Arrays of quantum rods could enhance TVs or virtual reality devices, research suggests

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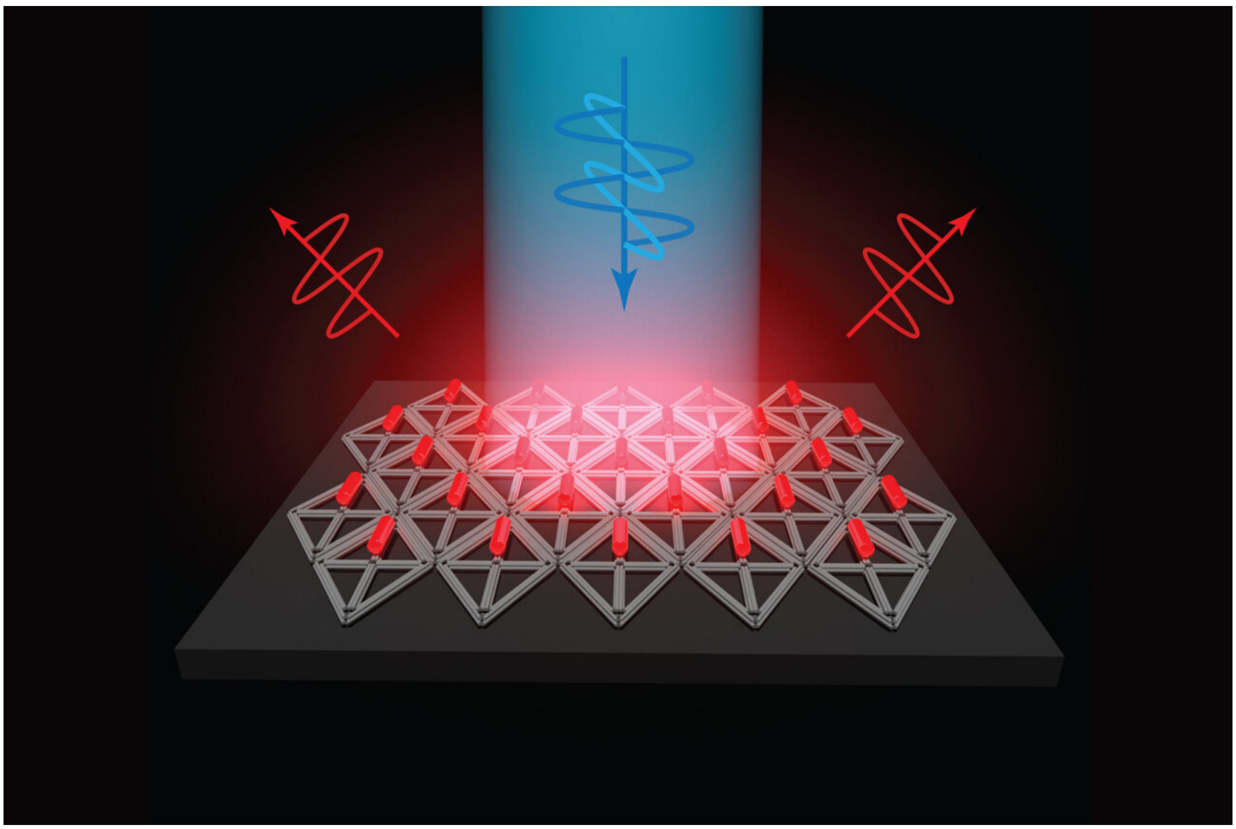

MIT engineers have used DNA origami scaffolds to create precisely structured arrays of quantum rods, which could be incorporated into LEDs for televisions or virtual reality devices. Credit: Dr. Xin Luo, BatheBioNanoLab

Flat screen TVs that incorporate quantum dots are now commercially available, but it has been more difficult to create arrays of their elongated cousins, quantum rods, for commercial devices. Quantum rods can control both the polarization and color of light, to generate 3D images for virtual reality devices.

Using scaffolds made of folded DNA, MIT engineers have come up with a new way to precisely assemble arrays of quantum rods. By depositing quantum rods onto a DNA scaffold in a highly controlled way, the researchers can regulate their orientation, which is a key factor in determining the polarization of light emitted by the array. This makes it easier to add depth and dimensionality to a virtual scene.

