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Shape of CdSe Quantum Rods Using Quantitative ADF STEM Imaging

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Semiconductor quantum dots and quantum rods have come under close scrutiny in the past decade because of their potential for use in technological and biological applications [1,2]. Though many various aspects of the quantum rods (QRs) have been studied, the exact shape of the QRs has not yet been reported. This is most likely due to the circumstance that most imaging of the QRs has been done using conventional TEM, which uses phase-contrast and projected shape imaging and it is a complicated task to untangle the information necessary to measure QR shape from these images. However, annular dark field (ADF) imaging in scanning transmission electron microscopy (STEM) provides a powerful and relatively straightforward method of determining QR shape owing to the lack of contrast reversal with focusing and the simplicity of image interpretation.

In this paper we present our initial study of a quantitative interpretation of colloidal CdSe QRs using ADF-STEM images. Sensitivity of the ADF image intensity to the atomic number (Z) and thickness of the specimen is now generally accepted [3,4]. However, quantitative interpretations of ADF images of crystalline samples require a careful approach due to strong channeling of the electron beam along the atomic columns.

Since QRs are nanoscale (~ 3 to 5 nm) and are expected to have a cylindrical cross-section, it is reasonable for a first approximation in the kinematical limit to compare the intensity of the ADF signal across the rod to a simple thickness profile of a cylinder (see Fig. 1). We should note here that all the images in this study were recorded with single-electron counting thereby ensuring that the image intensity is in direct proportionality to the incident beam current. The ADF image of a rod and the accompanying line-scan across the rod is presented in Fig. 2. After subtracting the background due to the carbon support film, the resulting measured profile of the QR was fitted to the analytical curve of cylinder thickness (see Figs 3, 4). With only one fitting parameter, ***t***, reasonable agreement is achieved.

Some discrepancies present at the edges of the rod suggest that the simple thickness model is not fully sufficient. The variation of the atomic fringe intensities in the image also cannot be explained with the simple model. Thus, simulations of the ADF images of the QRs are necessary in this study to understand the effect of electron beam channeling in our samples. Since the multislice method for calculating the electron beam propagation through the specimen has been successfully used to quantitatively explain some experimental observations [5,6], it is being undertaken here to understand details of the ADF imaging and to determine the limits of applicability of the simple model [7].

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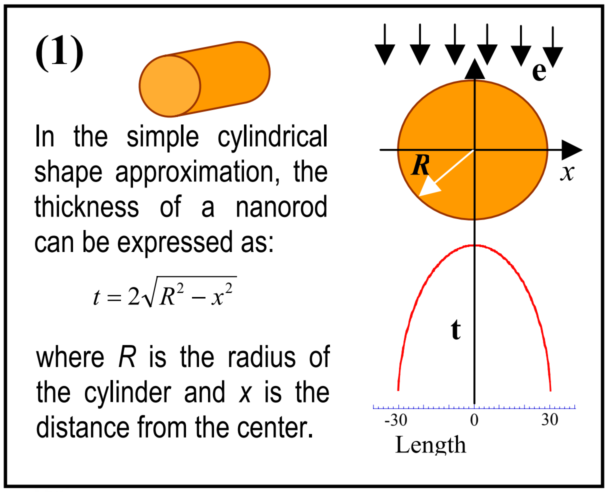
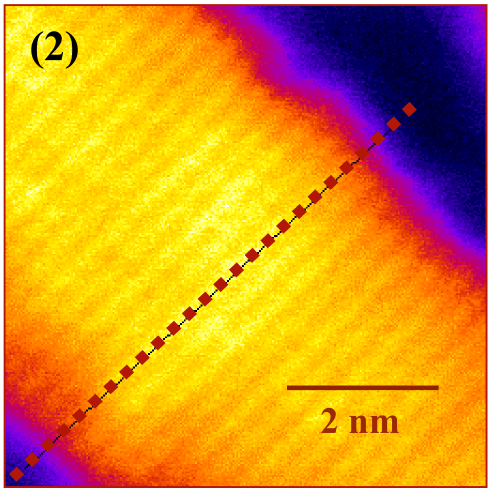
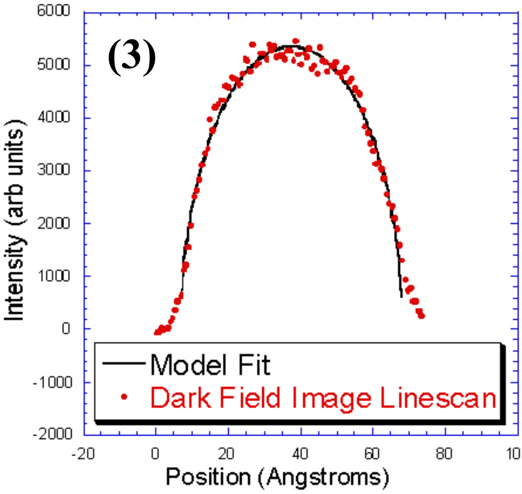

(1)

In the simple cylindrical shape approximation, the thickness of a nanorod can be expressed as:

$$t = 2\sqrt{R^2 - x^2}$$

where *R* is the radius of the cylinder and *x* is the distance from the center.





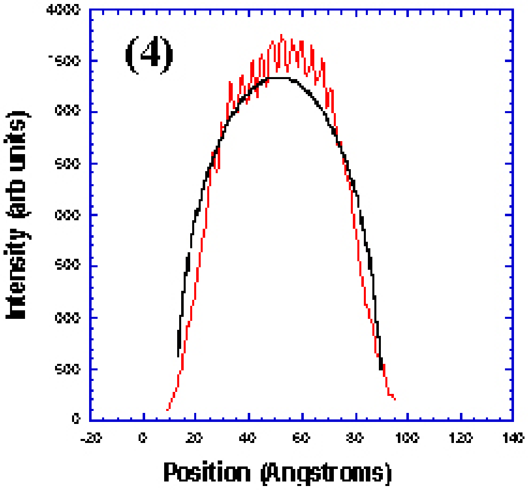


Fig. 1. Model for simple thickness profile of a cylindrical rod.
Fig. 2. High-resolution image of a QR with a dashed line showing the location of a linescan. Intensity data from the linescan is shown in Fig. 3.
Fig. 3. Linescan intensity data (red dots) are fitted with a simple thickness model (black line).
Fig. 4. Linescan from a different QR with intensity data (red line) fitted with a simple thickness model (black line). The oscillations at the peak of the intensity data result from lattice fringes.