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Electricity Generation From PV TR Cells at Day and Night Time from Space Energy

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Abstract:

Photovoltaic cells are used to convert solar energy into electrical energy during day-time with an average efficiency of 17-18%. To generate electrical power after sunset i.e. 24/7 electricity production, we have designed an alternative concept that can generate electricity from space. It is opposite to the solar panels i.e. it will use the Earth as heat source and Sky as the sink. We can call it as Anti-Solar panels. This concept has its self-explanatory industrial applications to generate electricity from Chimney's waste heat power and space. This paper covers the domain, scalability, limits, capacity, performance, and advancement of the new sustainable PV-TR technology.

Keywords:

Anti-Solar Panels, Radiative Cooling, Electrical Power, Photovoltaic Cells, Space Coupling,Thermoradiative Cells, PV TR Cells.

1. Introduction

The traditional photovoltaic cell can generate electrical power in the day time only. The need to generate sustainable and scalable electricity in the night is a must for today's fast-growing world that is committed to using more renewable energy in the future. Without a more sustainable power, we need to use other energy sources notably fossil fuels. In this paper, we are proposing a more efficient electrical power generation technology that can revolutionize the way we generate electricity from the conventional PV cells.

The PV cell (solar cell) works on the principle of difference in electrical potential.

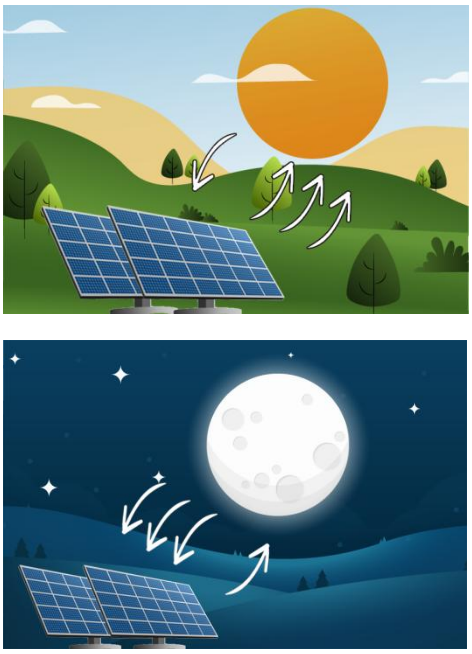

Figure 1: Energy Conversion at Day and Night time Photovoltaic Cell

The PV cell generates power taking the sun as a heat source and the cell as the sink. "The absorbed photons from the sun's radiations create electron-hole pairs across the silicon semiconductor bandgap and set up the voltage."[1] We gain the advantages of its reverse process. "By the principle of detailed balance"[2], each elementary process is in equilibrium with its reverse process at equilibrium. As a substitute, we are heating the PV cell making it a heat source and directing it to the deep space (night sky). In both forward and reverse cases, we have a hot body and a cold body and power can be generated through its difference.

In the first case, we use PV cells while in the second case, we use a different heat engine known as thermoradiative (TR) cell. The power is generated at the colder side in the case of PV cells while the same is generated at the hotter side in the case of TR cells. TR cell's basic function is to recover waste heat from hot reservoir like generators cooling towers and industrial heat exhaust pipes and chimneys. The TR cell establishes voltage as:

$$\text{Emission}_{\text{thermal radiations}} > \text{absorption}_{\text{irradiation}}$$

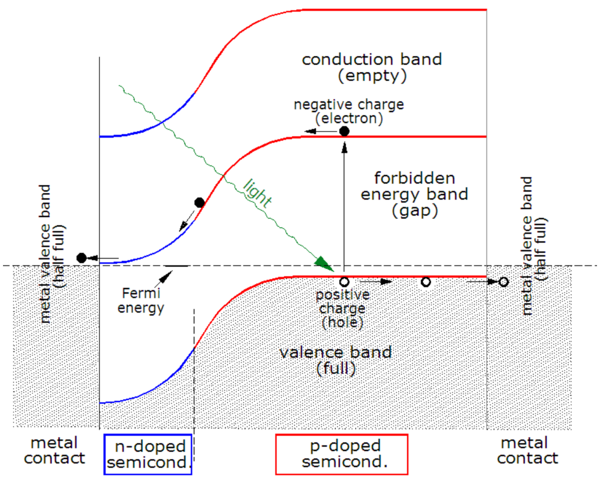

Figure 2. Band diagram of a silicon solar cell[3]

We are calling this concept as thermoradiative effect. The standard temperature for the cell is 300K and the deep space (night sky) is 3K. There is a need to optically couple the TR cell with deep space.

