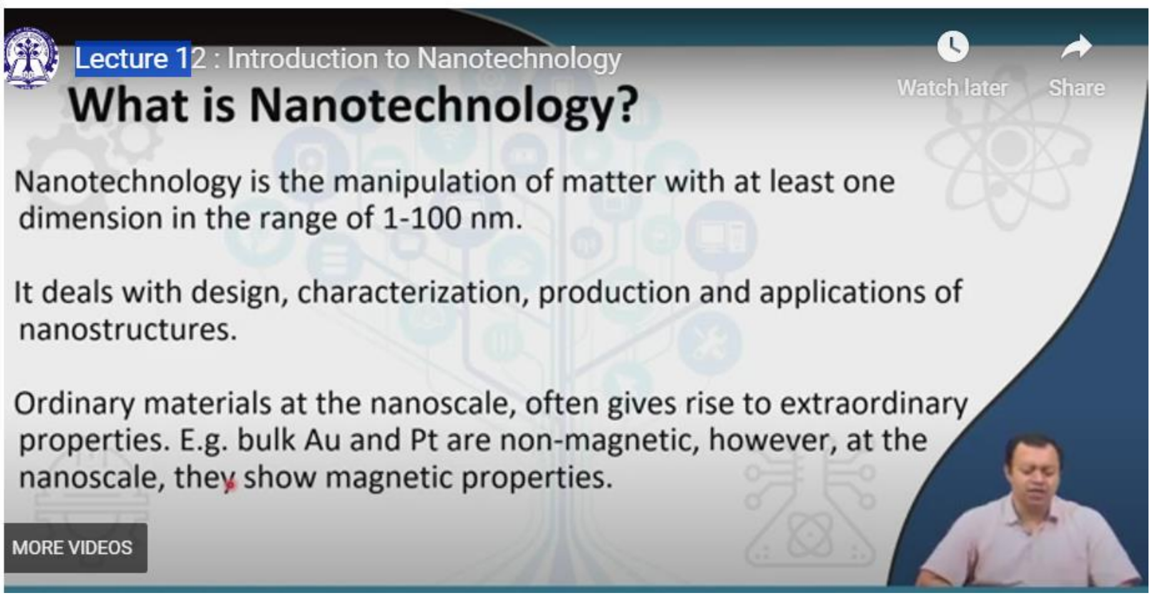
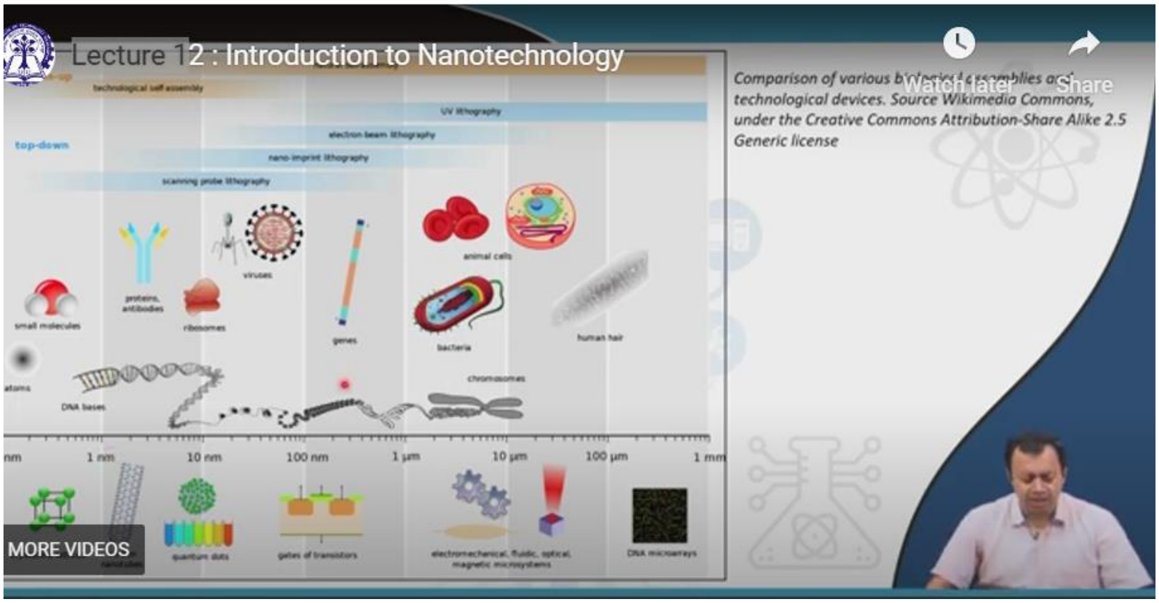
Nanobiophotonics: Touching Our Daily Life
Professor. Basudev Lahiri
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Lecture No. 12
Introduction to Nanotechnology

