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Efficiency of Solar Cell Design and Materials

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Abstract

Fossil fuels have dominated the energy world ever since their introduction in the Industrial Revolution, and the world has grown more dependent on them in the Postmodern Era. However, the limited amount of fossil fuels in the world poses a problem for future generations; solar energy is the solution to this potential future energy crisis. The purpose of this study is to provide a comprehensive review of solar panel materials so that solar panels can be refined until they can replace fossil fuels entirely. In this study, I have researched designs for solar cells and determined the most efficient design for commercial and residential use while finding the most cost-effective materials to produce these cells. I delved into previous research studies on solar cell production and efficiency and current research updates on the materials involved in high-efficiency cells, and I gathered sources that discussed the different materials involved in solar cell manufacturing. This study has allowed me to determine that gallium arsenide compounds combined with crystalline silicon cells are the most effective at absorbing and storing solar energy. I have also determined that factors such as multi-junction cells and the concentration of light increase the cell's efficiency. These advances in solar research will allow for more efficient cells to find their way into neighborhoods everywhere in only a matter of time.

Efficiency of Solar Cell Design and Materials

Since the Industrial Revolution, fossil fuels have made their mark on the world in both positive and negative ways. Coal has dominated the energy equation, producing approximately 33% of the world's energy, and it quickly began to replace the previous primary source of energy: biomass. In the nineteenth century when coal was in seeming abundance, "it very quickly made industrial and economic sense to use coal to supply the rapidly increasing energy demand" (McLamb, 2010). However, with the increasing population and decreasing coal deposits, it became apparent that another form of energy would have to eventually take coal's place as the world's primary source of energy. Luckily, research into using the sun's power to generate electricity began, marking the introduction of solar power as a clean, alternative type of energy. Unfortunately, coal is being consumed faster than ever before, yet it still remains the world's primary energy source. Therefore, a replacement for this fossil fuel has become even more necessary, and solar energy offers a solution. In the last decade, research into solar energy has allowed for the development of solar cells that can reach an average of near 20% energy conversion efficiency when sold commercially and at least double that while being tested in laboratories. By using typical crystalline silicon solar cells in combination with gallium arsenide compounds, solar cells have the potential to reach upwards of 50% conversion efficiency. By also utilizing design techniques, such as a light concentrator in conjunction with multi-junction cells, cells with theoretical efficiencies of close to 80% are created. By implementing this technology into the commercial production of solar cells, solar energy is a plausible replacement for coal as the world's primary source of energy.

The scope of my research, however, is limited. Since my research was directed to find the highest efficiency solar cells I primarily researched experiments and studies done on the materials and designs that have consistently increased energy conversion efficiency and electrical output. I did not delve into research on the worst possible solar cell materials, rather, I focused on studying what makes a solar cell more efficient from its base form of a single-junction cell with no external influence to allow more sunlight to enter the system.

Solar Cell Design and Light Concentration

The efficiency of solar cells is partially dependent on their design as a whole, taking into consideration a variety of factors such as the intensity of concentrated sunlight and the stacking of multi-junction cells. In a study conducted by Massachusetts Institute of Technology (MIT), a new system was created that uses sunlight to heat an absorber-emitter device that is placed over the photovoltaic cells (PV). The absorber "includes an array of multi-walled carbon nanotubes that efficiently absorbs the light's energy and turns it into heat," while the emitter consists of "a bonded layer of silicon/silicon dioxide photonic crystals...engineered to convert the heat back into light that can then be captured by the PV cells" (Giges, 2014). This system also includes a light concentrator, consolidating the light introduced into the system so that it can be absorbed and transformed into solar energy with less wasted light. This concentration of light that MIT implemented in their design allows for a smaller solar cell to have the same effectiveness as larger ones that rely solely on having small acceptance angles and reflection of light in nature to produce energy.

In order to measure the efficiency and effectiveness of solar cells, one must consider the incident flux of the cell, its area, and its maximum potential power output. Maximum efficiency is measured as the maximum power output divided by the product of the incident flux and the area of the cell (*Measuring PV Efficiency*). Therefore, concentrating the light gives a solar cell the same incident flux across a smaller area, increasing the maximum potential efficiency of the cell.

However, concentrating light is not the only way to increase efficiency inside of a solar cell. Engineers at the University of New South Wales developed a particular solar cell configuration that achieves a similar maximum efficiency without the use of concentrators. Led by Dr. Mark Keevers, the team utilized a multi-junction system embedded in a prism that splits "the incoming rays into four bands, using a hybrid four-junction receiver to squeeze even more electricity from each beam of sunlight" (University of New South Wales, 2016). This allows for each individual receiver to specialize in absorbing a certain band of light, giving the cell a higher sunlight to electricity conversion, therefore letting the cell produce more energy than a typical single-junction cell.

Since the multi-junction cell does not use concentrators to consolidate the sunlight entering the prism, however, this approach alone does not reach the total possible maximum energy output that solar cells will one day reach. Dr. Stephen Bremner and Professor Martin Green address this issue through their experiments with solar cells, claiming that "Increasing sunlight concentration increases efficiency limits...A maximum of 86.0% is possible when the lowermost cell bandgap approaches zero" (Green and Bremner, 2016). Their experimental results prove that by combining these two approaches to achieving maximum solar cell efficiency, scientists may be able to develop Creating a multi-junction solar cell supported with solar concentrators is the next step insolar cell technology, and it is ultimately taking the next step towards a cleaner world and a more effective replacement for fossil fuels.

