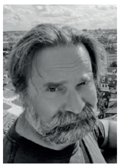
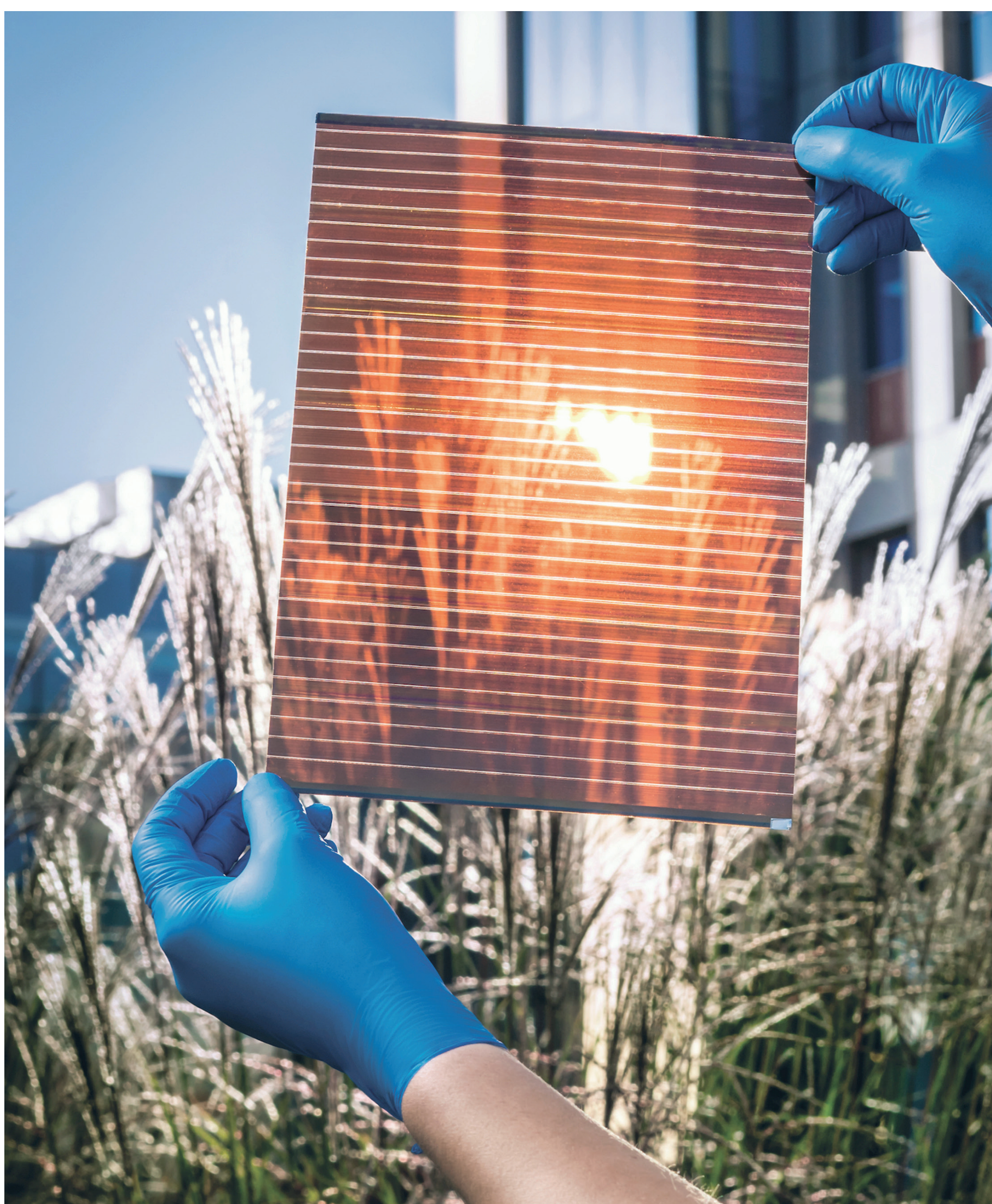
DOI: 10.24425/academiaPAS.2022.143997



Olaf Szewczyk
is Communications Director at Saule Technologies. He has led the science and technology sections in the Polish weeklies *Wprost* and *Przekrój*, and has authored columns popularizing science in Polish dailies including *Dziennik* and *Gazeta Wyborcza*.
pr@sauletech.com

Sunlight at the End of the Tunnel

Perovskite solar cells represent the biggest breakthrough in photovoltaics in decades, bringing a chance for affordable and widely available green energy. They are suitable in areas where silicon cells have fallen short.

