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Systematic Field Application of Enhanced Plasmonic Organic Solar Cell: An Overview

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ABSTRACT: Organic solar cells (OSCs) have attracted considerable research interestdue to their satisfactory properties including light-weight, low-cost, low-temperature fabrication process, semi-transparency and mechanical flexibility. Recent advances in OSCs have demonstrated above 10% efficiency in single-junction cells, indicating a strong competitiveness when compared with the commercial silicon photovoltaic system. To obtain maximum efficiency, there is a trade-off between light absorption and charge transport efficiency. Plasmonic light-trapping scheme is a feasible approach to maximize light absorption while maintaining charge transport efficiency. To give an overall look at the plasmonic organic solar cells, we review the recent progress on plasmonic-enhanced OSCs devices by integration with metal plasmonic enhancers, including both experimental and theoretical works.Among the varying proposed plasmonic structures, nanoparticles are preferable because of their strong scattering properties, particle size tunability, shape, and dielectric environment. In addition, design approaches based on plasmonics can be used to improve absorption in solar cells, permitting a considerable reduction in the physical thickness of solar cell absorber layers, and yielding novel options for solar-cell designs. Also, the simplicity in plasmonics preparation and integration methods is easily compatible with the standard solar cell fabrication process.

KEYWORDS: Organic Solar Cells (OSC), Surface plasmons (SP), Surface Plasmon polariton (SPP), Localized plasmonic resonance.

1. INTRODUCTION

In order to obtain cost-effective and green energy, renewable solar energy is harnessed via various technologies, i.e. thin film solar cells[1], quantum dot solar cells[2-4], nanostructured solar cells[5], plasmonic solar cells[6, 7], to mention but a few.Although solar cells based on inorganic materials are more technologically mature and able to produce high efficiency, it is still rewardingto look into organic materials because of their low cost and facile fabrication process, makingthis technology attractive for future mass production. Throughout the years, solar cells based on Si are introduced commercially and have already reached quite a stable market, as illustrated in Fig. 1(a). It can be said that they already have a firm role in supplying energy to humanity. However, the OSCs based on solution-processable materials can be fabricated over large areas by facile process, such as printing or coating and roll to roll machinery. Although they have a lower efficiency and shorter lifespan compared with their inorganic counterparts, they are cost-effective and demonstrate advantages that their counterpart don’t have. As the technology advances, an organic solar cell which yields efficiencies of up to 11.5%, as the latest world record for emerging organic solar cells[8]. Therefore is a large gap for researchers to boost its efficiency while maintaining low cost.

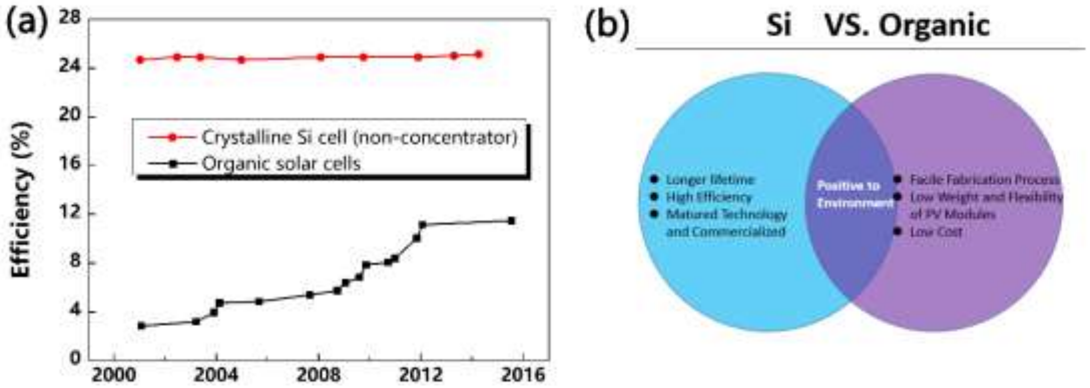

Figure 1. (a) Best research-cell efficiencies chart between crystalline Si solar cells and organic solar cells. Replotted from National Renewable Energy Laboratory (NREL) of the United States. (b) Advantagesof Si and Organic solar cells.

In order to increase the efficiency of OSCs, internal quantum efficiency and absorption efficiency need to be taken into consideration. The former can approach 100% and maximizing incoming light absorption becomes the major limitations towards efficient solar cells. The light trapping schemes are introduced to achieving maximum light absorption including surface texturing, quantum dots and photonic crystals. Metallic nanostructures, which utilize the collective oscillation of electromagnetic and free electrons, are applied as an effective light trapping method inside the active layer of OSCs and thin film solar cells. The noble metal nanoparticles (NPs)which induces surface plasmon resonance (SPR) can enhance the absorption of light by two mechanisms: far-field scattering and near-field enhancement [9].Chai-Shu Hsu et al. demonstrated a OSC device incorporating the Au NPs improved the power conversion efficiency to 4.24% from a value of 3.57% for the device fabricated without Au NPs [10]. As we known, there is a trade-off between the light absorption and the carrier collection in the OSCs. Therefore, the use of metallic nanoparticles can enhance the light absorption without compromising the architecture. For light trapping in OSCs application, the metal nanoparticles are usually rested outside and inside the active layers[10, 11].When located outside of the active layer (far from the active layer), the absorption enhancement can be ascribed to far-field scattering from the LSPR of NPs, rather than near-field enhancement. On the other hand, embedding NPs in the active layer is able to couple the light to active layer via near-field enhancement [12].

This research develops guidelines for the design of enhanced plasmonic solar cells to achieve the optimum absorption efficiency of the solar cell. To accomplish this objective, the following key issues is researched and reported: (1) Plasmonic organic Solar cells that studies the effects of the geometry and orientation on plasmonic properties of solar cells,(2) Organic solar cells enhanced by plasmonic enhancer, that is, investigate the Surface Plasmon -based properties which depends on the plasmonic nanostructures with respect to materials , (3) Investigate the effects and applications of the physical and structural property of the resulting nanostructures, (4) The effect of the shape and size of nanoparticles on performance enhancement, and (5) The applications of Solar cells. We finally look into Plasmonics for solar cells enhancement and applications.

