Electrodeposited PbSe nanocrystals: electrical and optical properties

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Spatial confinement of electrons and holes in semiconductor crystals with dimensions below ten nanometer changes dramatically the density of state (DOS) of electrons as a function of energy. This enables engineering of the electrical and optical properties of semiconductors by tuning the dimensions of the semiconductor crystal in one or more directions of space. For instance, semiconductor nanocrystals in which electrons are confined in all three dimensions, can show atomic-like discrete energy levels and a diameter-dependent bandgap absorption [1,2]. Lead chalcogenides like PbSe are an attractive class of materials with this respect, due to the low effective mass of both electrons and holes in the bulk semiconductor.
Chemistry offers the means to prepare semiconductor nanocrystals, either as colloidal particles in suspension or as electrodeposited nanocrystals attached to a conducting substrate [3]. We will discuss the electronic and optical properties of PbSe nanocrystals electrodeposited on gold. It is demonstrated that interrupted potentiostatic bulk deposition leads to individual PbSe nanocrystals (see Fig. 1). The nanocrystals have edge-to-height aspect ratios ranging from 10 to 1, when the deposition is interrupted shortly after the application of the deposition potential. Using tunneling spectroscopy at low temperature, we demonstrate that the density of state of these structures changes on going from high aspect ratio nanocrystals – where electrons are confined in one direction of space – to low aspect ratio nanocrystals, where electrons are confined in three spatial directions. We demonstrate that between the archetypical limits of a step-like and a peak-like DOS of 2D and 0D systems, respectively, a broad transition range exists in which the DOS features both steps and peaks.
When electrodeposition is continued after the initial formation of PbSe nuclei, one dimensional growth of the nanocrystals is observed. The resulting nanometer thick layers of PbSe quantum wells show a fascinating change of colour from pink over purple to blue with increasing layer thickness. The dielectric function of the PbSe layers has been studied by spectroscopic ellipsometry. It is demonstrated that this change of the optical properties originates from electron and hole confinement effects at points in the Brillouin zone, different from the fundamental bandgap.

References
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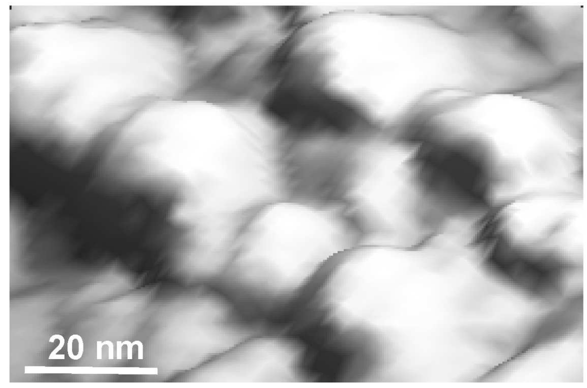

Figure 1. Low temperatur STM image (3D view) of PbSe nanocrystals electrodeposited on flame-annealed Au(111). The figure exaggerates the height of the nanocrystals, which are truly about 2 nm heigh.