Quantum Dot Nanostructure Fabrication Using DNA

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Introduction

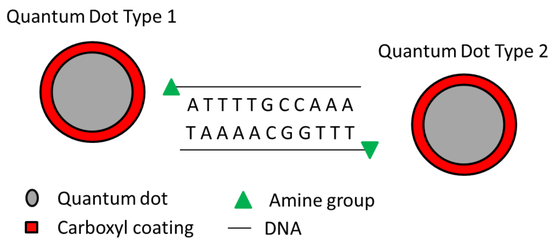
Quantum dots (QDs) are fluorescent semiconducting nanocrystals consisting of a thousand or so atoms that exhibit properties that are intermediate between discrete atoms and bulk solids. Additionally, certain properties of QDs (such as their band gap, absorption, and fluorescence) depend on their size. The tunability of these properties make QDs of interest for use in many scientific and industrial applications such as solar cells, transistors, LEDs, and biomedical imaging.

Single-strand deoxyribonucleic acids (ssDNAs) are chained molecules connected by a sugar-phosphate backbone which support nitrogenous bases. These bases - guanine (G), adenine (A), thymine (T), and cytosine (C) - can bond to their complementary nucleobases (A - T and C - G) if they run antiparallel to each other. Consequently, ssDNA can bind to its complementary sequence ssDNA* (when given enough energy) to form a stable duplex of the two strands.

In our ongoing research, we aim to overcome some of the inherent difficulty of ordering QDs on the nanoscale by combining the particle-like QDs with the programmable structure of DNA. Here, we link QDs together using short ssDNA strands to form larger nanostructures.

Methods

Linking of QDs with DNA:



Amine groups on the ends of ssDNA bind to carboxyl groups present on the surface of the QDs[1]. Short ssDNA strands are attached to one type of QD (QD1, 600 nm emission) and complementary ssDNA strands are attached to another type of QD (QD2, 450 nm emission). The two types are then mixed and heated to encourage the ssDNA strands to bind together, forming new structures composed of ordered QDs.

Confirmation of QD-DNA conjugates - Testing:

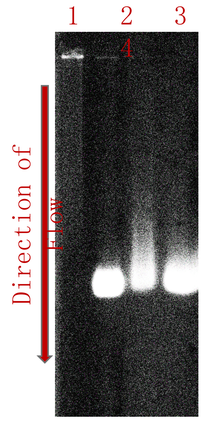
In order to confirm QD-ssDNA conjugation, gel electrophoresis and transmission electron microscopy (TEM) are employed. TEM allows for high resolution images to be captured on the nanoscale. These images are generated from the interactions that arise when a beam of electrons passes through a thin sample of material on a carbon grid. In this case, the TEM used is also equipped with scanning coils; the use of this mode is referred to as scanning transmission electron microscopy (STEM).

Results

Gel Electrophoresis

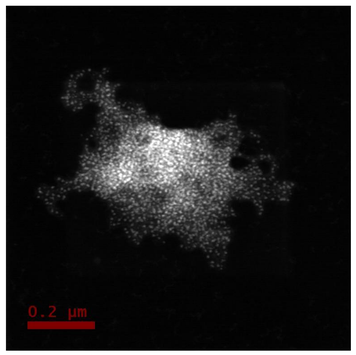
Gel electrophoresis allows for the separation of particles by mass and charge in a gel medium in the presence of an electric field.

