Abstract—Quantum theory grew out based on experiments and radical theoretical proposals that were not based on accepted classical physics. In this new approach emerge nanostructures such as quantum wells, wires and dots in which electrons or holes are confined to an ultra-small region. The application of this nanostructures are still mostly confined to research laboratories, but they are remarkable and often rely on the fact that quantum structures give access to the quantum mechanical degrees of freedom of only a few carriers. The purpose of this document introduce the basic theory in quantum nanostructures, its preparation and some applications that will revolutionize our lives in a near future.

Index Terms—Quantum dots, Quantum Physics, Quantum Wells, Quantum Wires.

I. INTRODUCTION

SEMICONDUCTOR nanocrystals, such as quantum dots and quantum wires are of intense scientific and technological interest. Their electronic structures can be tailored measure by their sizes and shapes, leading to many new applications from infrared detectors, laser, photoluminescence, to solar cells. The nanostructures are produced by the reduction of the structure resulting on the confinement of it electrons. The reduction of one dimension will result in a quantum well, two dimensions in a quantum wire and eventually three dimensions in a quantum dot. The confinement of these structures can be developing in two different methods: top-down and bottom-up approaches. Once these structures are developed is possible to use this nanostructures in many interdisciplinary applications such as medicine, biology, computation, and NEMS, among others.

This document introduce in chapter 2 a basic definition of the nanostructures, then in chapter 3 the theoretical concepts useful to describe the nanostructures, the chapter 4 present an overview of the techniques to develop quantum nanostructures, chapter 5 shows some applications of the quantum dot and wires and the review paper terminates with some conclusions in chapter 6.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Confinement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk</td>
<td>0</td>
</tr>
<tr>
<td>Quantum Well</td>
<td>1 (z)</td>
</tr>
<tr>
<td>Quantum Wire</td>
<td>2 (x,y)</td>
</tr>
<tr>
<td>Quantum Dot</td>
<td>3 (x,y,z)</td>
</tr>
</tbody>
</table>

Table 1. Confinement of a structure

The word quantum is associated with these three types of nanostructures because the changes in properties arise from the quantum mechanical nature of physics in the domain of the ultra-small figure 2 show the different cases of reduction.

II. DEFINITION

When a size or dimension of a materials reduced from a large size, let’s say centimeters to a smaller size below hundred nanometers, changes on it properties can develop.

If one dimension is reduced to the nanorange while the other two dimensions remain large, then we obtain a structure known as quantum well. This reduction in dimension produces confinement of the electrons that also refers to the number of degrees of freedom in the electron momentum.

If two dimensions are reduced (confined) and one remains large, the resulting structure is referred to as a quantum wire.

The last case is the reduction or the confinement in all three dimensions is called a quantum dot, Table 1 shows the confinement of materials.

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III. PHYSICAL PRINCIPLES

As mentioned in the previous section the confining electrons refers to the number of degrees of freedom in the electron momentum.

For a quantum structure the general three-dimensional equation can be described by the Schrödinger equation for constant effective mass:

\[ - \nabla^2 \Psi + \frac{\hbar^2}{2m} \nabla^2 V \Psi = E \Psi \]  
(1)

Where,
\[ \Psi \] = wave function
\[ \hbar \] = Reduce Planck constant
\[ \nabla^2 \] = Laplacian
\[ V \] = Potential Energy
\[ E \] = Confinement Energy

For the case of a quantum wire, the potential can be written as the sum of a two-dimensional confinement plus the potential along the wire,

\[ V = V_y + V_z \]  
(2)

And the wave eigenfunction can then be written as:

\[ \Psi(x, y, z) = \psi_y(x) \psi_z(z) \]  
(3)

After substituting (2) and (3) equations in the general Schrödinger equation (1) we obtain the following:

\[ - \psi''_y + \frac{\hbar^2}{2m} \psi_y'' + \frac{\hbar^2}{2m} \psi''_z = E \psi_y \psi_z \]  
(4)

\[ - \psi''_y + \frac{\hbar^2}{2m} \psi_y'' + \frac{\hbar^2}{2m} \psi''_z = E \psi_y \psi_z \]  
(5)

A. Quantum wire

Assuming the nanowire as an infinite rectangular structure as shown in Figure 3 [2], within the quantum wire the potential is zero, while outside it is infinite; thus in the latter case the wave function is zero. Hence, the Schrödinger equation is only defined within the motion in the two confined y and z direction, the equation (5) is reduced to,

\[ - \psi''_y + \frac{\hbar^2}{2m} \psi_y'' = E \psi_y \]  
(6)

\[ - \psi''_y + \frac{\hbar^2}{2m} \psi_y'' = E \psi_y \]  
(7)

That according to [3] give the components of energy as:

\[ \frac{n_y \pi^2}{L_y^2} \]  
(9)

\[ \frac{n_z \pi^2}{L_z^2} \]  
(10)

The total energy due confinement for a rectangular wire is,

\[ E = \sum \left( \frac{n_y \pi^2}{L_y^2} \right) + \sum \left( \frac{n_z \pi^2}{L_z^2} \right) \]  
(11)

\[ E = \sum \left( \frac{n_y \pi^2}{L_y^2} \right) + \sum \left( \frac{n_z \pi^2}{L_z^2} \right) \]  
(12)

Where \( n_y \) and \( n_z \) correspond to quantum numbers where you can obtain different charges of densities according to them.

