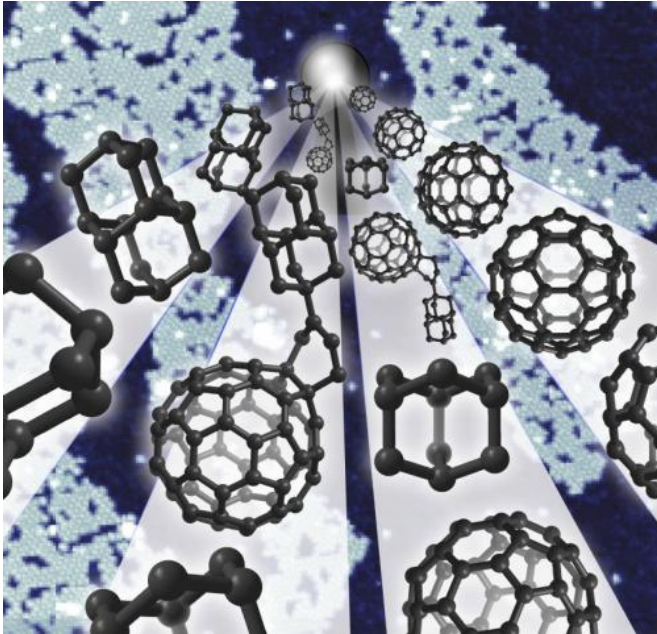


# Buckyballs and diamondoids join forces in tiny electronic gadget

9 September 2014



An international team led by researchers at SLAC National Accelerator Laboratory and Stanford University joined two offbeat carbon molecules -- diamondoids, the square cages at left, and buckyballs, the soccer-ball shapes at right -- to create "buckydiamondoids," center. These hybrid molecules function as rectifiers, conducting electrons in only one direction, and could help pave the way to molecular electronic devices. Credit: Manoharan Lab/Stanford University

Scientists have married two unconventional forms of carbon – one shaped like a soccer ball, the other a tiny diamond – to make a molecule that conducts electricity in only one direction. This tiny electronic component, known as a rectifier, could play a key role in shrinking chip components down to the size of molecules to enable faster, more powerful devices.

"We wanted to see what new, emergent properties might come out when you put these two ingredients together to create a

'buckydiamondoid,'" said Hari Manoharan of the Stanford Institute for Materials and Energy Sciences (SIMES) at the Department of Energy's SLAC National Accelerator Laboratory. "What we got was a basically a one-way valve for conducting electricity – clearly more than the sum of its parts."

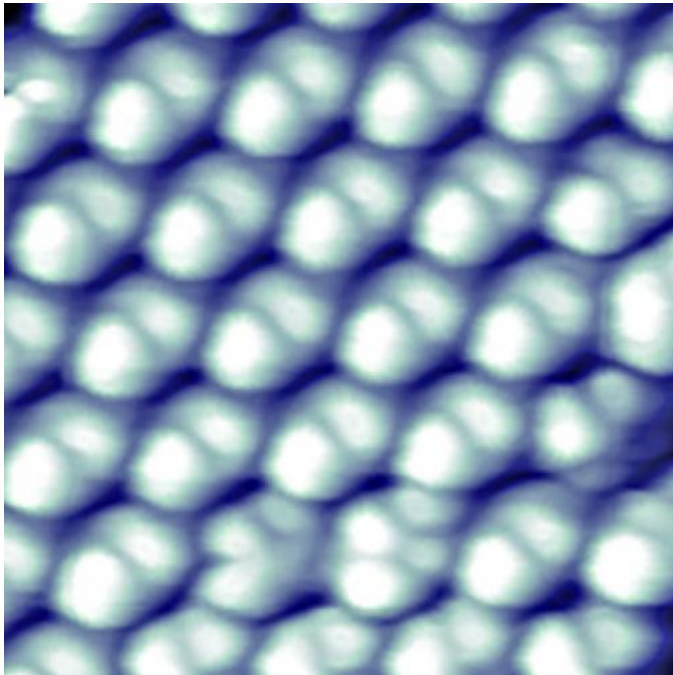
The research team, which included scientists from Stanford University, Belgium, Germany and Ukraine, reported its results September 9, 2014 in *Nature Communications*.

