Nanobiophotonics: Touching Our Daily Life
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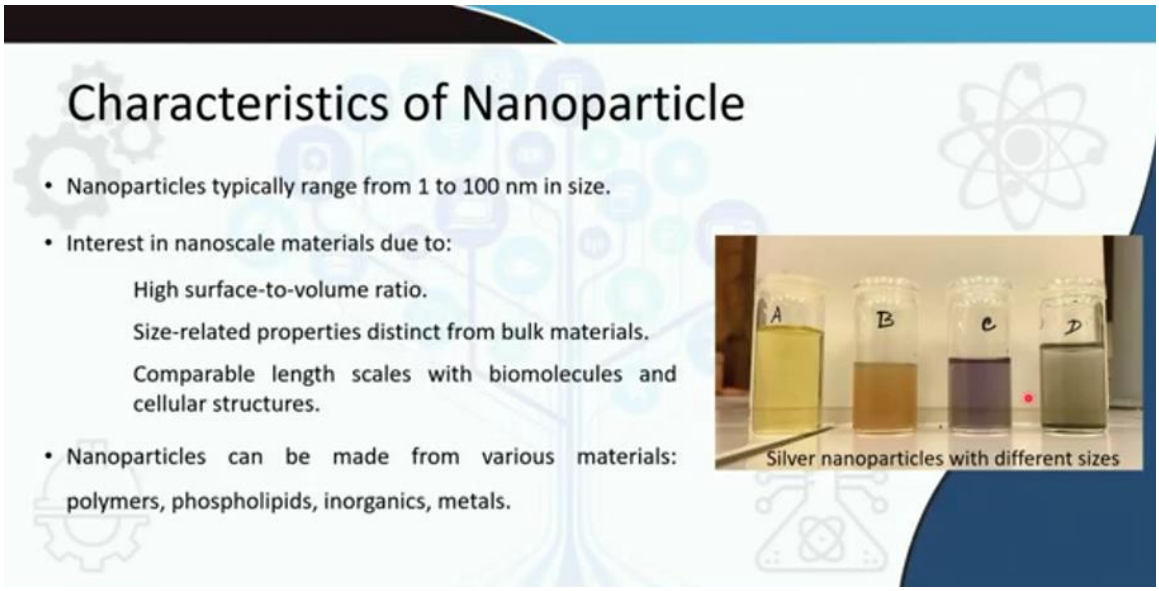
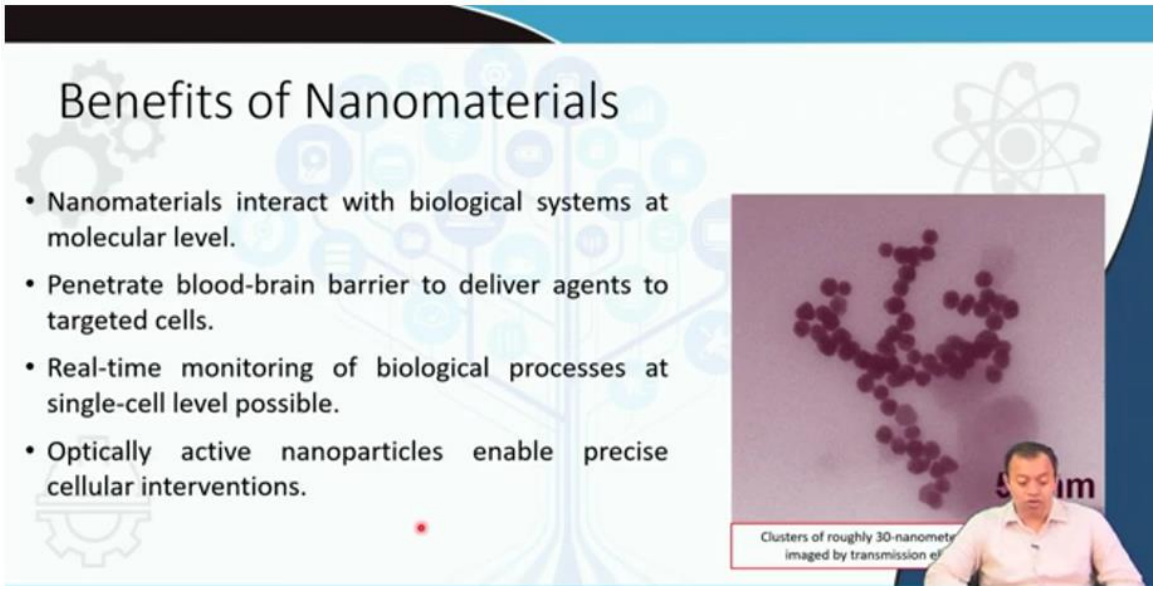
Lecture No. 52
Nanoparticles for Optical Modulation of Neuronal Behavior

Welcome back. So, we are continuing our discussion on the Applications and Emerging Research Areas in Neurophotonics and today I have got a very very interesting topic that is Nanoparticles for Optical Modulation of Neuronal Behaviour. So, this is the essence of Nanoneurophotonics or Nanopto genetics that true heart of nanobiophotonics. Just to recapitulate what exactly is a nanoparticle. So, nanoparticles typically range from 1 to 100 nanometer in size. We have discussed this in a completely in a total module, but I thought that couple of slides will help to recapitulate.



