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Prof. G P Raja Sekhar
Dean, Continuing Education
IIT Kharagpur

Jul-Oct 2021
(12 week course)

Prof. Debjani Chakraborty
Coordinator, NPTEL
IIT Kharagpur

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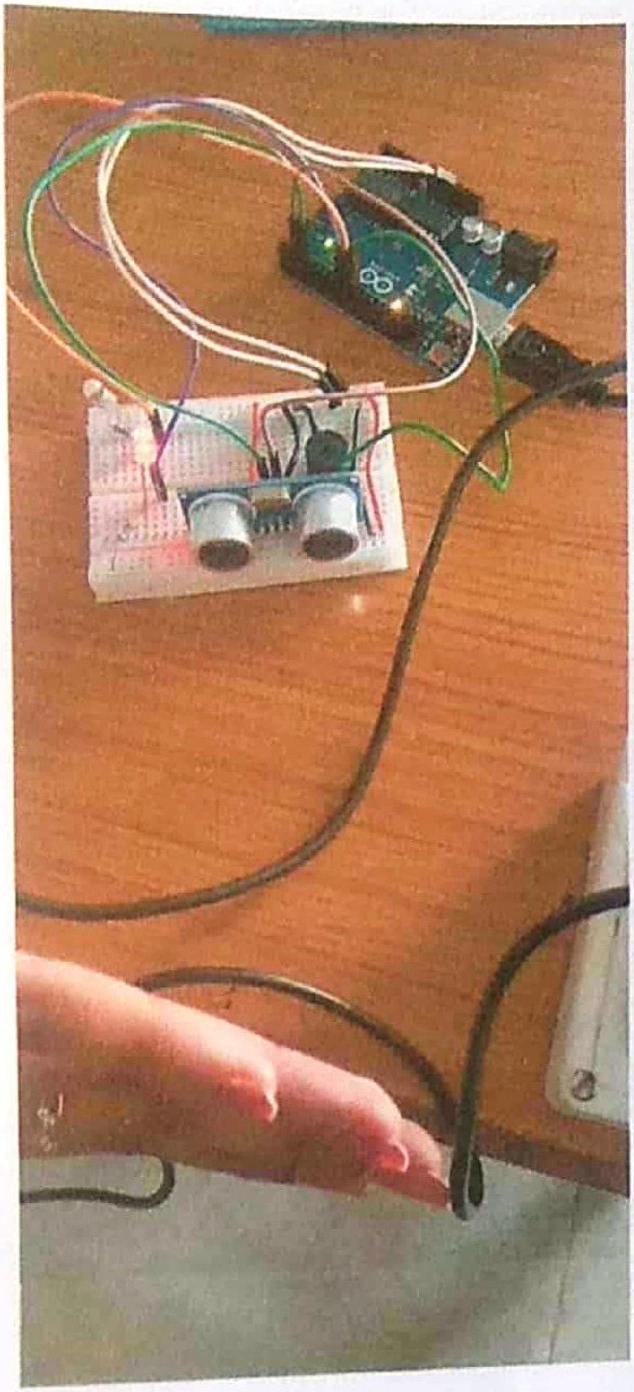
2.3.1

Solar Cell



Nano materials

Definition of nanomaterials

- According to International organization for standardization "Nanomaterial is material with any external dimension in the nanoscale or having internal structure in the nanoscale".
- Nanoscale is defined as "size range from approximately 1nm to 100nm".1nm=10-9m.

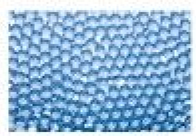
nanoparticles

- Nanomaterials have extremely small size having at least one dimension 100nm or less.
- They can exist in single, fused, aggregated , agglomerated forms with spherical , tubular , or irregular shapes.
- Common types of nanomaterials include nanotubes ,dendrimers , quantum dots and fullerenes.

Importance of nanomaterials

Nanomaterials have applications in the field of nanotechnology, and displays different physical ,chemical characteristics from normal chemicals

(i.e., silvernano , carbon nanotube ,fullerene ,photocatalyst ,carbon nano , silica).