2. ORGANIC SOLAR CELLS ENHANCED BY PLASMONIC ENHANCER

Organic solar cells (OSCs) arewidely studied for their potential in various organic compound fabrication processes (with modifiable structures and exhibit good flexibility, high power conversion efficiency (PCE) under low light irradiation, and power-generation windows)[13].One of the major advantages of organic materials is theoverall high absorptivity and the sharp absorption onset[14]. Thus, can beutilized to absorb the incident sunlight in the active organic material within a broad range of wavelengths in a device structure.

A single-junction OSC is made up of five or six layers arranged on the surface of a supporting substrate, that is usually a transparent plastic or a piece of glass. A transparent indium tin oxide (ITO))electrode, and flexible polyethylene terephthalate (PET) substrates coated with a transparent In_2O_3/Au/Ag) electrode were successively sonicated and treated under UV-ozone prior to device fabrication as reported and illustrated in **figure 2**[15]. The inverted device structure also helps to get good characteristics from devices on the PET substrates. W. Cao et al were successful in the fabrication of the organic solar cells on flexible substrates by using inverted device architecture. It has been proven that the introduction of a fabrication technique called “dry spray-coating” (DSC) for the manufacture of hetero-structured solar cells is suitable for the deposition technique for creating efficient multi-layered devices from solution[16]. A systematic study for the production of blade coated solar cells using a low band gap/fullerene blend was investigated and successfully demonstrated that blade coating is a valid process for research in printing technology[17].

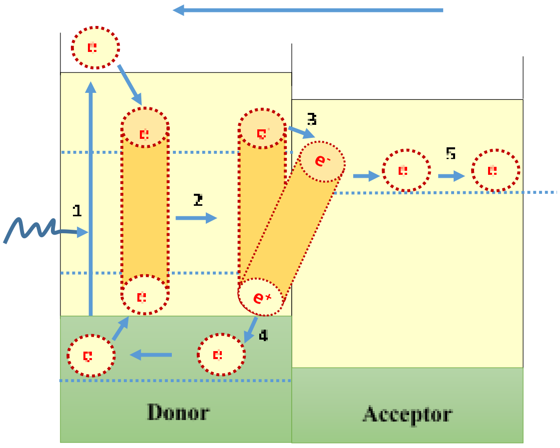

Figure 2(A) Schematic of active layers of an organic solar cell. 1) excitation of an electron by photon to the higher energy level (LUMO); 2) Diffusion ofthe exciton 3) formation of interface as ageminateelectronehole pair by charge transfer ; 4) delocalization of the interfacial electronehole pair;5)separated charges diffuse to electrodes, driven by the chemical or electrical potential[13]. copyright 2016 Journal of Power Sources.

Figure 3 shows how light is absorbed into the cell and then converted into electrical energy.

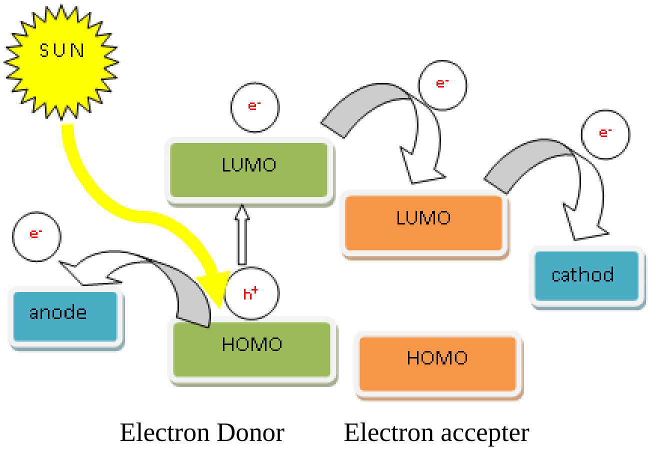

Figure 3. schematic of General Energy level diagram of a BHJ active layer

Organic solar cells comprises of in recent times, at least two different types of molecular materials, a donor compound and an acceptor that forms a charge transfer state[18-25].The charge recombination that is said to have a higher loss in Organic solar cells happens at the D/A interface[26].A detailed result of D/A combination towards high efficiency non-fullerene OSCs isshown in **Table 1**. Choosing right D/A pairs is very crucial for high-performance non-fullerene OSCs.The exciton diffusion length is of concern when administering proper organic dopants due to the degree of exciton diffusion from the bulk domain to the donor–acceptor interface affects the external quantum efficiencies (EQEs) strongly[27].

Table 1. Different D/A pairs in their best device conditions[28]. Reprinted with permission from copyright 2016 Organic Electronics

Donor	Acceptor	V_{oc}	$J_{sc}(mAcm^{-2})$	Calculated $J_{sc}(mAcm^{-2})$	FF(%)	PCE(%)	
						Average	Best
P_D	P_A	0.753	7.92	7.73	48.9	2.92 ± 0.08	3.04
P_D	S_A	0.761	1.04	1.11	33.1	0.26 ± 0.01	0.28
S_D	S_A	0.763	7.21	7.12	42.4	2.33 ± 0.12	2.52
S_D	P_A	0.772	0.94	0.88	35.9	0.26 ±0.01	0.29

Highest occupied molecular orbital(HOMOs) are mainly localized on the electron donor because of the electron Distributions.The electron distribution oflowest unoccupied molecular orbitals (LUMOs) are also localized on thep-spacer and acceptor units, that is often on the anchoring group, which shows that good electron-separated states between HOMOs and LUMOs are available[29].**Figure 4** shows the pattern of the HOMOs and LUMOs that are qualitatively similar with each other.One good way in the determination of the effective bandgap is measuring the HOMOs and LUMOs of both donor and acceptor respectively at the charge separation interface. Effective bandgap here is defined as the absolute difference in the HOMO(donor) and that of the LUMO(acceptor)[30]. One of the current techniques for the determination of band gaps to ultradilute samples and electron binding energies in vacuum ultraviolet when dealing with HOMO–LUMO gaps, is the combination of direct and resonant core-level photoionization spectroscopy[31].