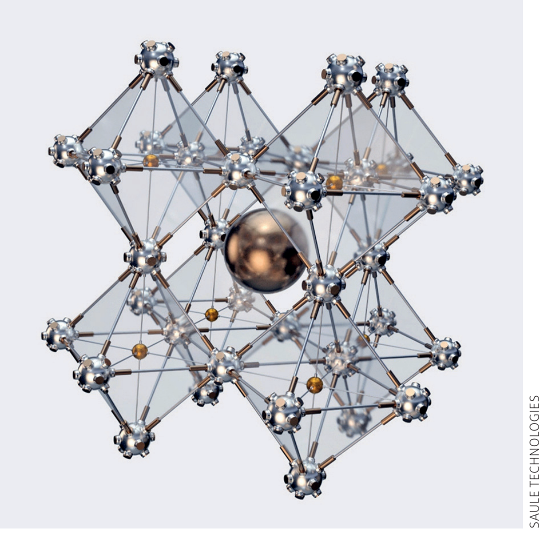


A lightweight and semi-transparent perovskite solar module

SAULE TECHNOLOGIES

Olaf Szewczyk

Saule Technologies in Warsaw



Model of a Perovskite crystal

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Out of all the Becquerels, a renowned family of brilliant French scientists, it was Henri Becquerel (1852–1908) who shined brightest. He discovered radioactivity, which earned him the Nobel Prize in Physics five years before his death (jointly with Maria Skłodowska-Curie and her husband, Pierre Curie). His grandfather, Antoine César Becquerel (1788–1878), was famous for his research into electricity and luminescence. Henri's son, Jean Becquerel (1878–1953), rose to prominence as a physicist thanks to his study of the optical and magnetic properties of crystals. Yet in this noble line of outstanding scientific minds, it is nevertheless probably Edmond Becquerel (1820–1891), the father of the Nobel Prize winner who lived in his son's shadow, who is likely to ultimately go down in history as the Becquerel to whom we owe the most. Edmond was just 19 years old when he discovered the photovoltaic effect and developed the very first photovoltaic cell.

Silicon cells

Traditional silicon photovoltaic cells are manufactured at very high temperatures (above 800°C). This means that during the manufacturing process they cannot be integrated with a substrate made of plastic or any other material that could be damaged by this temperature. Another problem is posed by the fragility and rigidity of silicon cells, which are therefore essentially always installed in the same way – as flat, dark wafers secured by rigid frames. For this reason, rooftop photovoltaic systems look practically the same everywhere, and nothing has changed in this respect for decades. Likewise, the dark color is a permanent feature of silicon cells, especially in single-crystalline silicon cells (sc-Si), which are now the most popular types of cells, whereas multicrystalline silicon cells (mc Si) are more bluish. Silicon cells on rooftops are therefore always unsightly, and it is no coincidence that architects genuinely loathe them. The reason is that it is simply impossible to mount silicon cells on buildings in any discreet, unobtrusive, neutral way.

The major limitation of silicon photovoltaic cells stems from a property we have become so accustomed to that we take it for granted: silicon cells work efficiently only when lit by sunlight, and indeed only when the Sun's rays hit them at an optimal angle. This is the major reason why they are mounted almost exclusively on rooftops, where it is easier to point the cells directly at the Sun, which is at its highest around noon. Silicon cells are almost never seen, for instance, mounted vertically on walls. In this position, the Sun's rays would hit them at a more oblique angle, which would greatly detract from the amount of electricity generated.

Despite all these limitations, the importance of photovoltaics is still growing, for a variety of reasons. The need for a quick shift away from fossil fuels became obvious to us years ago, once we realized that we were facing a climate disaster that could lead to the extinction of most of the plant and animal species on Earth. We already know that we are living in the Anthropocene, a human-dominated epoch that could end in another great extinction event, comparable to previous ones after which the Earth's ecosystem had to recreate itself almost from scratch. Photovoltaic technology, as the most promising, efficient, proven, and safest source of green energy, appears to be one of our strongest hopes for averting the crisis.

And so, Edmond Becquerel's discovery is clearly now more important than ever. However, the question remains: Where are we headed in the development of photovoltaic technologies, and how far can we go? In terms of crystalline silicon, we have almost hit the wall – there is not much that can still be achieved in this area of research. Alternative solutions developed so far have disadvantages that disqualify them as next-generation technologies. They are either inefficient, like amorphous silicon (a-Si) panels, or toxic, like cadmium telluride (CdTe) panels, or very expensive, like gallium arsenide (GaAs) cells.

A novel discovery

However, there is now a completely new photovoltaic technology that may already represent the kind of breakthrough in terms of performance and applications as cell phones did with respect to landline phones. It involves photovoltaic cells based not on silicon, but on perovskites.

Perovskites are materials with a distinctive crystal structure that have been known to science since 1839, when the first such mineral was discovered in the Ural mountains by the German mineralogist Gustav Rose. Perovskites are commonly found in nature, but the most important thing is that they can be easily manufactured in labs through chemical synthesis. For a long time, however, it was not realized that perovskites could successfully be used in photovoltaic cells.