Materials of Solar Cell Production

The other major contributing factor to the efficiency of solar cells and the cost-effectiveness of their designs is the materials involved in their creation and development. According to the Department of Energy, “Crystalline silicon PV cells are the most common solar cells used in commercially available solar panels, representing more than 85% of world PV cell market sales in 2011. Crystalline silicon PV cells have laboratory energy conversion efficiencies over 25% for single-crystal cells and over 20% for multicrystalline cells” (Department of Energy). In terms of efficiency, crystalline silicon cells neither excel nor fail in their energy conversion effectiveness, but there are more factors to consider when it comes to choosing which materials to use in a solar cell, especially when marketing to consumers outside of the laboratory.

Crystalline silicon is the second most abundant resource in the Earth’s crust, and it can be divided into two separate purities: monocrystalline silicon and polycrystalline silicon. According to Mathias Maehlum, an energy and environmental engineer, the purer silicon is, “the more perfectly aligned the silicon molecules are, [and] the better the solar cell will be at converting solar energy into electricity” (Maehlum, 2015). Monocrystalline silicon typically has a 5% higher efficiency than that of polycrystalline silicon, but with it comes an increase in price. Because monocrystalline has a more precisely aligned molecular structure, it costs more to produce than polycrystalline silicon, but it is a more viable replacement to fossil fuels.

However, studies conducted by Dr. Stephen Bremner and Professor Martin Green have shown that silicon is not the most efficient cell core. They have deduced that there is a positive correlation between energy conversion efficiency and external radiative efficiency (ERE). The “fraction of net recombination when the cell is open-circuited that is radiative,” meaning that it does not waste as much energy when the circuit is opened (Green and Bremner, 2016). Through their studies, gallium arsenide has a higher ERE than crystallized silicon and therefore has a higher energy conversion efficiency.

This is not the first time that gallium arsenide has been included in solar cell testing either. A team of researchers from MIT, and the Masdar Institute of Science and Technology led by Professors Ammar Nayfeh and Eugene Fitzgerald, have been experimenting with gallium arsenide phosphide coatings for silicon cells. They have found that its easy production, as well as the increase in efficiency that it brings, makes it a feasible addition to the future of solar technology. Professor Fitzgerald explains:“adding that one layer of the gallium arsenide phosphide can really boost efficiency of the solar cell but because of the unique ability to etch away at the silicon germanium and reuse it, the cost is kept low because you can amortize that silicon germanium cost over the course of manufacturing many cells” (MIT News Office, 2016). This coating layer acts as a step cell; the light encounters the gallium arsenide phosphate before it reaches the silicon germanium. Because the two materials bonded together, replacing and reusing the silicon germanium greatly reduces production costs while maintaining theoretical efficiencies of upwards of 50%. Introducing gallium arsenide to the commercial solar cell world will increase cell efficiencies across the world, allowing for a cheap alternative to fossil fuels, helping to make the world cleaner and save the environment.

Discussion

Research into the plausibility of solar cells as a replacement for fossil fuels has made decent progress over the last few years, and it is possible to see a future where solar energy becomes the world’s primary energy source. Through the recent work of researchers, I have discovered that crystallized silicon is the most cost effective and most plausible base for the cores of solar cells, but by introducing a multi-junction cell with the inclusion of gallium arsenide materials, solar cells will experience an increase in their energy conversion efficiencies. This will produce more energy with little financial drawback. If a concentration of light is also introduced to these cells, efficiency can increase even further and produce more power than they could without. However, even with these additions to current solar cells, maximum theoretical efficiency only reaches close to 80%. Therefore, further research into material interactions with solar activity as well as solar cell design should be initiated. I believe that science can bring solar cells to an even higher efficiency, and with a higher conversion efficiency, the fewer fossil fuels will be consumed. Further research will allow for a cleaner future and a cleaner world, allowing solar energy to replace fossil fuels.

References

Department of Energy, U. (n.d.). *Crystalline Silicon Photovoltaics Research*. Retrieved from https://www.energy.gov/eere/sunshot/crystalline-silicon-photovoltaics-research

Giges, N. S. (2014, April). *Making Solar Panels More Efficient*. Retrieved from https://www.asme.org/engineering-topics/articles/renewable-energy/making-solar-panels-more-efficient

Green, M. A., & Bremner, S. P. (2016, December 20). *Energy conversion approaches and materials for high-efficiency photovoltaics*. Retrieved from http://um9mh3ku7s.search.serialssolutions.com.libproxy.mst.edu/?url_ver=Z39.88-2003&ctx_ver=Z39.88-2003&ctx_enc=info:ofi/enc:UTF-8&rft_id=info:doi/10.1038%2fnmat4676&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rft.genre=article&rft.aulast=Green&rft.aufirst=M.A.&rft.issn=14761122&rft.volume=16&rft.issue=1&rft.date=2016-12-20&rft.spage=23&rft.epage=34&rft.pages=23-34&rft.artnum=&rft.title=Nature+Materials&rft.atitle=Energy+conversion+approaches+and+materials+for+high-efficiency+photovoltaics&rfr_id=info:sid/Elsevier:Scopus

Maehlum, M. A. (2015, May 18). *Which Solar Panel Type is Best? Mono-, Polycrystalline or Thin Film?* Retrieved from http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/

McLamb, E. (2010, September 15). *The Secret World of Energy*. Retrieved from http://www.ecology.com/2010/09/15/secret-world-energy/

Measuring PV Efficiency [PDF]. (n.d.).Retrieved from http://www.pvpower.com/assets/Measuring-PV-Efficiency-Solar-Panels.pdf

MIT News Office (2016, August 29). *New solar cell is more efficient, costs less than its counterparts.* Retrieved from http://news.mit.edu/2016/new-solar-cell-more-efficient-costs-less-its-counterparts-0829

University of New South Wales. (2016, May 17). *Milestone in Solar Cell Efficiency Achieved*. Retrieved from https://www.sciencedaily.com/releases/2016/05/160517121811.htm