2. TR cell Material and Architecture

The best way to make the idea of work is actually quite simple. The choice of material for the cell and the architecture plays a crucial role in power generation. Initially, we need to select a material with the desired bandgap (1-1.5eV) to optimize energy output. Secondly, the TR cell must be optically coupled. In ideal condition (~1000W/m^2 solar irradiations), PV cell made up of silicon can generate 200W/m^2. The same silicon gives an output of <2*10^{-14} W/m^2 due to the fact that the photons emitted are infrared at room temperature and their energy is less than the bandgap of the semiconductor silicon. Thus, we need to use a material with a very low bandgap in order to gain energy output. A material with an ultralow bandgap can establish about 55W/m^2 energy under the ideal condition and the same can establish ~10W/m^2 under ordinary conditions. It is clear that a negative potential and current is generated as the TR cell follows the reverse condition of the PV cell.

We can note that the TR cell is producing less power than the conventional PV cell but if we make a two-tier system where PV cells work in day-time and then TR cell at night, surely we can gain much power output throughout the day. Thus, what the world actually needs today is PV TR cells. The architecture of the cell is cleared to use a two-tier system. Unlike the photovoltaic cell used by a typical solar cell, the anti-solar cell uses the thermoradiative cell capable of capturing excessively long-wavelength light in order to generate electricity.

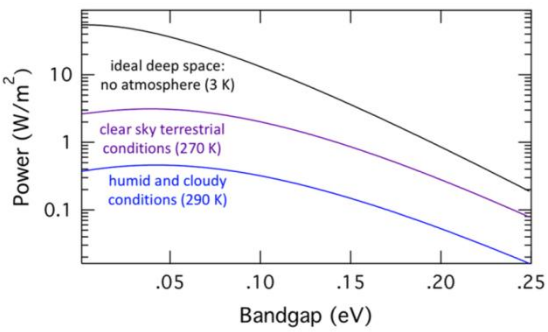

Figure 3. Power V/s Bandgap for terrestrial cell and three-night sky conditions[4,5].

The effectiveness of TR cells might be upgraded by using materials having a longer wavelength of light like mercury alloys. By using such materials, we may able to generate electricity greater than 50 milliwatts (mW). "A research conducted by Santhanam and Fan used a HgCdZnTe TR cell is successful in delivering 1 pW of power at 295 K."[6] The procedure to enhance the power output is discussed in the later section of the paper.

2.1 Electricity output from a TR cell; Mathematical approach

There are a number of models like Landsberg Model, WKBQ Model, Entropy Model, Wurfel Model, Shockley and Queisser Model that explains the working of p-n junction diode to design the system. The most effective formula is formulated by Shockley and Queisser. Planck's law for black body radiation is given by:

$$\dot{N}(T,\, \Delta\mu) = \frac{2\pi}{h^3c^2}\int_{E_g}^{\infty}\frac{\varepsilon(E)E^2}{e^{E-\Delta\mu/k_BT}-1}dE$$

Here, $\dot{N}$ is the flux emitted from a semiconductor, t is the temperature, $\Delta\mu$ is the emission potential, $\varepsilon(E)$ is the emissivity$_{\text{energy dependent}}$, c is the speed of light, E_g is the bandgap of the semiconductor, h is the Planck' constant, E is the photon energy, and k_B is the Boltzmann's constant.[7]

