SOLAR ELECTRICITY FROM SOLAR ENERGY AND FUTURE APPLICATIONS

Vinay Kumar Singh
Department of Physics, Raja Singh College, Siwan, Bihar, India, Pin-841226.

ABSTRACT: The present study examines the solar energy and solar cell research in extensively. Energy is an essence of any human activity. The energy system at the beginning of the 21st century is characterized by six billion people that live on the Earth and the total energy consumption of approximately 1.3×10^{10} kW. In order to make photovoltaic power generation an economically viable option, the cost of solar cell devices has to be lowered. South Africa represents the spot of highest solar insulation in the world. The main reason is that South Africa has the perfect climate for solar energy. A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction.

Keywords: Solar Energy, Solar Cells, Photovoltaic, Solar Electricity, Thin Film Solar Cells, Solar Materials, etc.

I. INTRODUCTION

The Sun is an average star. It has been burning for more than 4-billion years, and it will burn at least that long into the future before erupting into a giant red star, engulfing the earth in the process. Solar energy is clean, free and inexhaustible and is plentifully available on our planet in comparison with other energy sources. It is estimated that the amount of solar energy radiated by the sun in a day (1.34×10^{31} J/day) can satisfy the world's energy requirements in a whole year. Electricity produced from photovoltaic (PV) systems has a far smaller impact on the environment than traditional methods of electrical generation. During their operation, PV cells need no fuel, give off no atmospheric or water pollutants and require no cooling water. Unlike fossil fuel (coal, oil, and natural gas) fired power plants, PV systems do not contribute to global warming or acid rain. The use of PV systems is not constrained by material or land shortages and the sun is a virtually endless energy source. The solar radiation is an endless source of free energy to planet earth and could provide the entire current global energy needs even if used in partial capacity.

The device which converts solar energy into electricity is called solar cell or photovoltaic solar cell. Photovoltaic, or PV for short, is the word that describes converting sunlight into electricity: *photo*, meaning pertaining to *light* and *voltaic* meaning producing voltage. It took, more than 100 years, however, for the concept of electricity from sunlight to become more than a just an experiment. Photovoltaic solar energy is also known as *solar electricity or light-electricity*. The energy of solar radiation is directly utilized in mainly two forms:

- Direct conversion into electricity that takes place in semiconductor devices called *solar cells*
- Accumulation of heat in *solar collectors*.

So, solar cells and solar collectors are not the same systems. A group of solar cells is called photovoltaic panel. The direct conversion of solar radiation into electricity is often described as a *photovoltaic* (PV) energy conversion because it is based on the *photovoltaic effect*. Hence, Converting solar energy to electrical energy by means of solar cells is called *photovoltaic effect*. In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. The whole field of solar energy conversion into electricity is therefore denoted as the "*photovoltaic*". Photovoltaic literally means *light-electricity*. Because *photo* is a stem from the Greek word *phõs* meaning light and *Volt* is an abbreviation of Alessandro Volta's (1745-1827) name who was a pioneer in the study of electricity. Since a layman often does not know the meaning of the word photovoltaic, a popular and common term to refer to PV solar energy is *solar electricity*.

II. BIRTH OF THE PV CELL

In 1954, D.M. Chapin, C.S. Fuller and G.L. Pearson, of Bell Laboratory, patented a way of making electricity directly from sunlight using silicon-based solar cells. The next year, the Hoffman Electronics-Semiconductor Division announced the first commercial photovoltaic product that was 2% efficient, priced at $25 per cell, at 14 mill watts each, or $1,785 per watt (in 1955 dollars). By the mid-1960s, efficiency levels were nearing 10 percent. As an outgrowth of the space exploration in the 1960s-70s, PV development increased dramatically. But worldwide hostilities and the threat of war turned the world more and more away from oil and toward renewable energy. The types of solar cell are shown in fig. (1).