Welcome back. We are discussing the introduction to nanotechnology, the preliminaries, nanotechnology, nanotechnology in photonics. In our previous class, we have discussed atoms and why atoms need to form molecules. Today, in this particular lecture, we are going to discuss if we can manipulate a bulk matter which is made up of thousands of molecules into their individual components and thereby if we can get to solve some real-life problems. So, welcome to lecture number 12, Introduction to Nanotechnology which is part of the preliminary nanotechnology in photonics. In previous class, we have discussed what atoms are, how atoms behave, electrons etcetera and how atoms are forming molecules.



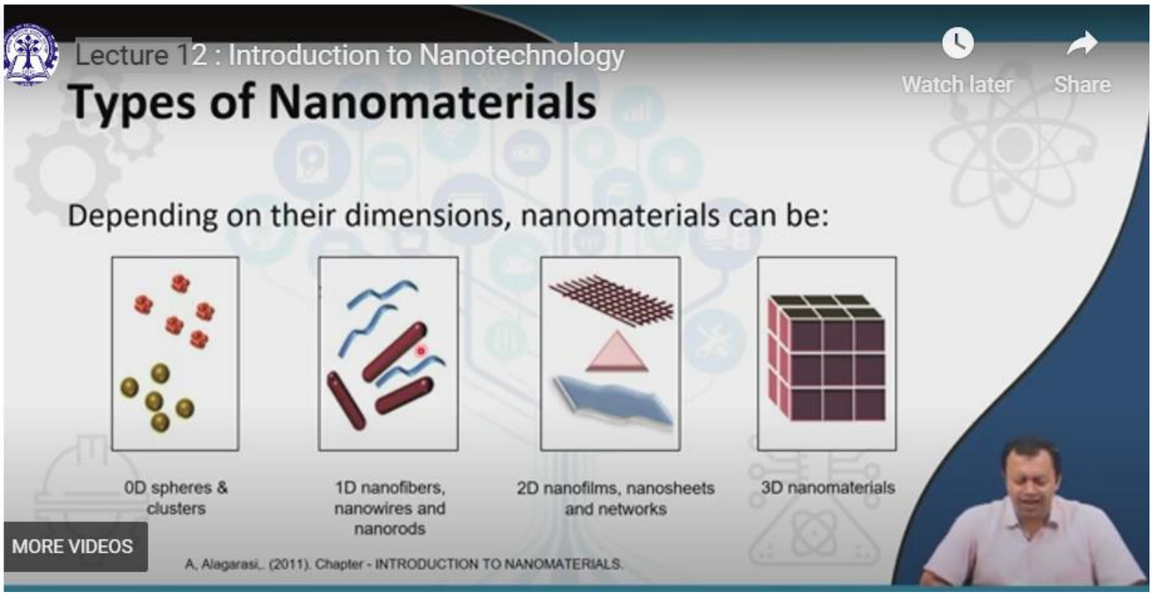
So, let us now try to understand what nanotechnology actually is. So, nanotechnology for all intent and purpose is manipulation of matter where at least one dimension in the range of 1 to 100 nanometer. It deals with design characterization and application of nanostructures and the most important thing is ordinary materials at the nanoscale often give rise extraordinary properties. So, a bulk material, a bulk material behaves certain way at a bulk level at a macroscopic level, but microscopic level its property changes.

Why exactly do you think that happens? Why exactly does a matter behave differently when it is combined together with large number of molecules in a bulk form as compared to when you have strip it down to its individual molecular part or a certain very specific area.



So, understand that when we are talking about why does this nanoscale region came up, see almost all the biological matter biological macromolecules that we need to deal with that are important for example, nucleic acid like DNA bases, proteins, antibodies, viruses, pathogens, your genes etcetera all have dimensions all have either they entirely belong in the nanometer scale region. For example, viruses are 20 to 200 nanometers or certain features of them falls in this particular category. So, from a biology point of view understanding or understanding nanotechnology helps because nanotechnology allows us tool to manipulate matter at nanoscale. What particular matter for biologist? Those matters which forms which are the building block of life proteins, carbohydrates, nucleic acids etcetera form the building blocks of life and their size are in nanoscale level.