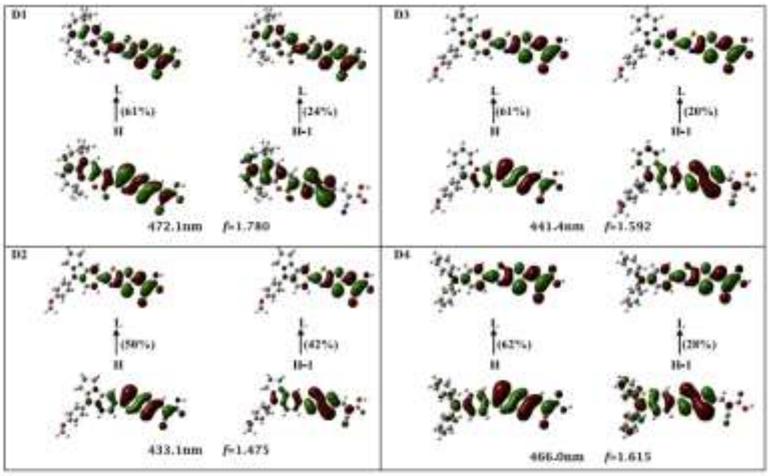

Figure 4. The results indicate that stronger electron-donating units lead to smaller HOMO and LUMO gaps[29].Copyright 2016, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

An investigation made by J.-J. Fuetal on molecular orbital spatial distribution of four phenothiazine dyes. It was found that the HOMOs were dominantly delocalized over the whole dye molecule. However, LUMOs were only localized on thep-linker and acceptor regions, which means that the dyes in their excited state may be of intramolecular charge transfer character[32].**Figure5c** indicates the UV–vis absorption spectra of PBDT2FBT-2EHO in various CB: CN solvent mixtures.Precipitation of some products within 6 h, indicated a high rate of conversion and poor solubility in toluene in a polymerization reaction and 12 h later terminated[33].The weak absorption of low energy photons (550–700 nm) are compensated for by microcavity-enhanced light trapping from back sub-cell, that help to improved light harvesting [34].

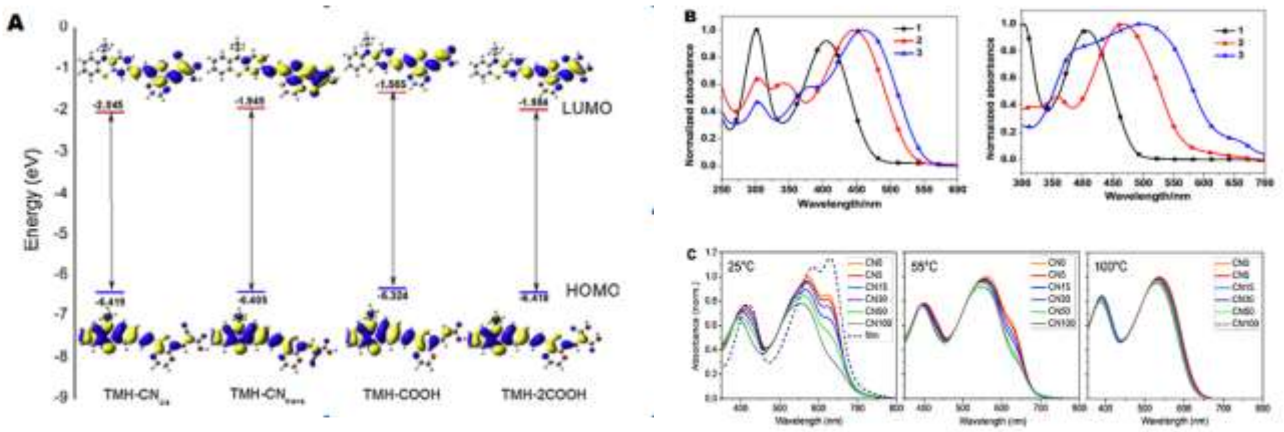

Figure 5. A) Schematic energy levels and the distribution of the HOMO and LUMO[32]copyright 2016 Computational and Theoretical Chemistry.B) spectra of optical absorption of compounds 1–3 in dichloromethane solution (10^{-6}M) and in solid film[35]) cross-coupling reaction between bis(trimethyltin) BDT and the dibrominated DT2FBT[33].

Nickel sulfide (NiS) was studied and investigated as a predictive alternative to replace Platinum for Dye-sensitized solar cells (DSSCs) because of its high conductivity, easy fabrication, and excellent catalytic activity among the inorganic materials[36].Dye-sensitized solar cells (DSSC) is one of the ways used in solar radiation as an alternative to conventional solar cells[37].This has led to numerous inorganic, organic and hybriddyes utilization as sensitizers in DSSCs[38]**. Figure 6** demonstrates CoS/graphene composite that is prepared by a facile one-pot hydrothermal method, in which CoS nanoparticles are well dispersed on the surface of grapheme structure of the DSSC.

