Perovskite and the Future of Solar Power

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Introduction

As the world is slowly but steadily shifting its energy production towards renewable sources, solar energy is the clear front runner. Out of 157 GW of new renewable power commissioned in 2017, a whole 98 GW was due to solar sources alone.[1] However, while fossil fuels can generate power at an average efficiency rate of about 38%[2], the best of current commercial-use solar panels, *Maxeon 3* made by *SunPower*, can only reach 22.6% efficiency.[3]

One way in which researchers are trying to close this gap is by combining the existing silicon photovoltaic panels with a titanium oxide compound called perovskite. This tandem approach could theoretically lead to efficiency of up to 43%.[4] This essay will thus discuss the mechanisms behind photovoltaic technology, how it can be improved by the use of perovskite and what are the problems faced by perovskite-silicon tandem solar panels.

Principles of Photovoltaic Cells

Photovoltaic solar cells work by converting solar energy directly into an electrical current via the photoelectric effect, which was first fully described by Albert Einstein in 1905.[5] In essence, the photoelectric effect occurs when light of high enough energy (E_p) is shone on a conductor or a semiconductor. The electrons absorb the photons and gain at least sufficient energy (called work function ϕ) to escape their atoms and become free electrons with kinetic energy $K = E_p - \phi$. Importantly, if individual quanta of light do not have enough energy, the electrons will not absorb them and will stay trapped within the material.[6]

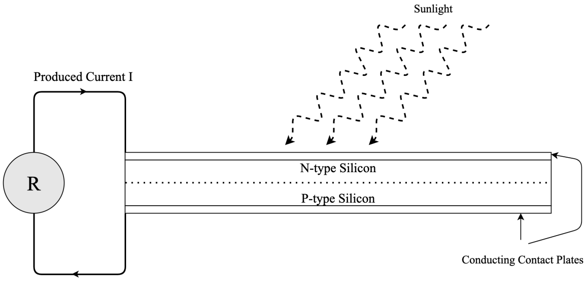

Figure 1: A basic diagram of a silicon-based photovoltaic cell exposed to sunlight and connected via conducting plates to an outside circuit with resistance R. The silicon has been doped by introducing impurities to create two layers: N-type and P-type. Electrons within the silicon can only flow from the P-type layer to the N-type layer which creates an electric field between the top and the bottom of the cell. Electrons ejected from the N-type layer are accelerated by this field, producing a current I in the circuit.

Figure 1 above shows the basic mechanism by which this effect is exploited in silicon photovoltaic cells to generate electricity. To make it work one has to introduce (i.e. ”dope”) impurities to pure silicon crystals two create two distinct layers of the semiconductor. The first one, called N-type, is typically produced by adding phosphorous atoms, which carry an extra electron in their outer shell compared to silicon atoms. The other layer, P-type, is made by adding boron atoms which carry one less electron than silicon. Consequently, the top layer (N-type) has a surplus of electrons as compared to the bottom (P-type).[7]

Normally, this imbalance would have been corrected by electrons spreading uniformly throughout. However, at the interface of the two layers, an interesting effect is at play which makes it almost impossible for the electrons to cross from N-type to P-type, while at the same time making the flow in the opposite direction relatively easy. Hence, an effective electric field is produced between the two layers which can be used to accelerate the electrons freed by the photoelectric effect in the same direction in the circuit, generating electricity.[7]

This simple model of photovoltaic cells is called a single-junction cell and it resembles well the current, commercially-available solar technology. The issue it faces is that the bandgap energy[1] E_g of crystalline silicon is just 1.1eV. This energy corresponds to the range of infrared light, and so silicon cells work best when transforming upper-range infrared and red light into electricity.[7] However, while it can absorb more energetic photons, the thermal effects lead to significant loses in efficiency. To work around this limitation, perovskite can be introduced in a tandem cell.[8]

PEROVSKITE'S USAGE IN PHOTOVOLTAIC CELLS

Somewhat counter-intuitively, perovskite cells' main benefit is that of higher bandgap energy, typically in the range of 1.5-1.8eV. These values correspond to the red light[6], so perovskite cells are especially good at efficiently gathering energy from the photons just a step farther in the visible spectrum - green and blue light. Therefore, if the perovskite cells are placed above silicon in a tandem cell, they will capture the more energetic photons, while letting the less energetic light through to the silicon cell.[8] As can be seen in figure 2 which shows the intensity of different wavelengths of sunlight at the sea level, the peak of the light reaching the surface of the Earth is well-covered by this range.

