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Mitigating Excessive heating and improving the Efficiency of Solar Cell: A Review

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ABSTRACT

Solar photovoltaic energy is the most abundant, efficient and secured source of energy for both small and large scale processes. It employs the conversion of the light component of the solar energy with sufficient frequency into electricity directly using solar cell. However, solar energy always reaches the earth in the form of two merged components i.e. light and heat. Whereas the light component is essentially useful for electricity generation in solar cells, the heat component increases the panel's temperature and therefore raises its resistance, hence decreases its efficiency. This review focuses on the two methods proposed for mitigating the excessive heating in solar cells thereby creating an avenue for increasing the efficiency of solar cells even beyond 25 ^{0}C.

Keywords: Phase change material, spectral splitting, PV cell, Thermal collector and Efficiency

I.INTRODUCTION

Incident sunlight can be converted into electricity by photovoltaic conversion using a solar panel. Solar panel consists of individual cells that are large-area semiconductor diodes, constructed so that light can penetrate into the region of the p-n junction, (Gilbert, 2004). The junction formed between the n-type silicon wafer and the p-type surface layer governs the diode characteristics as well as the photovoltaic effect. Light is absorbed in the silicon, generating both excess holes and electrons. These excess charges can flow through an external circuit to produce power.

Solar Cell System has many competitive advantages in comparison to other renewable energy resources. For instance, wind-turbine is very dependable to geographical location and has very high noise pollution if applied in residential area. Other example is micro-hydro, which depends on altitude and available in very limited locations. Furthermore, nuclear energy should be forgotten since it has high radioactive risk. On the other side, solar cell system has characteristics of zero pollution, no radioactive risk, and compact, portable and can be installed in any location and has relatively high energy availability in any location on the earth surface in a year round. In general, solar cell array, which cover a residential roof house can supply the basic electrical energy needs of the residences that live in the house, almost a year round. These competitive advantages of solar cell system over other renewable energy resources make solar cell system the most favorite renewable energy resource.

Mostly, world primary energy consumption is based on energy that already has but mainly of this energy can be depleted. Renewable energy contributes 14% energy to the world. Therefore, we should increase the usage of renewable energy. The bad effects on environment caused by the production and consumption of energy have resulted in harsh environmental impacts across the globe. The supply of energy is expected to remain as much as necessary in coming years. However, imbalance of energy consumption is common around the world. Energy consumption is high in most developed countries. On the other hand, the developing countries need to consume more energy to ensure economic growth. The economic development of many countries is caught up due to "energy poverty".

The major sources of energy in the world are oil, coal, natural gas, hydro energy, nuclear energy, renewable combustible wastes and other energy sources. Combustible wastes include animal products, biomass and industrial wastes. Renewable energy will be given concentration in this project.

PHOTOVOLTAIC SOLAR POWER

The energy generated by incident solar energy (light) into electricity is termed as Photovoltaic solar power. This is done using photovoltaic solar cells.

- Solar Electricity
- Photovoltaic Solar Lighting
- Photovoltaic Cooling

SEMICONDUCTOR MATERIAL

Semiconductors: Are materials with conductivity between that of conductors and insulators; e.g. germanium Ge, silicon Si, GaAs, GaP, InP. Material for which gap between valence band and conduction band is small; (gap width in Si is 1.1 eV, in Ge 0.7 eV). At T = 0, there are no electrons in the conduction band, and the semiconductor does not conduct (lack of free charge carriers); At T > 0, some fraction of electrons have sufficient thermal kinetic energy to overcome the gap and jump to the conduction band; fraction rises with temperature; e.g. at 20^{o}C (293 K), Si has 0.9×10^{10} conduction electrons per cubic centimeter; at 50^{o}C (323 K) there are 7.4×10^{10}. electrons moving to conduction band leave "hole" (covalent bond with missing electron) behind; under influence of applied electric field, neighboring electrons can jump into the hole, thus creating a new hole, etc. ⇒ holes can move under the influence of an applied electric field, just like electrons; both contribute to conduction. In pure Si and Ge, there are equally many holes ("p-type charge carriers") as there are conduction electrons ("n-type charge carriers"); pure semiconductors also called "intrinsic semiconductors" (Neamen, 2012).