So, if you manipulate with a technology matter at nanoscale level you can manipulate DNA bases, you can manipulate genes, you can manipulate viruses, you can manipulate your blood cells and if you can manipulate maybe you can modify them, maybe you can cure them, maybe you can destroy some of them. So, overall nanotechnology allows us to manipulate matter at a nanoscale level.



Now, when we talk about nanomaterials per say depending on their dimension's nanomaterials can be very simply 0D, 1D, 2D and 3D. Now, make no mistake many people think that 0 dimensions means that it does not exist even the nucleus of hydrogen atom has a particular dimension. Even the nucleus of hydrogen atom has a particular dimension.

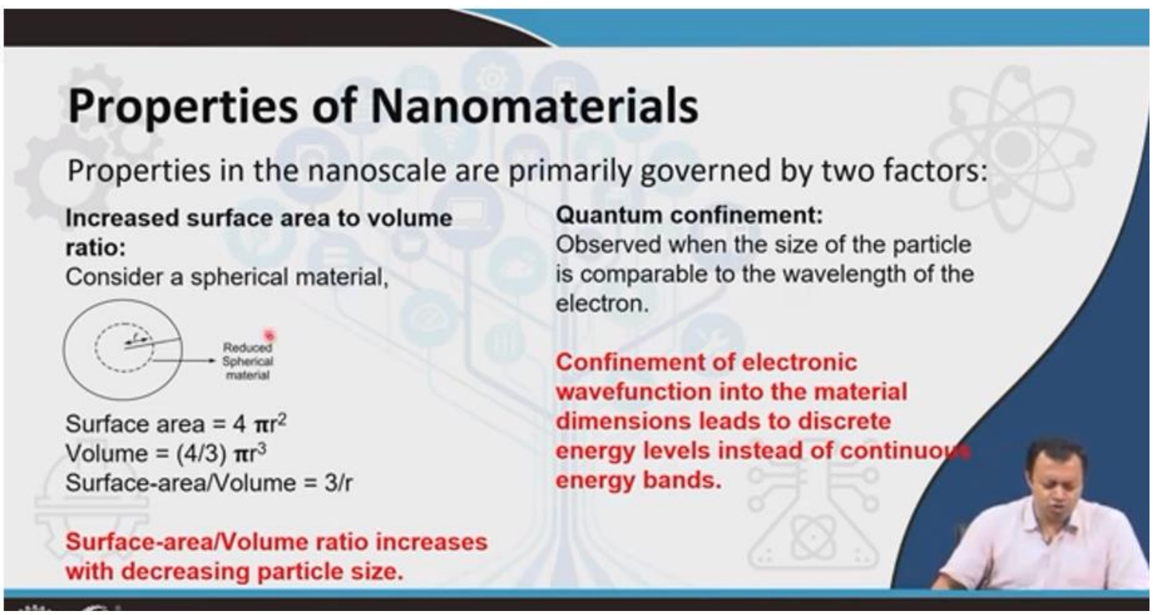
So, nothing is 0 dimension per say if it is 0 dimension it is not a normal matter. However, what actually simplistically colloquially we talk about 0D, 1D, 2D or 3D it means 0D material means that all of its dimension's length breadth and height all 3 dimensions are within nanoscale level. The length, the breadth and the height of a particular material is within the nanoscale level nothing is outside the nanoscale. So, everything is plus minus 100 nanometer length breadth and height certain spheres. So, the radius, the diameter everything is 100 nanometer and below.

1D material means 1 dimension either the length or the breadth is above 100 nanometers. If length is above 100 nanometer breadth and height or thickness is below 100 nanometers. So, it is like a rod the length is very high, but the thickness and the breadth the height and the breadth are below 100 nanometers. So, 1 dimensional freedom it has 1D is outside the nanometers range, 2D are like sheets the length and breadth are outside 100 nanometer boundaries, but the thickness is within. 3D nanomaterial it depends on you very few people actually call 3D nanometer because all 3 dimensions are beyond nanometer range.

