

## Comparison of Different types of Solar Cells – a Review

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**Abstract:** This paper deals with the various concepts of solar cells which include crystalline silicon solar cells, thin film plasmonic solar cells and dye sensitized solar cells. The scattering from metal nano particles near their localized Plasmon resonance is a promising way of increasing the light absorption in thin-film solar cells. Dye-sensitized solar cells have the potential of high commercial appeal, low cost investments, and high-efficiency conversion.

**Key words:** Plasmonic solar cell, Dye sensitized solar cell, photonic

### I. Introduction

The increasing demand for energy, have pushed mankind to explore new technologies for the production of electrical energy using clean, renewable sources, such as solar energy, wind energy, etc. Among the non-conventional, renewable energy sources, solar energy affords great potential for conversion into electric power. The conversion principle of solar light into electricity, called Photo-Voltaic or PV conversion. There are large varieties of solar cells available of which crystalline silicon solar cells are mostly used.

A plasmonic solar cell is another concept of solar cells [1]. The term 'Plasmonics' refers to the science and technology dealing with manipulation of electromagnetic signals by coherent coupling of photons to free electron oscillations at the interface between a conductor and a dielectric. This phenomenon is observed mainly in metallic nano particles (MNP).

A dye-sensitized solar cell (DSSC) is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photo electrochemical system [2]. The dye-sensitized solar cells (DSSC) provide a technically and economically credible alternative concept to present day p-n junction photovoltaic devices. In contrast to the conventional systems where the semiconductor assume both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor.

This paper mainly deals with the plasmonic and dye-sensitized solar cells and a very little about conventional PV device in the next sections.

### II. Conventional P-N Junction Pv Device

Photovoltaic, the conversion of sunlight to electricity, are a promising technology that may allow the generation of electrical power on a very large scale. It works on the basic principle of photovoltaic effect where when a photon of energy  $h\nu$  which is equal or greater than the energy gap, is absorbed by the semiconductor material the electron from the valence band gets excited to the conduction band and the excess energy, if any, gets dissipated by interaction with matter (phonon scattering). A solar cell is essentially a p-n junction under illumination. The electrons (holes) should be collected before they recombine with holes (electrons). Current due to light depends on how many photons with energy  $> E_G$  (band gap) are absorbed and how efficiently the resulting EHPs (Electron Hole Pairs) are collected [3].

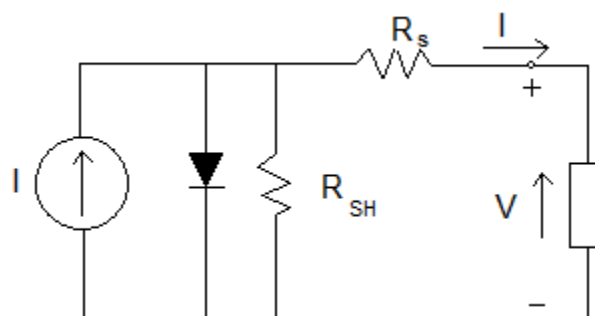


Fig 1: Schematic of Electrical circuit of the solar cell

### III. Plasmonic Solar Cell

A new method for increasing the light absorption that has emerged recently is the use of scattering from noble metal nano particles excited at their surface Plasmon resonance. The term ‘Plasmonics’ refers to the science and technology dealing with manipulation of electromagnetic signals by coherent coupling of photons to free electron oscillations at the interface between a conductor and a dielectric. Conventional crystalline Si solar cells require thick absorption layers for complete absorption, due to which 40% of price goes in buying crystalline Si itself. Therefore, to reduce cost there has been great interest in thin film solar cells with film thicknesses in the range 1–2  $\mu\text{m}$  [4]. Light scattering from a small metal nano particle embedded in a homogeneous medium is nearly symmetric in the forward and reverse directions. This situation changes when the particle is placed close to the interface between two dielectrics, in which case light will scatter preferentially into the dielectric with the larger permittivity.

The scattered light will then acquire an angular spread in the dielectric that effectively increases the optical path length (Fig 1). Light is preferentially scattered and trapped into the semiconductor thin film by multiple and high-angle scattering, causing an increase in the effective optical path length in the cell. Moreover, light scattered at an angle beyond the critical angle for reflection ( $16^\circ$  for the Si/air interface) will remain trapped in the cell. In addition, if the cell has a reflecting metal back contact, light reflected towards the surface will couple to the nano particles and be partly reradiated into the wafer by the same scattering mechanism. As a result, the incident light will pass several times through the semiconductor film, increasing the effective path length. Due to these properties of the Plasmon resonance we get Absorption enhancement by 10 to 100 folds & increased optical path length and hence we can have significant reduction in the thickness of the solar cell.

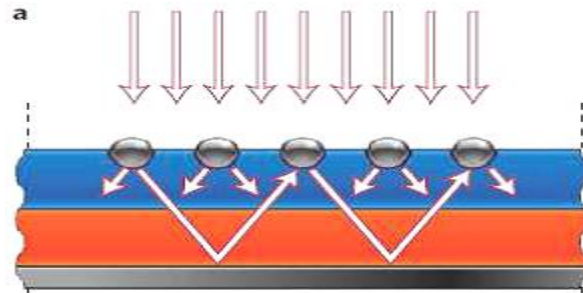


Fig 2: Light trapping by scattering from metal nano particles at the surface of the solar cell.