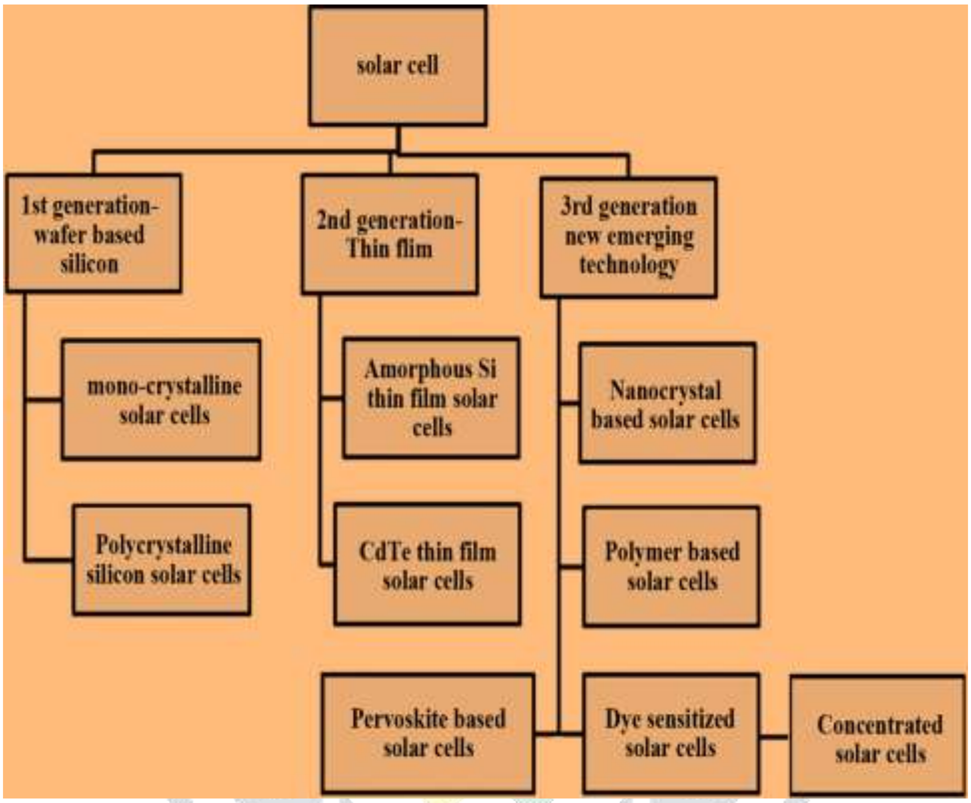

Figure 1: Various types of solar cell technologies and current trends of development

III. STEPS OF CONVERTING SOLAR ENERGY (LIGHT) INTO ELECTRICITY

- PV panels consist of semiconductors
- PV cells have two types of semiconductors: one positively charged and one negatively charged
- When light shines on the semiconductor, the electric field across the junction between these two layers causes an electric current
- The greater the intensity of light, the greater the flow of electricity.

IV. THE BEST CRITERIA FOR SOLAR CELL MATERIALS

It is not surprising that a lot of effort has been going and is going into the search for new semiconducting materials. The essential requirements for the ideal solar cell materials are:

(i) It must have band-gap (1.1eVto1.7 eV) or must have band gap from 1eV to 1.8eV.
(ii) It must have direct band structure
(iii) Good photovoltaic conversion efficiency
(iv) Cheap, non-toxic and easily available materials.
(v) Long-term stability
(vi) Easy, reproducible deposition suitable for large area production.
(vii) The dopant selected should have suitable energy level, solubility and an acceptable diffusion constant.

(viii) Cost of materials should be competitive.
(ix) It must have high optical absorption.
(x) It must have high electrical conductivity.
(xi) The raw material must be available in abundance and the cost of the material must be low.

V. SOLAR CELL STRUCTURE

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p-n* junction. Cross section of a solar cell. The schematic of the basic structure of a silicon solar cell is shown in fig. (2)

