Electrochemistry controlled with a plasma electrode

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Engineers at Case Western Reserve University have made an electrochemical cell that uses a plasma for an electrode, instead of solid pieces of metal.

The technology may open new pathways for battery and fuel cell design and manufacturing, making hydrogen fuel and synthesizing nanomaterials and polymers.

A description of the research is now published in the online edition of the Journal of the American Chemical Society at http://pubs.acs.org/doi/abs/10.1021/ja207547b.

"Plasmas formed at ambient conditions are normally sparks which are uncontrolled, unstable and destructive," said Mohan Sankaran, a chemical engineering professor and senior author of the paper. "We've developed a plasma source that is stable at atmospheric pressure and room temperature which allows us to study and control the transfer of electrons across the interface of a plasma and an electrolyte solution."

Sankaran worked with former students Carolyn Richmonds and Brandon Bartling, current students Megan Witzke and Seung Whan Lee and fellow chemical engineering professors Jesse Wainright and Chung-Chiun Liu.

The group used a traditional set up with their nontraditional electrode.

They filled an electrochemical cell, essentially two glass jars joined with a glass tube, with an electrolyte solution of potassium ferricyanide and potassium chloride.

For the cathode, argon gas was pumped through a stainless steel tube that was placed a short distance above the solution. A microplasma formed between the tube and the surface.

The anode was a piece of silver/silver chloride.

When a current was passed through the plasma, electrons reduced ferricyanide to ferrocyanide.

Monitoring with ultraviolet-visible spectrophotometry showed the solution was reduced at a relatively constant rate and that each ferrycyanide molecule was reduced to one ferrocyanide molecule.

As the current was raised, the rate of reduction increased. And testing at both electrodes showed no current was lost.

The researchers, however, found two drawbacks.

Only about one in 20 electrons transferred from the plasma was involved in the reduction reaction. They speculate the lost electrons were converting hydrogen in the water to hydrogen molecules, or that other reactions they were unable to monitor were taking place. They are setting up new tests to find out.

Additionally, the power needed to form the plasma and induce the electrochemical reactions was substantially higher than that required to induce the reaction with metal cathodes.

The researchers know their first model may not be as efficient as what most industries need, but the technology has potential to be used in a number of ways.

Working with Sankaran, Seung has scanned a plasma over a thin film to reduce metal cations to crystalline metal nanoparticles in a pattern.

"The goal is to produce nanostructures at the same small scale as can be done now with lithography in a vacuum, but in an open room," Seung said.

They are investigating whether the plasma electrode can replace traditional electrodes where they've come up short, from converting hydrogen in water to hydrogen gas on a large scale to reducing carbon dioxide to useful fuels and commodity chemicals such as ethanol.

The researchers are fine-tuning the process and testing for optimal combinations of electrode design and chemical reactions for different uses.

"This is a basic idea," Sankaran said. "We don't know where it will go."

Provided by Case Western Reserve University

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