INFLUENCE OF QUANTUM DOT SIZE ON THE CHARACTERISTICS OF FIELD EFFECT TRANSISTORS

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Abstract

A quantum dot (QD) with discrete energy levels connected to source and drain connections that display continuous energy distributions can be used to represent the channel in nanoscale field effect transistors (FETs). Contact states also permeate the channel region, and the initially sharp discrete states in the channel expand and "spill over" into the contacts as a result of this coupling.The result is a broadened density of states (DOS) in the channel that obeys a sum rule preserving electron count. This broadened DOS is commonly described by a Lorentzian function . This paper investigates how varying the size of cubic quantum dots affects the DOS and subsequent FET characteristics.

Introduction

This article provides a thorough analysis of the basic properties of Field Effect Transistors (FETs), with a particular emphasis on the impact of the size of the quantum dots (QDs) placed in the channel. We study the effects of QD dimension modifications on important parameters including the density of states (DOS) as an energy function. Since the source-to-drain current flow in FETs is directly impacted by these energy levels, it is essential to comprehend the DOS peaks and their location with different QD sizes. By analyzing QDs with side lengths $a = 7\,\text{nm}, 14\,\text{nm}, 28\,\text{nm}$, and $56\,\text{nm}$, we aim to identify trends and correlations to inform future current-voltage characteristic simulations and device optimization. This research contributes valuable insights towards tailoring QD dimensions for enhanced transistor performance .

Theoretical Background

In this section, we summarize the main theoretical formulas employed in the modeling of QD-based FETs.

$$E_n = \frac{\hbar^2\pi^2}{2m^*a^2}(n_x^2 + n_y^2 + n_z^2)$$

$$D(E) = \sum_n \frac{\Gamma/2\pi}{(E - E_n)^2 + (\Gamma/2)^2}$$

$$I = \frac{2e}{h}\int T(E)[f_L(E) - f_R(E)]dE$$

where E_n are discrete energy levels in the QD, Γ is the broadening parameter, $D(E)$ is the density of states, $T(E)$ the transmission function, and $f_{L,R}(E)$ are the Fermi functions of left and right contacts .

Results and Discussion

Density of States for Small QDs: $a = 7$ nm and $a = 14$ nm

Figures 1 and 2 show the density of states (DOS) as a function of energy for quantum dots with side lengths 7 nm and 14 nm, respectively.

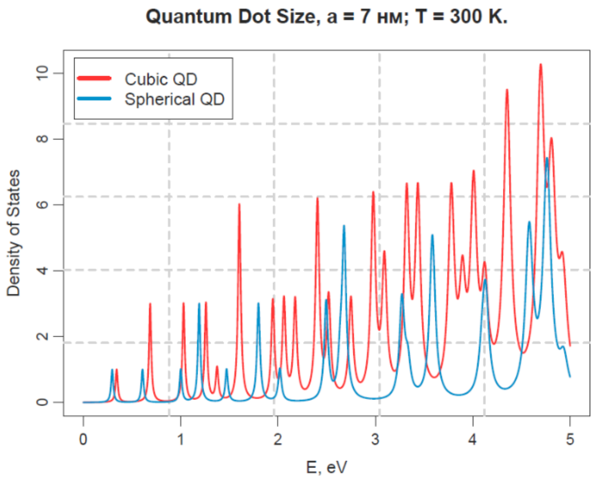

Figure 1:Density of States vs Energy for QD size $a = 7\,nm$ at $T = 300\,K$.

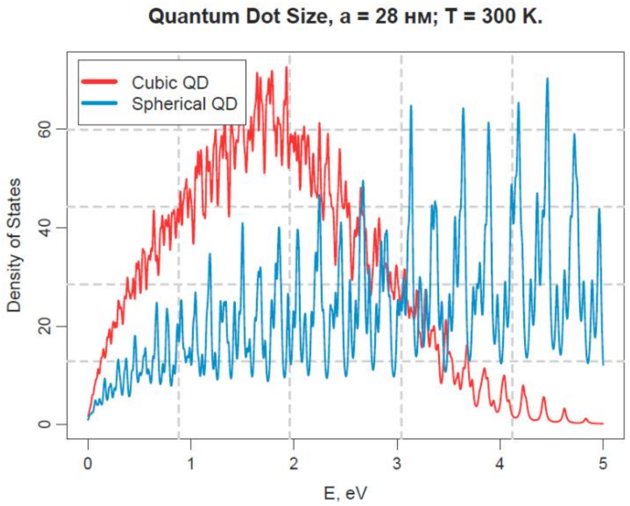

Figure 2:Density of States vs Energy for QD size $a = 14\,nm$ at $T = 300\,K$.

