Quantum Dots Precisely Placed by Controlled Flow

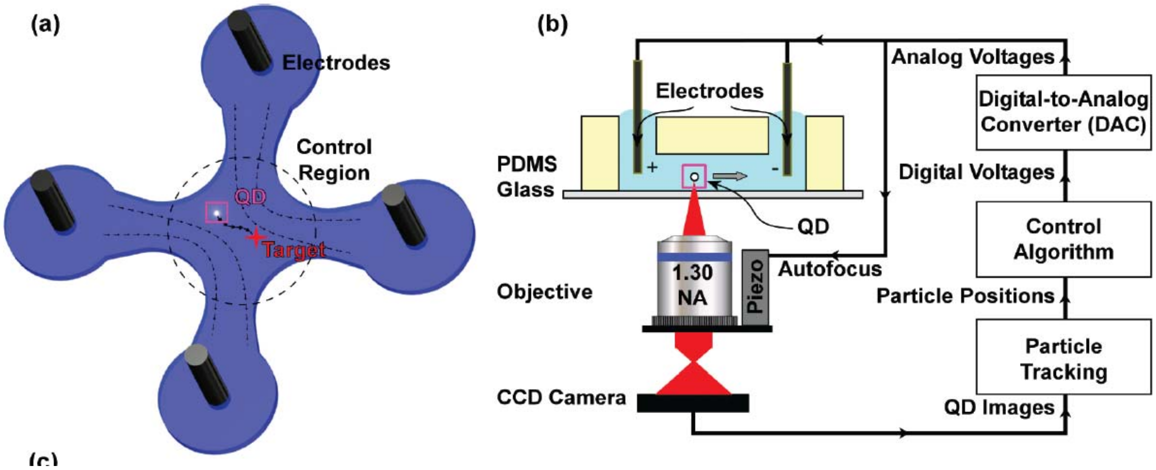
Ropp et al. report on the use of controlled flow to achieve nanometer precision placement of single quantum dots.

Solution-synthesized nanostructures have great potential as the active components in the areas of photonics, electronics and biology. Unfortunately, typical synthesis methods produce particles with a distribution of properties, while most applications require well-controlled and specific behavior. The challenge, then, is to take solution of a relatively random collection of particles, select a single one with the desired properties, and then place it in, for example, the active region of a device structure. The development of techniques for the manipulation of small particles has been an active area of research for many years, and great strides have been made using optical tweezers and dielectrophoretic devices. However, these suffer from a number of shortcomings, most notably the forces that can be exerted on a particle scale poorly as the particle size decreases (typically by the particle volume) and the force is also dependent on the type of particle under investigation.

Rather than trying to grab hold of the particle of interest directly, Ropp et al. chose an alternative approach – electro-osmotic flow (EOF) – that relies on controlling the flow of the fluid in which the particle is suspended to adjust its position. The EOF is established by applying a modest electric field to the fluid in the region of interest by controlling the potential between electrodes in contact with the fluid. The layer of ions that forms at the interface between the fluid and the walls of a channel is moved by the field and drags the rest of the fluid with it. This technique has the advantages that the makeup of the particle is largely irrelevant – it is simply swept up in the surrounding fluid flow –that no high optical or electrical fields are needed, thereby minimizing the potential for damage, particularly important in the case of sensitive biological structures and that there is no tendency to trap more than one particle. Large objects can be steered simply, but matters become more difficult as the particles become smaller. At the nanoscale, Brownian motion introduces relatively large random fluctuations in the position of the particle which would quickly cause the particle to wander from its desired trajectory. The authors use a closed-loop feedback control to overcome this problem. Images of the particle are acquired at regular intervals. Each time an image is collected, the actual particle position is measured and the degree to which it has diverged from the desired position is calculated. From this, the necessary correction is derived and the fluid flow adjusted accordingly.

Using this approach, the authors were able to control individual ellipsoidal quantum dots as small as 6 nm x 3 nm. One issue that might be expected to cause a problem is the phenomenon of “blinking” – quantum dots periodically cease to fluoresce and go dark, thus disappearing from the image. However, because the position is determined by capturing a full-field image, as soon as the dot lights up again, it can be brought back under control – unlike a particle that wanders out of an optical trap. Quantum dots were thus controlled for periods in excess of an hour. A simple microfluidic system with four control electrodes was used to select a single quantum dot and then to move it to an arbitrary position within a100 mm x 100 mm control area with a precision of approximately ± 50 nm in both x and y.

The use of EOF to control nanoscale objects clearly has a bright future, particularly since it can handle any type of material. One challenge remains, however, and that is fixing the particle in place once it has been positioned in the desired location.



a) Microfluidic device for generating controlled electro-osmotic flows. b) Experimental set up showing control loop that enables precise positioning of nanoparticles. (QD – quantum dot, PDMS – polydimethyl siloxane, NA – numerical aperture, CCD – charge-coupled device).

"Manipulating Quantum Dots to Nanometer Precision by Control of Flow", Chad Ropp, Roland Probst, Zachary Cummins, Rakesh Kumar, Andrew J. Berglund, Srinivasa R. Raghavan, Edo Waks, and Benjamin Shapiro|, *Nano Letters*, **10** 2525 (2010)