Quantum Dot

Pradeep Kumar

Assistant Professor, Department of Physics, CDLU, Sirsa

Abstract: **A quantum dot is a semiconductor nanostructure that confines the motion of conduction band electrons, valence band holes, or excitons (bound pairs of conduction band electrons and valence band holes) in all three spatial directions.**

The confinement can be due to electrostatic potentials (generated by external electrodes, doping, strain, impurities), the presence of an interface between different semiconductor materials (e.g. in core-shell nanocrystal systems), the presence of the semiconductor surface (e.g. semiconductor nanocrystal), or a combination of these.

A quantum dot has a discrete quantized energy spectrum.

Keywords—Quantum dot.

I. INTRODUCTION

The corresponding wave functions are spatially localized within the quantum dot, but extend over many periods of the crystal lattice.

A quantum dot contains a small finite number (of the order of 1-100) of conduction band electrons, valence band holes, or excitons, i.e., a finite number of elementary electric charges. Small quantum dots, such as colloidal semiconductor nanocrystals, can be as small as 2 to 10 nanometers, corresponding to 10 to 50 atoms in diameter and a total of 100 to 100,000 atoms within the quantum dot volume.

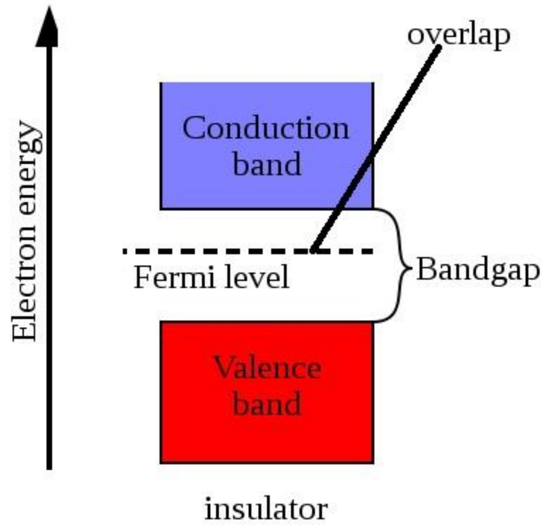
Self-assembled quantum dots are typically between 10 and 50 nm in size. Quantum dots defined by lithographically patterned gate electrodes, or by etching on two-dimensional electron gases in semiconductor heterostructures can have lateral dimensions exceeding 100 nm.

At 10 nm in diameter, nearly 3 million quantum dots could be lined up end to end and fit within the width of a human thumb.

Electronic characteristics of a quantum dot are closely related to its size and shape. For example, the band gap in a quantum dot which determines the frequency range of emitted light is inversely related to its size. In fluorescent dye applications the frequency of emitted light increases as the size of the quantum dot decreases. Consequently, the color of emitted light shifts from red to blue when the size of the quantum dot is made smaller.This allows the excitation and emission of quantum dots to be highly tunable. Since the size of a quantum dot may be set when it is made, its conductive properties may be carefully controlled. Quantum dot assemblies consisting of many different sizes, such as gradient multi-layer nanofilms, can be made to exhibit a range of desirable emission properties.

II. BAND GAP ENERGY

In solid-state physics, a band gap, also called an energy gap or bandgap, is an energy range in a solid where no electron states can exist. In graphs of the electronic band structure of solids, the band gap generally refers to the energy difference (in electron volts) between the top of the valence band and the bottom of the conduction band in insulators and semiconductors. It is closely related to the HOMO/LUMO gap in chemistry. If the valence band is completely full and the conduction band is completely empty, then electrons cannot move in the solid; however, if some electrons transfer from the valence to the conduction band, then current can flow (see carrier generation and recombination).



Therefore the band gap is a major factor determining the electrical conductivity of a solid. Substances with large band gaps are generally insulators, those with smaller band gaps are semiconductors, while conductors either have very small band gaps or none, because the valence and conduction bands overlap.

III. BULK-MANUFACTURE

Quantum dot manufacturing relies on a process called "high temperature dual injection" which has been scaled by multiple companies for commercial applications that require large quantities (hundreds of kilograms to tonnes) of quantum dots. This is a reproducible production method that can be applied to a wide range of quantum dot sizes and compositions.

The bonding in certain cadmium-free quantum dots, such as III-V-based quantum dots, is more covalent than that in II-VI materials, therefore it is more difficult to separate nanoparticle nucleation and growth via a high temperature dual injection synthesis. An alternative method of quantum dot synthesis, the “molecular seeding” process, provides a reproducible route to the production of high quality quantum dots in large volumes.

