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Vitality of Physics In Nanoscience and Nanotechnology

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Abstract: *Physics can be used to explain everything that goes on at the nano scale. There is active physics research going on in nanoscience and nanotechnology nanomechanics, quantum computation, quantum teleportation, artificial atoms etc. At nanometer scale physics is different. By learning about individual molecules properties, we can put basic physics laws together in very well-defined ways to produce new materials with new and amazing characteristics. These materials have unique structures and tunable properties necessary to meet the current technical requirements and many different real world applications. The basics of physics leading to Nanoscience and Nanotechnology which is currently in a very infantile stage leading to the creation of Useful and Functional materials, devices and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and physical properties at nano scale. The current paper focuses the vitality of basic physics in the development of new science and technology named nanoscience and nanotechnology.*

Keywords: *Nanoscience, Nanotechnology etc*

I. Introduction

Scientists have discovered that materials at small(10^{-9}m) dimensions—small particles, thin films, etc—can have significantly different properties than the same materials at larger scale. There are thus endless possibilities for improved devices, structures, and materials if we can understand these differences, and learn how to control the assembly of small structures [1]. There are many different views of precisely what is included in nanotechnology. In general, however, most agree that three things are important: Small size measured in 100s of nanometers or less, Unique properties because of the small size, Control the structure and composition on the nm scale in order to control the properties [2].

Nanostructures—objects with nanometer scale features—are not new and they were not first created by man. In the past decade, innovations in our understanding of nanotechnology have enabled us to begin to understand and control these structures and properties in order to make new functional materials and devices. We have entered the era of engineered nanomaterials and devices [3]. It is obvious that nanoscience, nanoengineering, and nanotechnology all deal with very small sized objects and systems. Our ability to control and manipulate nanostructures will make it possible to exploit new physical and chemical properties of systems that are intermediate in size, between single atoms, molecules, and bulk materials.

II. Need of Physics In Nanoscale

There are many specific reasons why the role of physics in nanoscale has become so important. The quantum mechanical (wavelike) properties of electrons inside matter are influenced by variations on the nanoscale. By nanoscale design of materials, it is possible to vary their micro and macroscopic properties, such as charge capacity, magnetization, and melting temperature, without changing their chemical composition[4]. We briefly discuss some of the strange interactions that quantum theories have predicted, making a significant contribution because nanotechnology operates on a small enough scale that the effects of a single atom (or small groups of atoms) become important, quantum theory is crucial to any explanation of phenomena on the nanoscale. Here, we will delve into some of the more specific aspects of quantum mechanics[5].Quantum theory remains a vital tool in explaining and predicting many of the marvels that occur within nanotechnology[6].We will see how the basic principles of physics and quantum mechanics apply to different manufacturing aspects of nanotechnology[7].Physical properties of materials benefits especially from nanoparticles, due to the following aspects.

Extremely large surface to volume ratio(S/V):

When the size of the object is reduced to the nanometric range the proportion of surface atoms no longer negligible. So a large fraction of the atoms are located at the surface of the object in the nanomaterials, it will modify its properties. The properties of nanomaterials become totally different from what is observed in the bulk solid system[8].

The size effect in nanoscale systems directly influence the energy band structure and can lead indirectly to changes in the associated atomic structure. The portion of atoms which are in contact with either a free surface, as in the case of an isolated nanoparticle, or an internal interface, such as a grain boundary in a nanocrystalline solid. Both the surface area to volume ratio (S/V) and the specific surface area (m2g-1) of a system are inversely proportional to particle size and both increase drastically for particles less than 100 nm in diameter[9].

The surface of a sphere scales with the square of its radius r, but its volume scales with r3.

The total number of atoms N in this sphere scales linearly with the volume. The fraction of atoms at the surface is called dispersion F, and it scales with surface area divided by volume, i.e. with the inverse radius or diameter, and thus also with N-1/3. All properties which depend on the dispersion of a particle lead to a straight line when plotted against r-1, d-1 or N-1/3[10]. Atoms at the surface have fewer direct neighbours than atoms in bulk. Therefore, particles with a large fraction of atoms at the surface have low coordination number. In a small isolated nanoparticle, a large proportion of the total number of atoms will be present either at or near the free surface. Similarly in nanocrystalline materials, where a large portion of atoms will be either at or near grain boundaries [11]. Such structural differences in reduced-dimensional systems would be expected to lead to very different properties from the bulk.