We are interested in nanoscale because high surface to volume ratio, the optical property of nanomaterial depends on their size. So, if they are of the same material silver nanoparticle, but of different sizes they can emit or reflect depending on the type of nanomaterial different types of light. So, silver by definition bulk is whitish in colour, but as you go on changing their sizes in a nanoscale level 1 to 100 nanometer, they keep on showing their individual distinct colour properties. Nanoparticles can be made from various materials polymers phospholipids in organics and of course, metals.

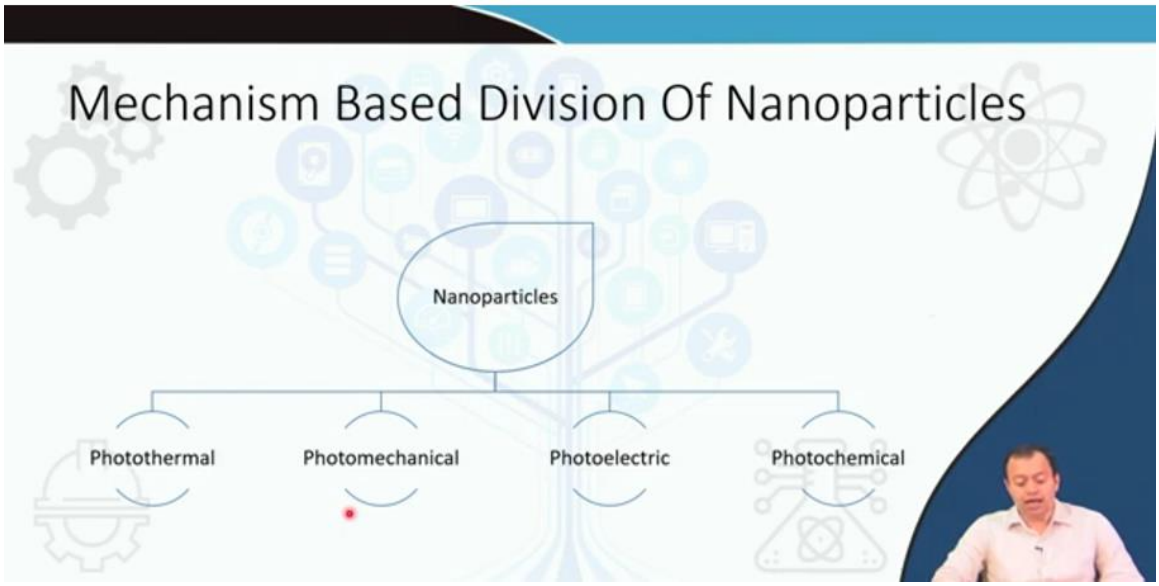


What are the benefits of nanomaterials? Well obviously, they are nano. So, nanomaterials interact with biological system at the molecular level. They penetrate the blood brain barrier to deliver agents to targeted cells. Remember we discussed about blood brain barrier. Blood do not go directly inside brain.

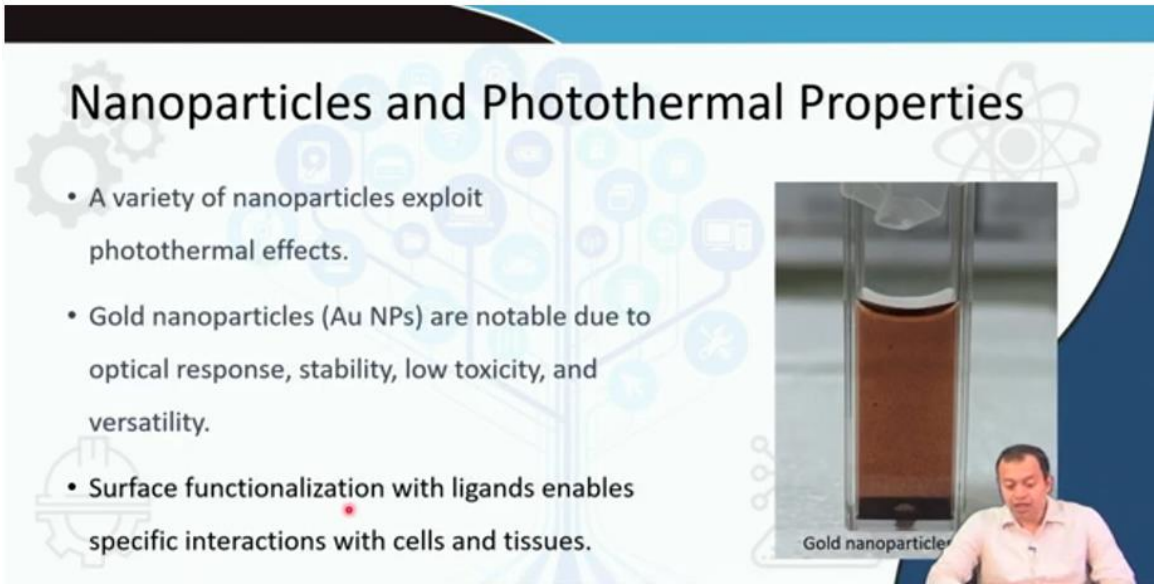
There are no capillaries, no veins, no arteries inside the brain. There is semi permeable membrane between brain and blood. So, it is specifically there. So, that any infection in blood do not get directly to the brain. Brain is thus far since the most important organ is protected fully.