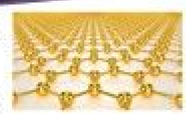


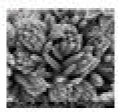
Classification of nanomaterials

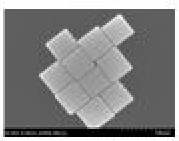
- According to siegel ,nanostructured materials are classified as :
- Zero dimensional nanostructures
- One dimensional nanostructures
- Two dimensional nanostructures
- Three dimensional nanostructures

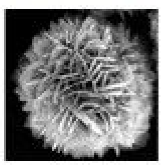
Examples of nanoparticles

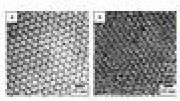
- AU (gold)nanoparticle , Buckminster fullerene.
- FePt nanosphere, titanium nanoflower.
- Silver nanocubes, Sno2 nanoflower.

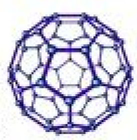












Physical and chemical characteristics of nanomaterials

- As compare to conventional bulk particles nanomaterials exhibits some unique physical properties including electrical, catalytic, magnetic, mechanical, thermal, or imaging features that make the nanomaterials a relevant topic in medical, pharmaceutical and different engineering sectors. The nanomaterial possesses some remarkable and specific peculiar properties which may be significantly distinctive from the physical properties of bulk materials.
- The specific features of those physical properties are discussed below

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- **Color**: There are few examples where the materials show the different color when they are converted to nanoparticles. As per example when the gold materials are converted to nanomaterials they turn into red color. Gold nanoparticles interaction with light is strongly govorened by the particle sizes of the materials. Small particle sizes (~2-150nm) have high surface electron densities which are called as surface plasmons undergo a collective oscillation when they are excited by light at specific wavelengths. This oscillation is dscribed as a surface plasmon resonance (SPR). For small (~30nm) monodisperse gold nanoparticles the surface plasmon resonance phenomona is responsible for an absorption of the blue-green portion of the spectrum (~450 nm) while red light (~700 nm) is reflected, producing a rich red color.

- **Melting point:** The melting point drastically falls when the particle size of the material approaches to the nanoscale ranges. This phenomenon related to melting point depression is very prominent in nanoscale materials which melt at temperatures hundreds of degrees lower than bulk materials.
- **Mechanical strength:** All the nanomaterials possess high mechanical strength as compared to their conventional counterparts. The mechanical strength of nanomaterials may be one or two times higher in magnitude than that of single crystals in the bulk form.

- **Electrical properties of the nanomaterials**: This is quite complex phenomenon. Reduction in material's dimensions would have two different contrasting effects on electrical conductivity. By its property nanoparticle product enhance the crystal perfection and as well as it reduce the defects. As a result electron scattering phenomenon due to crystal defects are also reduced and a reduction in resistivity is experienced
- **Optical properties**: Optical properties exhibited by nanomaterials are quite different from their bulk counterpart. The reason behind this change in property is mainly due to the effect of the surface plasmon resonance. In addition, the increased energy level spacing is also an important criterion for this changing behavior.

- **Chemical properties of the materials** are also changed when it converts to nano range. Due to increase of exposed surface area of the nanoparticlesas compared with conventional bulk objects, reactivity of those particles increase enormosly.
- some important features of the nanoparticle chemical properties are given below
- 1. In case of nanoparticles 50% of all the atoms are surface atoms and as a result electric transport properties of these particles are no longer dependent on solid state bulk phenomenon. Electrical properties are dirctly related to chemical properties.

- 2. Due to larger proportion of surface atoms, the atoms present in nanomaterials posses a higher energy as compare to atoms present in bulk structure.
- 3. The interactions between nanoparticles depend on the chemical nature of the surface. Due to large surface area high quantity charge species defects and impurities may be easily attracted to surfaces and interfaces of nano particles and thus chemical nature of the surfaces changes abruptly as compare to their bulk counterpart.
- 4. Surface properties of the nanoparticles and their interaction can be modified or altered by using molecular monolayer.