Quantum mechanical effect:

The quantum confinement effect is observed when the size of the particle is too small to be comparable to the wavelength of the electron. The word confinement means to confine the motion of randomly moving electron to restrict its motion in specific energy levels (discreteness) and quantum reflects the atomic realm of particles [12]. So as the size of a particle decrease to nano scale , the decrease in confining dimension makes the energy levels discrete and this increases or widens up the band gap and ultimately the band gap energy also increases. Since the band gap and wavelength are inversely related to each other the wavelength decrease with decrease in size and the proof is the emission of blue radiation. Size of structure is on same scale as the wavelengths of electrons, and quantum confinement occurs resulting in changes in electronic and optical properties[13]. According to the quantum mechanical Heisenberg Uncertainty Principle, the position and momentum of an object cannot be determined simultaneously and precisely . Then, the first question that may come into mind is, how one could be able to brush aside the Heisenberg Uncertainty Principle to work at the atomic and molecular level, atom by atom, as is the basis of nanotechnology [14].

1. The Heisenberg Uncertainty Principle helps to determine the size of electron clouds, the size of atoms and applies only to the subatomic particles like electron, positron, photon, etc. It does not forbid the possibility of nanotechnology, which has to do with the position and momentum of such large particles like atoms and molecules. Heisenberg Uncertainty Principle places no limit on how well atoms and molecules can be held in place [15].
2. The wave–particle duality is in all matter. Any single experiment can show either the wave-like properties or the particle-like properties, but not both.
3. Any system (or object) is completely described by a wave function. This description is probabilistic and the probability of an event is related to the amplitude of the wave function [16].

III. Manufacturing Approaches

There are mainly two major approaches to get nanomaterials [17]. One is the bottom up and the other is top down approach which are totally based on the basic principles of physics.

Bottom up manufacturing would provide components made of single molecules, which are held together by covalent forces that are far stronger than the forces that hold together macro-scale components. Furthermore, the amount of information that could be stored in devices build from the bottom up would be enormous. For example, use of AFM, liquid phase techniques based on inverse micelles, sol-gel processing, chemical vapor deposition (CVD), laser pyrolysis and molecular self assembly use bottom up approach for nano scale material manufacturing [18].

Top down method for manufacturing involves the construction of parts through methods such as cutting, carving and molding. Using these methods, we have been able to fabricate a remarkable variety of machinery and electronics devices. However, the sizes at which we can make these devices are severely limited by our ability to cut, carve and mold. Milling, Nano-lithography, hydrothermal technique (for some materials), laser ablation, physical vapor deposition, electrochemical method (electroplating) uses top down approach for nano-scale material manufacturing [19].

IV. Properties Of Nanomaterials

Nanomaterials have properties that are different from those of bulk materials. Most nanostructure materials are crystalline in nature and they have unique properties.

a)Physical properties:

Understanding the fundamental physical properties is crucial to the rational design of functional devices. When the material size is reduced to nanoscale, surface area to volume ratio increases. Due to increase of surface of surface area, more number of atoms will appear at the surface of compared to those inside. So Interatomic spacing decreases with size. Crystal structure of nanoparticles is same as bulk structure with different lattice parameters. The inter-atomic spacing decreases with size and this is due to long range electrostatic forces and the short range core-core repulsion. Due to large no of surface atoms there forms a strong network between the adjacent nanoparticles which enhances the strength as shown in the figure [20].

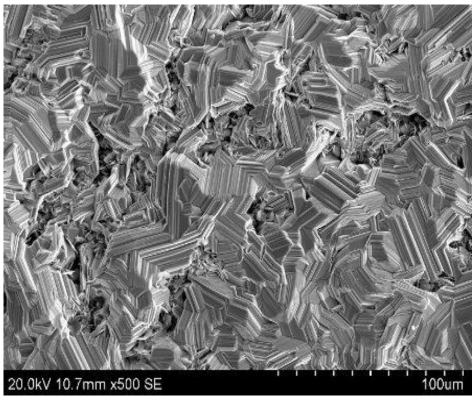

Fig 1: Showing the SEM image of network of ZnO nanoparticles coating on mildsteel sample.

b) Thermal properties:

Thermal properties of nano materials are different from that of bulk materials. The Debye temperature and ferroelectric phase transition temperature are lower for nano materials. The melting point of nano gold decreases from 1200 K to 800K as the size of particle decreases form 300A0 to 200A0. The variation of melting point in gold with decrease of particle. The melting point of nanoparticles decreases with size [21].

