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A Review on Design and Performance Evaluation of Solar Cells and Panels

SumanLataTripathi, *SobhitSaxena,SushmitaKumari
School of Electronics and Electrical Engineering, Lovely Professional University, Punjab India
**Email:sobhit.23364@lpu.co.in*

Abstract

In the era of green energy evolution, the design of efficient solar cell has become a potential area for the researchers. A semiconductor based solar cell converts light energy directly into electricity through photovoltaic effect. This reviewdescribes a comparative analysis for different generationsof photovoltaic (PV) solar cells to achieve high conversion efficiency from PV solar systems.The fabrication of solar cells has gone through several modifications in process steps from 1st-generation to 4th-generation solar cell. The conventional solar cells are mainly based on solid state material like Si cell that were grown on single crystal Si wafers. Paper deals withdevelopment ofthin-filmbased solar cell including dye sensitized solar cells and organic solar cells with more improvement in cell efficiency. The present paper covers the development of solar cell based on material, technology and fabrication steps to achieve efficient solar cell with high conversion efficiency.

Keywords: - Solar cell, Photovoltaic Cell, Single-Diode Model, Double-Diode Model,Renewable.

1. Introduction

A photovoltaic cell(PV)develops voltage proportional to the light intensity fall on the photosensitive semiconductor junction.Small PV cells (Figure 1) can be grouped in form a panels where panels are grouped into arrays of PV module.The photovoltaic effect is shown by direct-band semiconductors various materials [1]. When light fall down on a solar cell, the incoming photons can be reflected, absorbed or passed through it. The energy of incident photon on semiconductor junction of solar cell must be greater than the band gap energy difference of the cell [2-3].A semiconductor p–n junction can be made to operate as a solar cell[4-6].

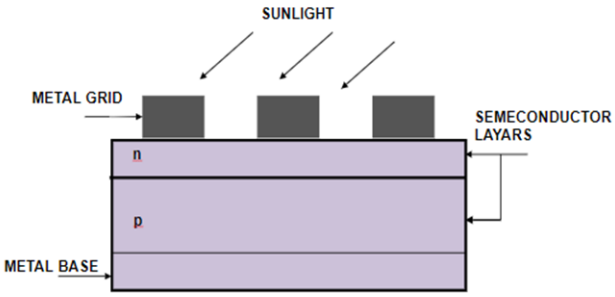

Figure 1 Photovoltaic cell StructureN-type silicon to P-type silicon.

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Design of Solid state Solar cell on TCAD

A prefabrication design and analysis of solar cell can be done on visual TCAD. Figure 2 (a)&(b) describes a silicon based solid state solar cell structure. Figure 3(a) present current versus voltage developed in presented cell. The simulated structure provides open circuit voltage developed upto ~ 0.7V and current density ~35mA/cm2. Figure 3(b) present anode current variation with respect to time showing a sharp peak in beginning when light energy converted into electrical current. The overall efficiency of presented cell is ~23%.