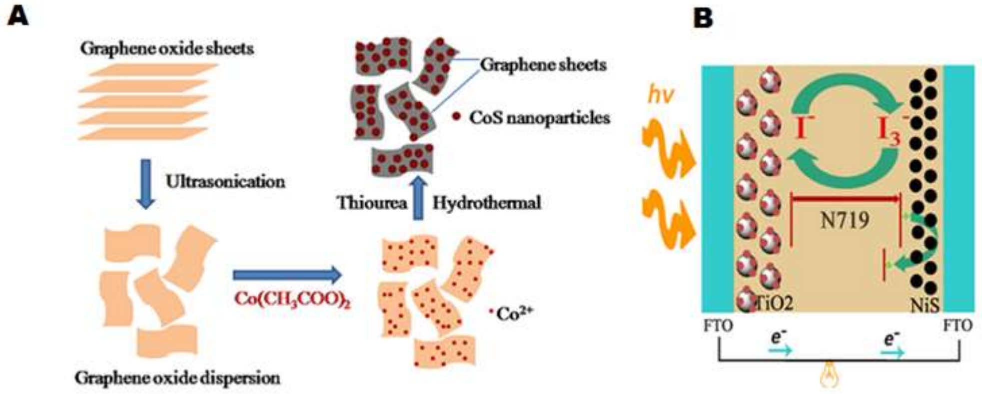

Figure6.A) Schematic exposition of the synthesis for CoS/graphene composite[39]. Copyright 2016,Journal of Power Sources B).A demonstration of the structure of the DSSC. [36]. Reprint permission copyright 2016,Materials Letters.

The typical porphyrin sensitizers used in DSSCs often have the porphyrin moieties as donors and the carboxyl-containing groups as acceptors that hold the dyes onto the surface of TiO_2. HOMO and LUMO compositions for these diarylamino-substituted zinc porphyrin sensitizer candidates have been calculated and shown in **Table 2**[40]. The HOMO of the compounds ZnDAAPorM and ZnDAAPorS are also mainly composed of the substituent, which is mainly from the contribution of the diarylamino group as explained by X. Zhang et al.

Table 2. Sub[a] represents all the meso-position substituted groups. DAA[b] represents the diamino-substituted group. Acc[c] represent the acceptor group [40].diarylamino-substituted zinc porphyrin(ZnDAAPor) where E, M, Q, R and S, are accepters and the porphyrin sensitizers(ZnDAAPorR); R = hydrogen. With copyright permission 2016,Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

Molecule	HOMO						LUMO					
	Zn	Sub[2]	DAA[b]	Acc[c]	COOH	CN	Zn	Sub	DAA	ACC	COOH	CN
ZnDAAPorE	0.27	59.6	56.5	2.6	0.6	0.5	0.13	5.8	4.3	50.7	6.4	2.5
ZnDAAPorM	0.33	55.0	51.5	8.8	0.2	0.2	0.08	3.3	2.5	69.7	7.1	3.2
ZnDAAPorQ	0.37	49.3	45.5	12.4	0.4	-	0.09	5.0	3.7	52.9	5.2	-
ZnDAAPorR	0.30	58.1	54.9	8.3	0.4	0.4	0.10	4.4	3.2	61.3	6.1	2.9
ZnDAAPorS	0.33	52.9	49.4	11.1	0.4	0.3	0.09	3.3	2.4	72.0	6.1	2.9
Compound5	0.34	-	-	5.77	0.37	-	0.11	-	-	21.4	3.7	-
YD-2	0.33	-	-	5.55	0.35	-	0.11	-	-	21.3	3.7	-
YD2-0-C8	0.31	-	-	4.61	0.30	-	0.12	-	-	26.40	5.01	-

Besides the utilization of materials, processes such as annealing have characteristic effects on organic solar cells. The effect of the annealing temperature on the film formation, morphology, and composition was reportedly investigated and correlated with the performance and device working mechanisms of photovoltaics[41]. The role of the annealing temperature used in the conversion process to form the perovskite material was investigated and found to have critical impact on perovskite film morphology.This indicates that a minimum temperature of 80 °Cform the $CH_3NH_3PbI_3$ perovskite as reported by A. Dualeh et al.Thermal annealing (TA) treatment have been observed to effectively reduce the oxide phases, such as Sb_2O_3 and oxidized sulfur, on the surface of Sb_2S_3. The surface of Sb_2S_3 is modified by TA-based sulfurization based on spin-coating substrates with TA solutions by thermal annealing at 300 °C under Ar. X-ray photoelectron spectroscopy (XPS) and DLTS[42].

Additionally, Plasmonicmetalsand their plasmonic performances for nanohole-array-based surface plasmon field-enhanced fluorescence spectroscopy (SPFS)are essentials for enhancement of organic solar cells.Plasmonic metals Au, Ag, Cu, Al, and their composites have been utilized to form, among various structures, nanoholearrays [43]. The findings provided the guideline on selecting appropriate plasmonic metals for nanohole-array surface plasmon field-enhanced fluorescence spectroscopy (SPFS) biosensors.**Figure 7** shows a typical characteristic interband transition wavelength and Nano hole in terms of transmitted power, reflected power, and power absorbed.

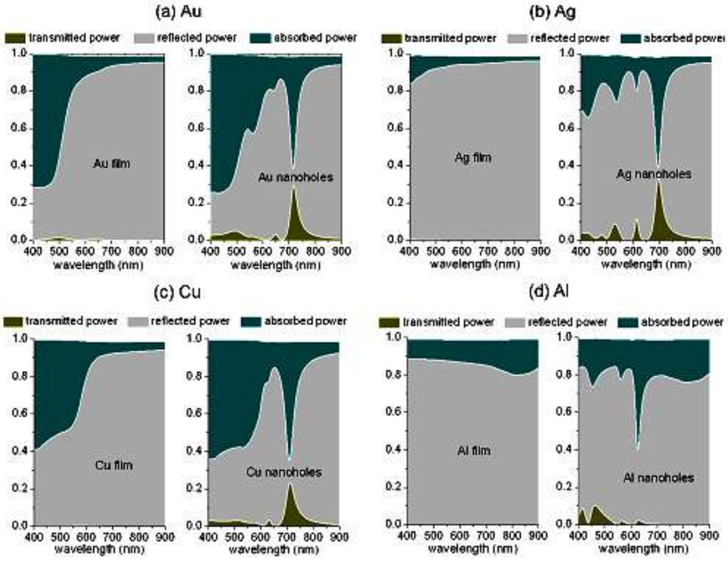

Figure 7. Schematic Analysis of Optical power, (a) Au , (b) Ag , (c) Cu , and (d) Al[43]. (For the interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