Now let me be absolutely clear I keep on saying the term 100 nanometer, 100 nanometer or below 100 nanometer and above this is an arbitrary value right. There are several text books which will come say that you can only call something 0D if the dimensions are below 5 nanometers in all length breadth and height or 10 nanometers different books determine different thing. So, it is like almost describing the infrared region of our electromagnetic spectrum we have a rough idea, but we still want to describe what is exactly near infrared what is exactly fire mid infrared and what is exactly far infrared the boundaries are very very vague. So, similarly when I say 100 nanometer or below that is something from this particular book other books can go 10 nanometer and below. So, overall you get the idea if length breadth and height are more or less within nanometer scale level they are 0D if 2 of that length and breadth are within nanometer scale level then it is 1D so on and so forth.

It has to be some kind of nano 1000 nanometer is micron so that is micro. So, 800 nanometer 500 nanometer are 0.5-micron 0.6 micron.

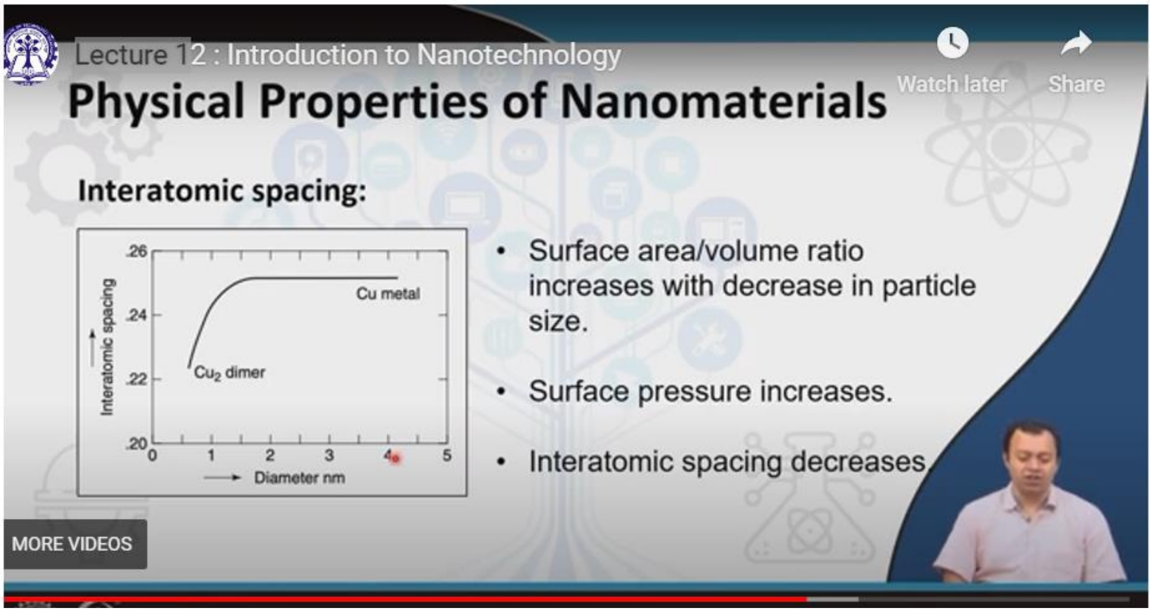
So, 0.1 micron and below is something that is certain books gives as standardized, but if you want to go below be my guest make 10 nanometer as your restrictive idea. So, these are the types of nanomaterials that we mostly deal with 3D nanomaterials are mostly powders individual particles, but they combine and form blocks right.



