Exploration of Existing Research on Solar cells with focus on Photogalvanics

Meenakshi Jonwal,

Department of Chemistry, Jai Narain Vyas University, Jodhpur-342001, Rajasthan, India

Abstract : The relentless pursuit of higher efficiency and lower production costs has led to significant breakthroughs in the field of solar cell research. Innovations in materials science, device architecture, and manufacturing processes have resulted in a diverse range of solar cell technologies, each with its unique advantages and applications. One prominent development is the emergence of third-generation solar cells, such as perovskite and organic photovoltaics, which promise greater efficiency and flexibility compared to traditional silicon-based cells. These advanced materials exhibit the potential to revolutionize the solar industry by offering improved performance in various lighting conditions and reduced environmental impact during production. Furthermore, tandem solar cells, combining multiple absorber materials, have demonstrated remarkable progress in achieving higher conversion efficiencies by effectively harnessing a broader spectrum of sunlight. Tandem solar cells can be fabricated using various materials, including perovskites, silicon, and III-V semiconductors, showcasing their adaptability to diverse applications. Integration of solar cells into building materials, such as solar windows and solar roof tiles, marks another innovative approach towards enhancing the adoption of solar energy in urban environments. These building-integrated photovoltaics not only generate electricity but also contribute to architectural aesthetics and energy-efficient design. Photogalvanics is another such promising technology which is different from photovoltaics. The photogalvanic cell is one of the prominent examples of the photoelectrochemical systems. The photogalvanic cells are based on "photogalvanic effect" which is a special case of the Becquerel effect in which the influence of light on the electrode potential is due to a photochemical process in the body of the electrolyte (as distinct from photochemical or photoelectric processes in the surface layer of the electrode, which are the basis of the original Becquerel effect).

Keywords: Solar Energy, Solar Cells, Photovoltaic Cells, Photogalvanic Cells

I. Introduction

Energy is everywhere around us in some or the other form. It is the possibility in a system to produce useful work. Energy is the very basic fabric of the universe which is manifested in different forms. There is a dynamic interconversion of one form of energy to another according to the first law of thermodynamics which states that the energy can neither be created nor destroyed, it can only be converted from one form to another. This interconversion of energy is never absolute, as there are always some losses to other forms of energy. This forms the basis of the 2nd law of thermodynamics which has the word entropy at its core.

Solar Energy is the energy we receive every day when we get up to the sunshine, we hardly realize the immenseness of it. Sun is the natural source of energy, as nuclear fusion reactor that will last for about 5 billion years. Life on Earth planet needs sunlight to survive, without the sun it would be impossible to survive. This planet is habitable due to its proximity to the sun. We have a source of energy so great that we can do almost anything technologically possible if we can harness even a small percentage of its radiant energy on the planet. Solar energy for power generation is now being used at an increasingly larger scale because of its immense potential. There are different ways of using solar energy for power generation.

Solar power is not available all the time. There is a need for energy storage, for which there are various technologies being worked upon these days. Solar cells like photovoltaic cells, dye-sensitized solar cells, quantum dot cells, perovskite solar cells, and various other cells, can generate electricity but without storage. Solar energy can be converted into electricity and then stored as chemical energy or heat energy or potential energy and then back to electricity as and when needed. There are numerous factors such as energy density, power to size ratio, and various other factors deciding the usability of such systems. All of this finally decides the utility of such energy generation and storage systems in various applications.

The technology to harness solar power has been evolving continuously because of the competitive nature of the market and the huge amount of investment and resources being put into research. There is an infinite number of possibilities that lie in energy conversion and storage.

II. Solar Energy Conversion & Storage

The conversion process for solar energy to useful energy forms can be divided into two technologies:

- *Photovoltaic solar technology*: Photovoltaic cells use semiconductor material and incident energy of the sun rays to produce a potential difference and thus generate electricity. The electrical energy produced can be stored in batteries for use when needed.
- *Solar thermal technology*: The heat from solar radiation is used to produce steam to generate electricity by using very large mirrors, this way of producing electricity from solar power is called concentrated solar power (CSP). Huge mirrors focus light onto a medium like molten sodium salt which gets heated due to solar radiation, this medium is then pumped through water to produce steam that turns turbines to generate electricity.