When we consider solid–state materials in terms of their electrical properties, we generally group them according to electrical conductivity as: conductors, semiconductors, and insulators. The distinction between these types of materials is relative.

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A pure semiconductor is strongly temperature dependent, and serves well as a temperature–sensitive resistance. Trace levels of impurities inhibit this thermistor behavior, and will strongly increase its conductive properties. Since a semiconductor is a poor conductor, it can accommodate separation(s) of charge and localized E–fields. Localized E–fields can block or enhance current flow. Since a semiconductor is a conductor, it can sustain an electrically significant transport of mobile charge carriers. And since the electrical conductivity of a semiconductor is strongly dependent on type and level of impurities, this feature can be patterned to provide channels, paths, and junctions. It is this degree of control that allows us to create many variants of current and voltage characteristics, and means for their control. Semiconductor devices may range from tiny semiconductor switches to huge power transistors (Abbas and Ahmad, 1986).

PRINCIPLES OF SOLAR PHOTOVOLTAIC CELLS

The working principle of solar cells is based on the photovoltaic effect, i.e. the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation (Neamen, 2012). The photovoltaic effect is closely related to the photoelectric effect, where electrons are emitted from a material that has absorbed light with a frequency above a material-dependent threshold frequency Neamen, (2012) in 1905, Albert Einstein observed that this effect can be explained by assuming that the light consists of well-defined energy quanta, called photons. The energy of such a photon is given by

$$E = h\nu \qquad (4)$$

where h is Planck’s constant and ν is the frequency of the light. For his explanation of the photoelectric effect Einstein received the Nobel Prize in Physics in 1921.

The photovoltaic effect can be divided into three basic processes:

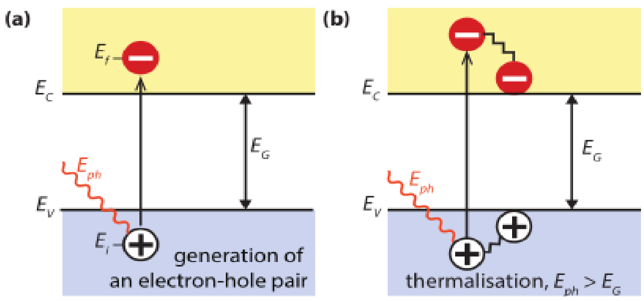

Figure 1.5: (a) Illustrating the absorption of a photon in a semiconductor with bandgap E_g. The photon with energy E_{ph}= hν excites an electron from E_i to E_f. At E_i a hole is created.

(b) If E_{ph}>E_g, a part of the energy is thermalized (Würfel, 2005).

Generation of Charge Carriers Due to the Absorption of Photons

Absorption of a photon in a material means that its energy is used to excite an electron from an initial energy level E_i to a higher energy level E_f, as shown in Fig. 1.5 (a). Photons can only be absorbed if electron energy levels E_i and E_f are present so that their difference equals to the photon energy, $h\nu = E_f - E_i$. In an ideal semiconductor electrons can populate energy levels be- low the so-called valence band edge, E_v, and above the so called conduction band edge, E_c. Between those two bands no allowed energy states exist, which could be populated by electrons. Hence, this energy difference is called the bandgap, $E_g = E_c - E_v$. If a photon with energy smaller than E_g reaches an ideal semiconductor, it will not be absorbed but will traverse the material without interaction (Würfel, 2005).

Separation of the Photo-Generated Charge Carriers in a Junction.

