Lighting the way to optimal photocatalysis

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Credit: Carnegie Mellon University Materials Science and Engineering

One afternoon, Carnegie Mellon University Materials Science and Engineering (MSE)'s Mohammad Islam walked into colleague Paul Salvador's office and asked what the biggest problem was in photocatalysis that he'd like to be able to solve. Salvador's answer: He'd like to determine how the oxidation and reduction reactions in photocatalysis could be separated into distinct channels in order to increase performance.

A photocatalyst, which uses energy from light to accelerate a reaction, typically facilitates two reactions: an oxidation reaction and a reduction reaction. They are used in generating hydrogen, in remediating environmental biofouling, and potentially for killing drug-resistant bacteria.

"We're making open carbon nanotubes," responded Islam, research professor of MSE, "so how about we put the photocatalyst on the outside and the co-catalyst on the inside of each nanotube?"

Salvador, professor of MSE, said he thought that was an elegant solution—but was it possible?

Thus was formed a team including Islam, Salvador, and MSE Professor and Department Head Greg Rohrer, with Ph.D. student Hang-Ah Park, master's student Siyuan Liu, and former postdoc Youngseok Oh (currently a senior scientist at the Korea Institute of Materials Science). Recently, the team published a paper on their new approach to optimizing photocatalysts. Like many Carnegie Mellon research projects, the project started with a problem that could only be solved through collaboration.

The challenge: photocatalysts need to be cheap, efficient, and environmentally friendly. Though current photocatalysts may be inexpensive, they either have high toxicity or don't perform well.

In a photocatalyst, both the oxidation reaction and the reduction reaction need to be optimized, as does the space between these reactions. Typically, a photocatalyst that is good at performing one type of reaction (such as oxidation) has a co-catalyst added to it that is good at performing the opposite reaction (reduction). Though this helps with optimization, the reactions are not entirely separated, and therefore, products such as hydrogen and oxygen are generated in the same space.

"Imagine that you have a micrometer-sized sphere known to be good at oxidation, and you add onto it small co-catalyst hemispheres known to be good at reduction (typically 10 nanometers)," says Rohrer. "Even though the reactions are technically separated, they are still occurring in close proximity, which decreases the photocatalyst's performance. So, we put them in completely different channels."

What makes their work novel is not the complete separation of the channels, which is well known in standard photoelectrochemical cells (PECs), but that they brought a PEC down to the nanoscale, developed massively parallel arrays of those nanoscale PECs, and maintained complete separation.

"It's a very simple idea," says Salvador. "Many of us have done lab experiments in high school or college using traditional PECs, which separate products into two large beakers. We have taken that huge PEC from chemistry lab and brought it down to the nanoscale, and then we fabricated thousands of them that operate in parallel. In that process, we found some interesting new fundamental materials behavior, including high activity in visible light, and saw a phenomenal performance that has many applications."

A big application of photocatalysts is in remediating environmental biofouling, or removing organisms like barnacles and algae from surfaces such as pipes. Another application is in killing drug-resistant bacteria. Many hospitals, for example, use paints loaded with titania and irradiated with UV light to disinfect walls or other surfaces. But with the new photocatalytic method, they can use visible light, which is much safer. Finally, during hydrogen generation their photocatalysts suppress the mixing of product gases, an important advancement.

"The question now is, why is it doing a lot better?" says Islam. "Why did it become photoactive in the visible light when I am doing this with carbon nanotubes and titanium? What are the parameters that we can tweak to make it better? That's the direction we're going."

More information: Hang-Ah Park et al, Nano-Photoelectrochemical Cell Arrays with Spatially Isolated Oxidation and Reduction Channels, *ACS Nano* (2017). DOI: 10.1021/acsnano.6b08387

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