So, ah that blood brain barrier can be penetrated by your nanoparticles right. This is a 30-nanometer gold nanoparticle transmission electron image. See how how how how small these are. We are presently working with them ah gold and silver nanoparticle, but our work is for ah detection of ah viruses and proteins, but they are fascinating. These days this is the current flavour.

I I am myself fascinated by ah nanoparticles. So, real time monitoring of biological processes at single cell level possible optically active nanoparticles enable precise cellular interventions. They are very small. So, they can affect very small area and very small area even though affected can trigger some very big you know biochemical modification. So, so you can understand what is going on.



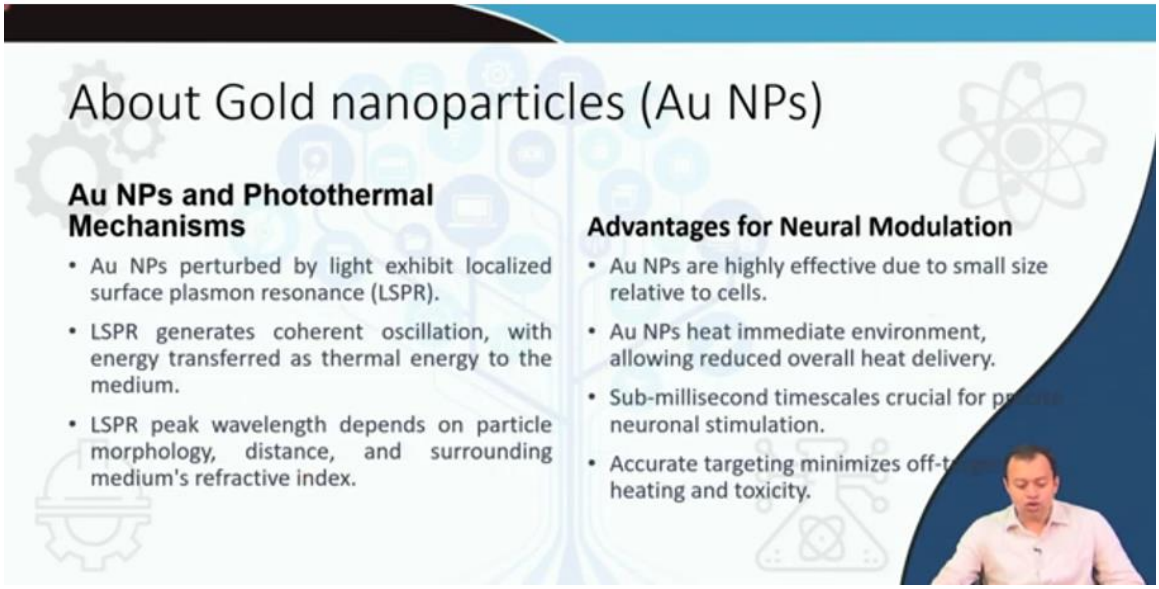
So, what are the ah optical ah effects of nanoparticles? So, mechanism-based division of nanoparticles, its photo thermal light falling on nanoparticle generating heat, photo mechanical light falling on nanoparticle generating some kind of a mechanical change pressure etcetera. Photoelectric light falling on two nanoparticles generating electric current and photochemical light falling on nanoparticle is triggering a biochemical reaction. So, be absolutely aware of these four categories and what they actually mean. So, nanoparticles and photothermal properties, a variety of nanoparticle exploit photothermal effects. Gold nanoparticles are notable due to optical response, stability, low toxicity and versatility.



They are low toxic. Usually gold do not react with anything else. So, it will if you have inserted gold nanoparticles inside ah this is gold yeah it is not yellowish, this is nanoparticle. So, it can be reddish. So, if you have inserted inside a cell, it will probably not react with its environment chemically right and when you have ah shine light on it, the

electrons inside can agitate and create some sort of temperature difference around it few Kelvin temperature difference, but good enough to you know modify the few nanometer cube volume around which around around the periphery of this individual nanoparticle.

Surface functionalization with ligands, ligands are you know cofactors are type of ligands. There is some sort of a similarity, but ligands are basically something that binds ah with you know it can be anything it can be proteins as well. So, ligands are those those materials that binds enable specific interactions with cells and tissues. So, gold nanoparticles and photothermal ah mechanisms, ah gold nanoparticles ah can create surface ah localized surface plasma resonance. I told you that ah metals have this electron

