



Criteria for Realizing the Multi – Crystal Silicon Solar Cell (PV Cell) With Efficiency, Which Could be used in Electricity Generation in Nigeria

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Received: November 2015

Revised and Accepted: December 2015

Abstract

This paper investigated the criteria used for development of efficient multi-crystalline silicon solar cell (PV cell). The criteria's that will enhance the production of silicon solar cell and cheaper method of obtaining silicon solar cell that is sufficiently pure was discussed. The objectives of this paper is to review the optimization processes involved in silicon solar cell design, quantum dots and ultra-efficient solar cells, extending the solar cell band gap into infrared, multiple excitons from one photon. The researcher find out that by far the most common material for solar cells (and all other semiconductor devices) is crystalline silicon. Crystalline silicon solar cells come in three primary categories (Single Crystal or Mono-Crystalline Wafers, Poly or Multi crystalline and Ribbon Silicon and others). Poly or Multi crystalline made from cast ingots – large crucibles of molten silicon carefully cooled and solidified. Poly or Multi crystalline cells are cheaper than single crystal cells, but also somewhat less efficient. Poly or Multi crystalline cells can easily be formed into square shapes that cover a greater fraction of a panel than monocrystalline cells, and this compensates for their lower efficiencies. Attention should be directed to the manufacture of semi-conductor devices like multi – crystal silicon solar cell (PV cell) devices, as there lies the future of electronics which can be accessible and very cheap for the purpose of electricity generation and other related applications.

Keywords: Multiple excitons, Multi – crystal silicon, Electricity, Solar panel and Efficiency.

1.0 INTRODUCTION

One of the problems of Africa and Nigeria in particular is erratic power supply. The factors

responsible for erratic power supply in Nigeria and Africa cannot be too far from our inability to

give attention to other sources of power generation methods. Hydro power generation and thermal power generation are the two major methods of power generation used in Nigeria and Africa. The efficiency of these two methods is fairly good. The methods mentioned above produce noise and dangerous gases which are threat to human health (Jenny, 2007). Therefore we need to take advantage of the free resources like sunlight and air (solar energy and wind energy) which are available in abundant for the generation of electricity (Markvart, 2000). There is no pollution or noise involved in using renewable sources of energy for the purpose of power generation. The only problem with generation of electricity through solar energy and wind energy is the in availability of infrastructures or instruments used in the capturing and conversion process of these resources. For example, the solar cell used in capturing the sunlight is scarce and very costly

2.0 MATERIALS AND METHODS

Solar cell is also called the photovoltaic cell (PV cell). The solar panel is made up of groups of solar cells or PV cells. Solar cell is powered by the photon of light from the sun. Planck show that the energy E of incident photon = hf - (1) (Bode, 1945).

Where; h = Planck constant and f = the particles frequency. The photon energy generates quantum efficiency of the cell (this is the ratio of the incidence photon over generated carrier electrons).

Solar cell utilizes energy from the sun to generate electricity. Solar cells are solid-state semi-conductor devices that convert light directly to electricity (Anderson, 2001).

When semi-conducting materials such as multi-crystal silicon are exposed to sunlight, they release small amount of electricity. This process is known as PHOTOELECTRIC EFFECT. The process refers to the emission or ejection of electron from the surface of a metal in response to light. It is the basic process in which a solar electric or PV cell converts sunlight to electricity;

while the wind turbine system used in capturing the air into wind energy electricity is too costly. For the present, the price of electricity generated with this renewable energy method is too costly compare with the price of electricity generated with Hydro generation method and thermal generation method respectively (Drummond, 1996). This is one of the reasons why government, utility companies and individuals cannot afford to buy the required solar cells or wind turbine systems that are needed to set up an efficient functional solar generation power plant in Nigeria/Africa. Scientist has discovered that multi – crystal silicon solar cell is very cheap with low efficiency (Anderson, 2001). Therefore, this is the major reason why we decided to investigate the criteria for realizing the efficient multi – crystal silicon solar cell (PV cell), which can be accessible and very cheap for the purpose of electricity generation and other related applications.