"As per Tristan Deppe and Jeremy N. Munday, the TR cell temperature is T_{TR} and the night sky (for cooler body) temperature be T_{NS} will generate a current density given by:

$$J = q[\dot{N}(T_{NS},0) - \dot{N}(T_{TR}, \Delta\mu_{TR})]$$

where $\Delta\mu_{TR}$ is the cell's chemical potential, which is equal to the quasi-Fermi level splitting and is related to the output voltage by $\Delta\mu_{TR} = qV$. It is evident that $T_{TR} > T_{NS}$. For an ideal TR cell that is a perfect emitter and absorber of photons at or above the bandgap energy of the semiconductor and is transparent to lower energy photons (i.e., $\varepsilon = 0$ for $E < Eg$, and $\varepsilon = 1$ for $E \geq Eg$)."[1] Thus the Power density is given by:

$$P_{(\text{power density})} = JV = qV[\dot{N}(T_{NS},0) - \dot{N}(T_{TR}, qV)]$$

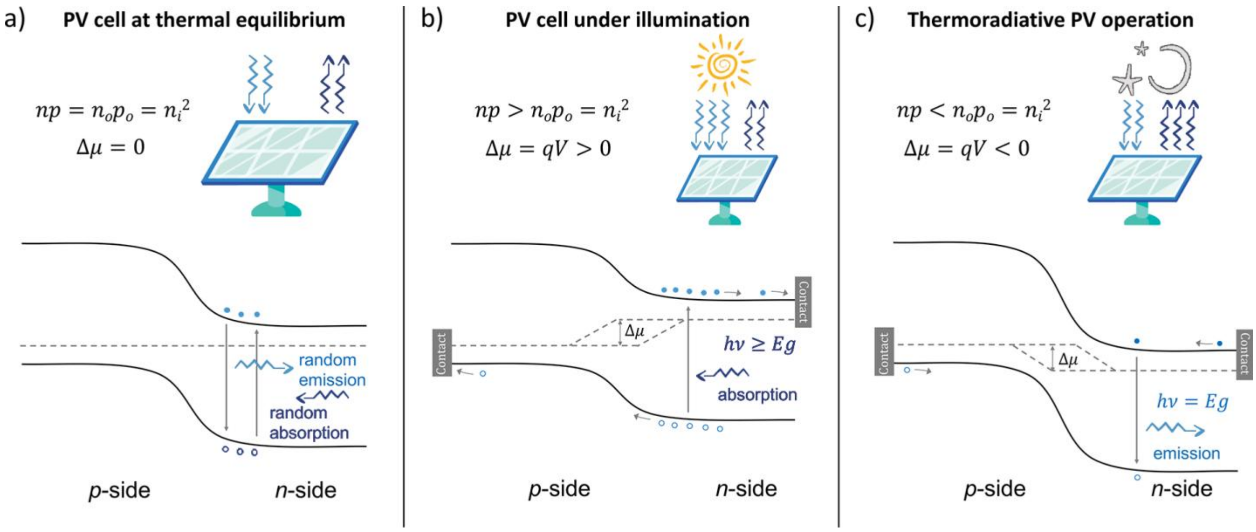

Figure 4: PV cells band diagram and electrons movements in different conditions. (a) When PV cell is at thermal equilibrium, (b) When PV cell is under Illumination, (c) When PV cell is at thermoradiative operation.

3. Enhancement in Power Generation

The generation of power depends upon the material and architecture of the TR cell and keeping in mind to enhance the power generated, researchers have developed a concept termed as Radiative Cooling. Radiative cooling is improving the refrigeration efficiency by ~20%. The method by which an object or a body loses heat by the thermal radiation phenomenon is radiative cooling.

The factors necessary for impactful radiative refrigeration are:

- The tendency to reinforce solar light.
- The potential for emitting wavelengths allowing heat transfer to the atmosphere.
- Thermal isolation from the surrounding.