However, Organic Solar cells (OSCs), materials used in light absorption play a role to convert light energy to electrical energy [44-46]. Excitons from these materials are generated by absorption of sunlight and are differentiated into holes and electrons in the active layer with a composition of electron donor and electron acceptor. Hence, the electron donor and acceptor are critical to the device performances of OSCs and there have been a lot of studies to develop organic materials for the active layer. Organic solar cells involving highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMOs) are also highlighted. We further elaborate on the enhancing factors in plasmonic organic solar cells measuring up the plasmonic effects and efficiency. Although hybrid active layers of polymer–nanocrystal contain both the features of polymer and nanocrystals, exhibiting strong absorption for the polymer connected with high carrier mobility in the inorganic semiconductors[47, 48], there is much to be desired in considering organic solar cells[49-55].A prominent advantage of organic solar cells (OSCs) aside allowing for low cost device fabrication without restriction in size and shape for substrates/devices is the ability to process solutions[56, 57].

Ratio between the thickness of the shell and the overall diameter of the nanoparticle accounting for an enhancement in the physical and structural property of the resulting nanostructuresare respectively discussed. The effect of the shape and size of nanoparticles on performance enhancement is also summarized. Organic solar cell (OSC) has a lot ofpotentials for the realization of thenext generation of solar cells because they can be fabricated by roll-to-rollprocesses and have some potential applications, such as building-integrated photovoltaics (BIPV), semitransparent solar cells, andflexible devices[58]. We will therefore discuss this in the preceeding session.

3. ENHANCING FACTORS IN PLASMONIC ORGANIC SOLAR CELLS

Several factors in unison determine the enhancement characteristics and features in plasmonic Organic solar cells. Light harvesting properties that lead to higher power conversion efficiency in organic solar cell, without altering the device configuration often have the inclusion of plasmonic nanoparticles due to the OSC enhancement[59]. They in turn affect the properties of the solar cells at the molecular and atomic levels. This section touches on the factors responsible for the enhancement qualities in plasmonic organic solar cells.

3.1 Plasmonic properties in Solar Cells

The broad application of plasmonics is geared by two factors that are interrelated: the availability of low-loss metals in the UV, visible or near-IR; and the ability to perform large area patterning of nanoscale structures[60]. K. Diest etal reported on the real and imaginary permittivity of broadband for Aluminum samples.An equation was fitted for the case of Aluminum samples using a nonlinear optimization with mesh adoptive direct search (NOMAD) algorithm,a gradient-free approach that varied the Drudeelectron relaxation time ($t^{(D)}$),interband transitions ($t^{(IB)}$), the Drude optical mass relative to the electron mass (m_{opt}/m), and the Fourier coefficients .The SP-based properties depend on the plasmonic nanostructures and how they can be controlled[61]. An ellipsometry data was utilized in characterizingthe Optical properties for five aluminum samples (**Table 3**).**Figure 8** [62]shows and demonstrates the maximum values for QLSP (bold) and the frequencies at which they occur for all non-group-f metals due to damping ratios, low probability interband transitions and hence low $\varepsilon'_{ib}(0)$, free electron such as metals is dominant in the periodic table so far as plasmonic performance is concern. M. G. B laberetal[62]reports that materials with partiallyoccupied d or f states performs poorly across the visible because of the inter band transitions, and even if the transitions do not extend into the IR, poorly at low frequencies becauseof the aforementioned residual low frequency effect on the polarizability. However, Plasmon frequencies can be tuned by varying the ratio between the thickness of the shell and the overall diameter of the nano particle, which can be accomplished by controlled chemical synthesis[63].It is also important to note that Roughness or smoothness of nano particles is a crucial feature in plasmonics solar cells[64].

Table 3. five aluminum samples with their optical properties extracted by fitting the ellipsometry data. Ref from[60]

	Crystal	CMP	MBE	RT Sputtered	Evaporated	Literature
$\tau^{IB} \times 10^{-14}(s)$	0.484	0.42.	0.353	0.334	0.227	0.5,0.38,0.26 [6,31,32]
$\tau^{D} \times 10^{-14}(s)$	2.64	3.00	3.00	3.00	3.00	$\geq 1.00[32,26]$
m_{opt}/m	1.30	1.40	1.56	1.56	1.92	1.45,1.55,1.76 [33,6,32]
$U_{200}(eV)$	0.744	0.738	0.729	0.736	0.744	0.73,0.74,[32,31]
$U_{111}(eV)$	0.25	0.19	0.19	0.19	0.19	0.25,0.19,[26,32]
Median Grain Diameter(nm)	>100,000	1438	939	124.2	52.2	