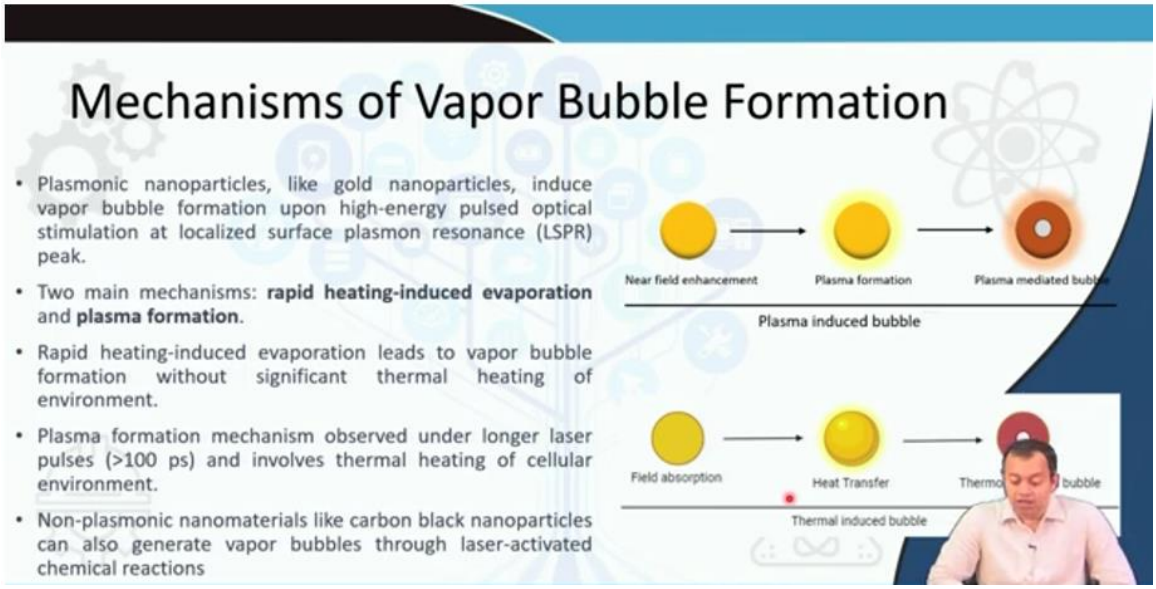


cloud and these electron clouds are moving at a very high frequency plasma frequency and whenever there is a external electric field, the ah local localized surface plasmons go there and try to screen it and ah in in essence generate vibration in molecules LSPR generates coherent oscillation where energy transferred as thermal energy to the medium.

The peak of the wavelength, the peak of this localized surface plasma resonance, this electrons which are at the surface activated because of the ah free electrons of the cloud of metals which go to screen external electric electromagnetic field at the surface ah LSPR localized surface plasma resonance. The peak wavelength depends on particle morphology, distance and surrounding mediums refractive index. So, you can control them. Ah They are highly effective due to small size. So, basically you are generating light to create specific amount of heat in the nanoparticle and that is affecting its surrounding areas.

AUNP heat immediate environment allowing reduced overall heat delivery sub

millisecond time scale crucial for neuronal simulation ah accurate targeting minimize off target heating and toxicity. Ah Another thing that is quite interesting and has recently caught ah scientists' eye is formation of vapor bubble. So, this is fascinating. Think about it. I will try to explain it.



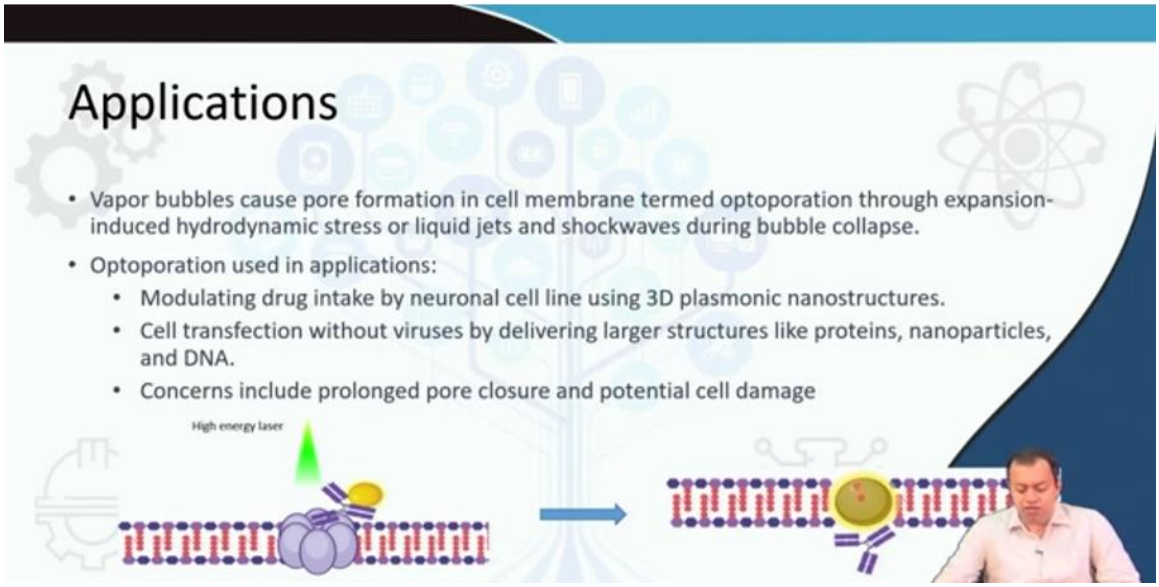
Both are more or less same plasma induced bubble or thermal induced bubble, but this is something that we discussed in that photo acoustic ah microscopy. So, you have a nanoparticle. You are sending light into it. The electrons insides are agitating and what not and they have created some sort of an ah heat inside it. That heat is you know heating thermally heating the surrounding area of the ah nanoparticle.

Usually as I said the surrounding area is water yeah surrounding area is water or waterish. So, they can simply heat up and become some kind of a steam, but this steam bubble this steam bubble is surrounding the nanoparticle. The nanoparticle has heated up the nanoparticle in terms the heat has transferred to its surrounding area. The surrounding area is water. The water has heated up and become steam water vapor.

