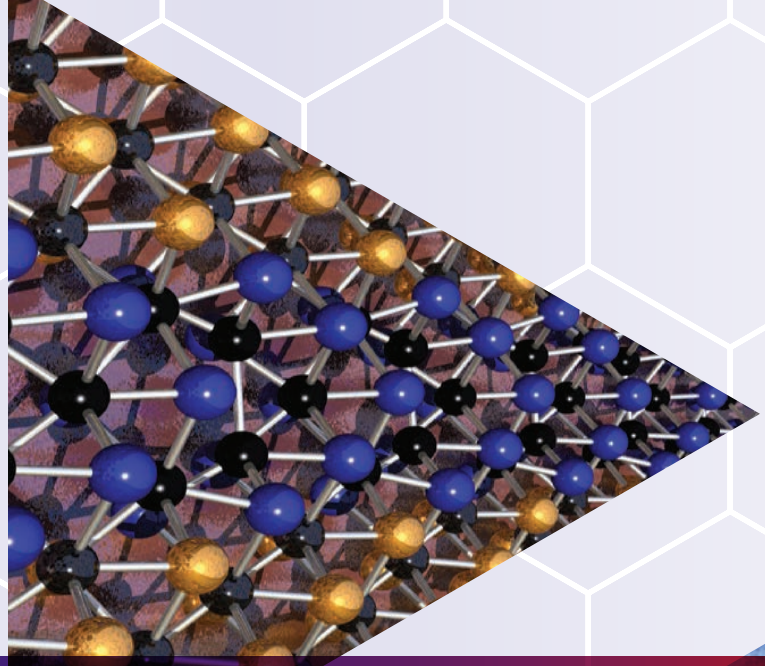
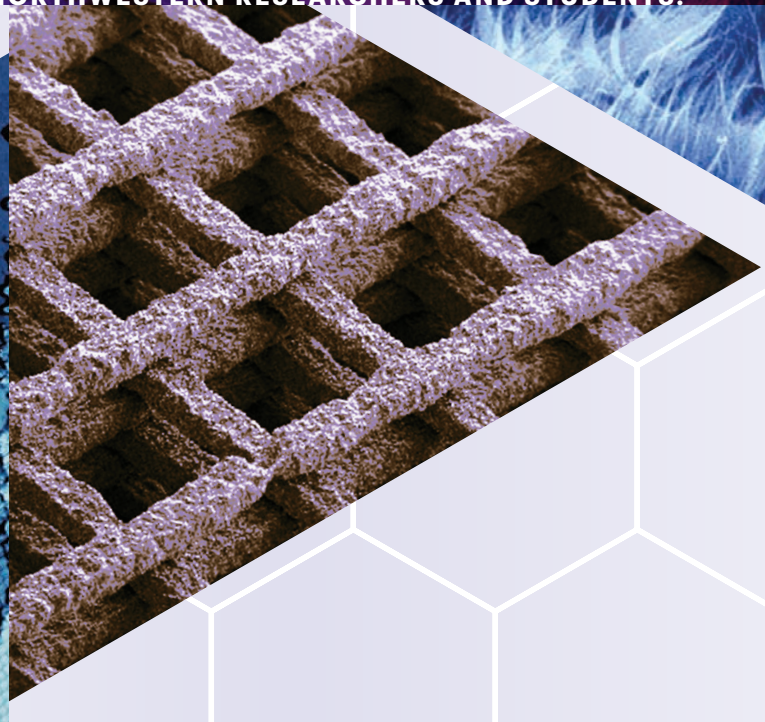


Diversification in the Materials World

WHILE NOT ALL PROMISING NEW MATERIALS DELIVER ON THEIR POTENTIAL, SPREADING BETS AMONG THEM BRINGS OUT CREATIVITY IN NORTHWESTERN RESEARCHERS AND STUDENTS.



Early in his career, Mark Hersam immersed himself in the study of carbon nanotubes. At the time, the ultra-lightweight, high-strength, flexible material appeared to have nearly unlimited potential. Researchers imagined using carbon nanotubes to build everything from bridges to solar cells to water filters to scaffolds for regenerative medicine.

Although these applications have not yet fully delivered on their promise, Hersam is not disappointed. After all, he has many more materials up his sleeve. His already bulging portfolio, which includes graphene, boron nitride, molybdenum disulfide, phosphorene, and borophene, is still growing—and likely will never stop. He intends to keep generating new materials of his own.

"If you look around a room, you see many different types of materials that serve different purposes," says Hersam, Walter P. Murphy Professor of Materials Science and Engineering. "I don't think that any single material will solve all the world's problems. That's why I prefer to diversify."

RESISTING THE "HYPE CYCLE"

A flagship material of nanotechnology, carbon nanotubes are rolled sheets of carbon—cylinders with a diameter that measures on the nanoscale. When they came onto the scene in the 1990s, many researchers touted their exceptional mechanical, thermal, optical, and electrical properties. Then, reality set in.