#### 1. Design Principles (Em) For Psc:

There have been design principles stated in the literature, but these are purely based on the Electromagnetic consideration. Metal nano particles (MNPs) are strong scatterers of light at wavelengths near the plasmon resonance, which is due to a collective oscillation of the conduction electrons in the metal. For particles with diameters well below the wavelength of light, a point dipole model describes the absorption and scattering of light well. The scattering and absorption cross-sections are given by:

$$C_{\text{scat}} = \frac{1}{6\pi} \left( \frac{2\pi}{\lambda} \right)^4 |\alpha|^2$$

$$C_{\text{abs}} = \frac{2\pi}{\lambda} \text{Im}[\alpha]$$

Where Polarizability is

$$\alpha = 3V \left[ \frac{\left( \frac{\epsilon_p}{\epsilon_m} - 1 \right)}{\left( \frac{\epsilon_p}{\epsilon_m} + 2 \right)} \right]$$

Where V is the particle volume,  $\epsilon_p$  is the dielectric function of the particle and  $\epsilon_m$  is the dielectric function of the embedding medium. When  $\epsilon_p = -2\epsilon_m$  the particle polarizability will become very large. This is known as the surface Plasmon resonance. At the surface Plasmon resonance, the scattering cross-section can well exceed the geometrical cross section of the particle.

Let us define a term called Albedo which is given by:

$$\text{Albedo} \cong \frac{C_{\text{scat}}}{C_{\text{scat}} + C_{\text{abs}}}$$

From above formula it is can be concluded that when the MNP is large the  $C_{\text{scat}}$  is much higher than  $C_{\text{abs}}$  as it follows square dependence on Volume (which is internally dependent on cube of radius) as opposed to linear dependence of  $C_{\text{abs}}$ . Therefore larger MNP size gives larger Albedo. On the other hand with increase in diameter the effective distance of the dipole from the Si top increases and therefore we have lower coupling

efficiency with larger MNP size. Therefore we can set our first design principle as follows (with a tradeoff between Albedo and coupling efficiency requirements):

- Larger MNP - Larger Albedo (Should be around ~50-100nm in diameter)
- Larger MNP - Lower coupling efficiency

Similarly for larger coverage (many MNPs) we would get larger scattering cross section but here the absorption cross section would also become significant (many MNPs hence higher absorption). Therefore second design principle can be stated as:

- Larger Coverage - Higher  $C_{scat}$   
~10-20% Coverage
- Larger Coverage - Higher  $C_{abs}$

On the same lines the spacer thickness (spacer : the material in which the MNP is placed, normally  $Si_3N_4$ ) have to be optimized to deal with the tradeoff between Albedo and fraction of light scattered in Si.

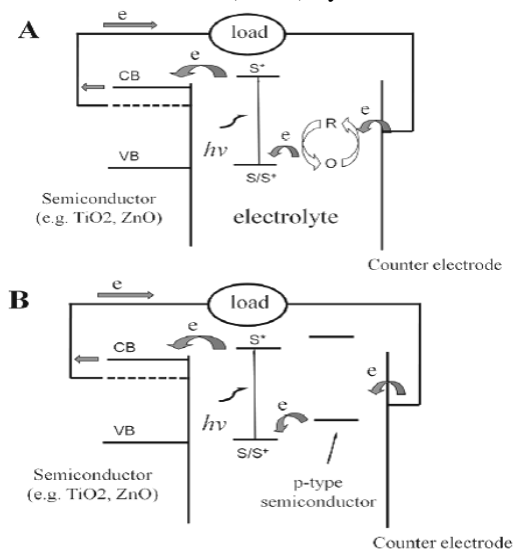
- Larger spacer thickness - Larger Albedo
- Larger spacer thickness - lesser fraction of light scattered into the substrate

Also other parameters like Distribution of Particles / Inter-particle distance need to be optimized.

#### IV. Dye Sensitized Solar Cells (DSSC)

DSSCs differ from conventional semiconductor devices in that they separate the function of light absorption from charge carrier transport. Dye sensitizer absorbs the incident sunlight and exploits the light energy to induce vectorial electron transfer reaction. Thus DSSCs have the following advantages comparing with the Si based photovoltaic: (1) It is not sensitive to the defects in semiconductors such as defects in Si. (2) The semiconductor-electrolyte Interface (SEI) is easy to form and it is cost effective for production. (3) It is possible to realize the direct energy transfer from photons to chemical energy. An intriguing feature in the nano crystalline  $TiO_2$  film is that the charge transport of the photo-generated electrons passing through all the particles and grain boundaries is highly efficient. In DSSC, the initial photo excitation occurs in the light absorbing dye as shown in Scheme 1 as in Fig.3.