It has become steam, but the steam by itself is semi insulating meaning the steam is bound the steam is bound to the nanoparticle. The steam is bound to the nanoparticle and if the nanoparticle is traveling the steam is traveling with this as long as the nanoparticle is heated right. It usually is not like this as soon as the light heat comes up and it goes down it takes some time to dissipate. And this nanobubble because of its semi insulating nature does not allow any other area to heat up, does not allow the heat to transfer, does not allow any other heat to go in it is steam semi insulating water vapor is semi insulating in nature. And it simply you know moves around or it is a localized heating environment that goes inside the cell.

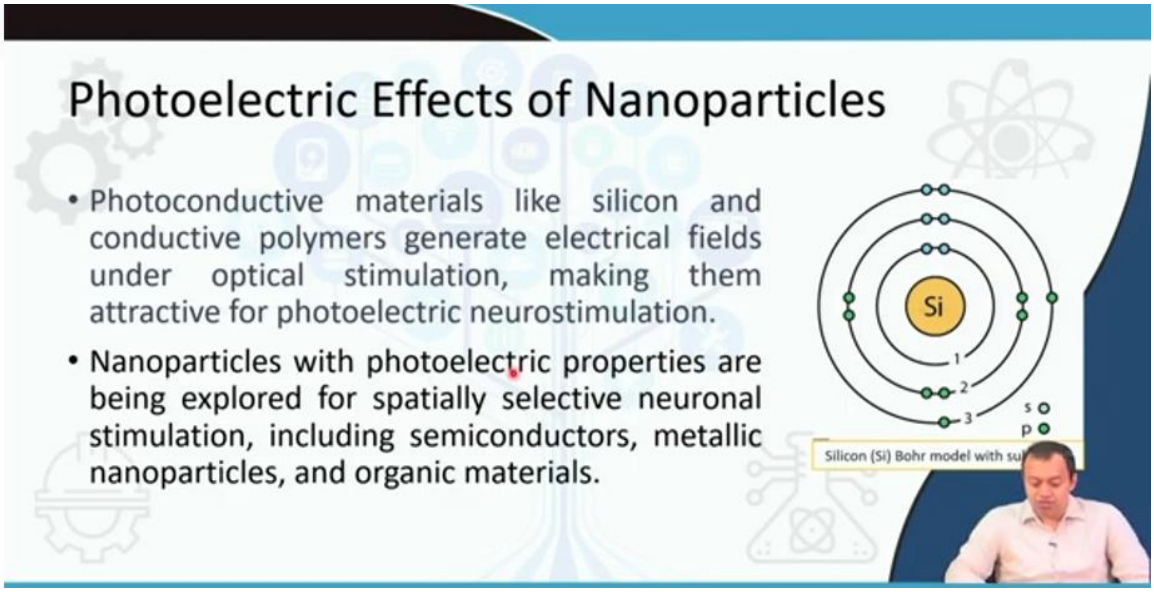
So, if you are targeting a particular organelle to be destroyed a particular protein to be destroyed this is one of the best options this is one of the best options and this is fascinating. Rapid heating induced evaporation and plasma formation rapid heating induced evaporation led to vapor bubble formation without significant thermal heating of the environment. Plasma formation mechanism observed under longer laser pulses and involves thermal heating of cellular environment. Nonplasmonic nanomaterials like carbon black can also generate vapor bubble through laser activated chemical reaction. So, there is a vapor surrounding the nanoparticle and it can move as I said previous in the photo acousto optic lecture that it could be considered as a mechanical wave mechanical waves rarefication and contraction could be considered as sound.

But nevertheless here very small nanoparticles can be created to generate this vapor bubble and then this vapor bubble can be utilized to target very very small very very specific areas inside the cell inside the neurons inside the dendrites inside the axons to affect specific areas right applications see this is exactly what I was telling you. Vapor bubble causes pore formation in cell membrane termed auto optoporation Christ through expansion induced hydrodynamic stress or liquid jets. So, basically you are breaking this