There are mainly two different types of electrical installations in use:

- Solar panel installations for individual homes to generate electricity for electrical appliances. Also, solar heaters are used for heating water for domestic use.

- Photovoltaics solar power plants for generating electricity on a large scale. Concentrated solar power plants are used to produce electricity for large scale use.

Storage is very important for solar technology to grow as the availability of solar power is limited to daytime. Most common storage method are batteries, but it is very expensive to store large amount of power. New technologies are being used to store solar energy. Thermal mass systems use various methods (adobe, earth, concrete, and water) to store solar energy for short or long duration (seasonal thermal store). Solar energy can also be stored thermo-chemically with phase change materials. Suitable material may be organic (paraffin, fatty acids, etc.) or inorganic (salts, metals, alloys, etc.).

III. Solar power techniques

The technology to harness solar power using the principle of photovoltaics can be listed as follows, Silicon Solar Cells, Thin Film Solar Cells, Perovskite Solar Cells, Quantum Dot Sensitized Solar Cells, Polymer Solar Cells, Dye-Sensitized Solar Cells, Photogalvanic cells.

Silicon Solar Cells are made by doping silicon to create a p-n junction diode. When light energy falls on a solar cell, electrons in the valence shell absorb the energy of the photon and move to the conduction band. A silicon solar cell made up of p and n-type silicon bonded together has free electrons on n-type and free holes on p-type, now these electrons near the junction jump on the other side which has free holes. This process continues until a band is formed. This consists of a band of excess electrons on p type silicon semiconductor and a band of holes on n type silicon semiconductor. Now when a conductor is applied across the semiconductor in the presence of light a current flow due to the photovoltaic effect.

There are two types of silicon solar cells-Monocrystalline Silicon Solar Cells which are more efficient but expensive, and Polycrystalline Silicon Solar Cells are cost effective but less efficient. “Photovoltaic (PV) conversion of solar energy starts to give an appreciable contribution to power generation in many countries, with more than 90% of the global PV market relying on solar cells based on crystalline silicon (c-Si).

Thin Film Solar Cells is a second-generation technology, made by depositing sub-micron thick semiconductor material on a thin film substrate which is flexible. There are 3 types of thin film solar cells: Amorphous Silicon (a-Si), Cadmium Telluride (CdTe), Copper Indium Gallium Deselenide (CIGS). “Thin-films have the potential to revolutionise the present cost structure of photovoltaics by eliminating the use of the expensive silicon wafers that alone account for above 50% of total module manufacturing cost.” [1].

Quantum Dot Sensitized Solar Cells are third generation solar cells, which are made of quantum dots as photovoltaic material to absorb solar energy and can be tuned across wide range of energy levels The dots can be grown over a range of sizes allowing them to express a variety of band gaps without changing the underlying material or construction techniques or by changing the size [2].

Polymer Solar Cells consist of materials responsible for the absorption of light which are the organic semiconductors making up the active layer. This class of materials is characterized by having a band gap of certain gap energy. This gap signifies the energetic separation between the valence electrons and the nearest free electronic states, for organic semiconductors this is defined as the difference between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO). A material is generally considered a semiconductor when the band gap is greater than the thermal energy available at realistic temperatures (*e.g.*, around room temperature), whereby valence electrons cannot be excited to the conduction states simply by thermal activation, rendering the material nonconductive in the dark because the absorption of a photon of energy greater than that required to excite an electron from the HOMO to the LUMO state. The excitation of photon from the HOMO state to a state above the LUMO level, leaves behind an unoccupied valence state, termed a ‘hole’, and the photon energy now resides as the potential energy difference between this excited electron hole pair. However, as there is a continuum of states above the LUMO level, the excited electron will quickly undergo thermal relaxation, ending up at the LUMO level. This signifies that all the photon energy exceeding the gap energy will be lost as heat. “Polymer–fullerene systems currently dominate the field of high-efficiency PSCs. PSC efficiencies are now approaching 10%, which indicates remarkable progress towards a promising future.” [3].