"One of the challenges with quantum rods is: How do you align them all at the nanoscale so they're all pointing in the same direction?" says Mark Bathe, an MIT professor of biological engineering and the senior author of the new study. "When they're all pointing in the same direction on a 2D surface, then they all have the same properties of how they interact with light and control its polarization."

MIT postdocs Chi Chen and Xin Luo are the lead authors of the paper, which appeared in *Science Advances*. Robert Macfarlane, an associate professor of materials science and engineering; Alexander Kaplan Ph.D. and Moungi Bawendi, the Lester Wolfe Professor of Chemistry, are also authors of the study.

Nanoscale structures

Over the past 15 years, Bathe and others have led in the design and fabrication of nanoscale structures made of DNA, also known as DNA origami. DNA, a highly stable and programmable molecule, is an ideal building material for tiny structures that could be used for a variety of applications, including delivering drugs, acting as biosensors, or forming scaffolds for light-harvesting materials.

Bathe's lab has developed computational methods that allow researchers to simply enter a target nanoscale shape they want to create, and the program will calculate the sequences of DNA that will self-assemble into the right shape. They also developed scalable fabrication methods that incorporate quantum dots into these DNA-based materials.

In a 2022 paper, Bathe and Chen showed that they could use DNA to scaffold quantum dots in precise positions using scalable biological fabrication. Building on that work, they teamed up with Macfarlane's lab to tackle the challenge of arranging quantum rods into 2D arrays, which is more difficult because the rods need to be aligned in the same direction.

Existing approaches that create aligned arrays of quantum rods using mechanical rubbing with a fabric or an electric field to sweep the rods into one direction have had only limited success. This is because high-efficiency light-emission requires the rods to be kept at least 10 nanometers from each other, so that they won't "quench," or suppress, their neighbors' light-emitting activity.

To achieve that, the researchers devised a way to attach quantum rods to diamond-shaped DNA origami structures, which can be built at the right size to maintain that distance. These DNA structures are then attached to a surface, where they fit together like puzzle pieces.

"The quantum rods sit on the origami in the same direction, so now you have patterned all these quantum rods through self-assembly on 2D surfaces, and you can do that over the micron scale needed for different applications like microLEDs," Bathe says. "You can orient them in specific directions that are controllable and keep them well-separated because the origamis are packed and naturally fit together, as puzzle pieces would."

Assembling the puzzle

As the first step in getting this approach to work, the researchers had to come up with a way to attach DNA strands to the quantum rods. To do that, Chen developed a process that involves emulsifying DNA into a mixture with the quantum rods, then rapidly dehydrating the mixture, which allows the DNA molecules to form a dense layer on the surface of the rods.

This process takes only a few minutes, much faster than any existing method for attaching DNA to nanoscale particles, which may be key to enabling commercial applications.

"The unique aspect of this method lies in its near-universal applicability to any water-loving ligand with affinity to the nanoparticle surface, allowing them to be instantly pushed onto the surface of the nanoscale particles. By harnessing this method, we achieved a significant reduction in manufacturing time from several days to just a few minutes," Chen says.

These DNA strands then act like Velcro, helping the quantum rods stick to a DNA origami template, which forms a thin film that coats a silicate surface. This thin film of DNA is first formed via self-assembly by joining neighboring DNA templates together via overhanging strands of DNA along their edges.

The researchers now hope to create wafer-scale surfaces with etched patterns, which could allow them to scale their design to device-scale arrangements of quantum rods for numerous applications, beyond only microLEDs or augmented reality/virtual reality.

"The method that we describe in this paper is great because it provides good spatial and orientational control of how the quantum rods are positioned. The next steps are going to be making arrays that are more hierarchical, with programmed structure at many different length scales. The ability to control the sizes, shapes, and placement of these quantum rod arrays is a gateway to all sorts of different electronics applications," Macfarlane says.

"DNA is particularly attractive as a manufacturing material because it can be biologically produced, which is both scalable and sustainable, in line with the emerging U.S. bioeconomy. Translating this work towards commercial devices by solving several remaining bottlenecks, including switching to environmentally safe quantum rods, is what we're focused on next," Bathe adds.

More information: Chi Chen et al, Ultrafast Dense DNA Functionalization of Quantum Dots and Rods for Scalable 2D Array Fabrication with Nanoscale Precision, *Science Advances* (2023). DOI: 10.1126/sciadv.adh8508. www.science.org/doi/10.1126/sciadv.adh8508

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