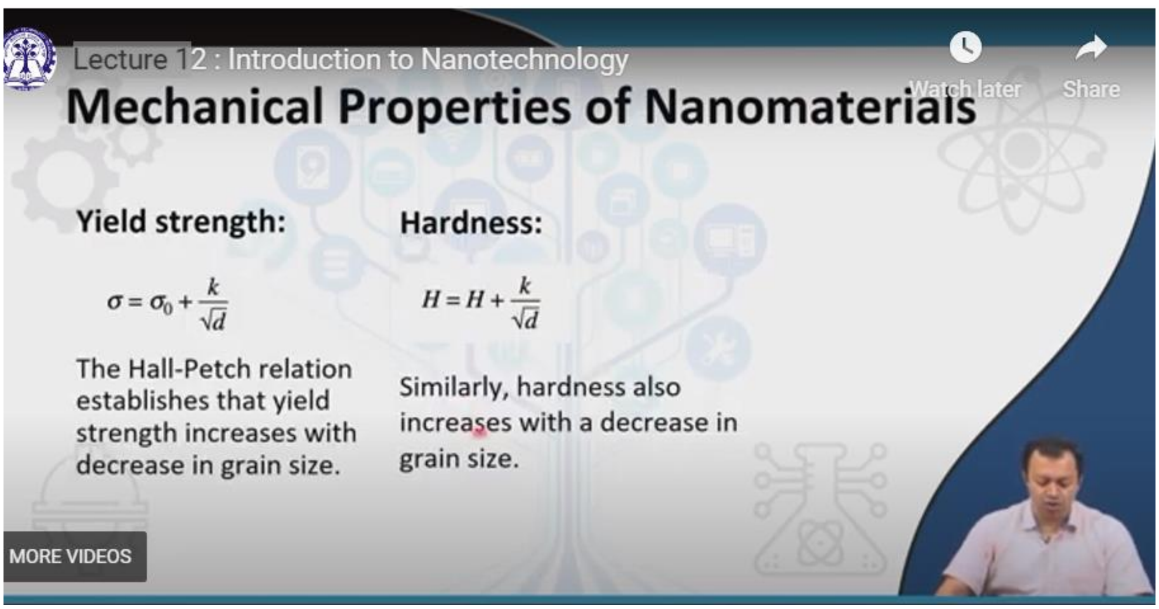
So, why do that was the previous question why do the property of a material change from a bulk value to its nano scale value well 2 main reasons. First and foremost, that if you have reduced the dimensions of a material if you have stripped it down bared it down to very very small dimensions and you have you are then trying to figure out what is the surface ratio to volume ratio. So, consider a sphere the surface area of a sphere is 4 pi r square where the volume is four third pi r cube we have taken some approximation then the surface area versus volume is given by this particular formula 3 by r very easy.

Now if you keep on reducing this r the dimension the surface area to volume ratio increases volume is reducing the size is reducing, but overall the surface area as compared to the volume this ratio is increasing very much. So, if you have a higher surface area you can functionalize it you can rearrange almost the atoms in a different particular manner that is what we see in 2-dimensional material and thereby property changes. At the same time remember that E I told you inversely proportional to length energy is inversely proportional to length when it comes to electron being restricted under around a nucleus particle in a box remember from last chapter. If you have now started imagine that same box now you have started reducing the size of the length of the box right electron was inside the box it was distributing itself into specific steps of the ladder according to the length according to the length of the box yes previous lecture. Now you are increasing or decreasing the length of the box your energy is changing your steps will have larger gaps or smaller gaps depending on whether the length is higher or lower energy is inversely proportional to length.

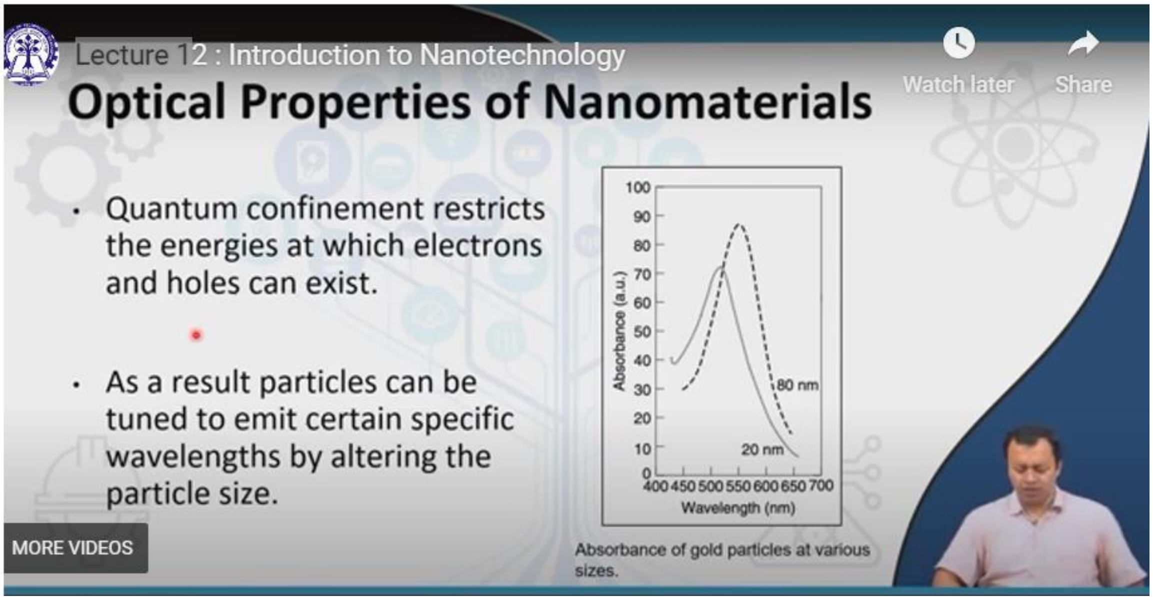
If you can control the length you control overall energy, if you control overall energy if you control overall energy you control the overall distribution of the electrons you control the distribution of the electrons you control so many things you control the bonding between electrons you control how the electron clouds are overlapping how much you energy that needs to be given to break the bond how much energy you can extract from it all of those things you can simply do when you are able to manipulate the length of the particle in a box go back to previous lecture and look at that. So quantum confinement one such effect when size of the particle is comparable to the wavelength of electron confinement of electronic wave functions leads to discrete energy level that is what I was saying that the band formations are taking place those ladder steps that we have is for one particular electron you put several of these boxes i.e. you bring in several of those atoms together and all of these electrons are combining together so they form bands you know this you have read it in high school I am merely repeating myself. So nanotechnology allows you to manipulate electrons or sorry beg your pardon manipulate matter at a nanoscale level by two main way one is quantum confinement you reduce or increase the L of the box thereby increase or decrease the energy and by changing the surface area to volume ratio if you have surface area very large as compared to the volume with that surface area you can do so many things you can adsorb you can add you can subtract you can rearrange the arrangement of atoms so on and so forth that is rearrangement is actually control or manipulation that is exactly is going on.