$$E = h\nu_0 + \frac{1}{2} m v^2 \quad - \quad - \quad - \quad (2) \text{ or}$$

$$h\nu = w_0 + kE \quad - \quad - \quad - \quad (3)$$

Sunlight is made up of photons, or particles of solar energy (Shive, 1959). Photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a solar cell, they may either be reflected or absorbed, or they may pass right through. Only the absorbed photons generate electricity. When this happens the energy of the photon is transferred to an electron in an atom of the solar cell (which is actually a semiconductor). With its newfound energy, the electron escapes from its normal position in an atom of the semiconductor material and becomes part of the current in an electrical circuit. By leaving its position, the electron causes a hole to form special electrical properties of the solar cell- a built in electrical field provides the voltage needed to drive the current through an external load (such as light bulb) (Drummond, 1996).

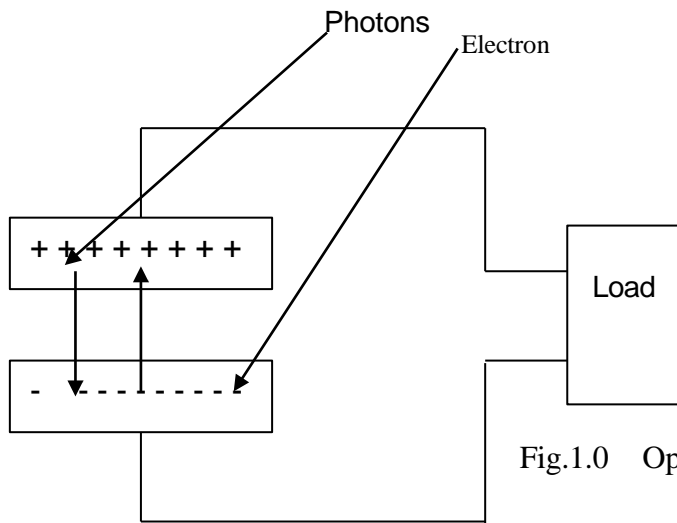


Fig.1.0 Operation of a PV cell or Solar cell.

2.1 OPTIMIZATION OF SILICON SOLAR CELL DESIGN

Figure 2 below illustrates the absorption and recombination profiles in a typical silicon cell, calculated using the p-n junction theory and the materials parameters presented in Table 1 below. From the graphs, we can make the following observations:

1. Absorption of light close to the band gap (near infrared) is poor

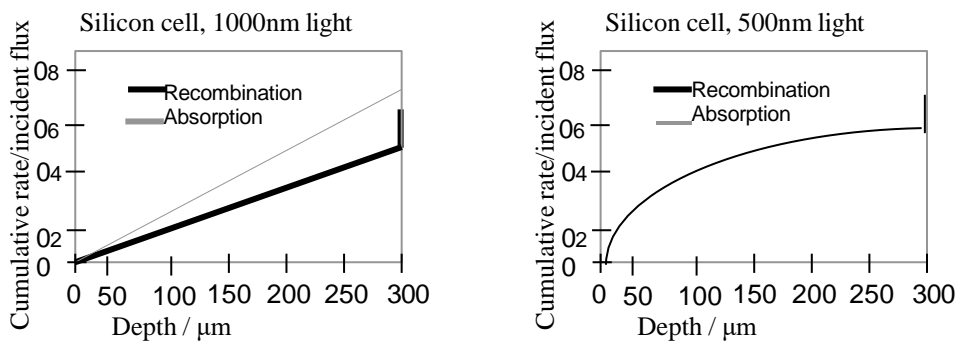


Fig. 2.0 represents the simulated cumulative absorption and recombination rates for a silicon solar cell with the parameters in Table 1.0 under monochromatic light at two different wavelengths at a bias close to open circuit. In each graph the cumulative absorption and recombination, normalized to the total incident flux, were plotted against depth through the cell. For a good cell at short circuit, recombination should be zero and cumulative absorption should be close to one. At open circuit (illustrated) the final values of recombination and absorption are equal (Markvart, 2000).

