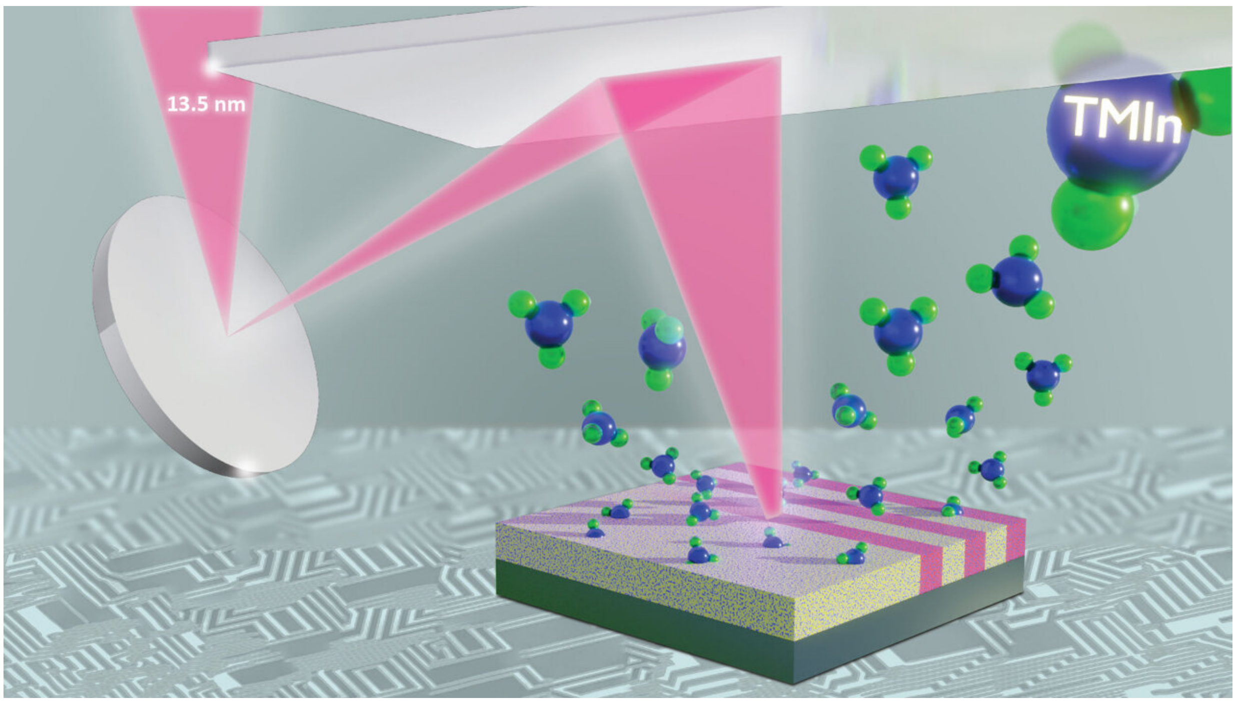
Innovative photoresist materials pave the way for smaller, high performance semiconductor chips

November 8 2023, by Denise Yazak



In this artist's visualization, mirrors focus extreme ultraviolet light to pattern a latent image in a polymer thin film infiltrated by indium-containing gaseous molecules. Credit: Brookhaven National Laboratory

For more than 50 years, the semiconductor industry has been hard at work developing advanced technologies that have led to the amazing increases in computing power and energy efficiency that have improved our lives. A primary way the industry has achieved these remarkable performance gains has been by finding ways to decrease the size of the semiconductor devices in microchips. However, with semiconductor feature sizes now approaching only a few nanometers—just a few hundred atoms—it has become increasingly challenging to sustain continued device miniaturization.

To address the challenges associated with fabricating even smaller microchip components, the semiconductor industry is currently transitioning to a more powerful fabrication method—extreme ultraviolet (EUV) lithography. EUV lithography employs light that is only 13.5 nanometers in wavelength to form tiny circuit patterns in a photoresist, the light-sensitive material integral to the lithography process.

The photoresist is the template for forming the nanoscale circuit patterns in the silicon semiconductor. As EUV lithography begins paving the way for the future, scientists are faced with the hurdle of identifying the most effective resist materials for this new era of nanofabrication.

In an effort to address this need, a team of scientists at the Center for Functional Nanomaterials (CFN)—a U.S. Department of Energy (DOE) Office of Science User Facility at DOE's Brookhaven National Laboratory—has designed a new light-sensitive, organic–inorganic hybrid material that enables high-performance patternability by EUV lithography. Their results were recently published in *Advanced Materials Interfaces*.