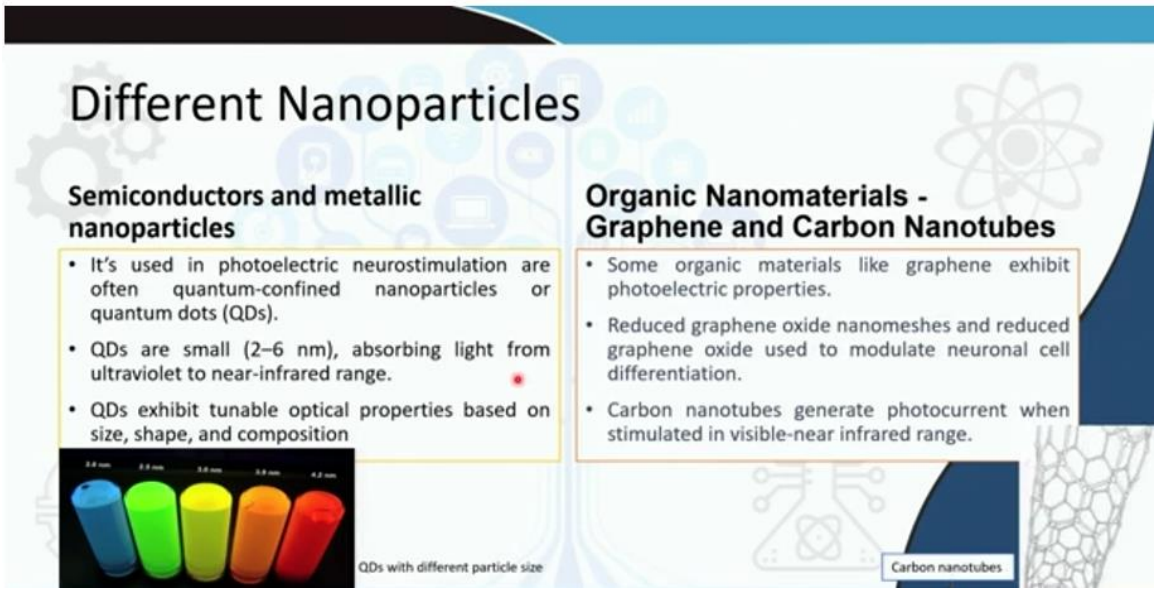


down you are melting just this part without affecting any other area right you have melted this area. Optoporation modulating drug intake by neuronal cells line with 3D plasmonic nanostructure cell transfections without viruses concerned including prolonged pore closure and potential cell damage here this is something that that that takes place. Photoelectric effect of nanoparticles.

So, this was photo mechanical effect this is ah the heat causes the mechanical steam wave to pass through. Photoelectric effect ah photo conductive materials like silicon and



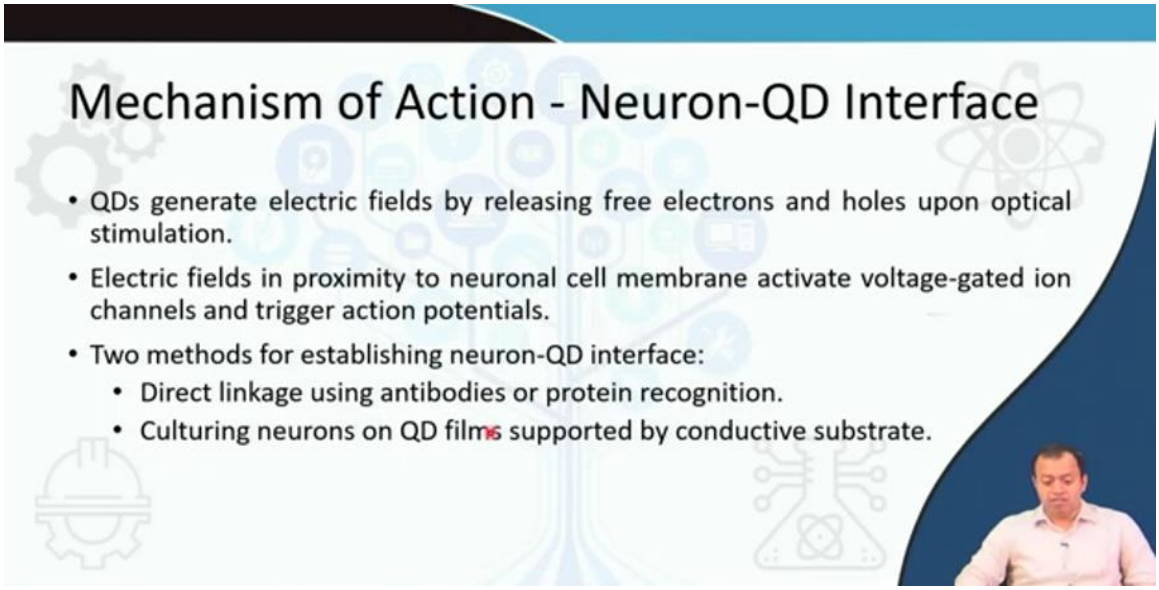
conductive polymers generate electric field under optical simulation you know this nanoparticle with photoelectric properties are being explored for especially selective neural stimulation. So, ah action potential is generated by the presence of a nanoparticle because when light is falling into the nanoparticle the nanoparticle is generating electric current that electric current can be considered as an electric action potential triggering



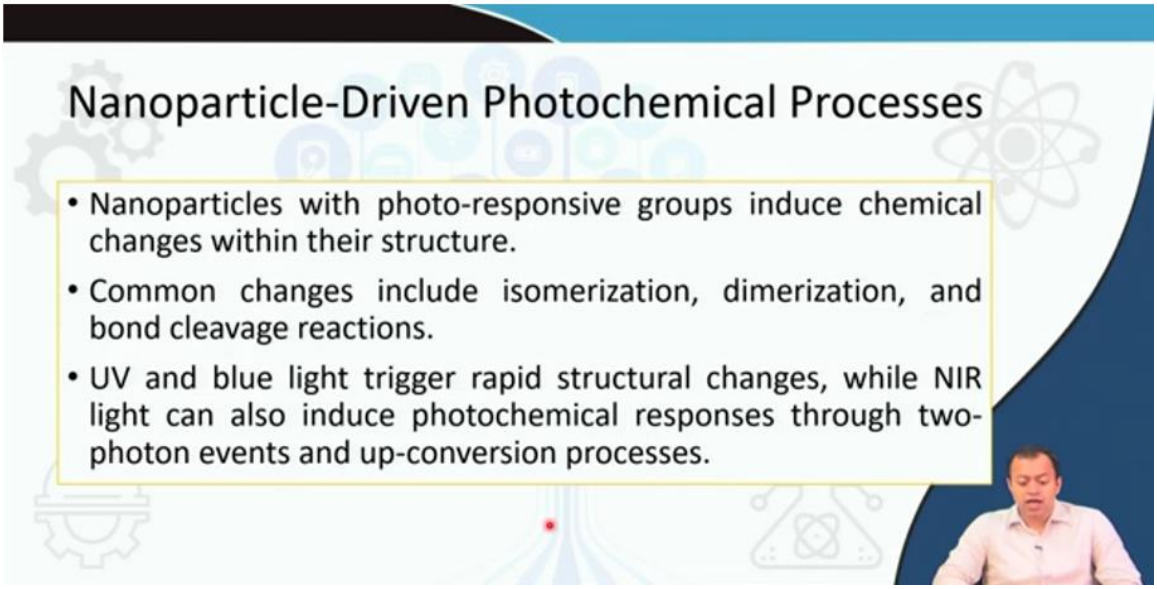
action potential resulting in the neuron getting fired. There are you know plethora of nanoparticles you have quantum dots ah tunable optical properties you do not necessarily have to use metals ah you can have organic materials like graphene these days graphene quantum dots are quite quite popular because it is made up of carbon and carbon is supposedly more biocompatible, but everything depends on those how much of graphene you are putting. Reduced graphene oxide nanomeshes ah are used to modulate neuronal