Table 1.0 Typical silicon material and cell parameters used for the calculations in Fig. 2.0

	EMITTER (N TYPE)	BASE (P TYPE)
Thickness/ μm	0.5	300
Doping/ cm^{-3}	1×10^{19}	1×10^{16}
Minority carrier diffusion constant/ $\text{cm}^2 \text{s}^{-2}$	2	40
Minority carrier lifetime/s	1×10^{-6}	5×10^{-6}
Minority carrier diffusion length/ μm	14	140
Surface recombination velocity/ cm s^{-1}	10000	10000
Reflectivity	0.05	
Absorption: at $500\text{nm}/\text{cm} \pm 1$	15000	
At $1 \mu\text{m}/\text{cm}^{-1}$	35	

2. Bulk recombination in the p region is the most important recombination process.

3. Rear surface recombination is important, particularly for photogeneration by red and infrared light. Front surface recombination and recombination in the junction region are relatively unimportant for photogeneration by long wavelengths.

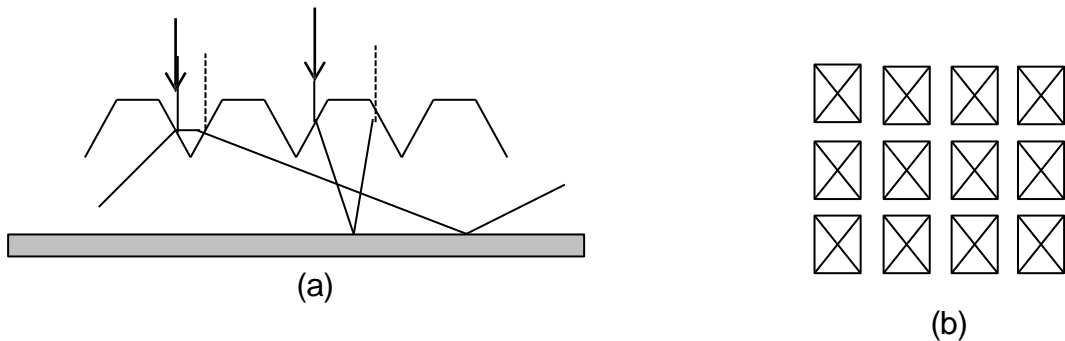


Fig. 3 surface texturing: (a) shows how the refraction of light rays at the texture increases the optical path length relative to light normally incident on a plane surface; (b) shows a plane view of regular pyramids.

To improve the performance of the cell it is necessary to maximize the absorption of red light, minimize recombination at the rear surface, and minimize series resistance (Nwankwo, 2005). Bulk recombination is

determined mainly by the method of wafer growth, and for good quality silicon it is already as low as can be expected.

Thus the main challenges in crystalline silicon cell design are to:

1. Maximize absorption
 2. Minimize rear surface recombination
 3. Minimize series resistance
- These are discussed below.

2.1.1 Strategies to Enhance Absorption

- i. Texturing of front surface: This reduces the net reflection of light and increases the optical depth of the cell. Texturing can be achieved by treating with anisotropy chemical etc., which acts preferentially along the (111) crystal planes and leaves a pattern of pyramids on the surface. Regular pyramids can be produced on a mono-crystalline surface by photolithographic definition. Light trapping can be improved by using inverted pyramids, which improve the total internal reflection of light reflected from the back surface, by asymmetric pyramids, or by texturing the rear surface.
- ii. Optimization of contacts: Shading of the incident light by as much as 10%. Reducing contact area increases the

available surface area but increases the resistance either in the emitter, if the contacts are too sparse, or in the metal, if the fingers are too narrow. The optimum arrangement is a grid of narrow, dense, highly conducting fingers. One solution is to use narrow, deep contacts partly buried in the surface of the cell. This may reduce shading to a fraction of a percent of the surface. By embedding the contacts in the semiconductor, a larger contact area can be achieved without increasing the surface shading. The grooves are created by laser or mechanical etching, and are doped more heavily than the main emitter to improve conductivity. However, the large-scale preparation of such contacts is more costly than screen-printing.

