Mastering chemical recipes to make new materials

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Mircea Dincă

Mircea Dincă playfully describes his very serious work making new materials in MIT's Department of Chemistry much like being a kid mixing and matching Legos. A self-described molecular engineer, Dincă assembles new materials from a variety of inorganic and organic building blocks, all carefully chosen to impart properties leading to a desired activity or function.

As a synthetic chemist in his third year at MIT, Dincă is always looking for new ways to make new materials for a variety of applications. His ideas are inspired by his colleagues, his students, and his industry relationships that have been a part of his life since graduate school. Dincă's PhD in hydrogen storage materials, from the University of California at Berkeley, was funded by General Motors as part of its interest in building hydrogen cars.

Dincă's love of chemistry began in seventh grade in his native Romania. "Having a dedicated teacher that did spectacular demonstrations with relatively limited regard for safety may have had something to do with that," he jokes.

But what may have begun from "spectacular demonstrations" has matured into a profession focused on producing lasting applications. Now he leads the Functional Inorganic and Organic Materials Group in the MIT Department of Chemistry.

"Chemistry enables me to follow an entire chain of events from coming up with a new material—drawing it out on paper—and having the ability to make it atom by atom and then hopefully at some point see a product," Dincă explains. "Having a holistic view of what a material is—how it is built from subatomic particles all the way to a device—that is incredibly exhilarating to me."

Conductive metal-organic frameworks

At the core of much of Dincă's current research is the goal of making a particular kind of porous material called metal-organic frameworks (MOFs), which have traditionally been used for gas storage and separation. Dincă and colleagues are intent on synthesizing new MOFs that conduct electricity, a function these materials currently lack.

"MOFs are attractive because they have very, very high internal surface areas," he explains. Think of the innards of one of Dincă's MOFs as analogous to a sponge—an intricate complex of organic and metal materials rationally pieced together atom by atom. If one were to lay out this spongy internal surface area, one gram of the material would cover a football field.

"Imagine the excitement if you could make these electrically conductive or ionically conductive," he says. "You would have this enormous surface area available for analyte binding or gas binding or gas capture, but you would also be able to make it conductive."

This type of new material would have significant real-world applications. Dincă foresees use in electrocatalysis related to renewable energy applications, like CO2 and O2 reduction in fuel cells. It could find use in high-density renewable batteries.

"But the question has always been, 'Can we make them?'" he says. The answer is yes: Dincă and his team have rebuffed the notion that high surface area is incompatible with electric conductivity. "We can achieve it because we engineer these materials; we make them tunable at an atomic level to impart the conductive properties," he says.

Heterogeneous catalysis

Dincă's group hopes to develop new MOFs as heterogeneous catalysts, which are immensely useful in industry, such as in the gasoline-refining industry. Many reactions done by heterogeneous catalysis are also achieved in biology, such as with natural enzymes that enable fundamental transformations; one example includes converting methane to methanol. Natural enzymes can do this at room temperature without any extreme temperatures or pressure—something traditional synthetic heterogeneous catalysis cannot achieve.

"We want to emulate what the enzymes do in a plant or a bacterium, but also take advantage of the good things heterogeneous catalysts do, like allowing you to recycle the catalyst and easily separate substrates and products," he explains.

Dincă's team is focused on engineering new catalysts capable of emulating the reactivity of these enzymes under much milder conditions. "This would be huge," he explains. "We could perhaps make reactions happen at lower temperatures. This is all about energy efficiency." Potential applications including delivering value-added products like alcohols, aldehydes, and ketones—what Dincă describes as feed stocks for the chemical industry—produced in conditions that are much milder than what has been possible before. "It would be a huge advantage to the chemistry industry," he adds.

Within Dincă's laboratory, researchers are working on many other projects. For example, the successful deployment of any of these new MOF materials hinges on the possibility of making them water stable. "Our new materials do not lose their porosity, their structural integrity, even when boiled in water," Dincă says. Not only do they remain stable but his MOFs can actually store water. A potential use would be in energy-efficient air conditioning. His team is also developing organic photovoltaic devices to collect light and transform it into electricity. And they are engineering novel membranes and thin films by precisely depositing materials onto metal surfaces with potential use in carbon reduction technology.

"As the people who make the materials, chemists have the best understanding of what a material can do and how it can interface with a device," Dincă says. Yet he is always looking to his MIT colleagues, other academic collaborators, and ILP industry members to address real-time engineering needs that will help new materials find life beyond the lab, in new devices.

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