cell carbon nanotube generates photo current when stimulated by visible near infrared range.

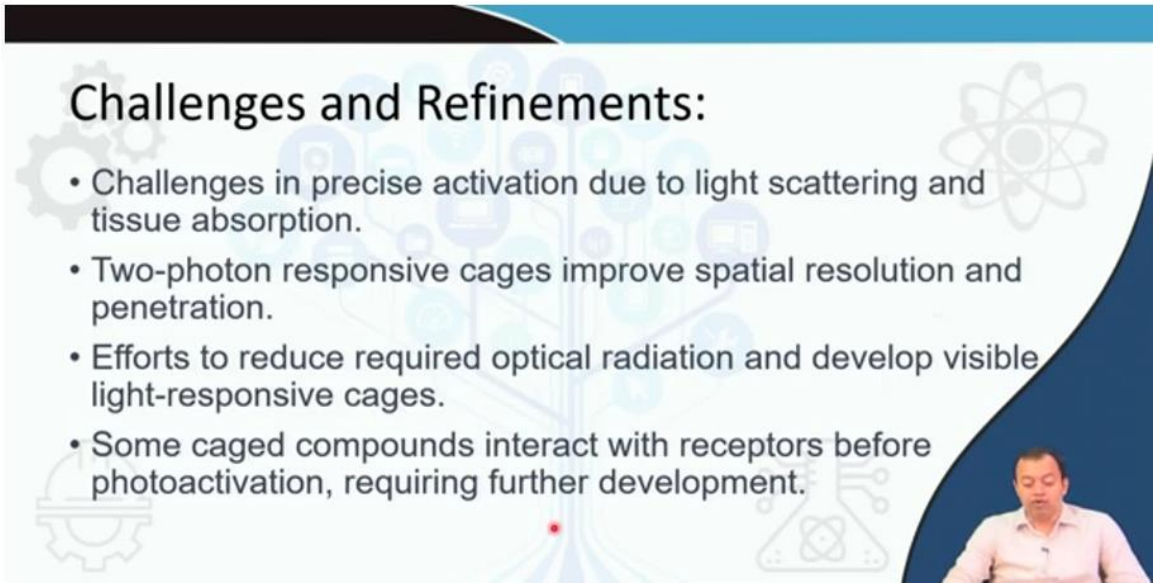
So, all of those semiconductor and metallic nanoparticles all of those can be inserted inside. So, their advantage is a they are small b they are because of their small have less cytotoxicity cellular toxicity b they can produce a plethora nanomechanic a photo thermal photo ah mechanical photo electric etcetera all those mechanism mechanisms of action neuron and quantum dot interface quantum dots generate electric fields. So, they generate electric field not necessarily electric current electric fields allows the attraction



or repulsion of specific ions positive ions or negative ions in specific direction resulting in ah you know free electrons and holes upon optical simulations ah resulting in either resting potential or action potential getting triggered. So, ah neuron quantum dot interface is something that is coming up very very strongly quantum dot we have discussed very small ah particles 0 d 0 dimensions and they can they can be used to target very very specific locations right. And what are the nanoparticle driven photochemical processes nanoparticle with photo responsive group induced chemical changes within their structure common changes include isomerization ah dimerization