0.5% gel at 100V for 65 minutes
Lane 1: (QD1+ssDNA1)+(QD2+ssDNA2)
Lane 2: QD1
Lane 3: QD2
Lane 4: QD1 + QD2

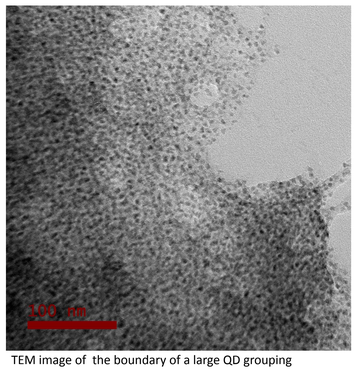


TEM/STEM

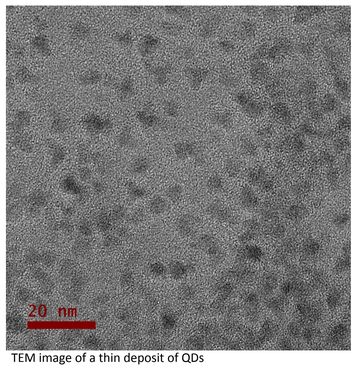
Control



STEM image of an isolated grouping of QDs

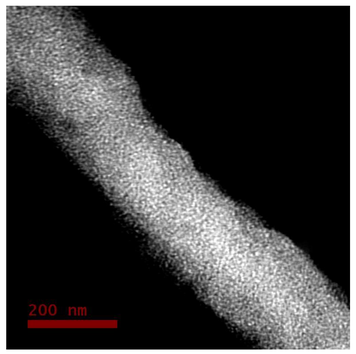


TEM image of the boundary of a large QD grouping

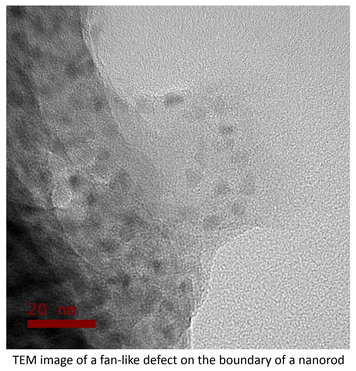


TEM image of a thin deposit of QDs

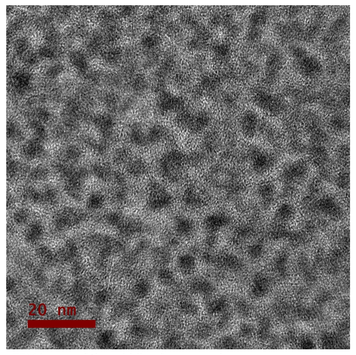
Product



STEM image of an isolated nanorod full of QDs



TEM image of a fan-like defect on the boundary of a nanorod



TEM image of the middle of a nanorod

Discussion

Gel Electrophoresis: The samples of QD1 and QD2 traveled about the same distance in the gel (QD2 traveled a bit less). The majority of our prepared product (the structures of interest) appears to be stuck in the well. This seems to suggest that the product solution contains structures that are too large to fit through the pores of the gel.

TEM/STEM: The control sample is a 50:50 molar mix of the two QD types and the product sample is a 50:50 mix of the two ssDNA functionalized QD types that has been heated at 65 ° C for 10 minutes. The most notable difference between the two samples is the presence of nanorods in the product. None of these rods were observed in the control.

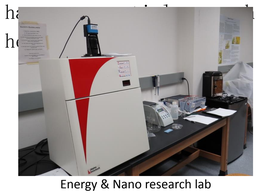
It seems reasonable that these rods are the structures that were trapped in the gel electrophoreses well. The analysis of these structures is still a work-in-progress.

The Next Steps

Further investigations into the Nanorod structures:
Steps to further purify our samples (to remove contaminants that were detected in the imaging process) would greatly improve our confidence that the nanorods are the result of the DNA-links.

UV/VIS absorption spectroscopy to test the optical properties:
The testing of the optical properties of these nanorods has proven difficult thus far due to these larger structures not dissolving well in solvents. However, we are interested in pursuing this further.

Attaching QD's to a DNA origami template:
In a technique called DNA origami, the self-assembly of very complex DNA nanostructures can be programmed. These structures could serve as a template from which to ha[illegible] as QDs, by similar methods as developed h[illegible]



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References

[1] Sun D., Gang O., (2013). DNA-Functionalized Quantum Dots: Fabrication, Structural, and Physiochemical Properties. *Langmuir*, 29, 7038-7046.

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