New 3-D structures assemble with remarkable precision

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(Phys.org) -- While it is relatively straightforward to build a box on the macroscale, it is much more challenging at smaller micro- and nanometer length scales. At those sizes, three-dimensional (3-D) structures are too small to be assembled by any machine and they must be guided to assemble on their own. And now, interdisciplinary research by engineers at Johns Hopkins University in Baltimore, Md., and mathematicians at Brown University in Providence, R.I., has led to a breakthrough showing that higher order polyhedra can indeed fold up and assemble themselves.

"What is remarkable here is not just that a structure folds up on its own, but that it folds into a very precise, three-dimensional shape, and it happens without any tweezers or human intervention," says David Gracias, a chemical and biomolecular engineer at Johns Hopkins. "Much like nature assembles everything from sea shells to gem stones from the bottom up, the idea of self-assembly promises a new way to manufacture objects from the bottom up."

With support from the National Science Foundation (NSF), Gracias and Govind Menon, a mathematician at Brown University, are developing self-assembling 3-D micro- and nanostructures that can be used in a number of applications, including medicine.

Menon's team at Brown began designing these tiny 3-D structures by first flattening them out. They worked with a number of shapes, such as 12-sided interconnected panels, which can potentially fold into a dodecahedron shaped container. "Imagine cutting it up and flattening out the faces as you go along," says Menon. "It's a two-dimensional unfolding of the polyhedron."

And not all flat shapes are created equal; some fold better than others. "The best ones are the ones which are most compact. There are 43,380 ways to fold a dodecahedron," notes Menon.

The researchers developed an algorithm to sift through all of the possible choices, narrowing the field to a few compact shapes that easily fold into 3-D structures. Menon's team sent those designs to Gracias and his team at Johns Hopkins who built the shapes, and validated the hypothesis.

"We deposit a material in between the faces and the edges, and then heat them up, which creates surface tension and pulls the edges together, fusing the structure shut," explains Gracias. "The angle between adjacent panels in a dodecahedron is 116.6 degrees and in our process, pentagonal panels precisely align at these remarkably precise angles and seal themselves; all on their own."

"The era of miniaturization promises to revolutionize our lives. We can make these polyhedra from a lot of different materials, such as metals, semiconductors and even biodegradable polymers for a range of optical, electronic and drug delivery applications," continues Gracias. "For example, there is a need in medicine to create smart particles that can target specific tumors, specific disease, without delivering drugs to the rest of the body, which limits side effects."

Imagine thousands of precisely structured, tiny, biodegradable, boxes rushing through the bloodstream en route to a sick organ. Once they arrive at their destination, they can release medicine with pinpoint accuracy. That's the vision for the future. For now, the more immediate concern is getting the design of the structures just right so that they can be manufactured with high yields.

"Our process is also compatible with integrated circuit fabrication, so we envision that we can use it to put silicon-based logic and memory chips onto the faces of 3-D polyhedra. Our methodology opens the door to the creation of truly three-dimensional 'smart' and multi-functional particles on both micro- and nano- length scales," says Gracias.

Provided by National Science Foundation

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