Applications of nanomaterials

- **Nanomaterial Applications using Carbon Nanotubes**
- Applications being developed for carbon nanotubes include adding antibodies to nanotubes to form bacteria sensors, making a composite with nanotubes that bend when electric voltage is applied bend the wings of morphing aircraft, adding boron or gold to nanotubes to trap oil spills, include smaller transistors, coating nanotubes with silicon to make anodes the can increase the capacity of Li-ion batteries by up to 10 times.

- **Nanomaterial Applications using Graphene**
- Applications being developed for graphene include using graphene sheets as electodes in ultracapacitors which will have as much storage capacity as batteries but will be able to recharge in minutes, attaching strands of DNA to graphene to form sensors for rapid disease diagnostics, replacing indium in flat screen TVs and making high strenght composite materials.

- **Nanomaterial Applications using Nanocomposites**
- Applications being developed for nanocomposites include a nanotube-polymer nanocomposite to form a scaffold which speeds up replacement of broken bones, making a graphene-epoxy nanocomposite with very high strenght-to-weight ratios, a nanocomposite made from cellulous and nanotubes used to make a flexible battery.

- **Nanomaterial Applications using Nanofibers**
- Applications being developed for nanofibers include stimulating the production of cartilage in damaged joints, piezoelectric nanofibers that can be woven into clothing to produce electricty for cell phones or other devices, carbon nanofibers that can improve the preformance flame retandant in funiture.

- **Nanomaterial Applications using Nanoparticles**
- Applications being developed for nanoparticles include deliver chemotherapy drugs directly to cancer tumors, resetting the immune system to prevent autoimmune diseases, delivering drugs to damaged regions of arteries to fight cardiovascular disease, create photocatalysts that produce hydrogen from water, reduce the cost of producing fuel cells and solar cells, clean up oil spills, water pollution and air pollution.

- **Nanomaterial Applications using Nanowires**
- Applications being developed for carbon nanotubes include using zinc oxide nanowires in a flexible solar cell, silver chloride nanowires to decompose organic molecules in polluted water, using nanowires made from iron and nickel to make dense computer memory - called "race track memory.

Surface to volume ratio

- Surface area to volume ratio in nanoparticles have a significant effect on the nanoparticles properties. Firstly, nanoparticles have a relative larger surface area when compared to the same volume of the material. For example, let us consider a sphere of radius r:
- The surface area of the sphere will be $4\pi r^2$
- The volume of the sphere = $4/3(\pi r^3)$
- Therefore the surface area to the volume ratio will be $4\pi r^2/\{4/3(\pi r^3)\} = 3/r$
- It means that the surface area to volume ration increases with the decrease in radius of the sphere and vice versa.

- It can also be conclude here that when given volume is divided into smaller piece, the surface area increases. Therefore as particle size decreases, a greater portion of the atoms are found at the surface compared to those inside. For example, a particle of size 3 nm has 50% of its atoms on its surface, at 10 nm 20% of its atoms and at 30 nm has 5% of its atoms on its surface. Therefore nanoparticles have a much greater surface area per unit volume compared with the larger particles. It leads to nanoparticles more chemically reactive. As growth and catalytic chemical reaction occurs at surfaces, therefore a given mass of nanomaterial will be much more reactive than the same mass of material made up of large particles. It is also found that materials which are inert in their bulk form are reactive when produced in their nanoscale form. It can improve their properties.

Quantum confinement

- The quantum confinement effect is observed when the size of the particle is too small to be comparable to the wavelength of the electron . To understand this effectwe break the words like quantum and confinement, 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 .So as the size of a particle decrease till we reach a 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.

- Quantum confinement describes how the electronic properties - the organization of energy levels into which electrons can climb or fall - and optical properties change when the material sampled is in sufficiently small amounts - typically 10 nanometers or less. Specifically, the phenomenon results from electrons and holes being squeezed into a dimension that approaches a critical quantum measurement, called the exciton Bohr radius. Holes are the positively-charge species left over when an electron vacates its position in a crystal.

  For quantum confinement, size matters, but so does shape