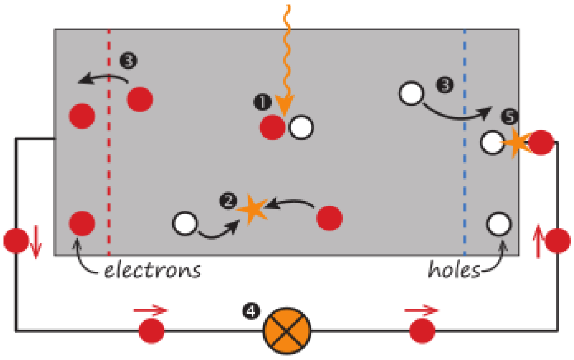

Figure 1.6: A very simple solar cell model (Sze, 2002)

Absorption of a photon leads to the generation of an electron-hole pair. Usually, the electrons and holes will combine. With semi-permeable membranes the electrons and the holes can be separated. The separated electrons can be used to drive an electric circuit, after the electrons passed through the circuit, they will recombine with holes (Sze, 2002).

Usually, the electron-hole pair will recombine, i.e. the electron will fall back to the initial energy level E_i, as illustrated in Fig. 1.6. The energy will then be released either as photon (radiative recombination) or transferred to other electrons or holes or lattice vibrations (non-radiative recombination). If one wants to use the energy stored in the electron-hole pair for performing work in an external circuit, semipermeable membranes must be present on both sides of the absorber, such that electrons only can flow out through one membrane and holes only can flow out through the other membrane as illustrated in Fig. 1.6. In most solar cells, these membranes are formed by n- and p-type materials (Sze, 2002).

A solar cell has to be designed such that the electrons and holes can reach the membranes before they recombine, i.e. the time it requires the charge carriers to reach the membranes must be shorter than their lifetime. This requirement limits the thickness of the absorber (Würfel, 2005).

Collection of the Photo-Generated Charge Carriers at the Terminals of the Junction.

Finally, the charge carriers are extracted from the solar cells with electrical contacts so that they can perform work in an external circuit. The chemical energy of the electron-hole pairs is finally converted to electric energy.

After the electrons passed through the circuit they will recombine with holes at a metal absorber interface (Würfel, 2005).

Typical values for solar cell efficiencies are 10-15% for thin film cells, 15-20% for crystalline silicon cells, and 30% or more for concentrating systems (focus sunlight onto small area sun, up to 1000 sun concentration). The best theoretical values for efficiencies are 20-28% for normal cells. The reason for this low value is simply that not all of the energy reaching a solar cell from sunlight can be converted into electricity. About 25% of incoming photons have energies below the band gap energy and cannot produce an EHP. About 30% of the photons will have too much energy and will either be re-emitted or wasted as heat. This accounts for a total of 55% of the energy that can't be used. Of the ~75% of absorbed photons, about 43% of the energy from absorbed photons is lost as heat. In addition to this, electrons can be lost due to recombination within the semiconductor material.

Furthermore, the distance between the light source and the panel also contributes in the increase/decrease in the output power of the panel. Thus a short distance was maintained as stated in chapter three which yield a rapid shoot-up in the efficiency.