Perovskite Solar Cells are made up of an active layer of perovskite structured compound such as calcium titanium oxide ($CaTiO_3$) which has a perovskite structure. Active layer is the light harvesting material with a hybrid organic-inorganic lead or tin halide-based material. Perovskite materials such as methyl ammonium lead halides are cheap to produce and relatively simple to manufacture. Perovskites possess intrinsic properties like broad absorption spectrum, fast charge separation, long transport distance of electrons and holes, long carrier separation lifetime, and more than that make them very promising materials for solid-state solar cells.

Dye Sensitized Solar Cells (DSSC’s) are the type of cells where light absorption and separation of charges occur in separate molecular layers. This simplifies the cell design, thus leading to lower costs. DSSC gives us a design where the semiconductor is involved in the transportation of charges and the dye layer in light harvesting in contrast to PV cells where both processes occur inside silicon.

Silicon in PV cells acts as both the source of photoelectrons, as well as separate the charges to create electric field. In the DSSC, electric charges move mostly through semiconductors while the photosensitive dyes provide for photoelectrons.

Photogalvanic cells, are one of the prominent examples of the photoelectrochemical systems. The photogalvanic cells are based on "photogalvanic effect” which is a special case of the Becquerel effect [4] in which the influence of light on the electrode potential is due to a photochemical process in the body of the electrolyte (as distinct from photochemical or photoelectric processes in the surface layer of the electrode, which are the basis of the original Becquerel effect). The photogalvanic cell is a device producing energy in the photochemical reactions in which light is absorbed within a highly absorbing electrolyte and which give rise to high energy products on excitation by a photon. These energy products loose energy electrochemically which leads to generate electricity. Not only this, the species like a semi and leuco forms of the photosensitizers involved in the solar energy conversion also enables solar power storage through the photogalvanic cells. The power storage holds significance for meeting the twenty-four hours of energy needs even during the daytime cloudy hours, night hours, and hours lacking suitable wind speed for the wind power generation.

IV. Review of photogalvanic solar cells

Photogalvanic cell is a type of solar cell capable of producing electricity as well as storing it for use in the dark. So, it is important to study the Photogalvanic cell which has promising storage capabilities. Photogalvanic cells are made of a calomel electrode and a Platinum electrode dipped in a solution of a dye, reductant, and surfactant in an alkaline medium.

The photogalvanic cells work on the principle of photogalvanic effect as the name would suggest which was first studied by Rideal and Williams [5]. Rabinowitch studied photogalvanic effects of thionine iron system [6]. This effect was further investigated, and it was found that photogalvanic cells can have a power conversion efficiency as large as 18 % [7]. The beauty of a photogalvanic cell is its ability to convert solar energy to electricity as well as store it at the same time. The endeavour to continuously improve and optimize photogalvanic cell by using different dye sensitizers, reductants and surfactants has been a consistent effort by researchers. Studies on various dye photosensitizers such as Bromophenol Red [8], Azur B [9], Methylene Blue [10], Brilliant Cresyl Blue [11], Bengal Rose [12], Safranine O [13], Rhodamine B [11]. Similarly, different reductants have been studied. Further it has been seen that the cell performance improved at higher pH in the range of 12 to 14, thus supporting the use of an alkaline medium like NaOH.

Surfactants are surface active agents that increase the stability and solubility of dyes with respect to photogalvanic cells. Some of the Surfactants used in the previous studies can be listed as follows, Sodium Lauryl Sulphate, Cetyl Pyridinium Chloride, Tween-80, Hexadecyltrimethylammonium Bromide, TritonX-100, and Dioctyl Sulfosuccinate [14][15][16][17][18]. The increase in the electrical output of photogalvanic cell reported in previous studies, is due to surfactant induced enhancement in the solubility and stabilization of dye photosensitizer. The diffusion characteristics of the cell is improved by the introduction of surfactants into the electrolyte system which is evident from the previous studies published on the role of surfactants in Photogalvanic cells. Surfactants are also used in various industries such as textile, paints, oil, paper, soaps, detergents, etc.