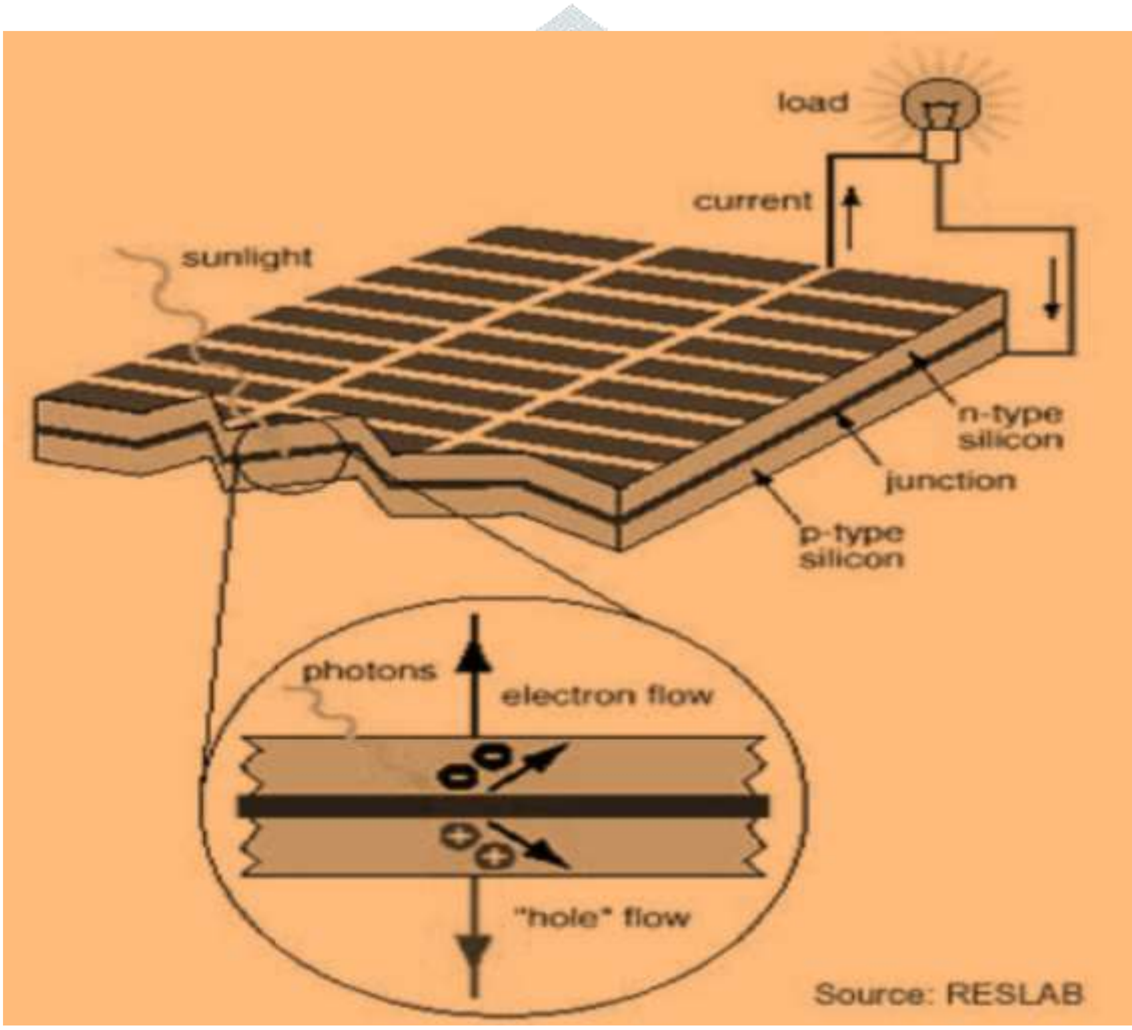

Figure (2) :. Schematic of the basic structure of a silicon solar cell

VI. THE BASIC STEPS IN THE OPERATION OF A SOLAR CELL

- **the generation of light-generated carriers;**
- **the collection of the light-generated carries to generate a current;**
- **the generation of a large voltage across the solar cell; and**
- **the dissipation of power in the load and in parasitic resistances.**

VII. WORKING PRINCIPLE OF SOLAR CELL

When light reaches the p-n junction, electron is excited to the valance band under the condition that light energy is higher than the band gap energy; it generates the electron and holes which are equal in number in the valance and conduction band respectively. These electron hole pairs move in opposite directions to the barrier field. Electrons move towards the n-side and the hole is moved towards the p-side. So a voltage is set up which is known as photo voltage and when a load is connected, the current flows. Schematic of the basic structure of a silicon solar cellis shown in fig.(3).