Spectrum Splitting

In this method, optically splitting material or devices are employed in order to filter out the unwanted frequencies and allow the wanted ones to pass through to the photovoltaic cell. Ahmad *et al.* (2015) developed a novel spectrally splitting hybrid solar receiver by combining a simple dichroic filter and a liquid channel as a selective absorbing medium. The combination acts as a band pass filter for silicon solar cells. In their research they optimised the design geometry for a commercially available linear roof top micro-concentrator. The optics of the concentrator at its focal region was also investigated using ray tracing. A simple 5-layer dichroic filter made of titanium dioxide and silicon dioxide was designed, optimised and fabricated with a focus placed on manufacturing simplicity. It wasat the end that such a filter was able to direct 54.5% of the concentrated light to thesiliconphotovoltaiccells;which translates to26.1%ofthisenergyinto electricity which is significantly higher than their 20.6% efficiency under the full spectrum. This is due to the fact that73.3%oftheincident flux is within the cell's relatively high spectral response range, which can be efficiently converted into electricity. The rest of the spectrum can be collected as high temperature heat. This research shows the possibility of employing low-cost direct absorption- dichroic filtering hybrid receivers in liner concentrators. Imenes and Mills (2005) explained that photothermal processes tend to convert solar energy to heat with an efficiency that is relatively constant over the solar spectrum, depending only on the optical properties of the window and/or coating of the thermal receiver employed. Photovoltaic conversion, on the other hand, is highly wavelength-dependent and most efficient when converting photons of energies close to the PV cell band-gap energy. Photons below the band-gap energy pass through the active area of the cell without being absorbed, and are ultimately dissipated as heat in other parts of the cell. Photons of energy larger than the band-gap can only be partly utilized, and the remainder of their energy is also dissipated as heat. Because of these factors, an optimal method of using solar cells is to direct onto them only the part of the solar spectrum for which high conversion efficiency can be achieved, and to recover the radiation outside this range by diverting it to a second receiver, i.e., thermal, chemical, or a different PV band-gap receiver. Very high conversion efficiencies can be achieved by directing different parts of the solar spectrum onto PV cells with matching energy absorption bands. In theory, efficiencies in the range of 85% are possible (Luque 1993: Brown and Green, 2001). This may be realized either by stacking the cells on top ofeach other in an optical and electrical series connection, commonly called a cascade, tandem, or multijunction cell, or placed next to each other in a parallel connection. Sunlight isincident on the largest band-gap cell where short-wavelength photons exciteelectrons to a higher potential. Light not absorbed by the upper cell is transmittedto the second cell ofa smaller band-gap value, where longer wavelengths will exciteelectrons to a potential somewhat lower than in the first cell. In theory, any numberof different cells may be stacked on top of each other to fully utilize the incident solarspectrum. Transmissive and reflective filtering methods Cape *et al.*(1978)and Masden and Backus [1978] studied a two-cell system in which the concentrated incident solar spectrum was split between GaAs and Si cells by a dielectric multilayer dichroic mirror. Predicted theoretical efficiencies were around the 30% mark, and a similar practical device reported by Vander Plas*et al.*(1979)measured efficiencies of 27% at 113 suns concentration and 26% at 489 suns concentration, using Si and AlGaAs cells. Moon *et al.*(1978)considered the same system ofSi and AlGaAs cells in combination with a computer-optimized dielectric multilayer filter, fabricated on a polished, fused silica substrate and mounted at 22_ to the incident beam. The filter and cells were tested experimentally, giving a total efficiency of 28.5% at 165 suns and AM1.23 spectrum, which represented a marked improvement in performance compared to the single PV receiver systems. For an ideal filter this corresponded to 31% efficiency for the two cells combined. Allowing for losses in the concentrator optics and filter, the system efficiency was estimated to 25%.

