Creating and customizing material at the atomic scale

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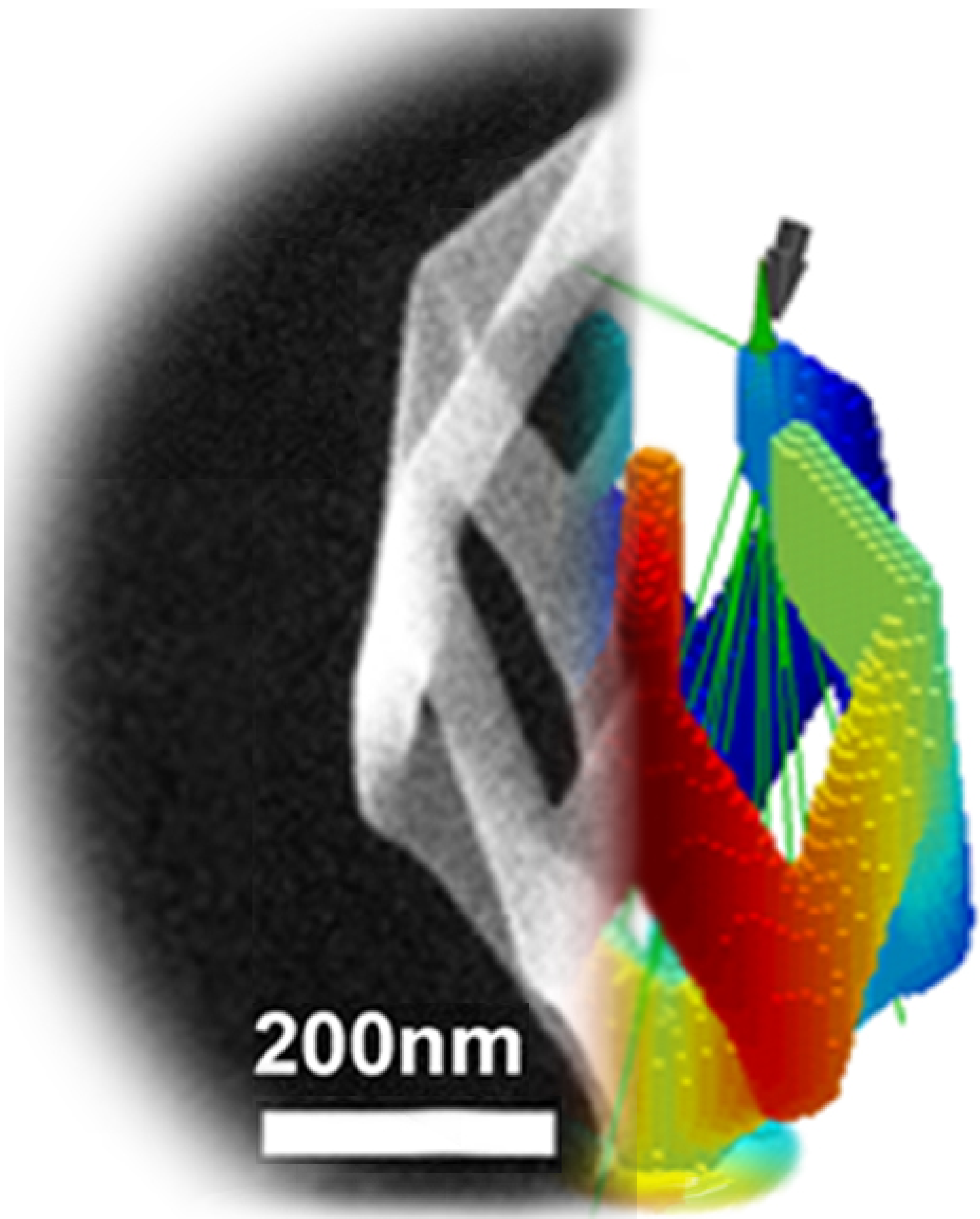

This 3-D structure was created in a microscope. On the left is the structure; on the right is the simulation that shows how to create such a structure.

Additive manufacturing techniques featuring atomic precision could one day create materials with Legos flexibility and Terminator toughness, according to researchers at the Department of Energy's Oak Ridge National Laboratory.

In a review paper published in *ACS Nano*, Olga Ovchinnikova and colleagues provide an overview of existing paths to 3-D materials, but the ultimate goal is to create and customize material at the atomic scale. Material would be assembled atom by atom, much like children can use Legos to build a car or castle brick by brick. This concept, known as directed matter, could lead to virtually perfect materials and products because many limitations of conventional manufacturing techniques would be eliminated.

"Being able to assemble matter atom by atom in 3-D will enable us to design materials that are stronger and lighter, more robust in extreme environments and provide economical solutions for energy, chemistry and informatics," Ovchinnikova said.

Fundamentally, directed matter eliminates the need to remove unwanted material by lithography, etching or other traditional methods. These processes have served society well, researchers noted, but the next generation of materials and products require a new approach.

"For the vast majority of recorded history, material transformation was limited to objects visible to the naked eye and patterned using hand-held tools," the researchers wrote. "We can admire the prowess of the rice grain writing, or fine engraving on a prized sword blade, but only two to three orders of magnitude separate these masterpieces from Stone Age technology."

Now, with the ability to direct matter with atomic precision, the payoff could be quantum computers, cell phones with more data storage and longer intervals between charging, higher efficiency solar cells, and stronger and less expensive lightweight materials.

"It's actually difficult to predict where this could go and how this technology could change our lives, but we intend to find out," Ovchinnikova said.

By using computation and modeling, researchers can precisely conceive, predict, create and control electrical and other properties of a material instead of having to compromise. Lead author Stephen Jesse noted that the directed matter approach builds on decades of research and uses instruments originally designed to examine materials to fabricate new ones with sub-10-nanometer (10 billionths of a meter) feature resolution.

For example, the transmission electron microscope, developed in the 1930s, has allowed single-atom imaging, chemical strain imaging and picometer-level structural mapping. Since its inception, however, the beam matter interaction had to be managed to prevent "beam damage," a hindrance to fundamental studies, the researchers said.

"However, this interaction, combined with imaging of electron – and recently ion – microscopy can be used as a basis for a next generation of nanofabrication tools," Jesse said.

The paper provides summaries of several other alternatives for atomically precise fabrication of 3-D materials based on electron and ion beams, including focused electron beam-induced processing from gas precursors and liquid precursors.

More information: Stephen Jesse et al. Directing Matter: Toward Atomic-Scale 3D Nanofabrication, *ACS Nano* (2016). DOI: 10.1021/acsnano.6b02489

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