So there are several properties of nanomaterial that changes as we go on reducing the inter atomic spacing between them. So this is a particular example of diameter of copper with respect to diameter as I said the surface area to volume ratio increases and several properties such as melting point reduces or tremendously surface free energy alters the chemical potential as the melting point reduces with decreasing particle size



the mechanical property the yield strength and the hardness also increases with decrease in grain size the hall page relations all the property of the material starts changing because you are manipulating the energy levels in which the electrons are occupying a bulk compared to a grain of size few 100 nanometers.

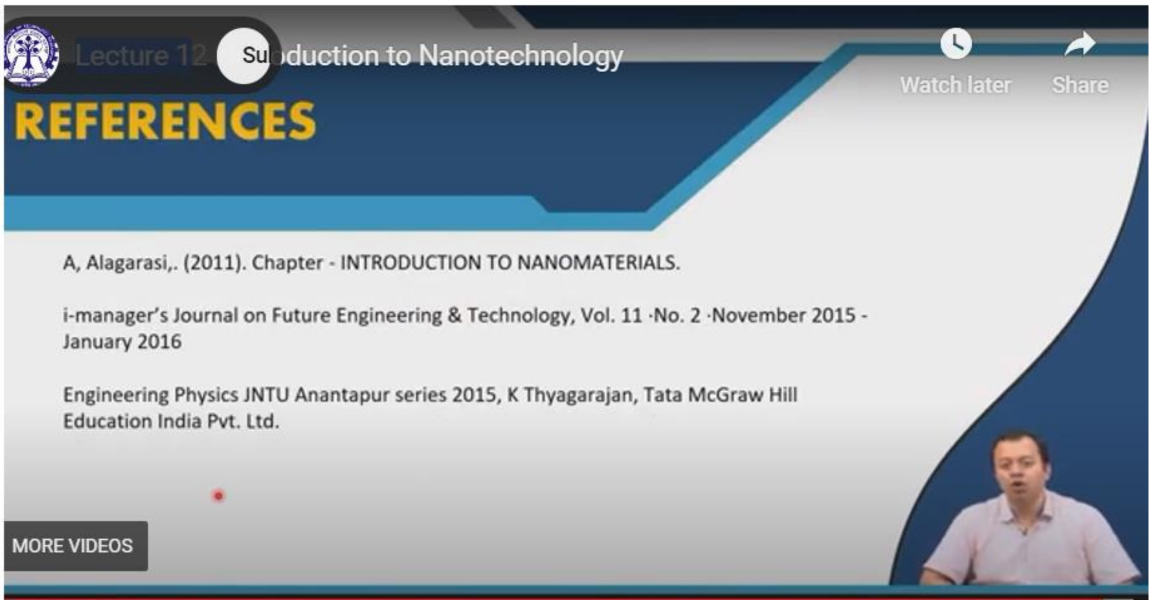


What we are mostly interested in are the optical properties of nanomaterials right. Nanomaterial is a huge field material scientist discuss with mechanical properties how they are changing because they want to create tough material which are light, but very tough so that they can make airplane coatings etcetera. Magnetic properties can also be changed melting properties can also be changed, but here we are mostly interested in understanding the optical properties of nanomaterials.