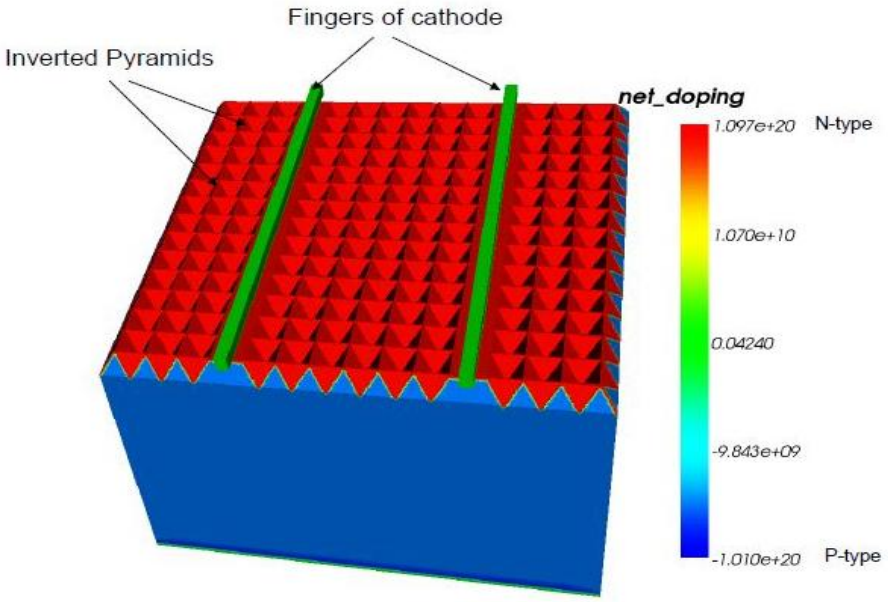

Figure 2(a)3-D view of solar cell array

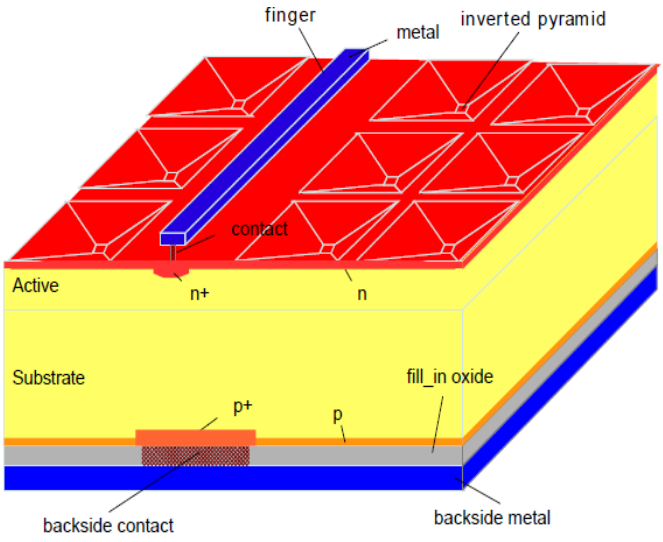

Figure 2(b) 3-D view of solid-sate solar cell

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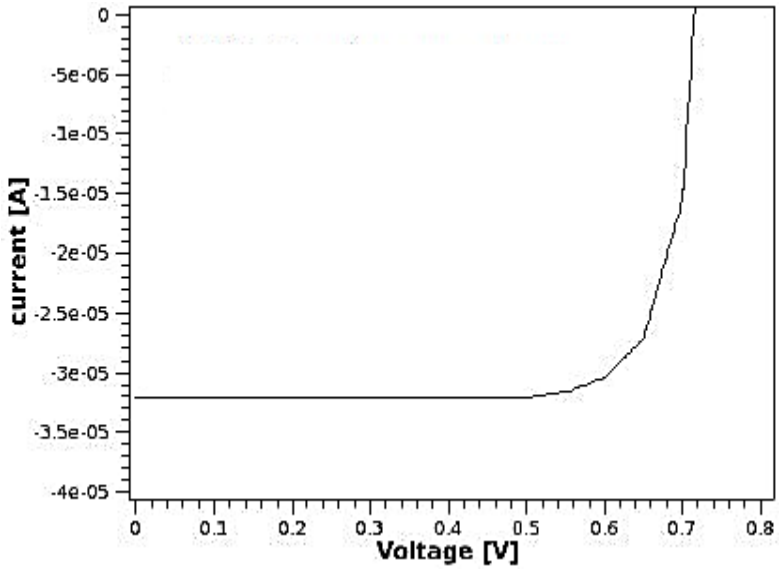