Hersam refers to the initial excitement and subsequent crash in enthusiasm as the "hype cycle," a recurring phenomenon in the materials science field. "A new material comes on the scene, possibly wins a Nobel Prize, and everyone starts working on it for every application they can imagine," he says. "When it doesn't quickly live up to the hype, people abandon it."

Hersam, however, is never so quick to abandon. Instead, he identifies a material's best application and continues to push in that direction. With carbon nanotubes, for example, he acknowledged that the material was too expensive—and not substantially better than existing materials—to use in structural pursuits. But their flexibility set them apart, making them excellent candidates for use in flexible, wearable electronics.

Hersam recognized the same hype cycle with graphene. Noticing the material's superlative electrical properties, researchers predicted its use in high-performance, high-speed electronics. The problem? Existing materials had already cornered that market.

"It will always be a tough proposition for a new material to supplant an incumbent technology," Hersam says. "If we stick with graphene for another 20 years, it may actually do that. But the world we live in is one where people expect quick returns. Our attention spans are getting shorter. It's important for a material to have some near-term successes."

Hersam believes that graphene's chemically inert nature—rather than its conductivity alone—could be the key to its near-term success. Graphene can survive in highly caustic environments without corroding, which is unusual for an electrical conductor. Materials of this type are particularly important for lithium-ion batteries, where chemical inertness is key to their stability and safety.

left to right
PHOSPHORENE Mark Hersam and Xiaolong Liu
CARBON NANOTUBES Mark Hersam and Laila Jaber-Ansari
GRAPHENE Adam Jakus, Ramille Shah, and Mark Hersam
BOROPHENE Mark Hersam and Xiaolong Liu

The Search for the Next Plastic

Professor Mark Hersam believes strongly that materials can change the world. "In the twentieth century, the advent of plastics changed everything," he says. "The advent of semiconductors changed communications and electronics. We know from history that new materials have profound impact on society. We will keep striving to find the next one."

Here's a look at what Hersam is currently studying:

CARBON NANOTUBES

Potential flexible, printable electronics and wearables

Advantages low weight, high strength, flexibility

Recent advances Hersam developed encapsulation layers to protect carbon nanotubes from environmental degradation.

GRAPHENE

Potential batteries, conductive inks

Advantages conductivity, inert nature

Recent advances Hersam demonstrated a scalable graphene composite material with superlative performance for lithium-ion battery cathodes.

BOROPHENE

Potential interactive displays, electrical conductors

Advantages two-dimensional metal, theoretically predicted to be a relatively high-temperature superconductor, mechanically flexible and stretchable

Recent advances Hersam has integrated borophene with organic semiconductors, forming a near-perfect interface that is useful for electronics applications.

MOLYBDENUM DISULFIDE

Potential solar cells, light-emitting diodes, lasers

Advantages semiconducting, efficient absorption and emission of visible light

Recent advances Hersam has developed a method to isolate atomically thin sheets of the material in a scalable manner.

PHOSPHORENE

Potential biomedical imaging, communication

Advantages semiconducting, absorbs and emits infrared light

Recent advances Hersam has developed a method to exfoliate phosphorene with higher yield while keeping it stable in open air.

Northwestern spin-off SiNode Systems, a company that Hersam advises, develops silicon-graphene composites for batteries that last longer and charge faster while remaining safe. The company, which grew out of research by Harold Kung, Walter P. Murphy Professor of Chemical and Biological Engineering, has cleaned up with awards in multiple venture competitions and landed a partnership with Motorola Mobility.

TRANSPARENT POSSIBILITIES

Borophene is the most recent material to enter Hersam's growing portfolio. A team of scientists, including Hersam, first synthesized borophene—a two-dimensional sheet of boron—in late 2015. Based on theoretical predictions, this new material should be a promising transparent conductor with potential applications in interactive displays. Borophene is also expected to be flexible and stretchable, enabling integration into wearable technologies.

"Having true metallic behavior and optical transparency would be fundamentally different than common alternatives that are semiconducting," Hersam says. "It has the potential to be orders of magnitude better. Without experimental confirmation, we don't know for sure yet, but there's certainly hope."

Theoretical models also predict that borophene should be a relatively high-temperature superconductor. Today's best high-temperature superconductors are ceramics, which are often too brittle for realistic applications. The flexibility and stretchability of borophene would again differentiate it from competing materials.

But if the impressive predictions about borophene's applications never come true, Hersam will continue to explore the new material until it reveals its best application, and then he will focus his research in that area. The whole process also provides a rare and powerful learning opportunity for his students.

"I don't get disappointed when a new material doesn't work exactly as predicted because the exercise of trying is very useful training for students," Hersam says. "Working on frontier problems forces students to be extremely creative. That's what I care about most."

AMANDA MORRIS