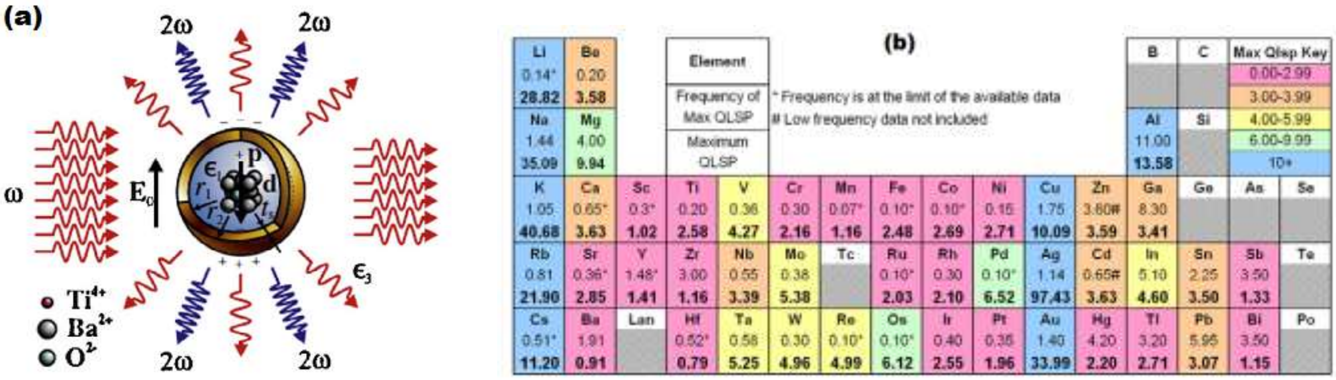

Figure 8.Schematic (a) the geometry made of a metallic shell and a BaTiO3[65]and (b) elements on the Periodic table with their various frequencies coloured by maximumQLSP. Reference by M. G. Blaber et al.(For the interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

4. MATERIALS FOR PLASMONIC ORGANIC SOLAR CELLS/ EFFECTS AND EFFICIENCY

In OSCs, the light absorbing materials play a role of absorbing sunlight to convert light energy to electrical energy. Therefore, the electron donor and acceptor are critical to the device performances of OSCs which has made researchers in the industry have a lot of studies to develop organic materials for the active layer, amongst the materials include polymers and molecule materials[66].Plasmonic materials can be exploited for the existing and emerging applications of plasmonics for renewable energy technologies. Integration of metals such as Au nanoparticles on the surface of TiO_2 electrodes enables visible part of the solar radiations and this enhances the radiation efficiency[67]. **Figure9** shows a hybrid device exploiting electrons and an autonomous solar water-splitting device

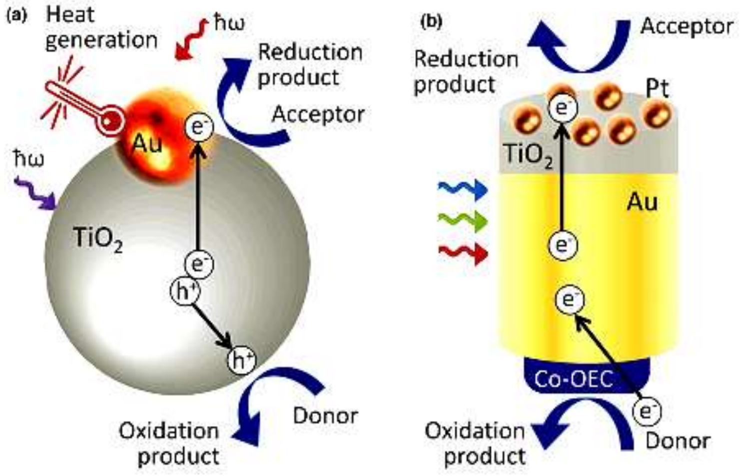

Figure 9. Schematic of (a) A hybrid device exploiting electrons and (b) autonomous solar water-splitting device. Reference by[67]copyright 2016 Materials Today.

Poly(3-hexylthiophene) (P_3HT) as a donor,phenylC61-butyric acid methyl ester (PCBM) as an acceptor and poly (3,4-ethylenedioxythiophene) oxidized with poly(4-styrenesulfonate) (PEDOT:PSS) buffer layer that incorporates the Ag NPSs were some of the materials used to investigate the photovoltaic characteristics of the BHJ–OSCs[68]. Furthermore, solar cell designs can also consist of a radial p–n junction silicon nano pillar arrays in combination with plasmonics metallic nano particles resolved at the top of the nano pillars[69].Butterfly scales can be used for bionic structures for nano plasmonics ensures a relatively straightforward fabrication of complex plasmonic structures[70].The synthesis of co-sputtered garnet-oxide composite layers prepared using a ceramic sputtering target of fully bismuth-substituted iron garnet and a separate sputtering target of dysprosium oxide[71].Plasmonic metal NPs at the back contact between active layers and cathode metal is effective since the placement of Ag NPs near the cathode contact minimally influences the open circuit voltage[51].Mole ratios of S:Se, tunable band gaps of $Cu2ZnSn(S_xSe_{1-x})_4$ nano particles were prepared successfully synthesized via a facile solvothermal method which gave the structural transitions and phase purities[72].

It has been demonstrated that the inclusion of 1,8-octaneditiol (ODT) in the active layer led to a reduced overall performance underlight soaking. Measurements of the fill factor (FF) as well as Atomic Force Microscope (AFM)and small- and wide-angle X-ray scattering (GISAXS/GIWAXS) enhances the initial performance with an optimized morphology that leads to long-term stability[73].The chemical composition and CdS buffer layer deposition conditions were adjusted to improve the efficiency, and the properties of the cell with the highest efficiency where $\eta = 0.94\%$, $V_{oc} = 451$ mV , $J_{sc} = 6.71$ mA/cm^2 and FF = 0.31[74]. The effects of double deposition potential (DDP) and singledeposition potential (SDP) processes on the structuraland morphological properties of Cu2ZnSnS4 (CZTS)films have been studied by X-ray diffraction (XRD),Raman, scanning electron microscopy (SEM) and energydispersive X-ray spectroscopy (EDS) measurements and found that the double deposition potential (DDP) process benefits the formation of Cu2ZnSnS4(CZTS) films while the J–V characteristics indicate that solar cell with a conversion efficiency of 3.68% can be obtained using CZTS absorber deposited by the double deposition potential (DDP) process[75].

