence extinction is dominated by absorption in the metal particles and as the size of the particles increases, extinction is dominated

by scattering. The optical properties of spherical nanoparticles are highly dependent on the nanoparticle diameter. The extinction spectra of 10 sizes of silver and gold nanoparticles at identical mass concentrations (0.02 mg/mL) are displayed in the figure-2 and figure-3 respectively. Smaller nanospheres primarily absorb light and have peaks near 400 nm in silver and near 520 nm in gold, while larger spheres exhibit increased scattering and have peaks that broaden and shift towards longer wavelengths.

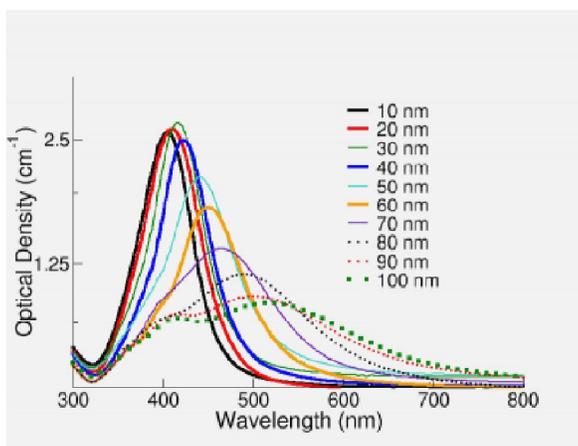


Figure-2. Extinction (the sum of scattering and absorption) spectra of silver nanoparticles with diameters ranging from 10 - 100 nm [14].

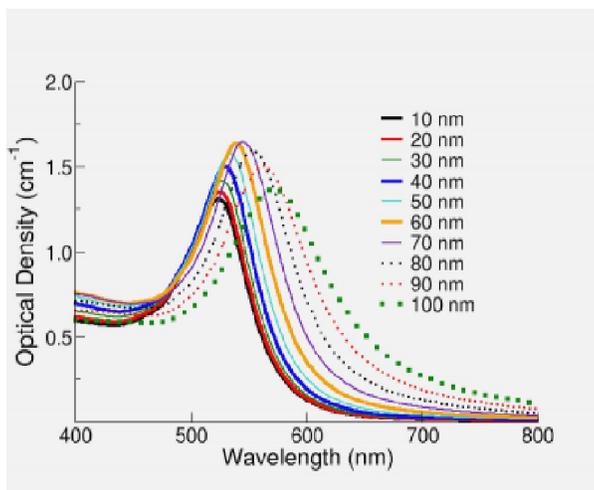


Figure-3. Extinction (the sum of scattering and absorption) spectra of gold nanoparticles with diameters ranging from 10 - 100 nm [14].

Besides the particle size, another factor affecting the absorption enhancement is the particle shape. Stuart et. al. [10] observed an increase in the photocurrent enhancement from silicon-on-insulator devices with metal islands of various sizes. According to their experiment, the particle size determines the scattering intensity of the particles. They also showed that dipole shaped

particles have high scattering efficiency, where scattering efficiency is the fraction of scattered light as a proportion of the total extinction.

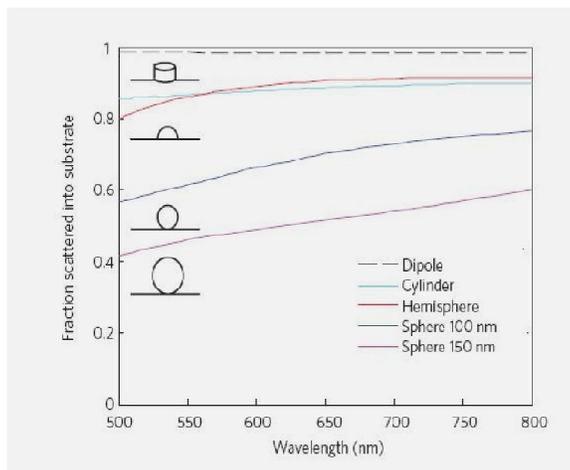


Figure-4. Fraction of light scattered into the substrate, divided by total scattered power, for different sizes and shapes of Ag particles on Si. Also plotted is the scattered fraction for a parallel electric dipole that is 10 nm from a Si substrate [1].

3.3 Effect of dielectric overcoating

Dielectric overcoating of the metal nanoparticles is utilized to tune the Plasmon resonance. Photocurrent enhancement in solar cell also depends on the refractive index near the nanoparticle surface. Due to dielectric coating, the nanoparticle extinction spectrum shifts to longer wavelengths also known as red-shifting, as the refractive index near the nanoparticle surface increases. Red shifting the plasmon resonance increases the possibility of absorption at the longer wavelengths. Practically, this means that the nanoparticle extinction peak location will shift to shorter wavelengths (blue-shift) if the particles are transferred from water ($n=1.33$) to air ($n=1.00$), or shift to longer wavelengths (red-shift) if the particles are transferred to oil ($n=1.5$).

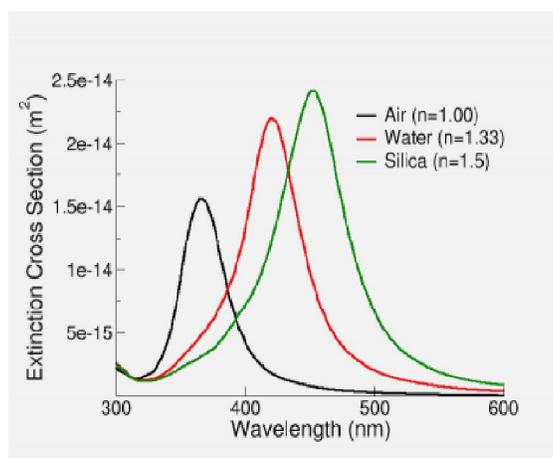


Figure-5. Extinction spectra of 50 nm silver nanospheres in air, water, and silica[14].