Nano porous semiconductors such as  $TiO_2$  not only act as support for dye sensitizer but also function as electron acceptor and electronic conductor. Subsequent injection of electrons from the photo-excited dye into the conduction band of semiconductors results in the flow of current travelling across the nano crystalline  $TiO_2$  film to the charge collecting electrode and then to the external circuit. Sustained conversion of light energy is facilitated by regeneration of the reduced dye sensitizer either via a reversible redox couple (O/R), which is usually  $I_3^-/I^-$  (Scheme 1A) or via the electron donation from a p-type semiconductor (Scheme 1B). Scheme 1A shows the mechanism of a traditional wet-type DSSC containing redox couples in electrolyte. The photo anode, made of a nano porous dye-sensitized n-type semiconductor, receives electrons from the photo-excited dye sensitizer which is thereby oxidized to  $S^+$ . The neutral dye sensitizer (S) can be regenerated by the oxidation reaction ( $R \rightarrow O$ ) of the redox species dissolved in the electrolyte. The mediator R will then be regenerated by reduction at the cathode ( $O \rightarrow R$ ) by the electrons circulated through the external circuit.



**Scheme1.** Operation mechanism of the dye sensitized electrochemical solar cell (DSSC).S: Dye sensitizer,  $S^*$ : Electronically excited dye sensitizer,  $S^+$ : oxidized dye sensitizer O/R:redox couple (e.g,  $I_3^-/I^-$ ). CB: Conduction band for semiconductors, VB: valence band for semiconductors. (A) Wet-type DSSC with redox couple in the liquid electrolyte. (B) Solid state DSSC with a p-type semiconductor to replace the electrolyte containing the redox couple.

The need for DSSC to absorb far more of the incident light was the driving force for the development of mesoscopic semiconductor materials with an enormous internal surface area. The major breakthrough in DSSC was the use of a high surface area nano porous  $TiO_2$  layer.

**Fig 3: Scheme of operation of DSSC**

A single monolayer of the dye on the semiconductor surface was sufficient to absorb essentially all the incident light in a reasonable thickness (several  $\mu\text{m}$ ) of the semiconductor film.  $\text{TiO}_2$  became the semiconductor of choice with advantage properties of cheap, abundant, and non-toxic. The choice of dye is also an important parameter. The first organic-dye photosensitization was reported in 1887 [12]. In traditional DSSC, the standard dye was tris(2,2'-bipyridyl-4,4'-carboxylate) ruthium (II) ( $\text{N}_3$  dye). The function of the carboxylate group in the dye is to attach the semiconductor oxide substrate by chemisorptions [9]. The dye must carry attachment groups such as carboxylate or phosphonate to firmly graft itself to the  $\text{TiO}_2$  surface. The attachment group of the dye ensures that it spontaneously assembles as a molecular layer upon exposing the oxide film to a dye solution. It will make a high probability that, once a photon is absorbed, the excited state of the dye molecule will relax by electron injection to the semiconductor conduction band. The photovoltaic performance of  $\text{N}_3$  dye has been irreplaceable by other dye complexes since 1993 [9]. A credible challenger was identified with tri (cyanato-2,2',2''-terpyridyl-4,4',4''-tricarboxylate) Ru (II) (black dye) [11], whose response extends 100 nm further into the IR than that of the  $\text{N}_3$  dye [10]. It is not until recently that a high molar extinction coefficient heteroleptic ruthium complex has been synthesized and demonstrated as more efficient sensitizer for DSSCs. To construct a full solid-state DSSC, a solid p-type conductor should be chosen to replace the liquid electrolyte. The redox levels of the dye and p-type materials have to be adapted carefully as Scheme 1B shows. It results in an electron in the conduction band of n-type semiconductors (e.g.,  $\text{TiO}_2$ ) and a hole localized on the p-type conductor. Hole transporting amorphous materials have been used in nanocrystalline  $\text{TiO}_2$  based DSSC to transport hole carriers from the dye cation radical to the counter electrode instead of using the  $\text{I}_3^-/\text{I}^-$  redox species.

## V. Conclusion

In the past few years, the field of plasmonics has emerged as a rapidly expanding new area for materials and device research mainly because of the large array of tools that have become available for nano scale fabrication and nano-photonics characterization, and also because of the availability of powerful electromagnetic simulation methods that are critical for understanding and harnessing plasmon excitations. Solid state and printable DSSCs will have a promising future for the development of efficient and flexible optoelectronics. Even though DSSCs have lower light to electricity conversion efficiency than the best thin film Si solar cells, they are considerably cheaper to be made and feasible to be printed on flexible substrate. Amorphous Si thin-film cells degrade in sunlight over time, and their efficiencies also go down if the sunlight hits them at some special incident angle. DSSCs are longer lasting and work at wide angles. In addition, DSSCs work more efficiently in indoor light, because the dye absorbs diffuse sunlight as well as fluorescent lighting. With improvements on nonvolatile electrolytes, organic dyes and nano porous semiconducting electrode, cheaper but more robust DSSCs will definitely take their share in the solar cell markets competing with the traditional thin film solar technologies.

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