Composition is key

The hybrid materials used to create these new photoresists are composed of both organic materials (those that primarily contain carbon and oxygen atoms) and inorganic materials (those usually based on metallic elements). Both parts of the hybrid host their own unique chemical, mechanical, optical, and electrical properties due to their unique chemistry and structures. By combining these different components, new hybrid organic-inorganic materials emerge with their own interesting properties.

In the case of organic photoresists, adding inorganic molecules can yield a vastly improved material for EUV. The hybrid materials have increased sensitivity to EUV light, which means that they don't need to be exposed to as much EUV light during patterning, reducing the required process time. The hybrid materials also have improved mechanical and chemical resistance, making them better-suited as templates for high-resolution etching.

"To synthesize our new hybrid resist materials, organic polymer materials are infused with inorganic metal oxides by a specialized technique known as vapor-phase infiltration. This method is one of the key areas of materials synthesis expertise at CFN. Compared to conventional chemical synthesis, we can readily generate various compositions of hybrid materials and control their material properties by infusing gaseous inorganic precursors into a solid organic matrix," explained Chang-Yong Nam, a materials scientist at CFN who led the project.

As the team experiments and refines their materials, resists with improved performance are emerging. With any pioneering field, there are challenges to be faced.

"One of the main problems we encountered when initially making these hybrids is that the inorganic content needs to be uniformly distributed inside the organic polymer while making sure that the infused inorganic components are not too strongly bound to organic matrix," said

Ashwanth Subramanian, the lead author of the paper. Subramanian is a former CFN-affiliated Ph.D. student from Stony Brook University's Department of Materials Science and Chemical Engineering who is now working as a process engineer at Lam Research.

"It was a little difficult to achieve that in previous research. In this work, however, we were able to choose a different precursor for the metal, the inorganic source, and that allowed us to make a hybrid with a uniform composition as well as weak binding between organic and inorganic components."

In their current research, the team noticed vast improvements after using indium as an inorganic component as compared to the aluminum that was used in the work that was done before. The scientists made the new resist using a poly(methyl methacrylate) (PMMA) organic thin film as the organic component and infiltrated it with inorganic indium oxide. This new hybrid exhibited increased sensitivity and a more uniform material makeup, which improved uniformity in subsequent patterning.

"In our previous work, we demonstrated this concept and were working with established resist composition as a proof of concept," explained Nikhil Tiwale, a materials scientist at CFN. "In this new paper, we used a composition that hasn't been studied in the resist community, yielding better EUV absorption and improved patterning performance."

Always moving forward

Scientists at CFN have been researching hybrid photoresist materials for several years, building a strong foundation of work culminating in the design of new, highly functional materials. Nam leads this research program with a goal of developing even more new materials and functionalities. In 2022, he was recognized as an Inventor of the Year by Battelle Memorial Institute.

Nam's hybrid resists show such promise that he was awarded major funding to pursue this concept through the DOE Accelerate Innovations in Emerging Technologies program. This multi-institute project will explore the development of new classes of hybrid photoresists and exploit machine learning to accelerate EUV research by making material validation easier and more accessible.

"It's currently really hard to do EUV patterning," explained Nam. "The actual patterning machine that industry is using is very, very expensive—the current version is more than $200 million per unit. There are only three to four companies in the world that can use it for actual chip manufacturing. There are a lot of researchers who want to study and develop new photoresist materials but can't perform EUV patterning to evaluate them. This is one of the key challenges we hope to address."

The research team includes CFN staff members Kim Kisslinger, Ming Lu, and Aaron Stein, as well as Won-Il Lee, a Ph.D. student from Stony Brook University, and Jiyoung Kim, a professor in the Department of Materials Science and Engineering at the University of Texas at Dallas. Their combined efforts have helped push EUV lithography techniques beyond current limits.

The team is currently working on other hybrid material compositions and testing how they perform, as well as the processes involved in fabricating them, paving the way for patterning smaller, more efficient semiconductor devices.

More information: Ashwanth Subramanian et al, Vapor-Phase Infiltrated Organic–Inorganic Positive-Tone Hybrid Photoresist for Extreme UV Lithography, *Advanced Materials Interfaces* (2023). DOI: 10.1002/admi.202300420

Provided by Brookhaven National Laboratory