Figure 3(a) Current versus voltage characteristic of solid state solar cell

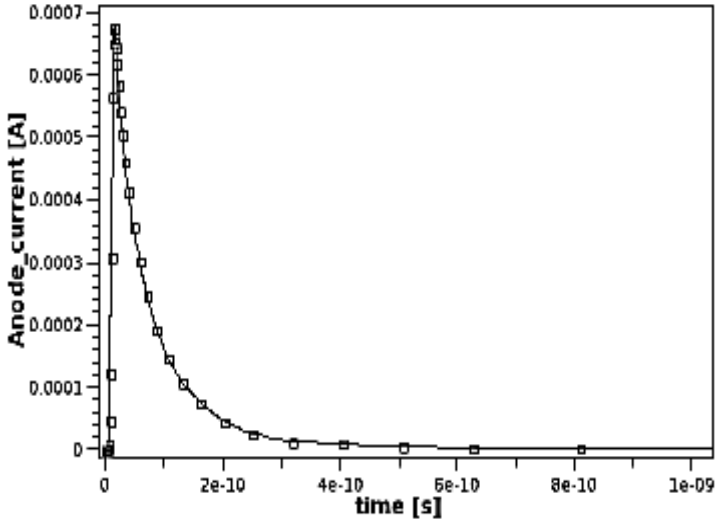

Figure 3(b) Anode current with respect to time

2. Fabrication process of solar cell

The nanoparticles based solar cells are now become popular for future development of solar cell. These solar cellhave low manufacturing cost than conventional silicon solar cell because the nanoparticles are synthesizable at room temperature[4].Figure 4 shows a new submerged-glowdischarge plasma (SGDP) utilises the nanoparticle synthesis for solar cells fabrication[8][9] that is useful because its non-equilibrium plasmawith fast reactions at atmospheric pressure.

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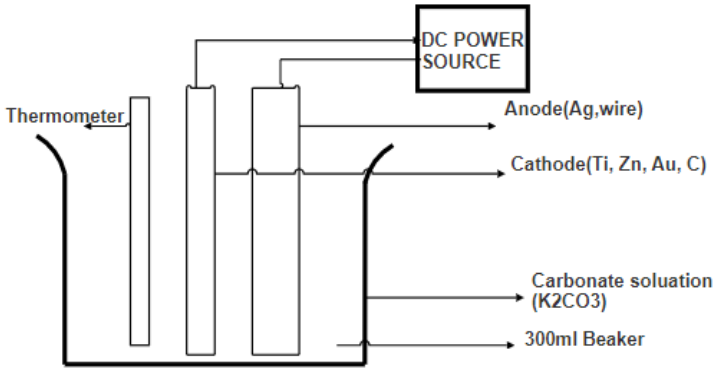

Figure 4SGDPmethod [4]

TiO2 is a dielectric material withwidebandgapranging 3.0eV-3.2eV.ZnOis an optoelectronic material that is widely used tuneable transparent conductive oxide. The efficiency of the photovoltaic layer in solar cell can be improved with Au NP nanoparticles.Carbon nanoparticles(CNP)based solar cell have also been fabricatedwith betterefficiency [10-12].The fabrication steps of carbon nanoparticle based cell are shown in Figure 5 (a)-(e).

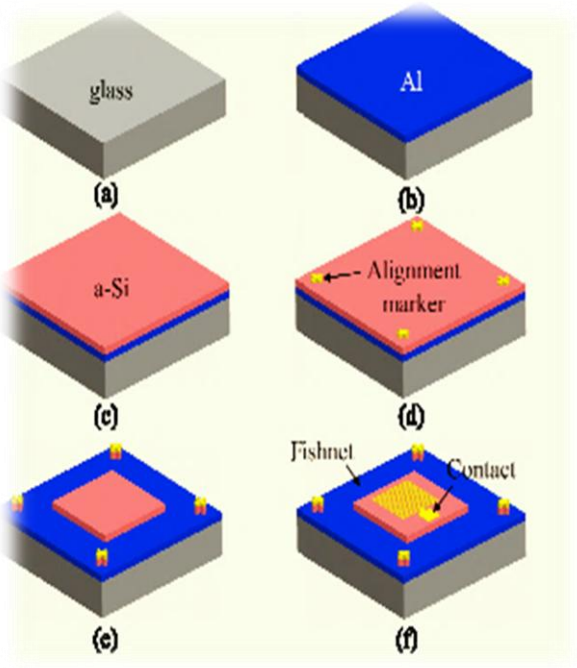

Figure 5fabrication process

4)The fishnet structures are aligned and arranged on A-Si by EBL. A 2nm Cr with 10 nm Gold is used followed by lift-off process Figure5 (f).