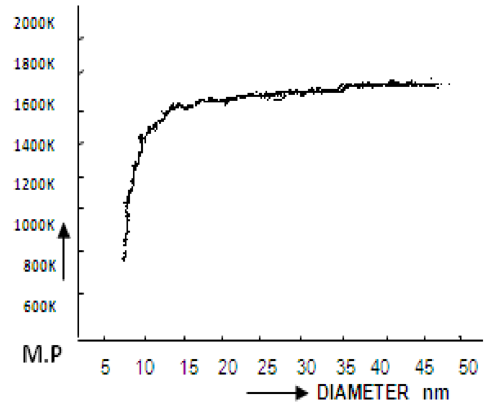

Fig 2: Graph Showing the varation of melting point of ZnO nanoparticle with respect to size.

c) Optical properties:

Different sized nano particles scatters different light intensities incident on it and hence they appear with different colors. For example nano gold does not act as bulk gold. The nano particles of gold appear as orange, purple, red or greenish in colour depending on their grain size. The bulk ZnO is opaque where as nanoparticle ZnO is semi transparent. Figure 4 shows room temperature PL(photoluminescence) spectrum of the ZnO nanoparticles shows a UV emission at 370nm and broad bands centered at 440 nm, 60 nm, 480 nm and 485 nm[22].

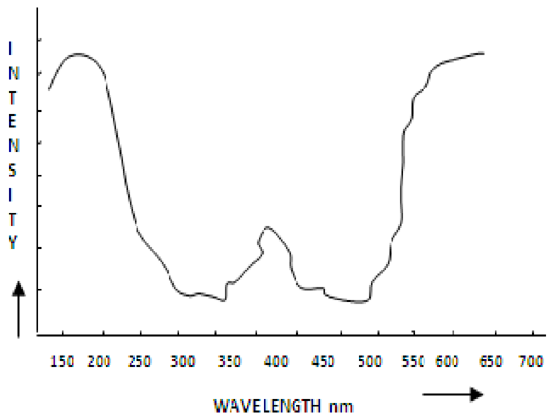

Fig 3: Graph Showing the photoluminescence of ZnO

d)Magnetic properties:

The magnetic moment of nano particles is found to be very less when compared them with its bulk size. Actually, it should be possible that non-ferromagnetic bulk exhibit ferromagnetic-like behavior when prepared in nano range. Bulk Gold and Pt are non-magnetic, but at the nano size they are magnetic.The magnetic properties of nano materials are different from that of bulk materials. The coercivity values of single domain is vary large. The variation of remanet magnetization and coercivity as a function of grain size is shown in figure. It is possible to induce room-temperature ferromagnetic-like behavior in ZnO nanoparticles without doping with magnetic impurities but simply inducing an alteration of their electronic configuration. Capping ZnO nanoparticles (~10 nm size) with different organic molecules produces an alteration of their electronic configuration [23] .

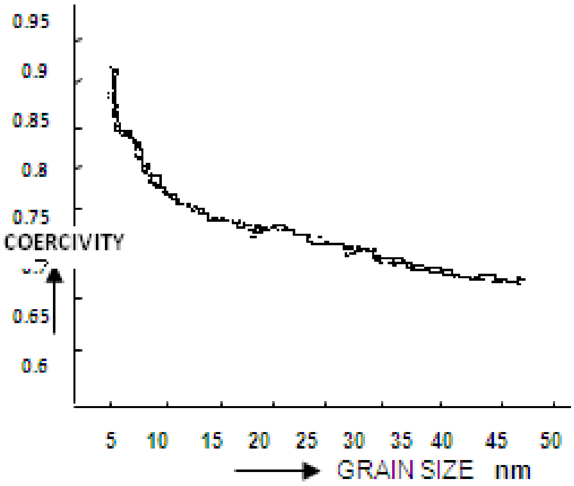

Fig 4: Graph Showing the varation of coercivity of ZnO nanoparticle with respect to grain size.

e)Mechanical Properties:

Many mechanical properties, such as toughness, are highly dependent on the ease of formation or the presence of defects within a material. As the system size decreases, the ability to support such defects becomes increasingly more difficult and mechanical properties will be altered accordingly. Novel nanostructures, which are very different from bulk structures in terms of the atomic structural arrangement, will obviously show very different mechanical properties. As the structural scale reduces to the nanometre range, for example, in ZnO nano-layered nanocomposite coating, a different scale dependence from the usual Hall-Petch relationship for yield strength often becomes apparent with large increases in strength[24] .