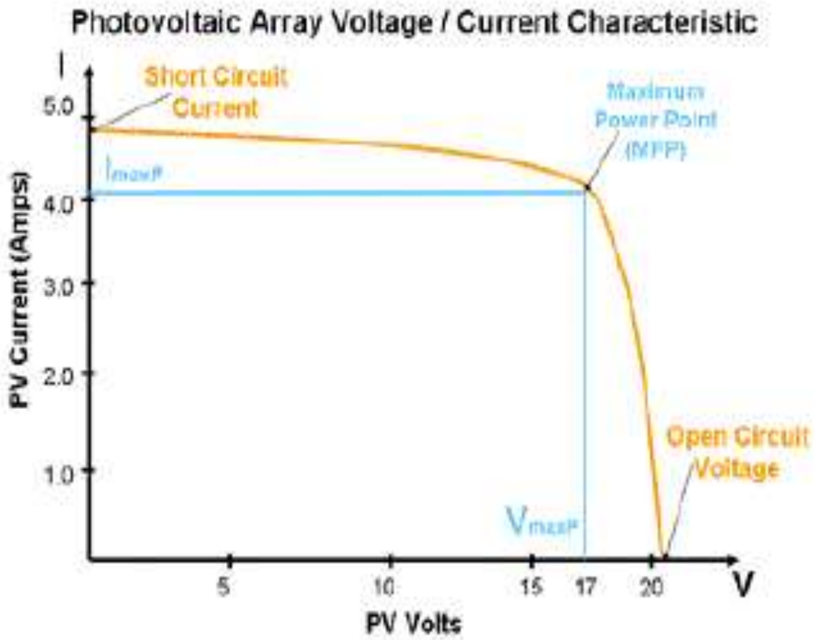

Figure (3): Working principal for the silicon solar cells

Silicon solar cells typically have two layers: a positive layer (p-type) and a negative layer (n-type). The positive layer is usually made by doping silicon with boron to create extra holes in the silicon lattice, and he negative layer is usually made by doping silicon with phosphorus to have extra electrons available in the silicon lattice. Working principal for the silicon solar cells is shown in Figure 4.

VIII. THE BASIC PRINCIPLE OF A SOLAR CELL

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. 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. In 1905, Albert Einstein understoodthat 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,

$$E = h\nu \tag{1}$$

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:

1. Generation of charge carriers due to the absorption of photons in the materials that form a junction.

2. Subsequent separation of the photo-generated charge carriers in the junction.

3. Collection of the photo-generated charge carriers at the terminals of the junction.

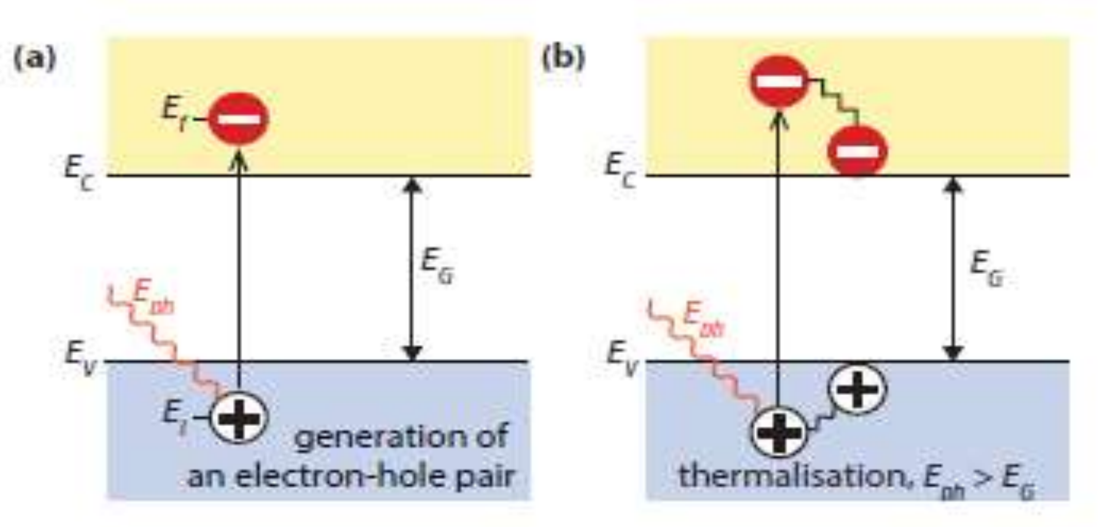

Figure (4): (a) Illustrating the absorption of a photon in a semiconductor with bandgap (Eg). The photon with energy Eph = h*n* excites an electron from Ei to Ef . At Ei a hole is created. (b) If Eph > Eg, a part of the energy is thermalised.

