Unique properties of 2-D materials and metals grown on carbon-coated surfaces

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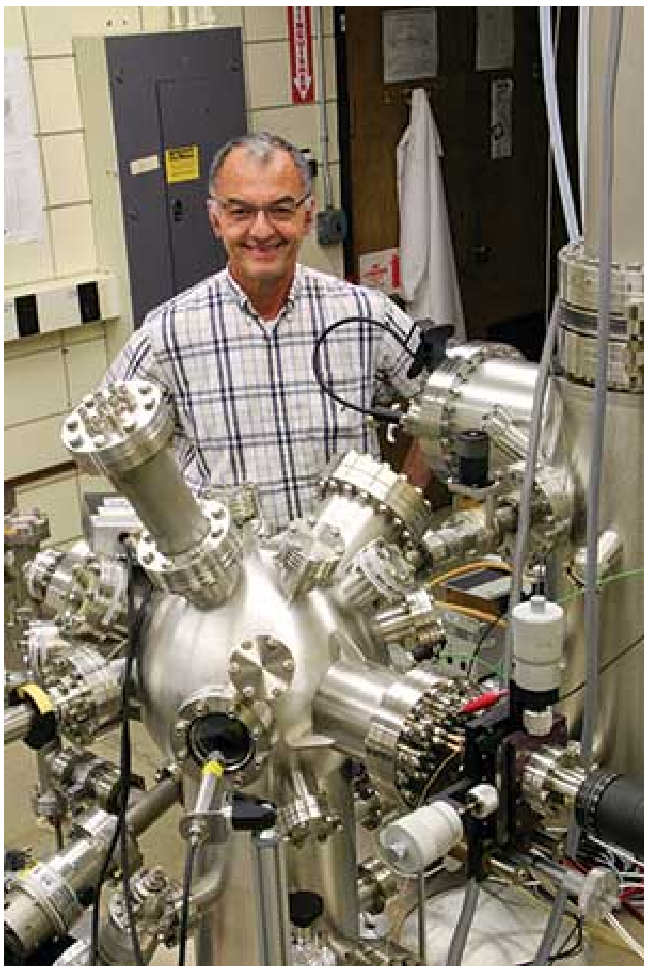


Credit: Ames Laboratory

Two-dimensional materials are a bit of a mind-bending concept. Humans live in a three-dimensional world, after all, where everything observed in our natural world has height, width, and depth. And yet when graphene—a carbon material unique in its truly flat, one-atom-deep dimension—was first produced in 2004, the mind-bending concept became reality and an unexplored frontier in materials science.

Ames Laboratory scientists Pat Thiel and Michael Tringides are explorers on that frontier, discovering the unique properties of two-dimensional (2-D) materials and metals grown on graphene, graphite, and other carbon coated surfaces.

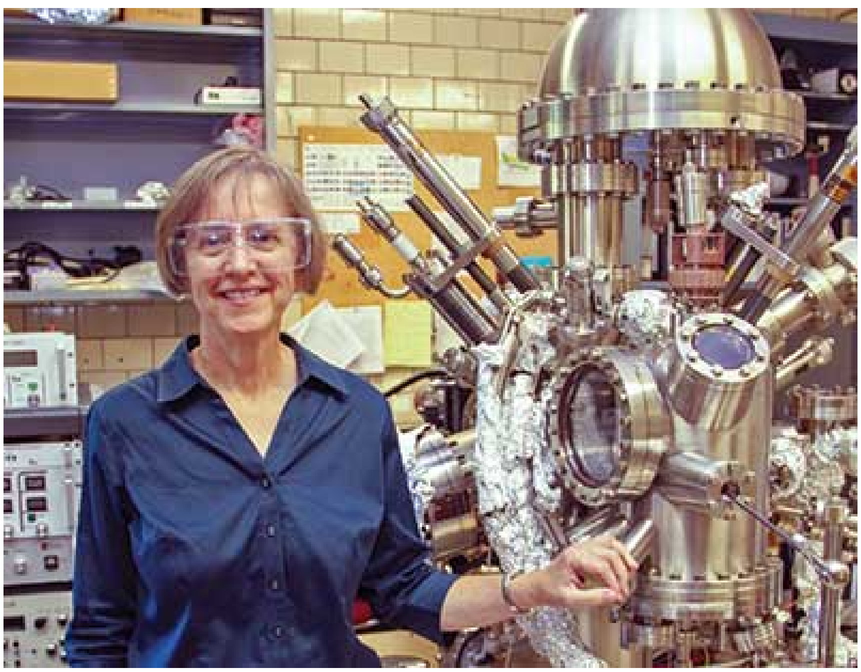
"Our work is somewhat of a miracle, if scientists can talk about miracles," said Tringides, who is also a professor of physics at Iowa State University. "Only a few decades ago, no one would have believed that we could see individual atoms, but our capabilities now not only allow us to see them, but manipulate them, like a child building with Lego bricks. We're able to create these materials from the bottom up, ones that could never happen in nature."