It was observed that stability of the system had improved as well as the storage capacity, conversion efficiency and other electrical parameters. It was also seen that the anionic surfactant performed much better (with cationic dye) than non-ionic and cationic surfactants [16]. Similar study was conducted by taking sodium lauryl sulphate, cetyl pyridinium chloride and Tween-80 as surfactants with ethylenediamine tetra acetic acid as reductant and toluene blue as photosensitizer dye [15]. In the presence of natural sunlight with Sudan I dye as photosensitizer, Fructose as reductant and sodium lauryl sulphate as surfactant in a solution of NaOH, the use of surfactant showed an improved performance of the cell. The reductant that have been used in photogalvanic cells are Dextrose [19], Ascorbic acid [20][21], EDTA [22][8], Oxalic acid [16].

The mostly reported photogalvanic cells have been fabricated from H shaped glass tube containing two electrodes dipped in very dilute and alkaline solutions of sensitizer(s), reductant(s), and surfactant(s). For practical applications, the electrical performance of these cells needs to be further increased. The electrical performance of these cells is affected by variables like nature and concentrations of the chemicals, physical parameters like diffusion length, electrode size, illumination intensity, etc.

The nature of the sensitizer, reductant, surfactant, and electrodes are the key factor determining the efficiency, stability, and power storage capacity of the PG cells. The use of more stable dye with good diffusivity, stability, and conductivity by using better surfactants which are naturally occurring, should be further researched in the future studies on Photogalvanics.

V. Conclusion

In conclusion, this overview of solar cell technologies showcases diverse approaches for sustainable solar energy harnessing. Silicon solar cells, the foundation of photovoltaics, include monocrystalline and polycrystalline variants, each with differing efficiency and cost. They approach the intrinsic efficiency limit of silicon. Second-generation thin-film solar cells (e.g., amorphous silicon, cadmium telluride, copper indium gallium deselenide) hold potential to revolutionize photovoltaics by reducing manufacturing costs through silicon wafer elimination.

Third-generation quantum dot sensitized solar cells, featuring tunable quantum dots, offer efficient energy absorption across various energy levels and promise advancements in solar technology. Polymer solar cells, characterized by band gap energy, provide an organic approach to solar energy conversion. The dominance of polymer-fullerene systems, with efficiencies nearing 10%, marks remarkable progress. Perovskite solar cells, cost-effective and simply manufactured, possess intrinsic advantages such as broad absorption, fast charge separation, and long carrier lifetimes. Dye-sensitized solar cells (DSSCs) present a unique design separating charge transport from light harvesting, reducing costs.

Photogalvanic cells are promising for electricity generation and storage. Operating on the photogalvanic effect principle, research continually optimizes them. They convert and store solar energy. Dye sensitizers, reductants, and surfactants improve their performance. Anionic surfactants, especially with cationic dyes, enhance diffusion and stability. Higher pH values, like NaOH in the electrolyte system, boost performance. Stability, storage, and efficiency successes indicate practical applications. Future photogalvanic research should focus on stable dyes and improved surfactants for enhanced performance. Continued innovation in photogalvanics is essential for clean and sustainable energy generation and storage. As the global energy landscape shifts toward renewable sources, emerging solar cell technologies represent a commitment to advancing efficiency, cost-effectiveness, and environmental sustainability. Ongoing research and development in these technologies will shape the future of clean energy generation.

VI. References

[1] M. A. Green, Thin-film solar cells: review of materials, technologies and commercial status, *J. Mater. Sci. Mater. Electron. 2007 181*, 18(1), 15–19 (2007).

[2] S. Baskoutas and A. F. Terzis, Size-dependent band gap of colloidal quantum dots, *J. Appl. Phys.*, 99(1), 013708 (2006).

[3] G. Li, R. Zhu, and Y. Yang, Polymer solar cells, *Nat. Photonics*, 6(3), 153–161 (2012).

[4] E. D. Korlyakov, The becquerel effect, *Sov. Phys. J.*, 12(8), 1054–1056 (1969).

[5] E. K. Rideal and E. G. Williams, XLIII. - The action of light on the ferrous ferric iodine iodide equilibrium, *J. Chem. Soc. Trans.*, 127 258–269 (1925).