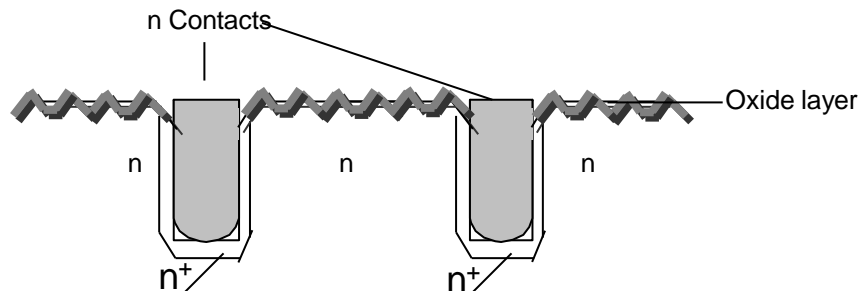


Fig. 4 Buried contacts. Differential n^+ doping in the contact grooves reduces series resistance.

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2.1.2 Strategies to Reduce Surface Recombination

Back surface field: A more heavily doped layer is formed at the back surface of the p type base by alloying with aluminum or by diffusion. This introduces a p⁺-p junction and presents a potential barrier to the minority electrons. This back surface field reflects electrons and reduces the effective rear surface recombination

velocity, to less than 100 cm s⁻¹. The extra p⁺-p junction also adds to the built in bias of the cell, and may enhance V_{oc} (Jenny, 2007). Front surface fields have also been used in some cell designs, but are less effective since the ratio of doping levels will be smaller.

2.2 QUANTUM DOTS AND ULTRA-EFFICIENT SOLAR CELLS

2.2.1 Limit of efficiency

The efficiency of solar cells is the electrical power it puts out as percentage of the power in incident sunlight. One of the most fundamental limitations on the efficiency of a solar cell is the 'band gap' of the semi-conducting material used in conventional solar cells: the energy required to boost an electron from the bound valence band into the mobile conduction band. When an electron is knocked loose from the valence band, it goes into the conduction band as a negative charge, leaving behind a 'hole' of positive charge. Both electron and hole can migrate through the semi-conducting material.

the electrodes. Photons with less energy than the band gap slip right through without being absorbed, while photons with energy higher than the band gap are absorbed, but their excess energy is wasted, and dissipated as heat. The maximum efficiency that a solar cell made from a single material can theoretically achieve is about 30%. In practice, the best achievable is about 25 % (Millian, 1970).

In solar cell, negatively doped (n-type) material with extra electrons in its otherwise empty conduction band forms a junction with positively doped (p-type) material, with extra holes in the band otherwise filled with valence electrons. When a photon with energy matching the band gap strikes the semiconductor, it is absorbed by an electron, which jumps to the conduction band, leaving a hole. Both electron and hole migrate in the junction's electric field, but in opposite directions. An electric current is generated. If the circuit is open, then an electrical potential or voltage is built up across

It is possible to improve on the efficiency by stacking materials with different band gaps together in multi-junction cells. Stacking dozens of different layers together can increase efficiency theoretically to greater than 70 percent. But this results in technical problems such as strain damages to the crystal layers. The most efficient multi-junction solar cell is one that has three layers: gallium indium phosphide/gallium arsenide/germanium (GaInP/GaAs/Ge) made by the National Center for Photovoltaics in the United States (US), which achieved an efficiency of 34 percent in 2001 (Bode, 1945).

Recently, entirely new possibilities for improving the efficiency of photovoltaics have opened up.

2.2.2 Quantum Dot Possibilities

Quantum dots or nanoparticles are semi-conducting crystals of nanometre (nm) dimensions. They have quantum optical properties that are absent in the bulk material due to the confinement of electron-hole pairs (called excitons) on the particle, in a region of a few nanometres.

The first advantage of quantum dots is their tunable band-gap. It means that the wavelength at which they will absorb or emit radiation can be adjusted at will: the larger the size, the longer the wavelength of light absorbed and emitted (Choon, 1987). The greater the band-gap of a solar cell semiconductor, the more energetic the

photons absorbed, and the greater the output voltage. On the other hand, a lower band-gap results in the capture of more photons including those in the red end of the solar spectrum, resulting in a higher output of current but at a lower output voltage. Thus, there is an optimum band-gap that corresponds to the highest possible solar-electric energy conversion, and this can also be achieved by using a mixture of quantum dots of different sizes for harvesting the maximum proportion of the incident light.