B. Quantum dot

With the purpose of avoid harder computational formulas, the quantum dots are assume as a square which all three-dimensions are confined as shown in figure 5 [2].

\[ E = \sum \left( \frac{n_y \pi^2}{L_y^2} \right) + \sum \left( \frac{n_z \pi^2}{L_z^2} \right) \]  
(13)

IV. DEVELOPMENT

A. Bottom-up preparation

This type of preparation of a nanostructure is made by collecting, consolidate and pattern individual atoms and molecules into the structure. This is developing by a sequence of chemical reactions controlled by catalysts. The catalyst involves the modification of the rate of a chemical reaction, usually speeding up the reaction rate by addition of a substance called a catalyst, which is not consumed during the reaction. With this process is possible to create nanostructures such as quantum wires and quantum dots.
B. Top-down preparation

This method starts with a large scale object or pattern and gradually reduces its dimensions. This is accomplished by a technique called lithography which casts radiation through a template on to a surface coated with a radiation sensitive resist; the resist is then removed and the surface is chemically treated to produce the nanostructure.

The first step of the lithographic procedure is to place a radiation-sensitive resist on the surface of the sample substrate. The sample is then irradiated by an electron beam in the region where the nanostructure will be located. This can be done by using either a radiation mask that contains the nanostructure pattern or a scanning electron beam that strikes the surface only in the desired region.

The third step in the process is the application of the developer to remove the irradiated portions of the resist. The fourth step is the insertion of an etching mask into the hole in the resist. The fifth step consists in lifting off the remaining parts of the resist. The six step the areas of the quantum structure not covered by the etching mask are chemically etched away to produce the quantum structure. Finally the etching mask is removed [4].

Incoming infrared radiation raises electrons to the conduction band, and the resulting electric current flow is a measure of the incident radiation intensity. The responsivity of the detector is the electric current generated per watt of the incoming radiation [4].

B. Quantum computing

A quantum computer is a computer design which uses the principles of quantum physics to increase the computational power beyond what is attainable by a traditional computer. By applying small voltages to the leads, the flow of electrons through the quantum dot can be controlled and thereby precise measurements of the spin and other properties therein can be made.

With several entangled quantum dots, or qubits, plus a way of performing operations, quantum calculations and the computers that would perform them might be possible.

Bits: a bit can be defined as a variable or computed quantity that can have only two possible values: 0/1 or on/off. Qubits: quantum mechanics allows the qubit to be in a superposition of both states at the same time, a property which is fundamental to quantum computing. A qubit can be 0, 1, or a superposition of both.

C. Photoluminescence

(QDLED) Quantum-dot light emitting diode

Quantum dot fabricated from a given material has the unusual property that its energy levels are strongly dependent on its size. For example, CdSe quantum dot light emission can be gradually tuned from the red region of spectrum for a 5 nm diameter dot, to the violet region for a 1.5 nm dot. The physical reason for QD coloration is the quantum confinement effect and is directly related to the energy levels of quantum dot.

Quantum-dot-based LEDs are characterized by pure and saturated emission colors with narrow bandwidth, and their emission wavelength is easily tuned by changing the size of the quantum dots. Moreover, QD-LED combine the color purity and durability of QDs with efficiency, flexibility, and low processing cost of organic light-emitting devices. QD-LED structure can be tuned over the entire visible wavelength range from 460 nm (blue) to 650 nm (red).

D. Quantum dot solar cell

- Quantum dot solar cells are an emerging field in solar cell research that uses quantum dots as the absorbing photovoltaic material, as opposed to better-known
bulk materials such as silicon, copper indium gallium selenide (CIGS) or CdTe. Quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the quantum dot size. The efficiency of solar cells could be increased to more than 60% from the current limit of just 30%.

![Fig 8. Quantum Solar Cell](image)

**VI. CONCLUSIONS**

With the development of this nanostructures we will have the possibility of produce stronger and lighter wires than the traditional wires, have the advantage of conduct electricity ten times faster and saving on the use of expensive metal conductors. Is worth mention that this nanostructure has less resistivity, whereby this structure doesn’t generate heat as the actual wires, producing cost savings in expensive cooling systems.

With this quantum structures have to consider that the prices are very expensive and the creation of a nanostructure requires a lot of dedication and time, for instance the automated manufacturing of wires is faster than the quantum wire development besides it high prices.

As final thought application of quantum structures are useful in many conditions due to their physiochemical properties, quantum dots may use in different fields by altering their surface property, internal structures, preparation techniques, inter alia. The future looks bright and exciting on all the possible applications of quantum structures.

**REFERENCES**