IX. THIN FILM SOLAR CELL (TFSC)

A thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous and other thin-film silicon (a-Si, TF-Si). Film thickness varies from a few nanometers (nm) to tens of micrometers (µm), much thinner than thin-film's rival technology, the conventional, first-generation crystalline in most solar PV systems. Despite these enhancements, market-share of thin-film never reached more than 20 percent in the last two decades and has been declining in recent years to about 9 percent of worldwide photovoltaic production in 2013. Other thin-film technologies, that are still in an early stage of ongoing research or with limited commercial availability, are often classified as emerging or third generation photovoltaic cells and include, organic, dye-sensitized, and polymer solar cells, as well as quantum dot, copper zinc tin sulfide, nanocrystal, micromorph and perovskite solar cells. The Structure of thin film solar cells is shown in fig. (5).

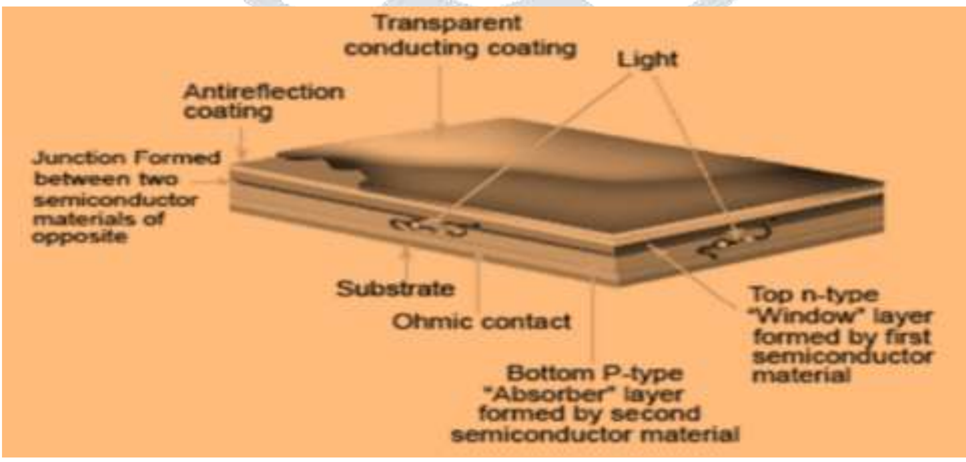

Fig. (5): Structure of thin film solar cells.

X. ENERGY CONVERSION EFFICIENCY

A solar cell's energy conversion efficiency is denoted by (η) *and* the percentage of power converted (from absorbed light into electrical energy) and collected, when a solar cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point, P_m, divided by the input light *irradiance* (E, in W/m^2) under standard test conditions (STC) and the surface area of the solar cell (A_c in m^2). Thus, the solar cell's energy conversion efficiency is expressed as,

$$\eta = \frac{P_m}{E \times A_c} = \frac{P_{max}}{P_{in}} = \frac{J_{mp}V_{mp}}{Pin} = \frac{J_{sc}\ V_{oc}\ FF}{P_{in}} \quad \text{…………..} \quad (1)$$

Typical external parameters of a crystalline silicon solar cell as shown are; Jsc 35 mA/cm2, Voc up to 0.65 V and FF in the range 0.75 to 0.80. The conversion efficiency lies in the range of 17 to 18%. STC specifies a temperature of 25°C and an irradiance of 1000 W/m^2 with an air mass 1.5 (AM1.5) spectrums. These correspond to the irradiance and spectrum of sunlight incident on a clear day upon a sun-facing 37°-tilted surface with the sun at an angle of 41.81° above the horizon. This condition approximately represents solar noon near the spring and autumn equinoxes in the continental United States with surface of the cell aimed directly at the sun. Thus, under these conditions a solar cell of 12 percent efficiency with a 100 cm^2 (0.01 m^2) surface area can be expected to produce approximately 1.2 watts of power. The losses of a solar cell may be broken down into reflectance losses, thermodynamic efficiency, recombination losses and resistive electrical loss. The overall efficiency is the product of each of these individual losses. Due to the difficulty in measuring these parameters directly, other parameters are measured instead: Thermodynamic Efficiency, Quantum Efficiency, V_{OC} ratio, and Fill Factor. Reflectance losses are a portion of the Quantum Efficiency under *External Quantum Efficiency*. Recombination losses make up a portion of the Quantum Efficiency, V_{OC} ratio, and Fill Factor. Resistive losses are predominantly categorized under Fill Factor, but also make up minor portions of the Quantum Efficiency, V_{OC} ratio. Generally, solar cells on the market today do not produce much electricity from ultraviolet light; instead it is either filtered out or absorbed by the cell, heating the cell. That heat is wasted energy and could even lead to damage to the cell.