5. STRUCTURES/GEOMETRY OF PLASMONIC ORGANIC SOLAR CELLS

The shape and sizes of nanoparticles in plasmonic solar cells cannot be underestimated when it to its enhancement. Silver tori of different R/r ratios are investigated under fixed size of D= R+ r = 42 nm where D is fixed size of torus ,R and r are the major and minor radii of the torus, respectively [76]. Q. Shi etal reports that spectrum of metal nano-torus is dominated by the localized surface plasmon resonance (LSPR) and the position the LSPR depends on torus’s size and environment material. The diagram in **figure 10** shows it clearly, a system consisted of one single silver torus to investigate the perpendicular polarization and parallel polarization as reported by Q. Shietal. Nano particles are able to scatter light depending on the nanoparticle size[7].spherical symmetry of a particle, are able to model realistic size nanoparticles that is in the situation where the plasmon energies are fully developed and quantum-size effects absent[77].**Figure 11** also exhibits the types of shapes and sizes of nanoparticles.

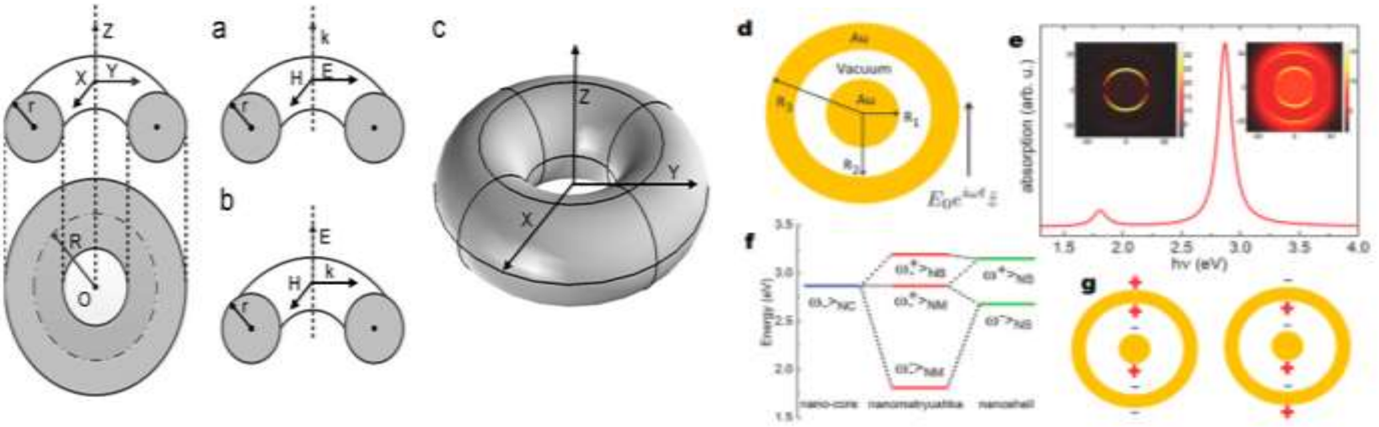

Figure 10. Schematic of a torus structure indicating R and r as the major and inner radii.(d) Geometry of a nanomatryushka. (e) Absorption cross section calculated (f) Plasmon hybridization diagram.(g) Schematic surface charge distributions Figure adopted from ref[76]and ref [77]respectively.Copyright permission 2016, American Chemical Society.

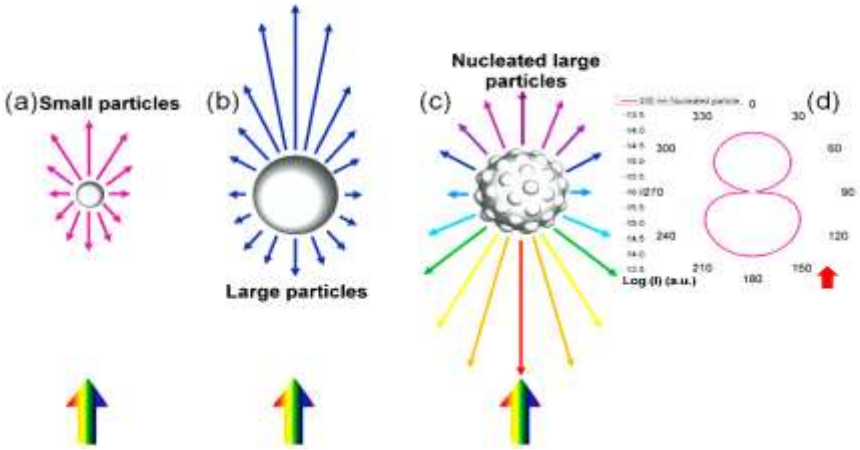

Figure 11. Schematic drawings showing the scattering patterns of (a) a small nanoparticle; (b) a large nanoparticle of 200 nm; (c) a nucleated large nanoparticle of 200 nm (color arrows are used to illustrate the broadband scattering of the nucleated nanoparticles only); and (d) the calculated scattering intensity versus scattering angle pattern for a nucleated large nanoparticle of 200 nm . Figure adopted from ref[7]. Copyright © 2012, American Chemical Society

Platinum(pt) and palladium(pd) disks of diameters of rang of 38 to 530nm and their height kept constant at 20nm was investigated and reported that it reported that all original particle sizes with diameters of the metal disks are slightly smaller than the corresponding diameter of the PS particles (nominal diameter)[78] as seen in **figure12**.Metal clusters exhibit a strong dependence on size and configuration because of quantum size effects, the discreteness of the electronic states becomes important as the size of metal particles become smaller[79].It is reported thatthe average primaryparticle size of the hierarchical hollow sphere decreases slightlyfrom 14.6 nm to 12.6 nm as the diameter of template solid spheres by the self-templating method forDSSC applicationsincrease from 220 nm to 800 nm which indicated that, the hierarchical hollow spheres are superior to mesoporous spheres[80].

