Earth-abundant solar pixels found to produce hydrogen for weeks

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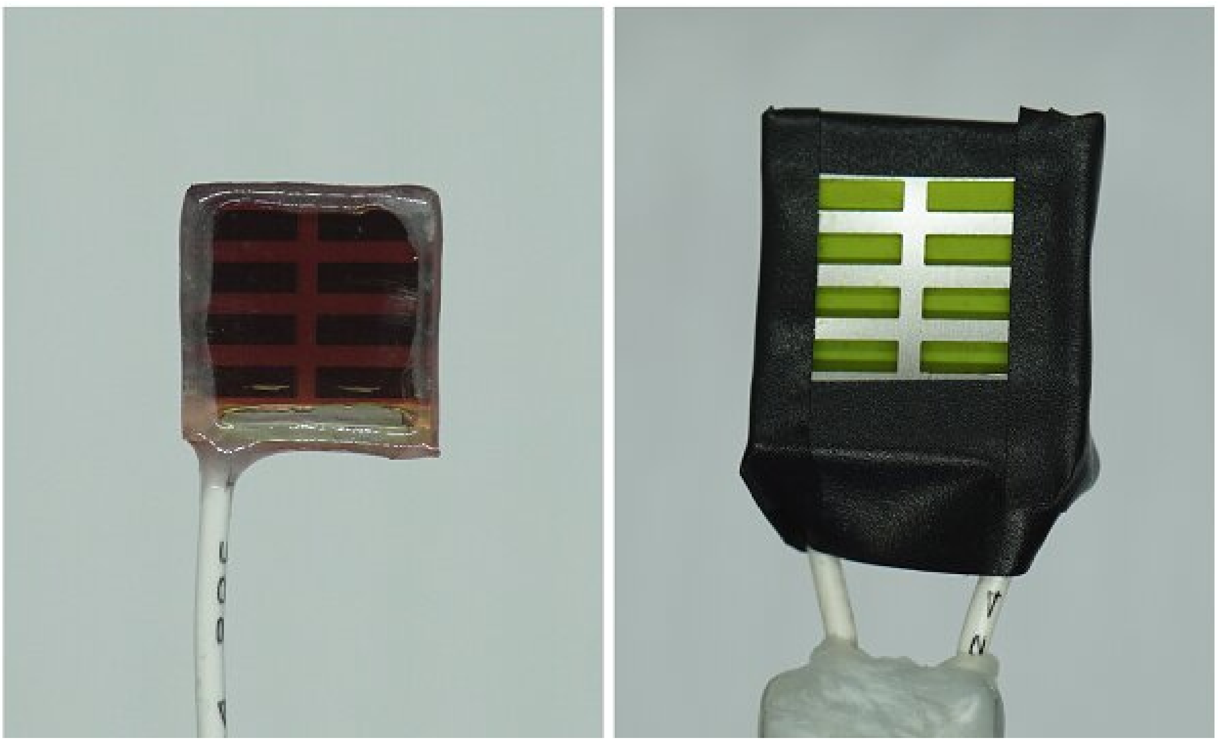


Multiple BiOI and BiOI-$BiVO_4$ pixels on a device. Credit: Dr Virgil Andrei.

Devices made of readily available oxide and carbon-based materials can produce clean hydrogen from water over weeks, according to new research.

The findings, co-led by Dr. Virgil Andrei, a Research Fellow at St John's

College, University of Cambridge, with academics at Imperial College London, could help overcome one of the key issues in solar fuel production, where current earth-abundant light-absorbing materials are limited through either their performance or stability.

Underexplored materials for light harvesting

Hydrogen fuel will play a critical role in the transition to full decarbonization and reaching the UK's goal of net-zero emissions by 2050. With most hydrogen currently supplied from fossil fuels, researchers are now working to find ways to generate hydrogen more sustainably. One way to achieve this is to make devices that can harvest sunlight and split water to produce green hydrogen.

While many light-absorbing materials have been tested for green hydrogen production, most degrade quickly when submerged in water. For example, perovskites are the fastest-growing materials in terms of light-harvesting efficiency, but are unstable in water and contain lead. This presents a risk of leakage; therefore, researchers have been working to develop lead-free alternatives.

Bismuth oxyiodide (BiOI) is a non-toxic semiconductor alternative which has been overlooked for solar fuel applications due to its poor stability in water. But based on previous findings into the potential of BiOI, researchers decided to revisit the promise of this material for the production of green hydrogen.

