MATHEMATICS
MATTERS

Perovskite: The Future of Solar Power Generation?

Solar panels are often seen as a future, large scale alternative to fossil fuels. However, current designs are limited by their efficiency. Using mathematics, researchers have transformed an obscure mineral into a potential game changer.

We are facing an energy crisis. With an ever increasing world population, and continuing technological growth around the globe, how to create the energy we need is one of the biggest challenges we need to tackle. An estimate by the U.S. Department of Energy predicts that by 2025 global energy production will need to rise by 29% from the levels in 2007 if the planet's voracious appetite for energy is to be met. Ten percent of the world's gross domestic product is spent on energy, but currently we are over-reliant on a dwindling supply of fossil fuels. Solar power is one of the alternative energy sources that has been lauded as a possible solution. After all, the sunlight falling on the planet in a single hour could provide the energy to keep the Earth going for a whole year. It is also much greener than the carbon emitting technologies that it is vying to replace.

Solar panels are constructed from photovoltaics – devices that can convert solar energy into electricity. Estimates suggest that photovoltaics could supply nearly a third of new electricity generation by 2030 and that

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solar energy could be the world's biggest source of electricity by 2050. The traditional photovoltaic material of choice – accounting for around 85% of the world's photovoltaics - has been silicon as it is relatively cheap. However, silicon has problems. First, forming it into the crystal structure required for use is difficult which drives the price up. Silicon is also rigid, which restricts the situations in which it can be deployed. So the search has been on for a silicon replacement, but it was slow going initially. Most alternatives had a lower efficiency than silicon (less than 12% compared to silicon's 20-22%) and they weren't that much cheaper either.

However, the last five years have seen a new material start from humble beginnings to rival silicon in the photovoltaics industry: perovskite, a mineral made of calcium, titanium and oxygen. First found in 1839, and named after Russian mineralogist Lev Perovski, it is easy to manufacture and more flexible than silicon. However, when it was first used in solar cells back in 2009 the resulting technology only had an efficiency of 3%. But an energy arms race between rival research groups has seen that rocket up to over 20%, approximately matching the efficiency of silicon. Such improvement in such a short space of time makes perovskite photovoltaics the fastest advancing solar technology in history. In 2013 it was named one of the breakthrough technologies of the year. What's responsible for the efficiency surge? In part it is mathematics.

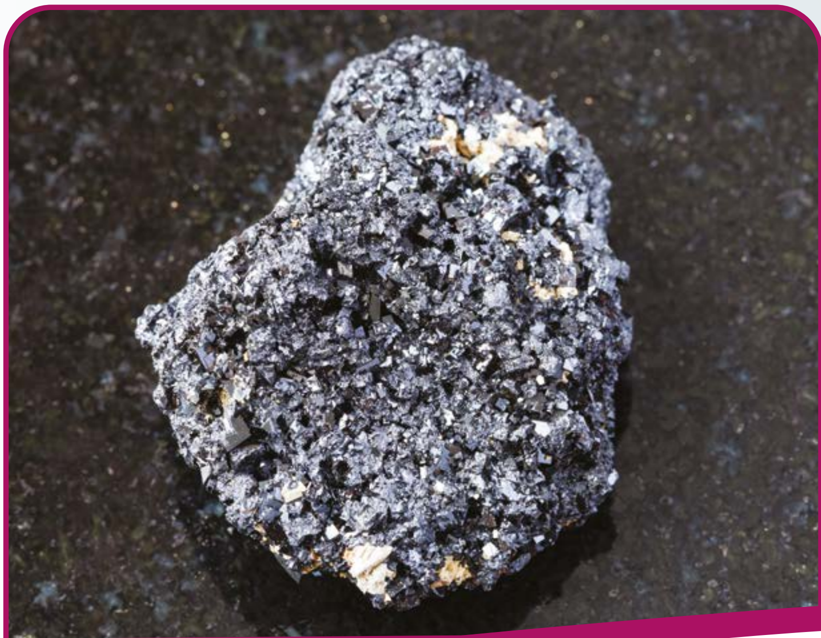
Institute of mathematics & its applications

The solar cells inside photovoltaics are semiconductors – they contain negatively and positively charged particles called electrons and holes respectively. When sunlight hits the material, the electrons and holes are given energy and they move towards the edges of the material where they are picked up by electrodes and used to create an electric current. But if an electron and a hole meet before they reach the electrodes, they combine and most of the energy gained from the sunlight is lost.

The average distance travelled by an electron or a hole before combination is known as the 'diffusion length'. If this is less than the thickness of the material then the electrons and holes are likely to combine before they reach the electrodes. It is a trade-off: thick cells absorb more light but can be less efficient at converting that to electricity. You want to optimise the distribution of holes and electrons and this can be done via mathematical modelling. That model can link the distribution of holes and electrons to the overall efficiency of the solar cell. Then you can start to play around with new ways of deploying the technology.

For example, because perovskite photovoltaics are flexible (unlike silicon), you could apply a thin film to all the windows in an office block. Some of the sunlight streaming through the windows would be converted into electricity to power the building. In future you could even run your computer or charge your smartphone by plugging it into the window. However, you don't want the films too thick because they will start to block out too much light. By mathematically modelling the situation you can reach a compromise between transparency and the ability to provide energy. It seems an efficiency of 5-6% can be reached without impeding too much light. This technology could be particularly useful in developing regions such as India and Africa where sunlight is plentiful. In non-window applications, some researchers have suggested the efficiency could climb as high as 50%.

For these reasons, perovskite is seen by some as the future of solar technology. Spin out companies from academic institutions are already working hard to scale up to commercially viable prototypes. This quest for a cleaner, greener energy has mathematics at its heart.



TECHNICAL SUPPLEMENT

Photovoltaic semiconductors are made of two types of material known as p-type and n-type semiconductors (where p and n stand for positive and negative). Positively charged 'holes' make up the majority of p-type semiconductors; n-types are mostly comprised of negatively charged electrons. The interface between the two materials is known as the 'p-n junction'.

If the diffusion length can be increased then so can the quantum efficiency – the current that is produced when the material is irradiated with photons of a particular wavelength. Mathematicians can model which of the many possible paths the electrons will travel through, with differential equations describing their distribution. This distribution can then be optimised to boost efficiency.

References

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