They're created in a controlled laboratory setting, in an ultra-high vacuum environment, and investigated with the aid of scanning tunneling microscopy. After heating the substrate to high temperature all impurities and defects are removed. The substrate is cooled and atoms of interest are deposited one by one from specially designed sources. By tuning the temperature and deposition rate, the researchers search for the Goldilocks-like condition: atoms move not too fast and not too slow, so a truly 2-D material forms.

While their research groups create a variety of surface materials in their work, the fabrications methods all have one thing in common: attempting to confine the assembly of the atoms to the 2-D plane. That's difficult, because it's counter to what atoms naturally want to do under most conditions, to assemble in three dimensions.

"Atoms are chaotic by nature; we are fighting this randomness in everything we do," said Tringides. "In our work, atoms are precisely arranged on a highly reactive surface in a vacuum. Every aspect of the environment is controlled. Our work is to fabricate very small, very clean, and very perfect. Working on materials in the nanoscale demands it."

Learning how these materials behave is paramount. Because 2-D materials are all surface with no bulk, a host of unique nanoscale properties—chemical, magnetic, electronic, optical, and thermal—can be attributed to them.



Credit: Ames Laboratory

"There's a rule book for the properties of bulk, or three-dimensional materials, and it contains big chunks that are universally understood and accepted," said Thiel, a physical chemist, materials scientist, and Distinguished Professor at Iowa State University. "But the rule book for 2-D materials is largely unwritten. There are lots of things we don't know. We get lots of surprises, and then we must explain them."

Writing the rule book to the behavior of these materials is only the first step in a larger goal; creating tunable materials that could be potentially useful in a host of tech applications, including ultrafast microelectronics, catalysis, and spintronics.

It's the reason that Thiel's and Tringides' research has focused upon growing metals on 2-D substrates over the last four years, turning it into a major strength of Ames Laboratory's materials research.

Graphene has gained much enthusiastic attention in both scientific research and the tech industry because electrons travel very fast along its surface, explained Tringides. But to create functional devices, it necessitates patterns of nanoscale-size metal contacts on its surface, designed specifically for a desired function.

"Whatever material we are trying to create, uniformity of the surface is the key to a functional device, and that is where our 'perfect' research comes in. That perfection makes us slow, but it's a trade-off," said Tringides. "If we can gain a thorough understanding of how these contacts can be produced under ideal conditions in a controlled environment, then these methods can be optimized eventually for commercial production and use."

Thiel and Tringides' most recent success is the intercalation of dysprosium onto graphite layers. Intercalation is the introduction of a material into compounds with layered structures. That's a real challenge with graphite, since its purely 2-D surface results in "slick" layers with no good way to form bonds between them.

"It's like a stack of blankets on a bed," said Thiel. "The blankets themselves are structurally sound, but two blankets stacked on top of each other slide around, slip off the bed, and are easily peeled off in layers." But the team has recently discovered the conditions under which they can create different types of intercalated metal-and-graphite systems, bonding those sliding blankets of material together two-dimensionally. It's a promising new way to form a thin coating of a metal protected by a carbon skin, and could lead the way to materials with unique magnetic or catalytic properties.

With such a narrowly focused and highly controlled experimental focus in basic science, it could be tempting to assume that their research, like their experiments, occurs in a vacuum. But Thiel credits the success of surface science at Ames Laboratory to the close collaboration of varied research groups. "Ames Laboratory is a fertile environment for surface science experiments because we have the opportunity to collaborate directly with many scientists in diverse areas of expertise addressing the same problem from a different viewpoint," said Thiel, including specialists in photonic band gap materials, optical physics, theory, and materials fabrication. "While that collaboration model has been adopted by other institutions and is the norm now, Ames Lab's intimate size and community culture really started it all, and our achievements in surface science have benefited greatly from it."

Provided by Ames Laboratory