[6] E. Rabinowitch, The photogalvanic effect I. The photochemical properties of the thionine-iron system, *J. Chem. Phys.*, 8(7), 551–559 (1940).
[7] W. J. Albery and M. D. Archer, © 1977 Nature Publishing Group, (1977).
[8] S. C. Ameta, P. B. Punjabi, J. Vardia, S. Madhwani, and S. Chaudhary, Use of Bromophenol Red-EDTA system for generation of electricity in a photogalvanic cell, *J. Power Sources*, 159(1 SPEC. ISS.), 747–751 (2006).
[9] C. Lal, Use of mixed dyes in a photogalvanic cell for solar energy conversion and storage: EDTA-thionine-azur-B system, *J. Power Sources*, 164(2), 926–930 (2007).
[10] S. Yadav and C. Lal, Photogalvanic cells as a device for solar energy conversion and storage: An eDTA-new methylene blue and safranine O system, *Energy Sources, Part A Recover. Util. Environ. Eff.*, 32(11), 1028–1039 (2010).
[11] P. Koli and U. Sharma, Photochemical solar power and storage through photogalvanic cells: Comparing performance of dye materials, *Energy Sources, Part A Recover. Util. Environ. Eff.*, 39(6), 555–561 (2017).
[12] S. A. Mahmoud and B. S. Mohamed, Study on the performance of photogalvanic cell for solar energy conversion and storage, *Int. J. Electrochem. Sci.*, 10(4), 3340–3353 (2015).
[13] P. Gangotri and K. M. Gangotri, Studies of the micellar effect on photogalvanics: Solar energy conversion and storage - EDTA-safranine O-NaLS system, *Energy Sources, Part A Recover. Util. Environ. Eff.*, 35(11), 1007–1016 (2013).
[14] P. P. Solanki and K. M. Gangotri, The Role of Surfactants in Photogalvanics: Solar Energy Conversion and Storage in the Sodium Lauryl Sulphate-Thymol Blue-Mannose System, *Arab. J. Sci. Eng.*, 37(1), 91–100 (2012).
[15] K. M. Gangotri and J. Meena, Role of surfactants in photogalvanic cells for solar energy conversion and storage, *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 28(8),. 771–777, 2006.
[16] K. R. Genwa and M. Genwa, Photogalvanic cell: A new approach for green and sustainable chemistry, *Sol. Energy Mater. Sol. Cells*, 92(5), 522–529 (2008).
[17] M. Mukhopadhyay and B. B. Bhowmik, Kinetics of photoinduced electron transfer in a photoelectrochemical cell consisting of thiazine dyes and Triton X-100 surfactant, *J. Photochem. Photobiol. A Chem.*, 69(2), 223–227 (1992).
[18] S. Pramila and K. M. Gangotri, Use of anionic micelles in photogalvanic cells for solar energy conversion and storage dioctylsulfosuccinate-mannitol-safranine system, *Energy Sources, Part A Recover. Util. Environ. Eff.*, 29(13), 1253–1257 (2007).
[19] K. M. Gangotri and V. Indora, Studies in the photogalvanic effect in mixed reductants system for solar energy conversion and storage: Dextrose and Ethylenediaminetetraacetic acid-Azur A system, *Sol. Energy*, 84(2), 271–276 (2010).
[20] K. R. Genwa and A. Chouhan, Studies of effect of heterocyclic dyes in photogalvanic cells for solar energy conversion and storage: NaLS-ascorbic acid system, *J. Chem. Sci.*, 116(6), 339–345 (2004).
[21] K. R. Genwa and K. Singh, Optimum Efficiency of Photogalvanic Cell for Solar Energy Conversion: Lissamine Green B-Ascorbic Acid-NaLS System, *Smart Grid Renew. Energy*, 04(03), 306–311 (2013).
[22] S. Madhwani, R. Ameta, J. Vardia, P. B. Punjabi, and V. K. Sharma, Use of fluoroscein-EDTA system in photogalvanic cell for solar energy conversion, *Energy Sources, Part A Recover. Util. Environ. Eff.*, 29(8), 721–729 (2007).