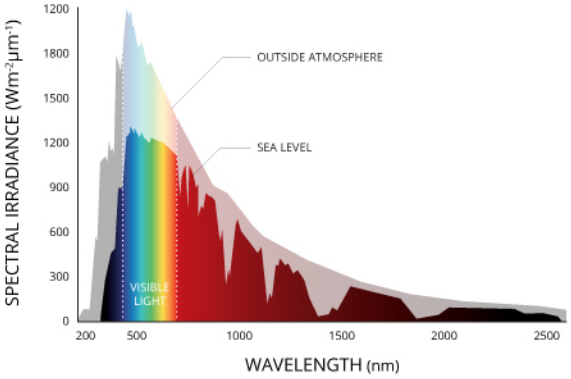

Figure 2: A graph of solar irradiance spectrum of sunlight of different wavelengths. The pale graph in the background shows the light as it leaves the Sun and the saturated graph in front shows the light reaching the surface of the Earth.[9]

Furthermore, perovskite compounds have one of the highest $\frac{eV_0}{E_g}$ ratios[10], comparing the work done by a stopping potential[2] V_0 on an electron of charge e with the

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[1] The energy difference between the conduction band and the valence band in electron's energy. Since in the photovoltaic cells electrons need only to begin conducting, not fully escape the material, providing energy equal to E_g is enough. $E_g < \phi$ for semiconductors.[6]

[2] The potential required to just stop the current in a photoelectric circuit where the ejected electrons face an electric field accelerating them back towards the surface from which they escaped.[6]

bandgap energy of the material. Since the current in a circuit is approximately proportional to the potential, this high ratio means that perovskite cells can produce a strong photocurrent relatively easily.[10] All this makes perovskite-silicon tandem cells highly impressive as solar panels, able to generate power with 28% conversion efficiency already and soon to cross the 30% boundary.[11] Considering all this, why are they not widely available already?

DIFFICULTIES WITH PEROVSKITE TECHNOLOGY

The single biggest difficulty with commercially viable perovskite solar panels is scalability. While the astounding results of 28% efficiency are real, most of them were accomplished on minuscule samples, less than $1cm^2$ in size. Whenever researchers try to upscale their experiments, the efficiency drops dramatically, far below what would be profitable. This is mainly due to fragility of the crystals. Meanwhile, silicon cells can be upscaled easily and with a much smaller drop in efficiency.[12]

Another problem faced by perovskite technology is its toxicity. Many of the newly built cells contain lead to make the overall structure more stable. However, lead is well-known to be a highly toxic substance, so such panels could be dangerous to humans and wildlife. On top of that, many countries have laws controlling lead content in commercial products, which would considerably complicate the distribution of the panels. In the end, it is genuinely unlikely that perovskite cells based on lead will see any success in the solar power industry. Another substance with properties comparable to lead in terms of stability but without the toxic effect must replace it.[13]

However, the issue of stability is bigger than simply replacing lead. Current perovskite-based cells last significantly shorter than their silicon counterparts, which often have a 25-year-long warranty. Perovskite crystals are highly prone to changes in moisture, air, temperature and light. While the first two can be avoided by wrapping the cells in protective plastic or glass, it is harder to protect against the latter. Swiss Federal Institute of Technology in Lausanne has developed a structure which combines cations of methylammonium and formamidinium with caesium and rubidium, resulting in a cell that is more resistant to temperature changes. However, the issue of light remains to be solved. Currently, a long-term exposition can change the crystal structure so much that its efficiency drops rapidly, hardly a trait acceptable in a solar cell.[12]

CONCLUSION

Will we see perovskite-based solar panels widely used any time soon? It is hard to say for sure. The technology unquestionably offers many promises in the photovoltaic cell industry, and the theoretical upper limit of efficiency for perovskite-silicon tandem cells would put them on par with fossil fuels. It is undeniable, however, that the challenges it faces are not straightforward to overcome. Minding that and the rate at which new technology is being discovered it may be best to stay cautiously optimistic.

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