Self-assembling, biomimetic composites possess unusual electrical properties

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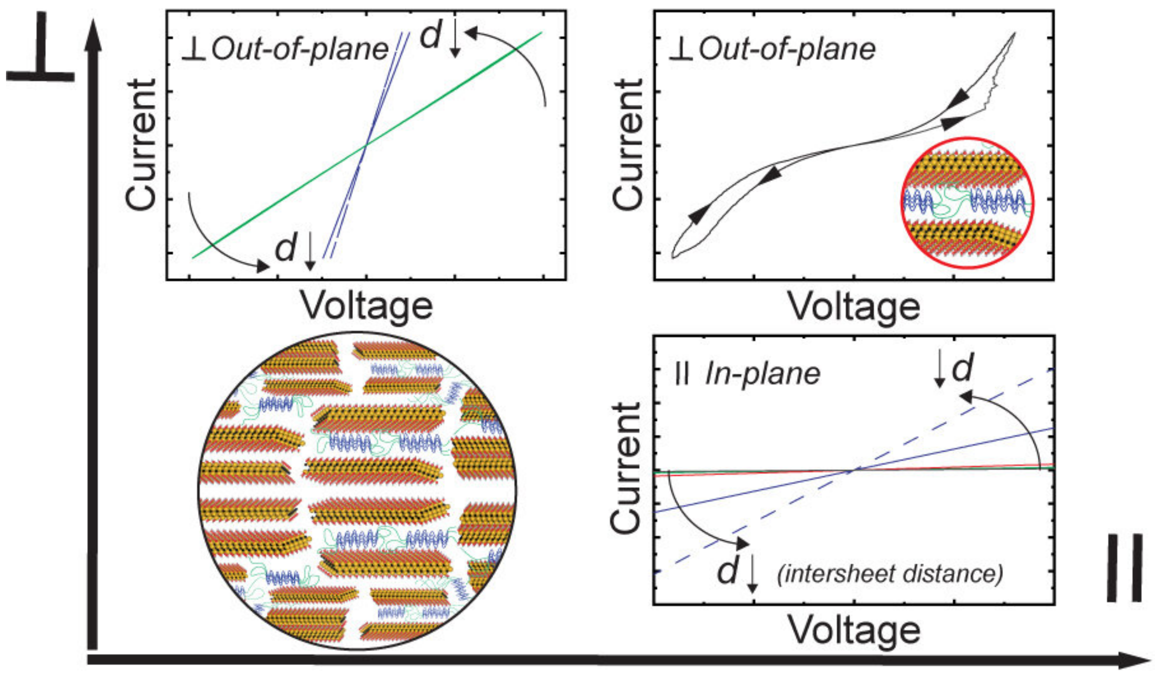

Biomimetic composites are produced by topological interactions, expanding the limits of the physical properties, such as electrical conductivity. Credit: Mert Vural, Penn State

Sometimes, breaking rules is not a bad thing. Especially when the rules are apparent laws of nature that apply in bulk material, but other forces appear in the nanoscale.

"Nature knows how to go from the small, atomic scale to larger scales," said Melik Demirel, professor of engineering science and mechanics and holder of the Lloyd and Dorothy Foehr Huck Chair in Biomimetic Materials. "Engineers have used mixing rules to enhance properties, but have been limited to a single scale. We've never gone down to the next level of hierarchical engineering. The key challenge is that there are apparent forces at different scales from molecules to bulk."

Composites, by definition, are composed of more than one component. Mixture rules say that, while the ratios of one component to another can vary, there is a limit on the physical properties of the composite. According to Demirel, his team has broken that limit, at least on the nanoscale.

"If you have a conducting polymer composite the amounts of polymer and metal compound are limited by the rule of mixtures," said Demirel. "The rules govern everything about the matrix and filler. We took materials—a biopolymer and an atomically thin conducting material—let them organize by self assembly, and broke the rule of mixtures."

The team's materials are composed of a biomimetic polymer based on tandem repeat proteins produced by gene duplication and inspired by the structure of squid ring teeth proteins, and conducting titanium carbide 2-D MXene, an only a few-molecules-thick layer of metal. This layered composite self-assembles and the polymer mediates the distance between the metal layers. By using genetic engineering of tandem repeat proteins—a biopolymer that repeats a conserved sequence—the researchers can control the inter-layer distance of conducting layers without changing the composite fractions. The researchers' goal is to create self-assembling materials with unprecedented control over their physical properties using synthetic biology.

Because the polymer self-assembles into a cross-linked network, the matrix-to-filler ratios in tiny areas can break the mixture rules, and the electrical properties of the layered material changes. The researchers report the results of their work in a recent issue of *ACS Nano*.

This biomimetic polymer metal composite can be both flexible and conductive in the proper bulk mixtures. On the microscopic scale, when the structural symmetry is broken, electrical conductivity depends on direction.

"What is unique is that now you can get in-plane electrical conductivity that differs from out-of-plane conductivity," said Demirel.

As long as the current is going along the plane of the 2-D material layers, the conductivity is linear, but if the current is directed across the layers, the conductivity becomes nonlinear.

"Now we can make a storage device," said Demirel. "We could also make diodes, switches, regulators and other electronic devices. We want to make materials that are designed with desired properties for building novel functionalities, which are difficult to achieve or previously unattainable."

More information: Mert Vural et al, Self-Assembly of Topologically Networked Protein–Ti3C2Tx MXene Composites, *ACS Nano* (2020). DOI: 10.1021/acsnano.0c01431

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