XI. TYPES OF SOLAR CELLS

Today, four generations of solar cells are available, thus, enabling the use of different types of solar cells according to our needs and preferences. Some of the significant ones have been described in this article.

1. **First-generation (1G) Solar Cells- Traditionally, the first-generation (1G) PV technology is known to comprise of photovoltaic technology based on thick crystalline films (mainly Si) which not only leads to high efficiency but also high cost.**
2. **Second- Generation (2G) Solar Cells- The second-generation (2G) solar cells were developed with the aim of reducing the high costs prevalent in 1G through the utilization of thin film technology; the idea being to save on bulk material cost with a significant reduction in the quality and quantity of the material used and the challenge of increasing the thin film absorption to compensate for the reduced thickness in the photoactive layers.**
3. **Third-Generation (3G) Solar Cells- Thereafter began a true race to design materials at the nanoscale and scale-up to the macroscopic areas. For the first time, significant attention was paid to the charge and energy transfer processes and the respective routes to optimize charge collection, thereby enhancing the energy capture within the solar spectrum. With the introduction of organic materials exhibiting photovoltaic properties, their potential for low cost and high optical absorption placed them as a 3G technology.**
4. **Fourth-generation (4G) Solar Cells- The fourth generation (4G) of PV technology which combines the low cost/flexibility of polymer thin films with the stability of novel inorganic nanostructures was introduced with the aim of improving the optoelectronic properties of the low-cost thin film PVs.**

XII. APPLICATIONS

1. Solar pumps are used for water supply.
2. Domestic power supply for appliances include refrigeration, washing machine, television and lighting
3. Ocean navigation aids: Number of lighthouses and most buoys are powered by solar cells.
4. Telecommunication systems: radio transceivers on mountain tops, or telephone boxes in the country can often be solar powered.
5. Electric power generation in space: To providing electrical power to satellites in an orbit around the Earth

XIII. CONCLUSIONS

In conclusion, we have reviewed the evolution of solar (photovoltaic) cells based on a series of materials over the years. The light from the Sun is a non-vanishing renewable source of energy which is free from environmental pollution and noise. For human, animals and plants solar energy is equally important. Solar energy is lauded as an inexhaustible fuel source that is pollution and solar energy is already economically viable in many applications, and will continue to expand as production continues to increase in scale. Solar PV is one of the very few low-carbon energy technologies with very high potential to grow to very large scale. The direct conversion of light into electrical energy is called *Photovoltaic* (PV). Photovoltaic devices which convert solar energy into electricity are called *solar cells.* Though solar cell has some disadvantage associated it, but the disadvantages are expected to overcome as the technology advances, since the technology is advancing, the cost of solar plates as well as the installation cost will decrease down so that everybody can effort to install the system. Furthermore, the government is laying much emphasis on the solar energy so after some years we may expect that every household and also every electrical system is powered by solar or the renewable energy source. Solar power generation has been developed as one of the most demanding renewable sources of electricity. It has several advantages compared to other forms of energy like fossils fuels and petroleum deposits. It is an alternative which is promising and consistent to meet the high energy demand. Solar energy is the need of the day and research on the solar cells has a promising future worldwide.

ACKNOWLEDGMENTS

One of the authors, **DR. VINAY KUMAR SINGH** takes this opportunity to thank Prof. M.K. Sharan, Ex-Principle and HOD, Department of Physics, Rajendra College, J.P. University, Chapra, for numerous discussions, valuable suggestion and help in preparing the present research paper for publication. I also feel indebted to some scientific spiritualists who provided us the enthusiasm to undertake scientific studies with a wholesome attitude.

LIST OF REFERENCES :

[1] World Commission on Environment and Development (WCED), *Our Common Future*, Oxford/New York: Oxford University Press (1987).

[2] 2003. ASTM G 173-03, Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface, *ASTM International*.

[3] Solar Spectral Irradiance: Air Mass 1.5. National Renewable Energy Laboratory, Retrieved February 22, 2009.

[4] Silicon Nanoparticle Film Can Increase Solar Cell Performance. *AutoblogGreen*. Retrieved February 22, 2009.

