

Assembly and Control of Light-Emitting Nanostructures for Near-Field Imaging

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Abstract:

A uniform thin film of cadmium selenide quantum dots (CdSe QDs) was self-assembled by using a hydrophobic colloidal suspension. CdSe QDs suspended in hydrophobic solvent were dispensed on a convex water surface. After evaporation of the solvent, the free-floating film can be then used as an “inking pad” for hydrophobic polydimethylsiloxane (PDMS) stamps with various patterns, ranging from 10 μm to 100 μm and be stamped onto flat substrates. Atomic force microscopy (AFM) was used to measure the thickness of each film, which was then correlated to fluorescence intensity of the QDs. To demonstrate the electroluminescence of these particles, an inorganic light emitting diode (LED) was. The well-controlled assembly and stamping technique opens the door for near-field imaging applications with the resolution beyond 10 nm.

Introduction:

Near-field scanning optical microscopy (NSOM) enables nano-scale topographic measurements as well as optical imaging. This imaging feature requires a miniature light source, such as a fibre tip, that can scan over the surface based on scanning probe technology [1,2]. The size of the light source directly correlates to the imaging resolution. Direct fabrication of nano-scale light source (Nano-LED) on silicon probe has been demonstrated through electrostatic attraction of light-emitting CdSe QDs on the tip [3]. Position control of QDs attachment is critical. Here, we report a technique that would enable the controlled deposition of QD nanoparticles onto the silicon probes by using a uniform, self-assembled film of QDs and micro-contact printing methods. Electroluminescence of stamped films is demonstrated by assembling a LED device.

Experimental Procedure:

To create the film self-assembly set-up, 30.0ml of DI water was added to a glass Petri® dish. A Teflon® disk, with an outer diameter of 5 cm, inner diameter of 2 cm, and thickness of 2 mm, was placed in the center, pinning down the water at the edge and forming an upward convex curvature (Figure 1). Specific amounts of CdSe/ZnS core-shell QDs suspended in hexane were added to a 50:50 (v/v) solvent of 1,2-dichloroethane (EDC) and hexane to create the colloidal suspension. This was pipetted onto the water surface. The film was formed after ~ 15 minutes of evaporation. PDMS stamps, fabricated using the rapid prototyping technique, were used to deposit film onto flat, hard substrates, either glass or silicon by placing the stamp down for ~ 30 seconds.

We then fabricated an LED device, through stamping the film onto p-type silicon coated with 10Å of native oxide.

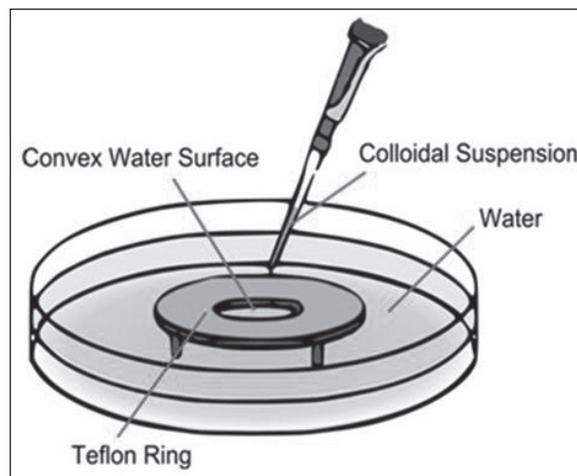


Figure 1: Set-up for quantum dot film self-assembly.

Zinc oxide and tin oxide (400Å) was co-sputtered to form the electron transport layer. We then deposited 50Å gold and 120Å silver, using electron beam evaporation to form the electron transport layer. Voltage was applied for light emission of the QDs.

Results and Discussion:

Uniform films of nanoparticles were stamped as 100 μm diameter circles on flat substrates (Figure 2). This was done with QDs of emission wavelengths 560 nm, 580 nm, 600 nm, and 620 nm. Light emissions from the constructed LED devices were observed for QDs with all the expected wavelengths.