The breakthrough that made it possible to consider their practical applications came with a discovery made by the Polish physicist Olga Malinkiewicz while studying at the University of Valencia in Spain. The year was 2013, and the Polish student spent every spare moment she had in the lab, attempting to do what the world's best research teams had failed to achieve. As had been the case for the discovery made by Edmond Becquerel at the age of 19, the decisive role here was played by the young Olga Malinkiewicz's brilliant intuition, determination, and luck. The perovskite-based photovoltaic cell she developed worked, and surprisingly efficiently at that. Developing a technology for producing flexible perovskite-based photovoltaic cells at low temperatures earned Olga Malinkiewicz the top prize in the Photonics21 science competition, which she received from European Commission Vice President Neelie Kroes on 28 March 2014.

Malinkiewicz, aware of the significance of her discovery, certainly did not waste this opportunity. She accepted a collaboration proposal from Polish businessmen Artur Kupczunas and Piotr Krych. Later in 2014, they founded Saule Technologies in Wroclaw, Poland, to refine the technology for producing perovskite photovoltaic cells and commercialize the product. Today, Saule Technologies is one of the world's most important companies pursuing this technology. It was also the first to start producing perovskite cells and launch the finished products onto the market.

Perovskite's advantages

Perovskite cells can be manufactured at low temperatures, so the amount of energy consumed in this process is small. Perovskite cells are therefore more environmentally friendly and easier to produce than traditional silicon cells. The materials needed to manufacture them are easily available in Europe. In addition, the low manufacturing temperatures allow perovskite cells to be printed on virtually any substrate: PET foil, textiles, or even paper. The cells are also extremely thin (and therefore ultralight) and flexible, which means that their potential applications are virtually endless. For example, they can be printed on truck tarpaulins, sails, tents, jackets, and backpacks. Perovskite cells are translucent and can be dyed in a variety of colors. Let us imagine corrugated roofing sheets, car bodies, carports, and bicycle sheds, as well as smartphone, computer, and drone casings that are covered in a non-invasive way with invisible photovoltaic cells and can therefore work for longer and are

The Saule Technologies printing team holding a 1×1 meter module

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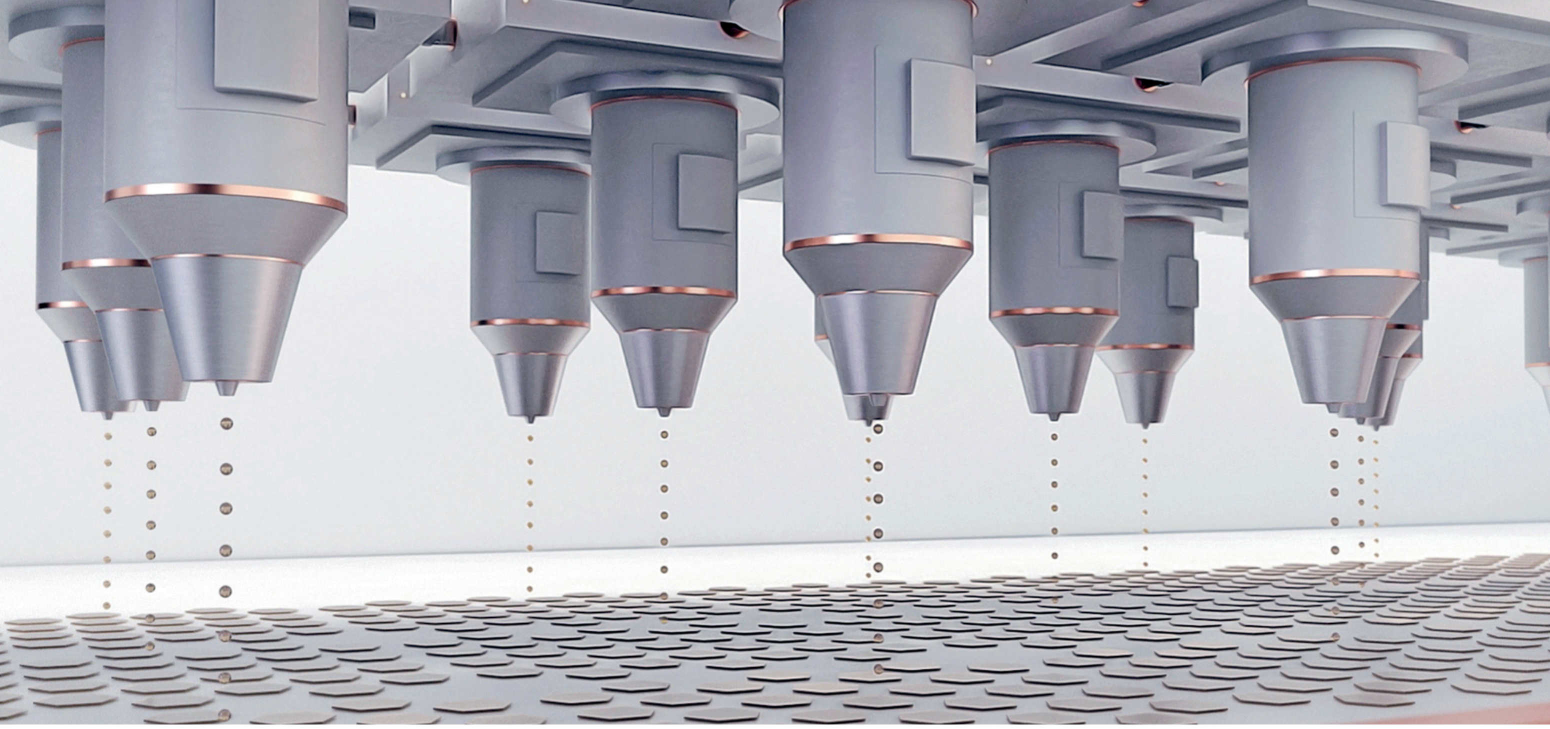