The process utilises identical molecules of a molecular cluster compound as the nucleation sites for nanoparticle growth, thus avoiding the need for a high temperature injection step. Particle growth is maintained by the periodic addition of precursors at moderate temperatures until the desired particle size is reached. The molecular seeding process is not limited to the production of cadmium-free quantum dots; for example, the process can be used to synthesise kilogram batches of high quality II-VI quantum dots in just a few hours.

IV. THEORETICAL MODELS:

- Quantum Mechanics
- Semiclassical
- Classical Mechanics

Quantum Mechanics

Quantum mechanics (QM; also known as quantum physics, or quantum theory) is a fundamental branch of physics which describes physical phenomena at scales typical of the quantum realm of atomic and subatomic length scales, where the action is on the order of the Planck constant. At these scales, many everyday concepts concerning physical objects and energy (including the photons making up visible light) are believed to behave and interact extremely differently than is usually seen in daily life. Quantum mechanics provides an extremely accurate description of the behavior of photons, electrons, and other atomic- and molecular-scale objects. At larger (macroscopic) scales its predictions simplify to become the laws of classical mechanics familiar in the everyday world, although even in the everyday world, many phenomenae can be observed with the naked eye, which cannot be explained classically but require a quantum mechanical explanation. Important applications of quantum mechanical theory include superconducting magnets, LEDs and the laser, the transistor and semiconductors such as the microprocessor, medical and research imaging such as MRI and the electron microscopy, and explanations for many biological and physical phenomenae.

Semiclassical

Semiclassical physics, or simply semiclassical refers to a theory in which one part of a system is described quantum-mechanically whereas the other is treated classically. For example, external fields will be constant, or when changing will be classically described. In general, it incorporates a development in powers of Planck's constant, resulting in the classical physics of power 0, and the first nontrivial approximation to the power of (-1). In this case, there is a clear link between the quantum-mechanical system and the associated semi-classical and classical approximations, as it is similar in appearance to the transition from physical optics to geometric optics.

Classical Mechanics

In applied mathematics, classical mechanics and in physics, (quantum mechanics) are the two major sub-fields of mechanics. Classical mechanics is concerned with the set of physical laws describing the motion of bodies under the action of a system of forces. The study of the motion of bodies is an ancient one, making classical mechanics one of the oldest and largest subjects in science, engineering and technology. It is also widely known as Newtonian mechanics.

Classical mechanics describes the motion of macroscopic objects, from projectiles to parts of machinery, as well as astronomical objects, such as spacecraft, planets, stars, and galaxies. Besides this, many specializations within the subject deal with solids, liquids and gases and other specific sub-topics. Classical mechanics also provides extremely accurate results as long as the domain of study is restricted to large objects and the speeds involved do not approach the speed of light. When the objects being dealt with become sufficiently small, it becomes necessary to introduce the other major sub-field of mechanics, quantum mechanics, which reconciles the macroscopic laws of physics with the atomic nature of matter and handles the wave–particle duality of atoms and molecules. When both quantum mechanics and classical mechanics cannot apply, such as at the quantum level with high speeds, quantum field theory (QFT) becomes applicable.

V. FRAME OF REFERENCE

In physics, a frame of reference (or reference frame) consists of an abstract coordinate system and the set of physical reference points that uniquely fix (locate and orient) the coordinate system and standardize measurements.

In n dimensions, n+1 reference points are sufficient to fully define a reference frame. Using rectangular (Cartesian) coordinates, a reference frame may be defined with a reference point at the origin and a reference point at one unit distance along each of the n coordinate axes.

In Einsteinian relativity, reference frames are used to specify the relationship between a moving observer and the phenomenon or phenomena under observation. In this context, the phrase often becomes "observational frame of reference" (or "observational reference frame"), which implies that the observer is at rest in the frame, although not necessarily located at its origin. A relativistic reference frame includes (or implies) the coordinate time, which does not correspond across different frames moving relatively to each other. The situation thus differs from Galilean relativity, where all possible coordinate times are essentially equivalent.

An observational frame of reference, often referred to as a physical frame of reference, a frame of reference, or simply a frame, is a physical concept related to an observer and the observer's state of motion. Here we adopt the view expressed by Kumar and Barve: an observational frame of reference is characterized only by its state of motion. However, there is lack of unanimity on this point. In special relativity, the distinction is sometimes made between an observer and a frame. According to this view, a frame is an observer plus a coordinate lattice constructed to be an orthonormal right-handed set of spacelike vectors perpendicular to a timelike vector. See Doran.[26] This restricted view is not used here, and is not universally adopted even in discussions of relativity.

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