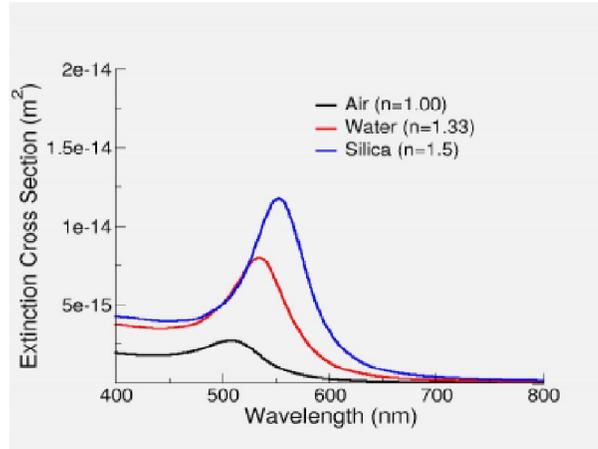


Figure-6. Extinction spectra of a 50 nm gold nanosphere in air, water, and silica[14].

Figure-5 displays the extinction spectrum of a 50 nm silver nanosphere and figure-6 depicts the calculated extinction spectrum of a 50 nm gold nanosphere as the local refractive index is increased. For silver, increasing the refractive index from 1.00 to 1.60 results in an extinction peak shift of over 90 nm, moving the peak from the ultraviolet to the visible region of the spectrum and for gold, increasing the refractive index from 1.00 to 1.60 results in an extinction peak shift of over 40 nm, moving the peak from the green to the red region of the spectrum.

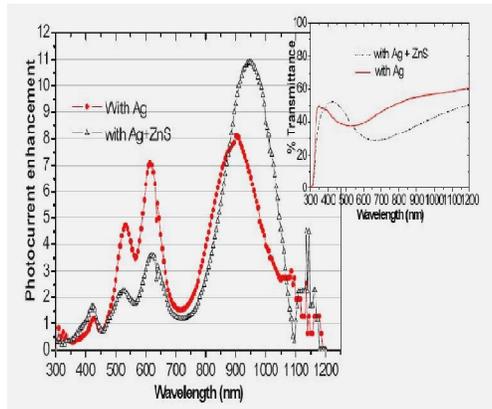


Figure-7. Photocurrent enhancement plots for the case with metal islands and for the case of metal islands overcoated with ZnS for 95nm Si on SOI with 35nm top oxide[11].

In figure-7 photocurrent enhancement in two different condition is plotted. It is observed that, photocurrent enhancement is better when silver is overcoated with zinc sulphide rather than in only silver nanoparticle.

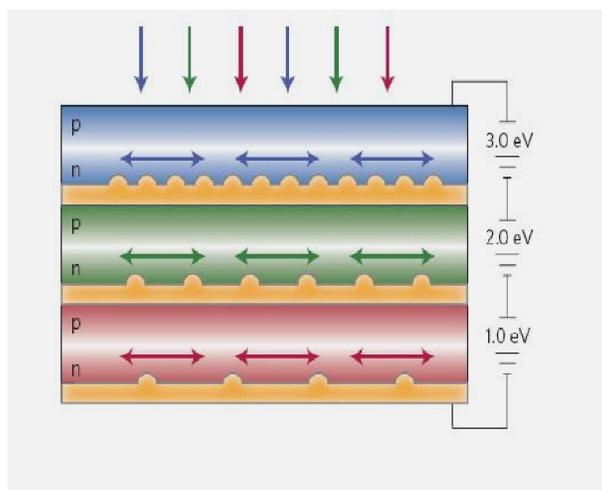


Figure-8. Plasmonic tandem solar-cell geometry. Semiconductors with different bandgaps are stacked on top of each other, separated by a metal contact layer with a plasmonic nanostructure that couples different spectral bands of the solar spectrum into the corresponding semiconductor layer.

4. Conclusion

Solar cells can contribute significantly to solve the energy crisis that our society facing. Currently a large fraction of the solar cell market is based on crystalline silicon wafers with a thickness of 180-300 μm [5], and a major fraction of the cell price is due to Si materials and processing costs. Therefore great interests in thin film photovoltaics have been established now. As using thin film technology reduces the solar cell efficiency, nanoparticles can be used to increase the efficiency. Besides, different parameters which dominate nanoparticles should also be taken account. Each particle size has various advantages for solar cell applications. Small particles have long plasmon lifetimes, while large particles scatter the incident light more and have higher extinction efficiencies. For silver, whereas particles smaller than 30 nm exhibit only absorption, light extinction of particles larger than about 50 nm is dominated by resonant scattering. At 50 nm, both the absorption and scattering become equal but their spectral maxima are shifted relative to each other. By considering all parameters, a system should be designed to get a cost-effective high efficiency solar cell. Moreover plasmonic tandem cells (figure-8) can be a better choice where different multijunctions of plasmonic nanostructures are used to get higher efficiency than a single plasmonic solar cell.

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