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Saule Technologies uses inkjet printing to manufacture perovskite cells

more environmentally friendly thanks to the supply of extra energy. One great advantage of perovskite cells is their high efficiency, even in non-optimal lighting. They can be installed on building facades, even though the Sun's rays hit them at a non-optimal angle. Being semi-transparent, perovskite cells can also be used to coat window glass.

Saule Technologies has already shown a functional solution in this category. The first solar lamellas, functioning as a brise-soleil covered with perovskite cells, were mounted on the facade of the head office of the Aliplast company in Lublin, Poland, over a year ago. In addition to fulfilling their traditional functions, which include providing protection against strong light and overheating in the summer, and against cold in the winter, the perovskite solar lamellas also supply electricity to the offices in the building.

The most interesting advantages of perovskite cells include their high efficiency. They are already competing with silicon in term of efficiency, and they hold promise to push the limits of their capacity even further. But even this is not their main advantage over silicon cells. Most importantly, perovskite cells also work efficiently in artificial light. Therefore, this technology opens up completely new possibilities. After all, there has long been talk of the new industrial revolution soon to be ushered in by the rise of the Internet of Things (IoT) – independent devices fitted with microcomputers that connect remotely to the Internet. Examples include sensors that automatically transmit measurement data, machines that regulate their work according to remote commands, and so on. All these things make for a grand vision that has nevertheless not yet been able to materialize, for one simple reason – all these devices need power.

Low-weight and efficient perovskite cells also work in adverse lighting conditions and even in artificial light, so they are perfectly suited to respond to this challenge. Recently, Olga Malinkiewicz's Saule Technologies announced that we have already crossed another threshold of efficiency. As confirmed by an independent research team from the Fraunhofer Institute for Solar Energy Systems ISE, Saule Technologies' perovskite cell has achieved an impressive 31% efficiency in the kind of artificial lighting that is typical for IoT applications (1,000 lux).

Saule Technologies already offers the first IoT products with a perovskite cell designed to work in artificial lighting – the Perovskite Electronic Shelf Label (PESL), an electronic price label that enables multiple remote changes in the displayed price and other messaging during the course of the day. These products are now being tested in pilot stores in the Orlen and Żabka chains in Poland, saving time for the staff and also, for instance, allowing easier sale of food products that are close to their expiry dates.

These are, of course, only some of the possible applications of perovskite cells. Their unique performance characteristics mean that they can be installed almost everywhere, and the number of possible applications is practically unlimited. Cells developed by Saule Technologies have already attracted interest from the space industry, as they hold the potential to be an ideal power source in space. More importantly, however, for reasons related to their versatility and assumed wide availability (after the launch of mass production), perovskite cells have the potential to become a driver of developmental change: not only as a universal source of green energy, but also as a great development opportunity for the poor communities and countries in the Global South. Capable of providing electricity even in areas far away from power grids or in post-disaster crisis situations, perovskite cells seem destined for success, as they can fill market niches where they now have no competitors. After all, they do not even have to successfully compete with silicon over rooftops. All they have to do is prove that they can be of use in places where silicon cannot be used, due to its drawbacks. The Internet of Things (IoT) is the first obvious area of such expansion. ■

Further reading:

Kaku M., *Physics of the Future*, 2012.

Perlin J., *Let It Shine: The 6000-Year Story of Solar Energy*, 2013.

Sivaram V., *Taming the Sun: Innovations to Harness Solar Energy and Power the Planet*, 2019.