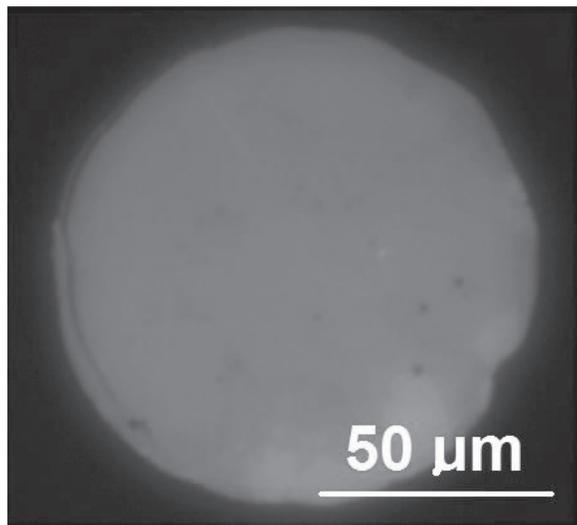


Figure 2: Quantum dot film stamped (580 nm emission wavelength) as 100 μm-diameter circle.

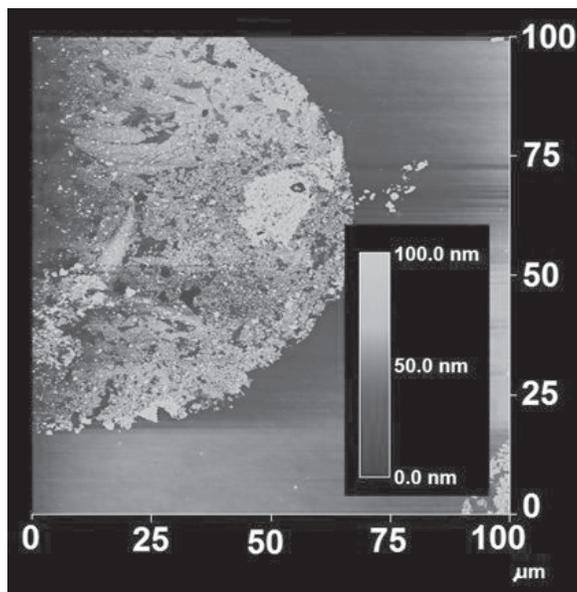


Figure 3: AFM topographic measurement.

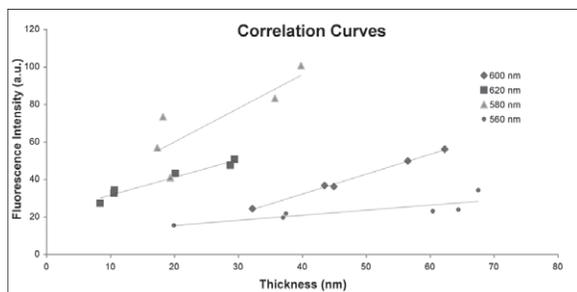


Figure 4: Correlation of thickness of stamped film to its photoluminescence.

The film of nanoparticles is formed due to evaporation, capillary immersion and convective forces. As the hydrophobic solvent begins to evaporate, nanoparticles in the center of water surface is exposed due to the convex shape. Solvent menisci form between individual exposed nanoparticles, and an attractive capillary immersion force collects nanoparticles into densely-packed hexagonal arrays called the nucleus [4]. As the solvent further evaporates, the contact line grows outward radially and convective flow of the solvent attracts nanoparticles from the colloidal suspension to the contact line, where they self-assemble onto the outer edge of the growing nucleus. As the contact line approaches the Teflon ring, where the water is pinned down, meniscus slope angle increases and multilayers are formed [5].

To measure the thickness of these films, stamped films scanned with the AFM (Figure 3). Thickness measurements were then correlated with photoluminescence using Matlab-extracted fluorescent intensity data from the optical micrographs. The plot indicated that there is a positive, linear correlation between film thickness and photoluminescence, especially for the 600 nm and 620 nm nanoparticles (Figure 4).

Conclusions:

Uniform films consisting of hexagonally-packed array of QDs were self-assembled by dispensing a hydrophobic colloidal suspension on top of a convex water shape. We found that the film thickness and fluorescence intensity had a positive, linear correlation. Electroluminescence of stamped films was successfully demonstrated in an LED device made using this self-assembly and stamping technique. Direct integration of single quantum dot light source onto the scanning probe will have significant impact on molecular scale near-field imaging and sensing.

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