CHAPTER 1

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Modern research has made it possible to design and fabricate semiconductor nano particles, especially those belonging to II-VI, III-V and IV-V group of the periodic table. These semiconductors exhibit considerable quantum size effects leading to size dependent electronic and optoelectronic [1-36] devices. The fact that the band gap of any of these materials varies with size, gives a great potential for electronic and optoelectronic applications. The dramatic change, as one goes from bulk to nanometer sized material called nanomaterials, is principally due to redistribution of the electronic states and changes in the corresponding wave function. In nano material the particle sizes are restricted in one, two or three dimensions resulting in the restrictions of electronic motions in these directions. Based on the dimensional confinements nano materials are classified in three categories as quantum well, quantum wire and quantum dot.

1.1 Definitions of nano particles

I. Quantum well

If the thickness of any structure / particle becomes comparable to de-Broglie's wavelength of electron at Fermi energy and the electronic motion is restricted along the thickness only, the structure is called quantum well.

II. Quantum wire

If the thickness as well as width of any structure are comparable to de-Broglie's wavelength of electron at Fermi energy and the electronic motion is restricted along both thickness and width, the structure is called quantum wire.

III. Quantum dot.

If all the three dimensions, that is thickness, width and length of any structure are comparable to de-Broglie's wavelength of electron at Fermi energy and the electronic motion is restricted in all the three dimensions, the structure is called quantum dot. It is ideally a quasi zero structure. Practically, its dimensions range from a few nm to few hundred nm that are circular, elliptical or rectangular in shape.

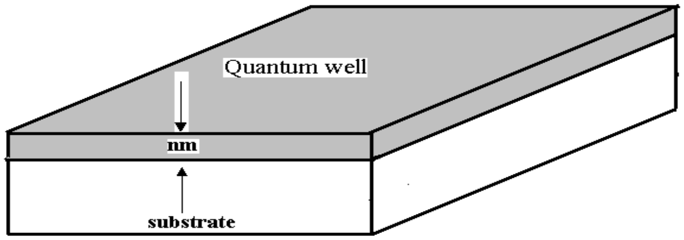

Fig.1.1: **Schematic diagram of quantum well**

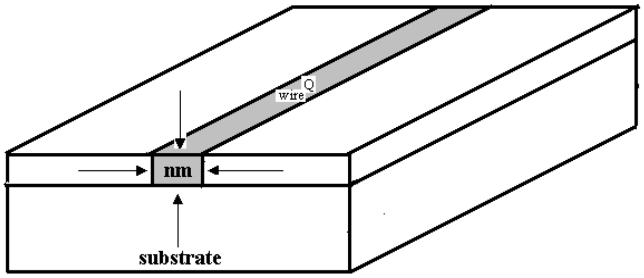

Fig.1.2 : Schematic diagram of quantum wire

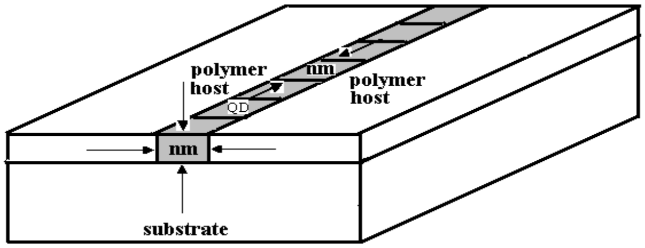

Fig.1.3: Schematic diagram of quantum dot array

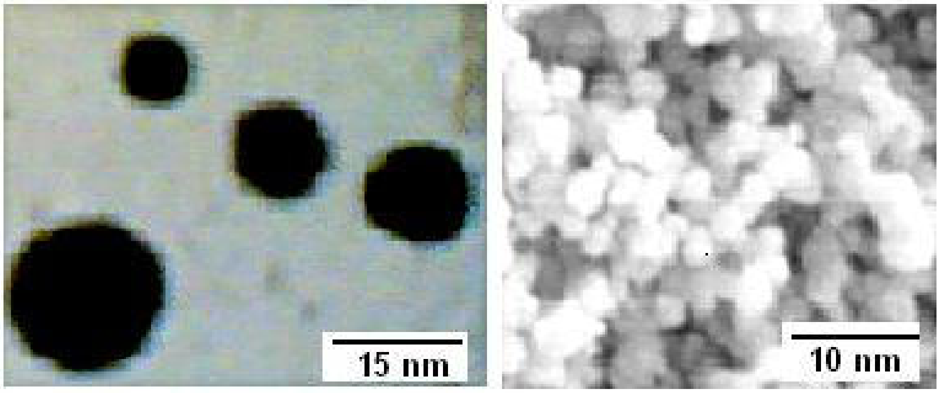

Fig. 1.4: TEM images of quantum dot assembly

1.2 Properties of quantum dots

The basic properties of quantum dots are [29] :

I. Large surface to volume (S/ V) ratio

Due to three dimensional confinements of quantum dots, it possesses large surface to volume ratio resulting in producing discrete electronic energy states called “trap” on the surface.

