Proofreading and error-correction in nanomaterials inspired by nature

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Mimicking nature, a procedure developed by researchers at the University of Illinois at Urbana-Champaign can find and correct defects in self-assembled nanomaterials. The new proofreading and error-removal process is based on catalytic DNA and represents a paradigm shift in nanoscale science and engineering.

Despite much progress made in the self-assembly of nanomaterials, defects that occur during the assembly process still present major obstacles for applications such as molecular electronics and photonics. Efforts to overcome this problem have focused on optimizing the assembly process to minimize errors, and designing devices that can tolerate errors.

“Instead of trying to avoid defects or work around them, it makes more sense to accept defects as part of the process and then correct them during and after the assembly process,” said Yi Lu, a chemistry professor at Illinois and a researcher at the Beckman Institute for Advanced Science and Technology. “This procedure is analogous to how nature deals with defects, and can be applied to the assembly of nanomaterials using biomolecules or biomimetic compounds.”

In protein synthesis, nature ensures accuracy by utilizing a proofreading unit that detects and corrects errors in translation, often through hydrolysis of incorrect amino acid building blocks. In a similar fashion, Lu and graduate students Juewen Liu and Daryl Wernette utilized catalytic DNA to locate and remove errors in a DNA-templated gold nanoparticle assembly process. The researchers describe the procedure in a paper accepted for publication in the journal Angewandte Chemie International Edition, and posted on its Web site.

Catalytic DNA contains a substrate strand and an enzyme strand. In the presence of certain ions, the substrate is cleaved by the enzyme into two pieces of unequal length. The cleaved fragment with the shorter binding arm can be easily released. This catalytic DNA serves as a template for assembly of nanoparticles.

There are three kinds of nanoparticles encoded by different DNA in the system: two are defined as "correct" particles and one is defined as a "wrong" particle. Besides the difference in coding DNA, the nanoparticles can also be different in other aspects, such as size.

"To allow the catalytic DNA substrate to be a template for nanoparticle assembly, the substrate strand must be complementary to the DNA attached to the nanoparticles," Lu said. "A defect can occur in a DNA-templated gold nanoparticle assembly when the wrong particle is incorporated into the structure."

When a particle of the correct size is encountered, binding of the longer arm of the enzyme to the DNA template is permitted, while binding of the shorter arm to the DNA template is inhibited. "The active structure of the catalytic DNA cannot form," Lu said. "As a result, the template is not cleaved and the particle is incorporated into the assembly."

When a particle of the wrong size is mistakenly incorporated into the assembly, the enzyme can bind both its arms to the substrate template and form an active structure to cleave the substrate and remove the particle.

By showing that defects – the wrong size particles, in this case – can be identified and removed, the researchers demonstrated that proofreading and error-correction can take place during and after the assembly of nanoparticles.

“This was a small, but definite, step in the right direction,” Lu said. “The error-correction procedure can be expanded to include many other biomolecules and biomimetic compounds for controlling the assembly of nanoparticles of defined particle sizes, shapes or compositions; as well as other nanomaterials, such as nanotubes and nanowires.”

The researchers have applied for a patent. The work was funded by the U.S. Department of Defense and the National Science Foundation.

Source: University of Illinois at Urbana-Champaign