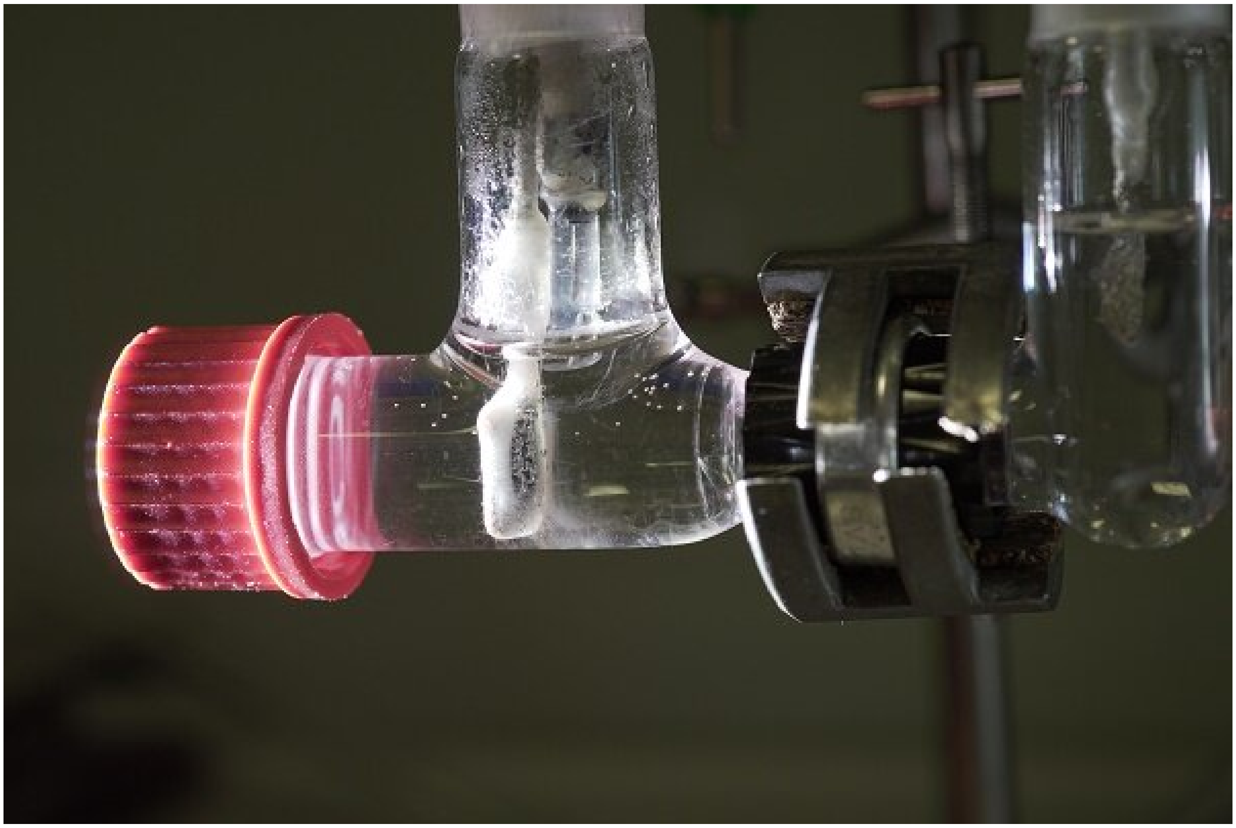
Dr. Robert Hoye, Lecturer in the Department of Materials at Imperial College London, explained: "Bismuth oxyiodide is a fascinating photoactive material that has energy levels at the right positions for water splitting. A few years ago, we demonstrated that BiOI solar cells are more stable than those using state-of-the-art perovskite light absorbers. We wanted to see if we can translate that stability to green hydrogen production."

Professor Judith Driscoll, Department of Materials Science and Metallurgy, University of Cambridge, says that "we have been working on this material for some time, due to its wide-ranging potential applications, as well as its simplicity of fabrication, low toxicity and good stability. It was great to combine the expertise of the different research groups across Cambridge and with Imperial."

Breakthrough in solar fuel production

The team of researchers created devices that mimicked the natural photosynthesis process occurring in plant leaves, except they produce fuels like hydrogen instead of sugars. These artificial leaf devices were made from BiOI and other sustainable materials, harvesting sunlight to produce O_2, H_2 and CO.

Researchers found a way to increase the stability of these artificial leaf devices by inserting BiOI between two oxide layers. The robust oxide-based device structure was further coated with a water-repellent graphite paste, which prevented moisture infiltration. This prolonged the stability of the bismuth oxyiodide light-absorbing pixels from minutes to a couple of months, including the time the devices were left in storage.



BiOI pixels produce hydrogen bubbles under illumination. Credt: Dr Virgil Andrei.

This is a significant finding that transforms BiOI into a viable light harvester for stable green hydrogen production.

"These oxide layers improve the ability to produce hydrogen compared to stand-alone BiOI," said Dr. Robert Jagt (Department of Materials Science and Metallurgy, University of Cambridge), one of the co-lead authors.

Researchers further found that artificial leaf devices comprising of multiple light harvesting areas (called 'pixels') demonstrated a higher performance over conventional devices with a single larger pixel of same total size. This finding could make the scale up of novel light harvesters much easier and faster for sustainable fuel production.

Dr. Virgil Andrei, a co-lead author from the Department of Chemistry in Cambridge, explains: "Even if some pixels are faulty, we were able to disconnect them, so they don't affect the rest. This meant we could sustain the performance of the small pixels on a larger area." This increased performance enabled the device to not only produce hydrogen but also reduce CO_2 to synthesis gas, an important intermediate in the industrial synthesis of chemicals and pharmaceuticals.

Looking to the future

The findings demonstrate the potential for these new devices to challenge the performance of existing light absorbers. The new ways of making BiOI artificial leaf devices more stable can now be translated to other novel systems, helping to bring them towards commercialization.

"This is an exciting development. At the moment, few solar fuel systems show stabilities which are compatible to real-world applications. With this work, we make a step forward towards establishing a circular fuel economy," said Prof Erwin Reisner (Department of Chemistry, Cambridge), one of the corresponding authors.

The findings have been published in the journal *Nature Materials*.

More information: Virgil Andrei et al, Long-term solar water and CO_2 splitting with photoelectrochemical BiOI–$BiVO_4$ tandems, *Nature Materials* (2022). DOI: 10.1038/s41563-022-01262-w

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