II. Enhancement in band gap

As a consequence of size confinement, the continuum of states in conduction and valence band are split into discrete states with energy spacing relative to the band gap, which is approximately inversely proportional to the square of the particle radius, resulting in widening the band gap in comparison with the bulk [33-36].

III. Blue shift

As the band gap of quantum dot enhances, the strong absorption of optical signals occurs in UV region that is, absorption edge shifts towards UV which is called blue shift.

IV. Change in optoelectronic property:

Unlike in bulk material, electronic transition between traps and valence band as well as traps and conduction band is faster due to fast trapping and de trapping of charge carriers by traps [14, 19] than band edge transition. This property of quantum dot makes it efficient for faster response.

1.3 Technological importance of quantum dots

The road map of so called Semiconductors Industries Association (SIA) For Silicon Process Technology has now been established. According to it, the minimum design rule, which was 0.35 μm in 1995 will be multiplied by 0.7 every 3 years. In 2010 it will be possible to create 64 GB DRAM with average area of 'FET' being 1.1μm. But this conventional technology has some serious constraints[4] which are completely absent in semiconductor quantum dots as discussed below:

I. In conventional devices, as the gate length shrinks to 0.1 μm or less, some of physical effects like (a) Hot electron effects (b) Oxide tunneling (c) Silicon Tunneling (d) Drain induced barrier lowering etc. comprise to make successful 'CMOS' operation difficult.

In quantum dot devices, the above said physical effects are absent

II. In silicon technology, when the device size shrinks, the capacitances of their interconnections become increasingly important. If very small conductors are used, the capacitances of their inter connections becomes the limiting factor in circuit speed.

But in quantum dots, the transition speed of the charge carriers between two different energy states defines the operation speed [20] and there is no affect of capacitance.

III. In conventional devices, power must be supplied to each component through different power connections. Moreover, the various components themselves are connected to each other by various interconnections. This causes loss of power in these connections as well as in the individual components of the devices.

Quantum dot (or its assembly) itself is a complete device, that can perform several functions depending on various input conditions only. For example, the same quantum dot can act as optic as well as photonic device if the input is optical signal. On the other hand, if the input is electrical signal it can function as electronic switch or sensor. This proves that need for inter connections does not occur.

IV. In silicon technology, power dissipation becomes a great problem as the size reduces. For example, to work at 10 GH_z, it requires power dissipation over 3 kW / cm^2.

But quantum dot and its assembly need very less power for its successful operation and so the power dissipation problem does not occur.

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1.4 Present work

In the present investigation an attempt has been made to synthesize metal oxide semiconductor quantum dots and to test them for the detection of reducing gases/ vapors present in the atmosphere as there is a growing demand for sensitive and selective gas sensor. In this work**,** we have synthesized three metal oxide semiconductor quantum dots. These are-

(i) Zinc Oxide (ZnO)
(ii) Tin Oxide (SnO_2) and
(iii) Ferric Oxide (Fe_2O_3)

To synthesize quantum dots, we have adopted quenching method as it has several advantages such as simplicity, safety, suitable for large scale production and low cost over other techniques like molecular beam epitaxy (MBE), radio frequency sputtering (RF), liquid phase epitaxy (LPE), chemical etc.[17] .

The quantum dot samples are then characterized by UV-VIS spectrophotometer, X-ray Diffraction study (XRD), and High Resolution Transmission Electron Microscopy (HRTEM) for optical, structural, and morphological investigations. After a detailed characterization, the sensing characteristics of the quantum dot have been investigated for a variety of gases/vapors namely acetone, ethanol and methanol. It has been observed that gas sensing property is completely surface related phenomenon of sensor and depends on adsorption and desorption of gas .As quantum dot sample has large surface to volume ratio (S/V ratio), adsorption and desorption occurs very efficiently over its surface at very fast rate producing efficient and fast gas sensitivity[16,17]. Reducing gases (which inject or supply electron to sensor surface by chemical reaction so that sensor resistances decreases) has been selected for sensing purpose.

Reasons for selection metal oxide semiconductor quantum dots:

1. Metal oxide semiconductor quantum dots are very efficient gas sensor.
2. It is easier and cheaper to fabricate metal oxide semiconductor quantum dots.
3. Metal oxide semiconductors are highly sensitive to reducing and oxidizing gases.

Reasons for choosing reducing gases:

1. Reducing gases are very important in day to day life and these gases are always needed to be detected for different purposes.

1.5. Thesis outline: -

In this thesis, the whole research work has been arranged in the following way---

Chapter 1: Introduction

Chapter 2: Literature Survey

Chapter3: Synthesis of quantum dots

Chapter 4: Characterizations of quantum dots.

Chapter5: Applications of quantum dots as gas sensors

Chapter 6: Conclusion and further direction

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