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3. Development of Solar Cells

Conventionalsolar cells are thin Si-wafers that transform optical energy (solar) into electrical energy based on principle of photovoltaic effect. Inadvanced photovoltaic cell, there is electron-hole creation in each cell composed of 2 different semiconductor material layers (n-type layer and p-type layer).The photovoltaic solar cells are classified into following categories[13-14]:

3.1First-Generation [14] [16]

It is conventional and the most popular technology because of its easy process and high power efficiencies. Figure 6 shows silicon based solar cell thatis further divided into two category named as:

- **Single-Crystalline Si solar cell**
  In this, the solar cells are made from thin wafers of Si. These are called mono-crystalline solar cells [17][18].
- **Multi-crystalline Si solar cell**
  Basically, the molten silicon is poured into a cast in form of multiple-crystal. The highest recorded efficiency of polycrystalline silicon cell is 21%.Also, It is cost effective than mono–crystalline silicon solar [18].

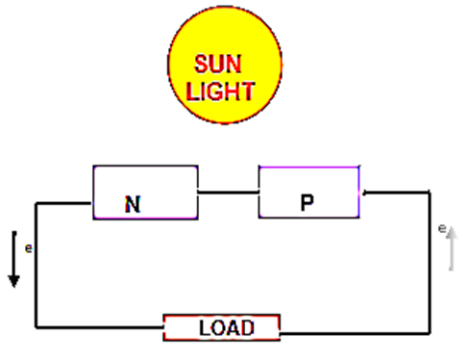

Figure 6Semiconductor p-n junction solar cell

3.2Second-Generation Solar Cells

These cells have 350 µm thick light absorbing layers whilethin-film solar cells which have very thin light absorbing layers up to 1 µm thickness (Figure 7). Thin film solar cells are categorised as[13] [14]:

- **A-Si (Amorphous-silicon)**
  It is non-crystalline form of cell that is widely used in pocket calculators, domestic application,remote facilities and buildings[19][20].
- **Cadmium-telluride**
  Cadmium telluride(CdTe) PV is available at lower costs than conventional solar[22][23][24].
- **CIGS(Copper indium gallium di-selenide)**
  The CIGS materials have high absorption coefficient with the help of thinner photosensitive film than of other semiconductor materials [25].

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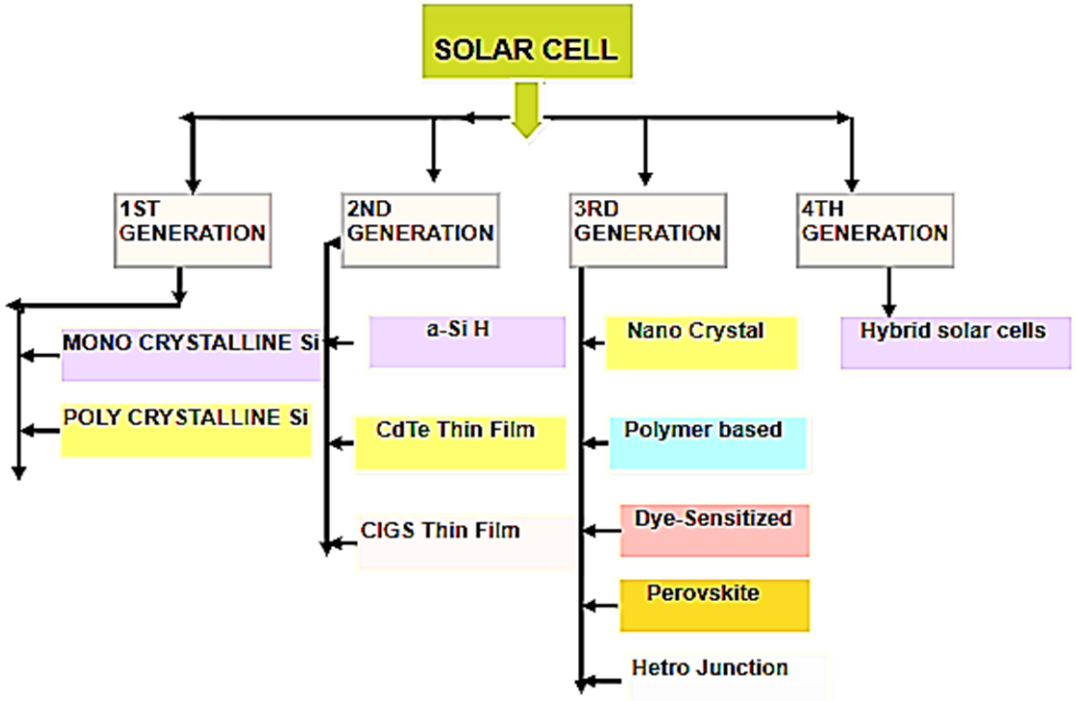