Comparing these two figures reveals that as the quantum dot size increases from 7 nm to 14 nm, the discrete energy levels become more closely spaced, and the overall DOS broadens. This behavior is expected from quantum confinement effects, where smaller QDs have more widely spaced energy levels due to stronger confinement .

Density of States for Large QDs: $a = 28\,\text{nm}$ and $a = 56\,\text{nm}$

Figures 3 and 4 display the DOS for larger quantum dots with side lengths of 28 nm and 56 nm.

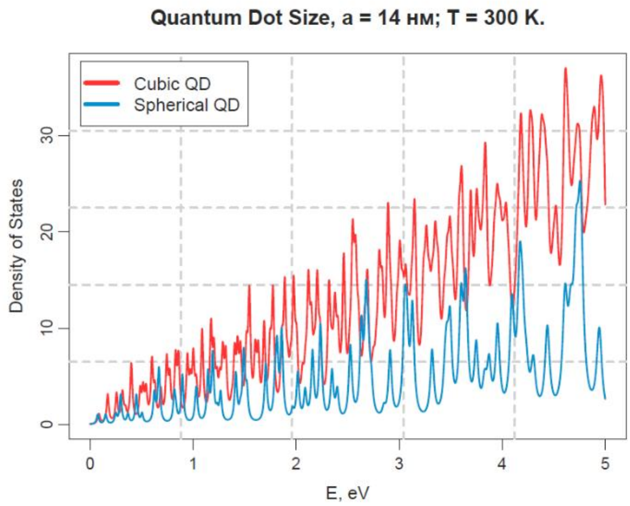

Figure 3:Density of States vs Energy for QD size $a = 28\,nm$ at $T = 300\,K$.

As the QD size further increases, the energy levels become very closely spaced and the DOS approaches a quasi-continuous distribution, similar to bulk materials.

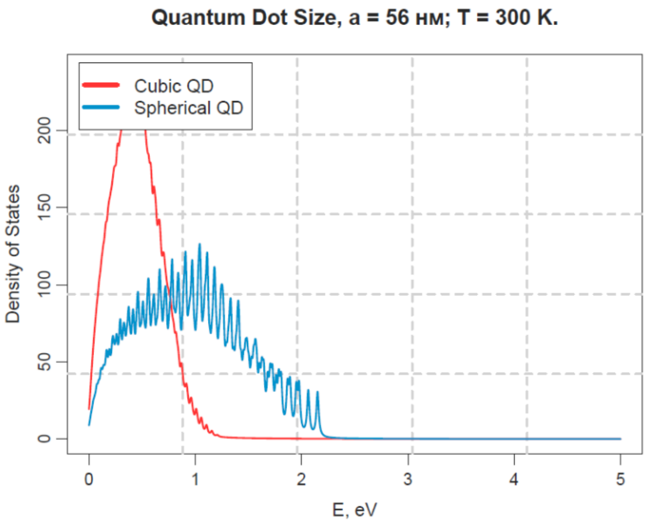

Figure 4: Density of States vs Energy for QD size $a = 56\,nm$ at $T = 300\,K$.

This indicates the diminishing effect of quantum confinement and the transition towards classical behavior .

Conclusion

Our study confirms that quantum dot size strongly influences the electronic structure and density of states in FET channels. Smaller QDs exhibit discrete, wellseparated energy levels leading to sharper DOS peaks, while larger QDs show broadened levels approaching bulk-like continuous distributions.These differences have a direct impact on the device's performance and electron transport characteristics. In order to completely mimic current-voltage characteristics for QD-based FETs and enable improved nanoelectronic device design, future work will concentrate on integrating tunneling rates, Coulomb interactions, and temperature dependency.

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