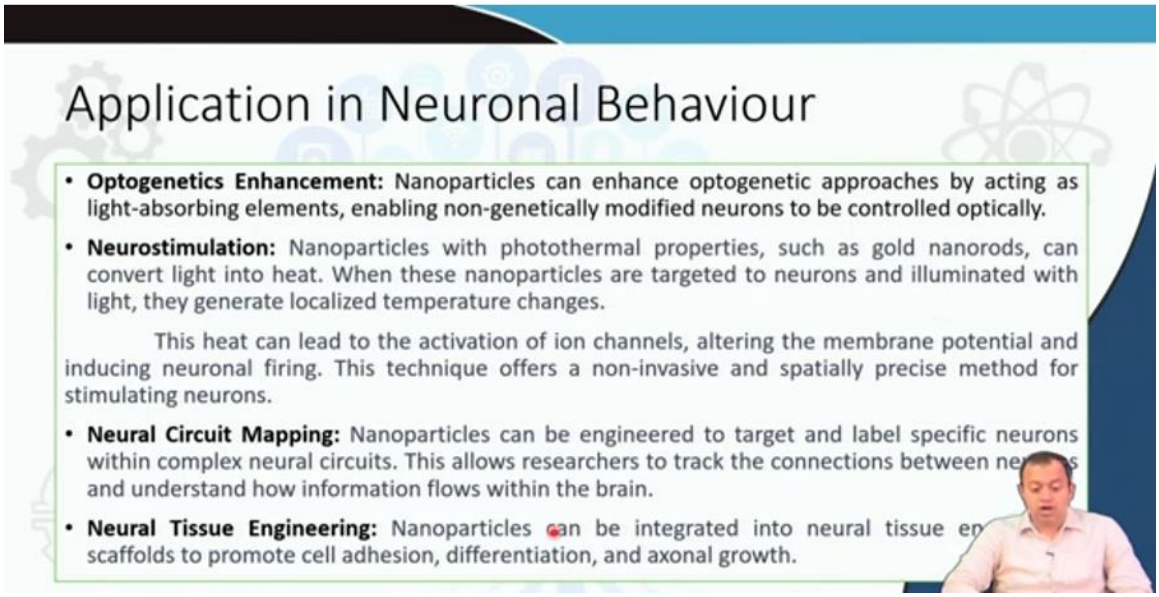


combined together isomerization the cis and trans all those things are changing and bond cleavage reaction UV and blue light trigger rapid structural changes whereas, near infrared response can also induced photochemical responses through two photon events and up conversation non-linear processes can take place.



So obviously, huge huge challenges remain this is ah much easier you know said than done ah how do you precisely activate one nanoparticle here not other nanoparticle in the periphery how do you target specific specific nanoparticle at specific specific cellular or neuronal areas non-linearity effect ah whenever you have excited ah gold nanoparticle say for example, with the light which one of these four photothermal, photo conductive, photomechanical or photochemical do you think is going to happen it may so happen that more than one effect plays together simultaneously what then it is very very uncommon that only one thing will happen right several of these can combine together you both

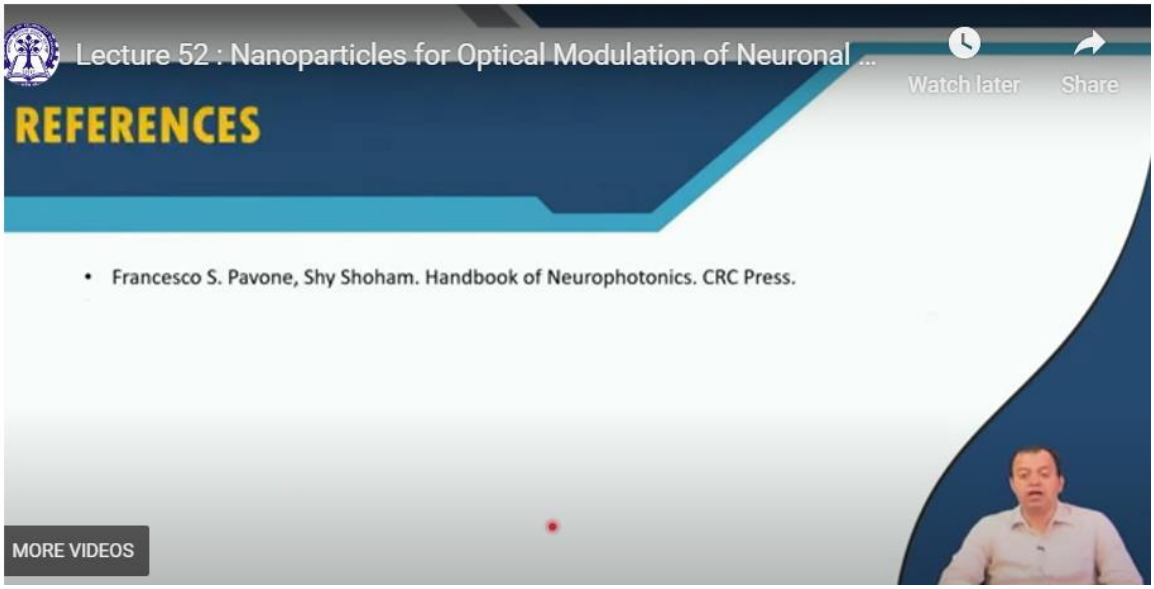
generated heat as well as generated mechanical wave as well as it targeted some kind of a electric current as the same time it has created some kind of a biochemical reaction it has triggered a biochemical reaction. So, we have to create some of these nanoparticles which are very specific for specific purposes some caged compounds interact with receptors before photo activation requiring further development. So, 2D materials are coming up very strongly ah, but this is a completely unexplored area. So, those of you who are from chemistry or biochemistry chemical engineering field I would recommend you to take on these nanoparticles that modify neurons nanoparticles that modify neurons. 1001 application against optogenetic enhancement, neurostimulation, neural circuit mapping and neural tissue engineering several of these are there read it at your own leisure time and these are the conclusion.



The integration of nanotechnology and neuroscience presents a fascinating frontier that has the potential to reshape our understanding and the more people such as you come and work at the interface of new nanotechnology and neuroscience nano neuroscience think how fascinating it would be where not only you will be understanding the brain

from a comprehensive standpoint, but you also will be able to manipulate it using

nanotechnological materials, tools, instruments etcetera right. So, these are the concepts



covered and these are my references. Thank you very much.