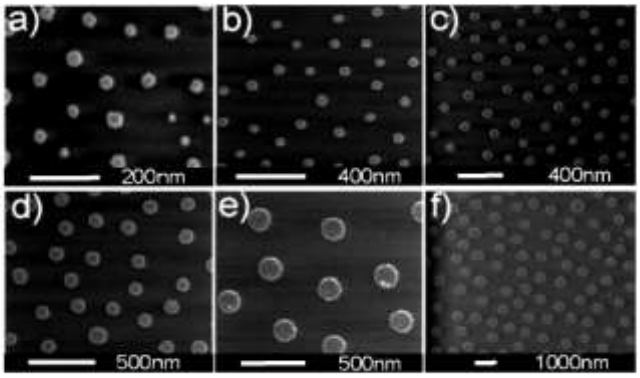

Figure 12. SEM micrographs of typical Pt nanodisk arrays of nominal particle diameters correspond to: a) 38 nm, b) 51 nm, c) 76 nm d) 110 nm, e) 190 nm and f) 530 nm. adopted from ref[78].Copyright © 2006, American Chemical Society

6. PLASMONICS FOR SOLAR CELLS ENHANCEMENT AND APPLICATIONS

Nanometer scale surface texturing in the thin active layer of the solar cells have drawn attention because of their special physicaland optical properties[81].The hybridization ofplasmonic modes in nanoparticle assemblies are used for rational engineering of plasmonic structures with expected optical feedback and local field profile[82].**Figure 13** shows the results of the quantum mechanical phenomenon and its enhancement of two identical spherical nanoparticles separated by distance. Mie theory is used for computational analysis in the scenario where the enhancement and quenching of fluorescing molecule outside and inside a silver metallic nanoshell have a strong wavelength dependence arising from plasmon resonances excited within the particle[83]. In the case of gold nano-objects, it is proposed that by using thenovel method, gold nanowire enhancement can be performed without a flow cell by simply coating the surface of the sample substrate with theenhancement solution[84].It is also known that the combination between FDTD simulations and the roughness of a random metal sample (real 3D nanostructures) can give results that are in very good agreement with experimental data[85].W. Ding etalproposed and experimentally demonstrated anew plasmonic nonlinear light generation structure, p-CASH. High second-harmonic generation (SHG) enhancement (76-fold), large SHG tunability by bias (8%/V), wide tuning range (280%), high effective conversion efficiency (7.8×10^{-9}), high effective$\chi^{(2)}$ (1586 pm/V), and high stability in generating UV (400 nm) light with 800 nm pumping[86] was achieved.

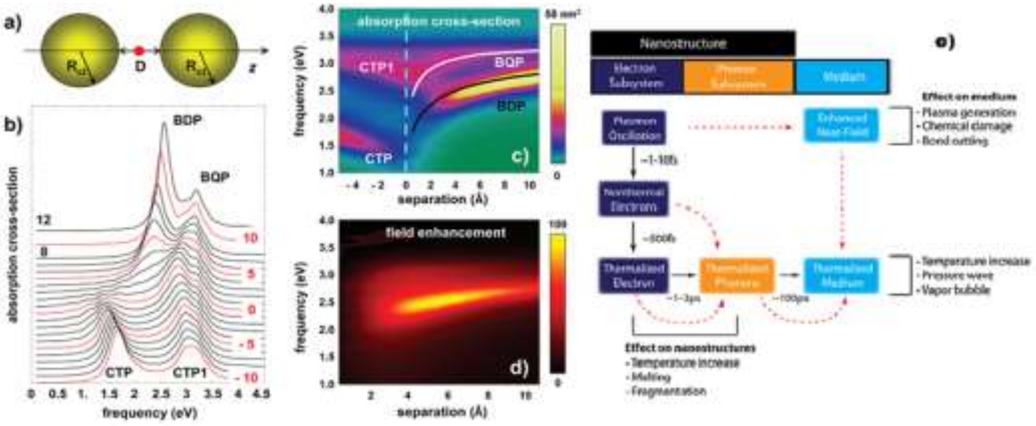

Figure 13. Schematic (a) geometry of the nanoparticle dimerenhancement determined from the fields (redpoint). (b) Optical absorption cross-section using TDDFT. (c)Optical absorption cross-section. (d) Calculated TDDFT field enhancement as function of the interparticle separation and frequency ω.adopted from reference [82]. (e)mechanisms of energy absorption and dissipation in laser-excited plasmonic nanostructures creating an enhanced near-field in the medium around the nanostructure[87].Copyright © 2013 Elsevier B.V. All rights reserved.

Standard micro and nano fabrication tools were used to investigate a chip-scale resonant plasmonic nanostructures, in order to manipulate light on the plasmonic chips from nano to micro scales significantly improved the coupling efficiency of the single plasmonic element[88]. The investigation of silver Atomic layer deposition (ALD) films over a complex 3D nanotopography with special interestin the films' microstructure and conformality demonstrated a reproducible means for depositing ultra-thin plasmonic material within the confines of a high aspect ratio nanopore[89]. The use of a hexagonal boron nitride (hBN) substrate for Ag is found to shift plasmonic coupling towards surface modes, both diminishing bulk losses and enhancing the surface plasmon resonance (SPR) peak amplitude[90]. Ultrafast carrier relaxation and recombination dynamics of relativistic Dirac fermions in gapless linear band structures of optically increased negative dynamic conductivity in wide terahertz (THz) range[91].

7. CONCLUSION

A variety of approaches is explored, and continues to emerge for the enhancement of plasmonic organic solar cells.In this review, we have described recent advances in organic and organic/inorganic hybrid solar cells and their methods in terms of plasmonics.We have highlighted how these methods can provide detailed insights into the microscopic origin of organic plasmonic solar cells. Experimental and theoretical works on the absorption properties of some plasmonic organic solar cells were discussed. Materials for plasmonics/ effects and efficiency have also been reviewed. We further reviewed some factors that affect the enhancement of some of these organic solar cells taking into consideration the shape and sizes. We ended this review by discussingPlasmonics for/and the enhancement of organic solar cells and its applications.

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