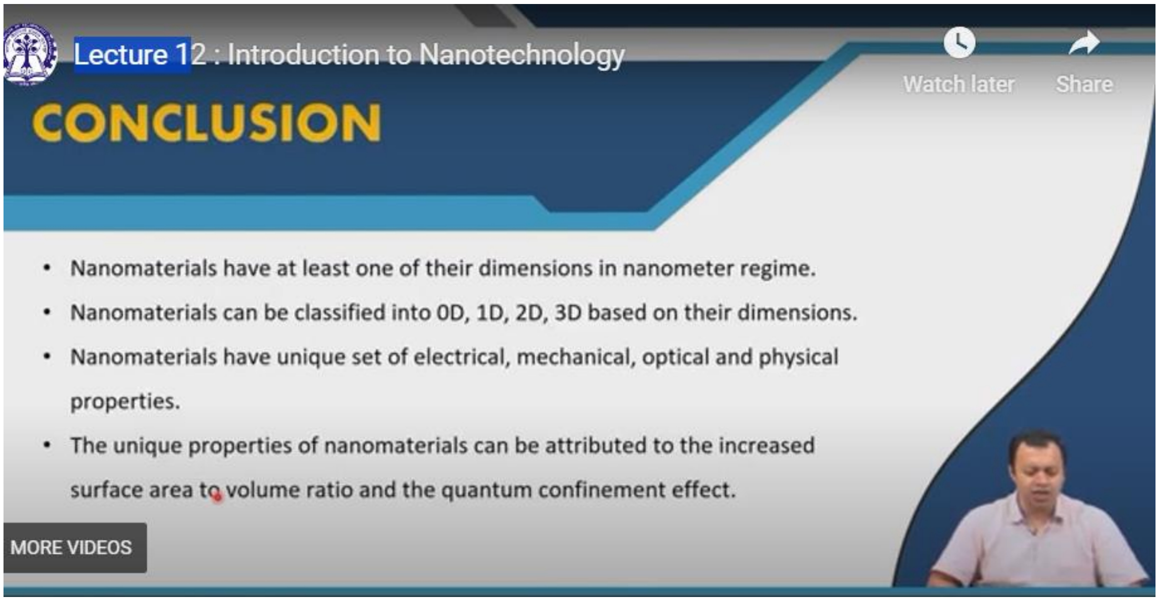
Now imagine the step ladder there are discrete energy states right there is a gap between the level 1 and level 2. If you want you can consider it as HOMO and LUMO lowest unoccupied molecular state highest occupied molecular orbital right there is a particular gap and this gap is because of that condition E is inversely proportional to L. Now this HOMO and LUMO has formed because conjugated molecules have come together and this formed is complex structure in which HOMO and LUMO has formed. Now you are looking at it at a nanoscale point of view where you have created a conjugated molecule at a nanoscale dimension. You have created a conjugated molecule at a nanoscale dimensions where this L has reduced.

So the HOMO and LUMO has also the gap has increased energy is very high right the length has decreased so energy has increased. So previously this gap you need to submit some amount of energy for this electron to go above and come back. Now you have to go higher amount of energy for the electron at HOMO to go into LUMO. If you can customize that whatever energy you are sending for the electron to go up in order for electron to come down it will go for a spontaneous emission and if it is a fluorescence material remember your previous lectures it will emit a particular wavelength. Now if you can manipulate the L the length the confinement length quantum confinement they call it you can increase or decrease the band gap the band gap between HOMO and LUMO.

If you can increase or decrease the band gap you can change the wavelength of the emitted photon. So same material exact same material all you have done is reduced its size you have taken the size to nanoscale level thereby changing the gap between valence band and conduction band changing the gap between HOMO and LUMO. The result is emission of different wavelengths we do it exactly in quantum dots that we are going to see in not next but next to next lectures. Particles can be tuned to emit certain specific wavelengths by altering the particle size.



That is my overall explanation in which I give you a brief introduction to nanotechnology. In the next lecture we will discuss how to make materials at such a small material how do you reduce the size of such materials.



So, these are my conclusions and thank you very much.