Figure 7Solar cell technology generations[15] [16]

3.3Third-Generation Solar Cells

In this category, the solar cells developed, have efficiency up to 40%[14]. A detailed investigation is required to achieve the required efficiency.

Third-generation solar cells areclassified as[25]

- **Nano-crystal solar cells**
  The nano-crystals are typically made on silicon, CdTe and the base material isnormally silicon or different organic conductors.
- **Polymer solar cells**
  A flexible polymer solar cell based on organic solar cell concept thatdevelops electrical power from sunlight based on principle of photovoltaic effect.
- **Dye-sensitized solar cells (DSSC)**
  It enables the user to convert artificial as well as natural light into energy to be supplied to different electronic devices[27].
- **Perovskite solar cells**
  Perovskite solar cells are latesttechnology. The perovskitessolar cells can have efficiency approximately equal to31%. Althoughsome current issues with perovskite solar cells but they have better stability and durability. These materialsmay degrade over the time and thereforeleads to a drop in overall efficiency[14].
- **Multiple-junction(MJ) solar cells**

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These cell have multiple p–n junctions made of different semiconductor materials that produce electricity in response to different range wavelength of light. Multi-junction cells have shown performance above than 43% [27].

3.4Fourth-Generation Solar Cells

4th G solar cells offer various advantages. Several researchers areworking to get better efficiency bu using different fabrication technique. **Hybrid solar cells**made of conjugated polymers (organic) that absorb light by the donor and transport by the holes. The acceptor and electron transporters are used in inorganic materials based hybrid cells[28].

4. Advances in Solar Cell

The average solar cell efficiency is 15% approximately that means 85% of the sunlight does not get converted into electricity when incident on photosensitive junction[25].

Quantum-dot solar cell

Quantum dot has enormous potential that replaces bulk materials with other materials (e.g. silicon, copper indium gallium selenide (CIGS) or CdTe). Quantum-dots showsa tunablebandgapacross a good range of energy levels by its changing size of dots[26]. Quantum dots are also known as artificial atoms[29].

Light-Sensitive Nanoparticles

The quantum dots can actually function outdoors which was lacking in previous designs for any practical applications to the solar market. The colloidal quantum dots don't bind to air. Therefore, it can maintain their stability outside[29] and helpful in increasing radiant light absorption. Panels using this technology improveby 8% efficiencyduring conversion of sunlight.

Gallium-Arsenide

These cells havehighly efficient triple junction cellsthat arecapable enough to capture chemically transformed sunlight[26].

5. New Solar Applications

Solar cell based Roadways

Scientists are searching for a ways toroads and line highways with solar panels. This would help overcome an industrial scale solar system, whichneed to cover up too much land. Figure 8 present a solar cell based roadways.

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Figure 8 Solar cell based roadways

Floating Solar cell arrays

A wide scale solar plant has growing their importance which is floating on the water, since the Earth's surface is covered 70%of water. Figure 9 present a floating solar cell based panel.