Another advantage of quantum dots is that in contrast to traditional semiconductor materials that are crystalline or rigid, quantum dots can be molded into a variety of different forms, in sheets or three-dimensional arrays. They can easily be combined with organic polymers, dyes, or made into porous films (“organic Solar Power”, this series). In the colloidal form suspended in solution, they can be processed to

2.3 EXTENDING THE SOLAR CELL BAND GAP INTO INFRARED

Infrared photovoltaic cells – which transform infrared light into electricity- are attracting much attention, as nearly half of the approximately 1000Wm^2 of the intensity of sunlight is within the invisible infrared region. So it is possible to use the visible half direct lighting while harvesting the invisible for generating electricity (Cunningham, 1958). Photovoltaic cells that respond to infrared ‘thermovoltaics’ – can even capture radiation from a fuel-fire emitter; and co-generation of electricity and heat are said to be quiet, reliable, clean and efficient. A 1cm^2 silicon cell in direct sunlight will generate about 0.01W, but an efficient infrared photovoltaic cell of equal size can produce theoretically 1W in a fuel-fired system.

One development that has made infrared photovoltaics attractive is the availability of light-sensitive conjugated polymers-polymers with alternating single and double carbon (Sometimes carbon-nitrogen) bonds. It was discovered in the 1970s that chemical doping of conjugated polymers increased electronic conductivity several orders of magnitude. Since then, electronically conducting materials based on conjugated polymers have found many

create junctions on inexpensive substrates such as plastics, glass or metal sheets.

When quantum dots are formed into an ordered three-dimensional array, there will be strong electronic coupling between them so that excitons will have a longer life, facilitating the collection and transport of ‘hot carriers’ to generate electricity at high voltage. In addition, such an array makes it possible to generate multiple excitons from the absorption of a single photon (James, 1979).

Quantum dots are offering the possibilities for improving the efficiency of solar cells in at least two respects, by extending the band gap of solar cells for harvesting more of the light in the solar spectrum, and by generating more charges from a single photon.

applications including sensors, light emitting diodes, and solar cells (Anderson, 2001).

Conjugated polymers provide ease of processing, low cost, physical flexibility and large area coverage. They now work reasonably well within the visible spectrum.

In order to make conjugated polymers work in the infrared range, researchers at the University of Toronto wrapped the polymers around lead sulphide quantum dots tuned (by size) to respond to infrared (Donald, 1975). The polymer poly [(2-methoxy-5-(2'-ethylhexyloxy)-p-phenylenevinylene)] (MEH-PPV) on its own absorbs between ~400 and ~600nm. Quantum dots of lead sulphide (PbS) have absorption peaks that can be tuned from ~800 to ~2000 nm. Wrapping MEH-PPV around the quantum dots shifted the polymer’ absorption into the infrared.

The researchers demonstrated a convincing, albeit very small photovoltaic effect, giving a power-conversion efficiency of 0.001%. Professor Ted Sargent, the lead scientist, is optimistic however, emphasizing that their device is simply a prototype of how to capture

infrared energy (Lorenzo, 1994), and predicts commercial implementation within 3-5 years.

2.4 MULTIPLE EXCITONS FROM ONE PHOTON

Researchers led by Arthur Nozik at the National Renewable Energy Laboratory Golden, Colorado in the United States really grabbed the headline when they demonstrated that the absorption of a single photon by their quantum dots yielded – not one exciton as usually the case – but three of them (Green, 1981).

The formation of multiple excitons per absorbed photon happens when the energy of the photon absorbed is far greater than the semiconductor band gap. This phenomenon does not readily occur in bulk semiconductors where the excess energy simply dissipates away as heat before it can cause other electron hole pairs to form. But in semi-conducting quantum dots, the rate of energy dissipation is significantly reduced, and the charge carriers are confined within a minute volume, thereby increasing their interactions and enhancing the probability for multiple excitons to form.