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

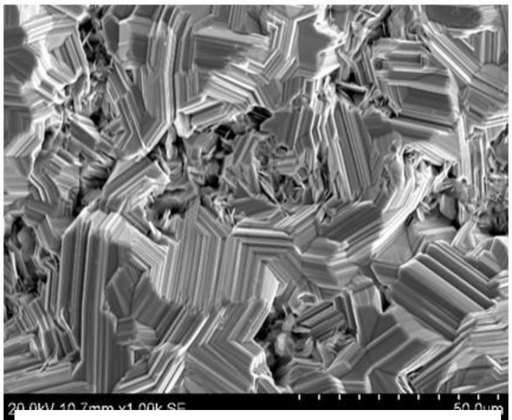

Fig 5: SEM image of ZnO nanocomposite coating yielding strength to milsteel sample

f) Chemical properties:

A large fraction of the atoms are located at the surface of the nanomaterial which increase its reactivity and catalytic activity. The large surface area to volume ratio, the variations in geometry and the electronic structure of nano particles have a strong effect on catalytic properties. ZnO nanoparticles coated on mildsteel sample shows high reactivity and catalytic activity with mildsteel sample.ZnO Nanocrystalline coated materials are strong, hard, erosion and corrosion resistant[25]. They are chemically active and have the following chemical properties.

1. In electrochemical reactions, the rate of increase in mass transport increases as the particle size decreases.
2. The equilibrium vapour pressure, chemical potentials and solubilites of nanoparticles are greater than that for the same bulk material.

Fig 6: Showing the image of salt spray test on ZnO nanocomposite coating on milsteel sample.

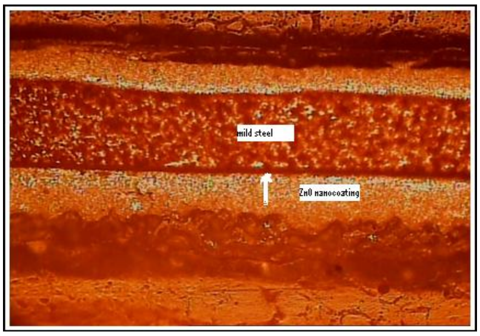

Fig 7: Showing the image for high reactivity and catalytic activity.

g) Electrical properties:

ZnO has wide direct band gap (3.37 eV or 375 nm at room temperature) .ZnO nano particles are different from their bulk and in turn will have modified electronic properties of the materials. Nanoparticles made of semiconducting materials like Germanium, Silicon and Cadmium are not semiconductors. Nanoclusters of different sizes will have different electronic structures and different energy level separations [26]. So they show diverse electronic properties which depend on its size.

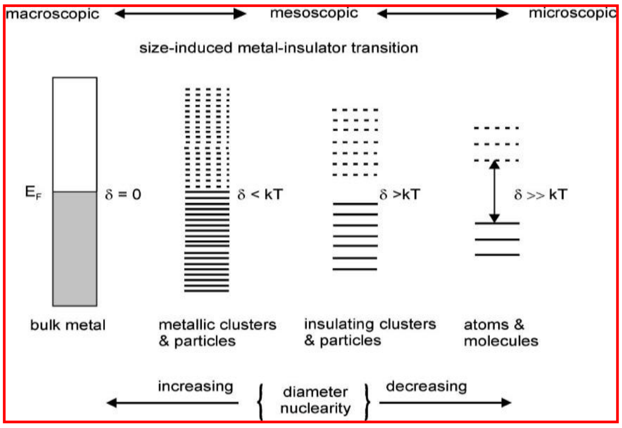

Fig 8: Showing the varation of electronic energy levels from bulk to nanoparticle.

V. Conclusion:

In this way we see that nanotechnology is an enabling technology comprised of basic physics laws that will impact electronics and computing, medicine, materials and manufacturing, catalysis, energy and transportation. It will revolutionize future world by changing the current using materials in durability and reactivity. We have great opportunities to make things smaller in size, lighter in weight and stronger in strength. Therefore physicists, scientists and engineers have great interest in this emerging field.

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