[5] K.L. Chopra, P. D. Paulson, and V. Dutta. 2004. Thin-film solar cells: An overview. Progress in Photovoltaic: Research and Applications 12:69-92

[6] Lorenzo, Eduardo. 1994. *Solar Electricity: Engineering of Photovoltaic Systems*. Sevilla, ES: Progensa.

[7] Lugue, Antonio, and Steven Hegedus, 2003, *Handbook of Photovoltaic Science and Engineering*, Chichester, UK; Hoboken, NJ: John Wiley and Sons.

[8] Mc Donald, S.A., G. Konstantatos, S. Zhang, P.W. Cyr, E.J. Klem, L. Levina, and E.H. Sargent. 2005. Solution-processed PbS quantum dot infrared photodetectors and photovoltaics. *Nature Materials*, 4(2):138–42.

[9] Nelson, Jenny. 2003. *The Physics of Solar Cells*. London, UK: Imperial College Press.

[10] PVNET European Roadmap for PV R&D Ed Arnulf Jager-Waldan Office for Publications of the

European Union, 2004.

[11] Würfel, Peter. 2005. *Physics of solar cells*. Weinheim, DE: Wiley-VCH.

[12] Rural Integrated Development Service-Nepal (RIDS-Nepal). Source: http://www.rids-nepal. org/index.php/Solar_Photo_Voltaic.html

[13] Photovoltaics Report, Fraunhofer ISE. 28 July 2014. Archived from the original (PDF) on 31 August 2014. Retrieved 31 August 2014.

[14] Choubey, P.C., Oudhia, A. and Dewangan, R. (2012) A Review: Solar Cell Current Scenario and Future Trends. *Recent Research in Science and Technology*, 4, 99-101.

[15] Srinivas, B., Balaji, S., Nagendra Babu, M. and Reddy, Y.S. (2015) Review on Present and Advance Materials for Solar Cells. *International Journal of Engineering Research-Online*, 3, 178-182.

[18] Dmitrijev, S. (2006) Principles of Semiconductor Devices. Oxford University Press, Oxford.

[19] Chopra, K.L., Paulson, P.D. and Dutt, V. (2004) Thin-Film Solar Cells: An Overview. *Progress in Photovoltaic*, 12, 69-92.

[20] Green, M.A., 2006. Third-Generation Photovoltaics: Advanced Solar Energy Conversion. Springer, Berlin.

[21] Klaus JägerOlindo IsabellaArno H.M. Smets René A.C.M.M. van Swaaij Miro Zeman : Solar Energy Fundamentals, Technology, and Systems- VVI

[22] Grove, A.S., 1967, Physics and *Technology* of *Semi*conductor *Devices.* New York, NY: John Wiley and Sons.

[23] Hovel, Harold J. 1975. Solar Cells. New York, NY: Academic Press; pp. 181-190.

[24] Johnston, W.o., Jr., 1980, *Solar Voltaic Cells.* New York, NY: Marcel Dekker, Inc.; pp. 53-72.

[25] Chapin D. M, Fuller C. S. and Pearson G L (1954) A new silicon pn junction photocell for converting solar radiation into electrical power *J. Appl. Phys.* 25, 676-677.

[26] V.K. Singh, M. K. Sharan, & K.P. Srivastava, Amorphous Semiconducting Carbon Thin Films from Castor Oil. *Material Science Research India,* Vol. 03, No. (2a), 2006, pp (263-266).

[27] V.K. Singh, M. K. Sharan, & K.P. Srivastava, Amorphous Semiconducting Carbon Thin Films for Carbon PV-Cells, *Acta Ciencia Indica of Chemistry*, Vol. XXXIVC, No. 1, 27, (2008), pp (127-132).

[28] V.K. Singh, M. K. Sharan, & K.P. Srivastava, Spray Paralyzed Semi-Conducting Carbon Thin Films from Turpentine Oil, *International Journal of Chemical Sciences*, Vol. 4(3): 2006, pp (660-664).

[29] V. K. Singh & H. N. Sah, Review of Carbonaceous Materials in Castor Oil for Thin Films Deposition, *Journal of Emerging Technologies and Innovative Research*, Vol. 4, Issue 7, July 2017, pp 205-211.

[30] V. K. Singh & H. N. Sah, Versatility of Spray Paralysis Technique for the Deposition of Carbon Thin Films, *Journal of Emerging Technologies and Innovative Research*, Volume 4, Issue 8, August 2017, pp 312- 318.