Figure 9 Floating Solar Plant

The maximum power tracking point (MPPT) was proposed to achieve maximum power from solar intensity with sensors and different searching technique[28]. Figure 10 represent DC-Dc connections for MPPT searching circuit technique.

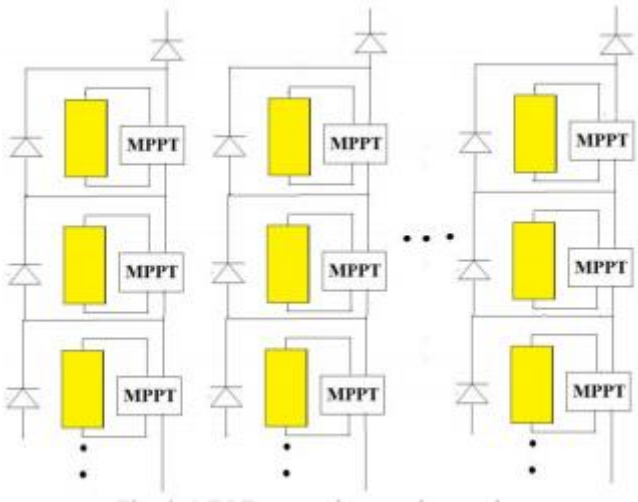

Figure 10Connections in MPPT Panel

Solar Power Plant

Design of solar power plant also plays important role in green energy evaluation of pollution free environment. Concentrated solar power and photovoltaic solar power both together are to be developed at large scale for proper exploitation of these technologies [21]. Figure 11 represents a solar energy based power plant.

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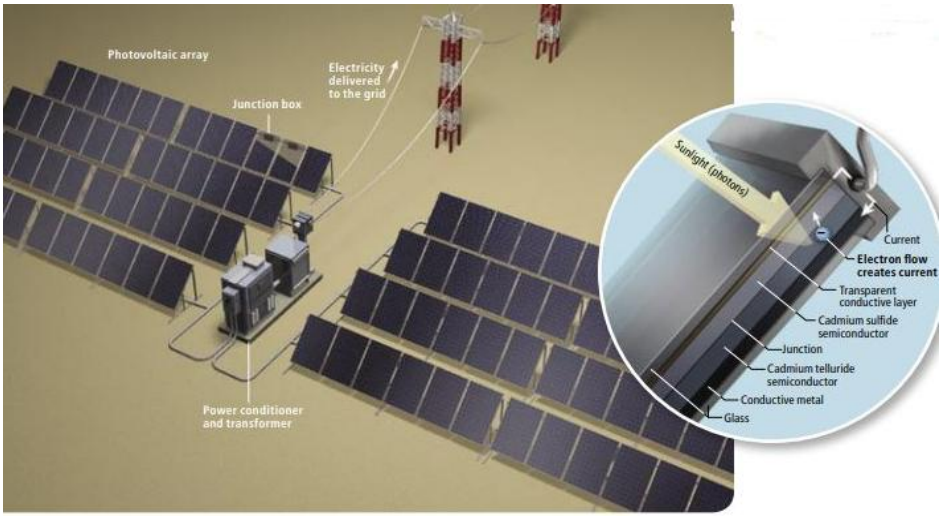

Figure 11Solar Power Plant

Satellitebased solar cell

This type of solar cell basedtechnology has potential to capture significant amount of sunlight 90%. India, Japan and China are investing a lot of money in these technologies [29]. Figure 12 represent a satellite based solar power station.

Figure 12 Satellite based Solar Power

6. Conclusion

Solar power generation developedis potential candidate for futurenon-conventional sources of electricity. Solar power has many advantages in comparison to other forms of conventional energy sources [30]. This paper discussed theprocess technology of utilizing various solar energy based on advance solar cell design and fabrications. Use of nanoparticles can improve solar cell efficiency.Solar cell has enormous potential for future development its environmentally friendly synthesis method and supportive to country economy.

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