4. Features of TR Cells

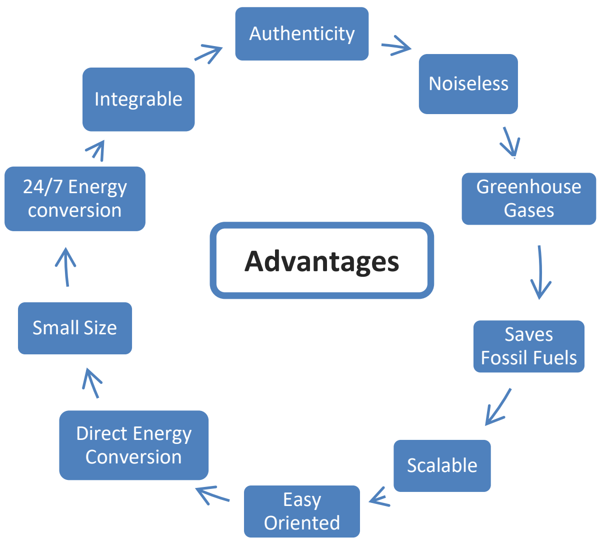

Figure 5: Features of TR Cells

5. Limits of PV TR CELL

At 300K, the PV TR cell establishes a good amount of voltage keeping in mind that the material bandgap is less than 0.1eV. When the device is held at 300K and the deep sky is at 3K, the power conversion is $\sim 54 W/m^2$. If there is a restriction to emissivity and we assume zero-emission from the sky, the power output will be as lower as $\sim 10 W/m^2$. Thus the power output is limited by the emission. The prime purpose of emission is to make certain that it radiates IR to maximize output. Thin metal layers are also used to cool the cell while there is no such requirement of a metallic layer at night for TR cell operation.

For 24 hours of power output, solar reflectivity should be less than 0.5 to produce $> 1 W/m^2$. Thus there is a need to include non-radiative generation too. "Auger inverse process of impact ionization is considered the nonradiative process in low bandgap semiconductors, especially near room temperature. After including $\dot{N}_{NR}$ (non-radiative term), the power outcome become:

$$P_{(\text{power density})} = JV = qV[\dot{N}(T_{NS},0) - \dot{N}(T_{TR}, qV) + \dot{N}_{NR}]$$

While $\dot{N}_{NR}$ would be a function of voltage for an actual p–n device."[8]

6. Conclusion

To sum up, Solar panel confronts several physical and logistical challenges and also we have inconsistent and uneven distribution of sun radiations across the globe due to which it has became necessary to use an Anti-Solar panel for the generation of electrical energy. The less efficiency (17-18%) of the currently available panels being a limitation to the use of renewable energy and not only the need of efficient ways of generation and storage of sustainable energy but also it is evident that a billion people don't have any kind of access to electric power in their complete lifespan. Thus, the PV TR cell will revolutionize the world with its scalability to generate power output throughout the day. Yet, there is a big way to go and such technology will surely save a wide range of fossil fuels. It is reliable and efficient and it comes with a lot more possibilities to work upon.

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7. References

[1] Tristan Deppe, Jeremy N. Munday. "Nighttime Photovoltaic Cells: Electrical Power Generation by Optically Coupling with Deep Space", ACS Photonics, 2019

[2] Shockley, W.; Queisser, H. J. Detailed Balance Limit of Efficiency of P-n Junction Solar Cells. J. Appl. Phys. 1961, 32, 510− 519.

[3] Figure 2: Band diagram of a silicon solar cell by GianniG46

[4] Sun, X.; Sun, Y.; Zhou, Z.; Alam, M. A.; Bermel, P. Radiative Sky Cooling: Fundamental physics, materials, structures, and applications. Nanophotonics 2017, 6, 997−1015.

[5] Zhao, D.; Aili, A.; Zhai, Y.; Xu, S.; Tan, G.; Yin, X.; Yang, R. Radiative sky cooling: Fundamental principles, materials, and applications. Appl. Phys. Rev. 2019, 6, 021306.

[6] Santhanam, P.; Fan, S. Thermal-to-Electrical Energy Conversion by Diodes under Negative Illumination. Phys. Rev. B: Condens. Matter Mater. Phys. 2016, 93, 161410.

[7] Würfel, P. Thermodynamic Limitations to Solar Energy Conversion. Phys. E 2002, 14, 18−26.`

[8] Tennant, W. E. Rule 07"' Revisited: Still a Good Heuristic Predictor of p/n HgCdTe Photodiode Performance? J. Electron. Mater. 2010, 39, 1030−1035.