## Two Offbeat Carbon Characters Meet Up

Many electronic circuits have three basic components: a material that conducts electrons; rectifiers, which commonly take the form of diodes, to steer that flow in a single direction; and transistors to switch the flow on and off. Scientists combined two offbeat ingredients – buckyballs and diamondoids – to create the new diode-like component.

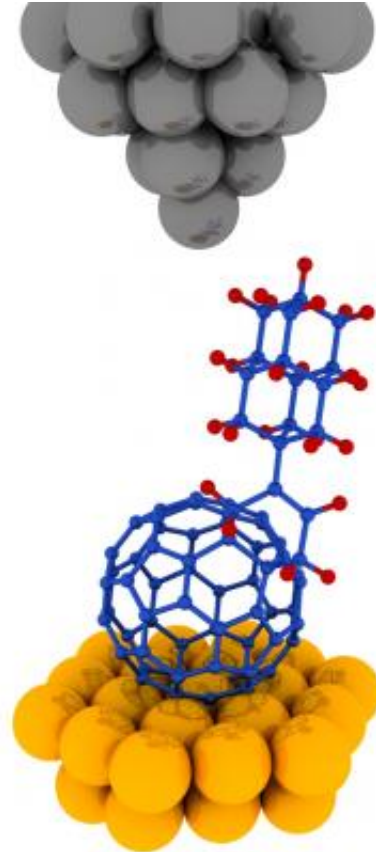
Buckyballs – short for buckminsterfullerenes – are hollow carbon spheres whose 1985 discovery earned three scientists a Nobel Prize in chemistry. Diamondoids are tiny carbon cages bonded together as they are in diamonds, but weighing less than a billionth of a billionth of a carat. Both are subjects of a lot of research aimed at understanding their properties and finding ways to use them.

In 2007, a team led by researchers from SLAC and Stanford discovered that a single layer of diamondoids on a metal surface can efficiently emit a beam of electrons. Manoharan and his colleagues wondered: What would happen if they paired an electron-emitting diamondoid with another molecule that likes to grab electrons? Buckyballs are just that sort of electron-grabbing molecule.



An image made with a scanning tunneling microscope shows hybrid buckydiamondoid molecules on a gold surface. The buckyball end of each molecule is attached to the surface, with the diamondoid end sticking up; both are clearly visible. The area shown here is 5 nanometers on a side. Credit: H. Manoharan et al., *Nature Communications*

was up to 50 times stronger in one direction, from electron-spitting diamondoid to electron-catching buckyball, than in the opposite direction. This is something neither component can do on its own.



### A Very Small Valve for Channeling Electron Flow

For this study, diamondoids were produced in the SLAC laboratory of SIMES researchers Jeremy Dahl and Robert Carlson, who are world experts in extracting the tiny diamonds from petroleum. They were then shipped to Germany, where chemists at Justus-Liebig University figured out how to attach them to buckyballs.

The resulting buckydiamondoids, which are just a few nanometers long, were tested in SIMES laboratories at Stanford. A team led by graduate student Jason Randel and postdoctoral researcher Francis Niestemski used a scanning tunneling microscope to make images of the hybrid molecules and measure their electronic behavior. They discovered the hybrid is an excellent rectifier: The electrical current flowing through the molecule

This is an illustration of a buckydiamondoid molecule under a scanning tunneling microscope (STM). The sharp metallic tip of the STM ends in a single atom; as it scans over a sample, electrons tunnel from the tip into the sample. In this study the STM made images of the buckydiamondoids and probed their electronic properties. Credit: SLAC National Accelerator Laboratory

While this is not the first molecular rectifier ever invented, it's the first one made from just carbon and hydrogen, a simplicity researchers find appealing, said Manoharan, who is an associate professor of physics at Stanford. The next step, he said, is to see if transistors can be constructed from the same basic ingredients.

"Buckyballs are easy to make – they can be

isolated from soot – and the type of diamondoid we used here, which consists of two tiny cages, can be purchased commercially," he said. "And now that our colleagues in Germany have figured out how to bind them together, others can follow the recipe. So while our research was aimed at gaining fundamental insights about a novel hybrid molecule, it could lead to advances that help make molecular electronics a reality."

**More information:** J. C. Randel et al, *Nature Communications*, 9 September 2014. [DOI: 10.1038/ncomms5877](https://doi.org/10.1038/ncomms5877)

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