3.0 FURTHER FINDINGS

Various materials have been investigated for solar cells. There are two main criteria efficiency and cost. Efficiency is a ratio of the electric power output to the light power input. Ideally, near the equator at noon on a clear day, the solar radiation is approximately 1000W/m². So a 10% efficient module of 1 square meter can power a 100W light bulb. Costs and efficiencies of the materials vary greatly. By far the most common material for solar cells (and all other semiconductor devices) is crystalline silicon (Ibrahim, 1979). Crystalline silicon solar cells come in three primary categories:

1. **Single Crystal Or Mono-Crystalline Wafers** made using the Czochralski process. Most commercial mono-crystalline cells have efficiencies on the order of 14%; the sun-Power cells have high efficiencies

The researchers report a quantum yield of 300 percent for 2.9nm diameter PbSe (lead selenide) quantum dots when the energy of the photon absorbed is four times that of the band gap. But multiple excitons start to form as soon as the photon energy reaches twice the band gap. Quantum dots made of lead sulphide (PbS) also showed the same phenomenon.

The findings are further confirmation of Nozik's theoretical prediction in 2000 that quantum dots could increase the efficiency of solar cells through multiple exciton generation. In 2004, researchers Richard Shaller and Victor Klimov at Los Alamos National Laboratory New Mexico were the first to demonstrate this phenomenon experimentally using quantum dots made of lead selenide.

“We have shown that solar cells based on quantum dots theoretically could convert more than 65 percent of the sun's energy into electricity, approximately doubling the efficiency of solar cells”, said Nozik (Gross et al, 1979)

around 20%. Single crystal cells tend to be expensive, and because they are cut from cylindrical ingots, they cannot completely cover a module without a substantial waste of refined silicon. Most mono-crystalline panels have uncovered gaps at the corners of four cells. Sunpower and Shell Solar are among the main manufacturers of this type of cells.

2. **Poly or Multi crystalline** made from cast ingots – large crucibles of molten silicon carefully cooled and solidified. These cells are cheaper than single crystal cells, but also somewhat less efficient. However, they can easily be formed into square shapes that

cover a greater fraction of a panel than monocrystalline cells, and this compensates for their lower efficiencies. See GT Solar HEM Furnace, Bp Solar, Sharp Solar and Kyocera Solar.

3. **Ribbon Silicon** formed by drawing flat thin film molten silicon and has a multicrystalline structure. These cells are typically the least efficient, but there is a cost savings since there is very little silicon waste since this approach does not require sawing from ingots.

These technologies are wafer-based manufacturing. In other words, in each of the above approaches, self supporting wafers of ~300 micrometers thick are fabricated and then

soldered together to form a module. Thin film approaches are module based. The entire module substrate is coated with the desired layers and a laser scribe is then used to delineate individual cells. Two main thin film approaches are amorphous silicon and CIS:

4. **Amorphous Silicon Films** are fabricated using chemical vapor deposition techniques, typically plasma enhanced (PE-CVD). These cells have low efficiencies around 8%.
5. **CIS** stands for general chalcogenide films of $\text{Cu}(\text{In}_x\text{Ga}_{1-x})(\text{SexS}_{1-x})_2$. While these films can achieve 11% efficiency, their costs are still too high (IEEE, 1980).

4.0 CONCLUSION

The researcher investigated the criteria for realizing the multi – crystal silicon solar cell (PV cell) with efficiency. Quantum dot possibilities of silicon solar cell was discussed and analyzed. The criteria's that will enhance the production of silicon solar cell that will be a cheaper method of obtaining silicon that is sufficiently pure was discussed.

The researcher find out that by far the most common material for solar cells (and all other semiconductor devices) is crystalline silicon. Crystalline silicon solar cells come in three primary categories (Single Crystal or Mono-Crystalline Wafers, Poly or Multi crystalline and Ribbon Silicon and others). Poly or Multi crystalline made from cast ingots – large

5.0 RECOMMENDATION

Much attention should be directed to the manufacture of semi-conductor devices like

crucibles of molten silicon carefully cooled and solidified. Poly or Multi crystalline cells are cheaper than single crystal cells, but also somewhat less efficient. Poly or Multi crystalline cells can easily be formed into square shapes that cover a greater fraction of a panel than monocrystalline cells, and this compensates for their lower efficiencies. Attention should be directed to the manufacture of semi-conductor devices like multi – crystal silicon solar cell (PV cell) devices with efficiency, as there lies the future of electronics which can be accessible and very cheap for the purpose of electricity generation and other related applications.

multi – crystal silicon solar cell (PV cell) devices with efficiency, as there lies the future of electronics engineering, and the production of

the solar panel should be made in our country to reduce the cost. Indigenous authors should be

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