II.PHASE CHANGE MATERIAL

Phase change materials as the name implies are class of materials that usually undergoes a change in phase when subjected to changing temperature. They are classified into low, medium and high temperature. This class of materials has been proposed by many researchers as a very good alternative for use in photovoltaic cooling system. It involves attaching the PCM material on the rear side of the solar panel so that as temperature rises, the heat is transferred to the PCM from the panel and thus makes the temperature of the panel to remain stable. This is mostly in the combined photovoltaic solar thermal system and the PCM is usually used for double purposes of cooling the panel as well as generating heat for other applications. Malvi*et al.* (2011) worked on the energy balance model of combined photovoltaic solar thermal system incorporating phase change material. The main aim of the work is to minimize energy losses both in the PV as well as in the ST systems. In their work, they figured out the major characteristics to be considered in the choice of PCM material includes thermal conductivity, specific heat capacity, chemical stability, volume variation during phase change, supercooling and degree of solidification. The work though conducted earlier than the work of Tao *et al.* (2015) mentioned above, however, it highlights some of the issues raised later by Tao *et al.* (2015) who reviewed the usage of Phase Change materials in photovoltaic systems for thermal regulation and electrical efficiency improvement. They explained that though various cooling methods have been devised and utilized with recent introduction of PV-PCM system. Such systems have the capability of both regulating the heat of the PV system and improving the efficiency of the PV system. However, such system if utilized only for thermal regulation and efficiency improvement, it will be uneconomical and therefore not useful and can't be transmitted to the market for commercial purposes. In the light of this, another hybrid system is introduced which will perform the two tasks mentioned above as well as an additional task of supplying heat for a thermal system. This system is called PV-ST-PCM (PhotoVoltaic-Solar Thermal-Phase Change Material) system. In such system, the PCM is made to perform two functions in the PV system and one function in the ST system. Such improvement will make it more economical, versatile and marketable. One of the biggest challenges with this system is in the selection of materials, selection of suitable PCMs and environmental impacts. They explained in their conclusion that the choice of materials that will withstand the corrosion effect of PCMs over time, ability of the PCM to absorb heat from the PV system and immediately transfer or transmit same to the ST system within a short time, environmental impact due to degradability over time, reliability in the long term as well as commercial availability are all serious factors that must be overcomed or improved upon to pave way for an economically viable, technologically advanced and versatile system. Some of these problems can be overcomed by more research in the area of materials selection and improvement like using special alloys, and martensites, PCM selection in the type and category as either organic, inorganic or eutectic materials and improvement through overcoming of sub-cooling and supercooling by addition of some hybrid nanoparticles. Christopher *et al.* (2014) worked on global analysis of photovoltaic energy output enhanced by phase change material cooling with the sole aim of utilising phase change material as a heat sink that will prevent overheating of solar cell and at the same time increasing the efficiency of a solar photovoltaic cell. He utilizes the one-dimensional energy balance model with ambient temperature, wing speed and irradiance extracted from ERA – Interim reanalysis climate data over a 1.5^0 longitude x 1.5^0 latitude global grid. Phase change material (PCM) was utilized for temperatures ranging from 0^0C to 50^0C. It was observed that PCMs response to higher temperatures and its effect on the performance of PV cells is higher in areas with high amount of insolation such as Africa, South America, Arabia and Southern Asia as compared with areas of low insolation especially Europe. The discerning point here is that there is high positive correlation between average high temperatures and higher optimal PCM melting temperatures. However, a cost analysis of utilising PCMs for cooling of PV cells indicates that it's not economically feasible for a single junction PV cell. But technically, this technique will be highly feasible in many parts of India and Nigeria which are located in the tropics with both having a high amount of solar insolation daily throughout the year.Oussama*et al. (2015)*while performinga numerical investigation of a photovoltaic thermal (PV/T) collector focuses on the development of a hybrid solar collector PV/T. They held that this model will be applied to optimize the operation of the PVT collector in the semi-arid climate. A mathematical model was developed to determine the dynamic behavior of the collector, based on the energy balance of six main components namely a transparent cover, a PV module, a plate absorber, a tube, water in the tube and insulation. It has been validated by comparing the obtained simulation results with experimental results available in literature, where good agreement has been noted. They concluded that the uncovered PV/T yields the best electrical performance, payback period and economic efficiency.

III.CONCLUSION

The efficiency of a solar photovoltaic system can be significantly improved if there is success in the choice of suitable PCM based on thermophysical properties. Same goes to the successful choice of a suitable spectrum splitter based on optical characteristics. This will go a long way in improving the efficiency of the solar cell which has been a source of concern for both researchers and manufacturers. Such improvement can be seen in the result obtained by Ahmad *et al* (2015) where the Si cells used was able to convert 26.1% of the energy into electricity which is a significant improvement as compared to the 20.6% efficiency of same type of cells under the full spectrum.This is also the case with PCMs as reported by Tao *et al.* (2015) and Malvi*et al.* (2011) that the PV performance can be improved by average of about 9% with a corresponding increase in temperature of water to about 20^0C.

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