Nanobiophotonics: Touching Our Daily Life
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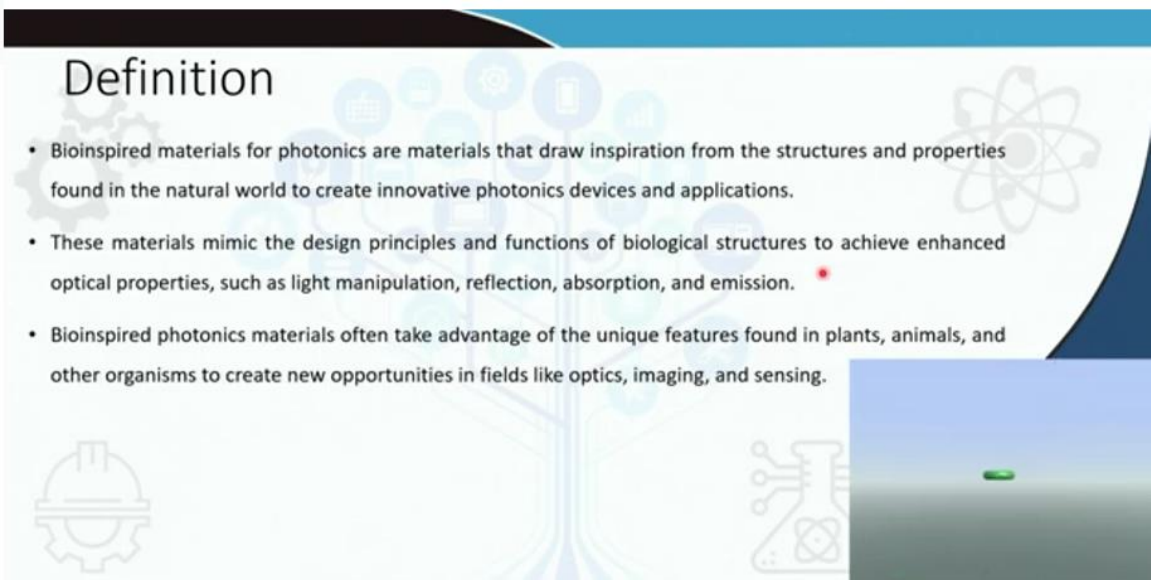
Lecture No. 56
Bioinspired materials for photonics

Hello and welcome. It seems that we are at the final moments of nanobiophotonics course. To the best of my ability and knowledge, I have tried to impart everything that I could about this fascinating topic on nanobiophotonics and whatever I had to teach, I have already finished. This chapter, chapter number 12, the final chapter, the ultimate chapter is where it is more or less an opinion, it is more or less a prediction, it is more or less like looking at the future through some sort of a crystal ball, where we try to forecast what is coming and like any forecast, it will happen that several things may not come true. So, in this particular lecture, the topics, the most important topics of nanobiophotonics is already covered in chapter 1 to 11. In the final chapter, I decided to give you a direction of the future of the overall nanobiophotonics field as a whole.

Chapter number 11 was also looking at the future high potential, but from a very narrow optogenetics or neurophotonics perspective. Module 12 is the overall general of the entire field of nanobiophotonics. So, welcome to the final chapter of nanobiophotonics course, where we discuss research in nanobiophotonics overview and future directions. And today, I thought that I will bring in a slightly different, but very interesting topic and that is bio inspired materials for photonics.



So, the interesting part here is that thus far, we have been utilizing light to reveal biological materials. That is the essence of biophotonics interaction of light with biological matter. It could be nucleic acid, it could be proteins, it could be an organic assemble like a virus, bigger organs, tissues and cells of various different part. Here I would like to change it slightly and here I would like to think or discuss about biologically already existing or inspired by biology, biological materials, organic materials, their interaction with light. Understand the difference.

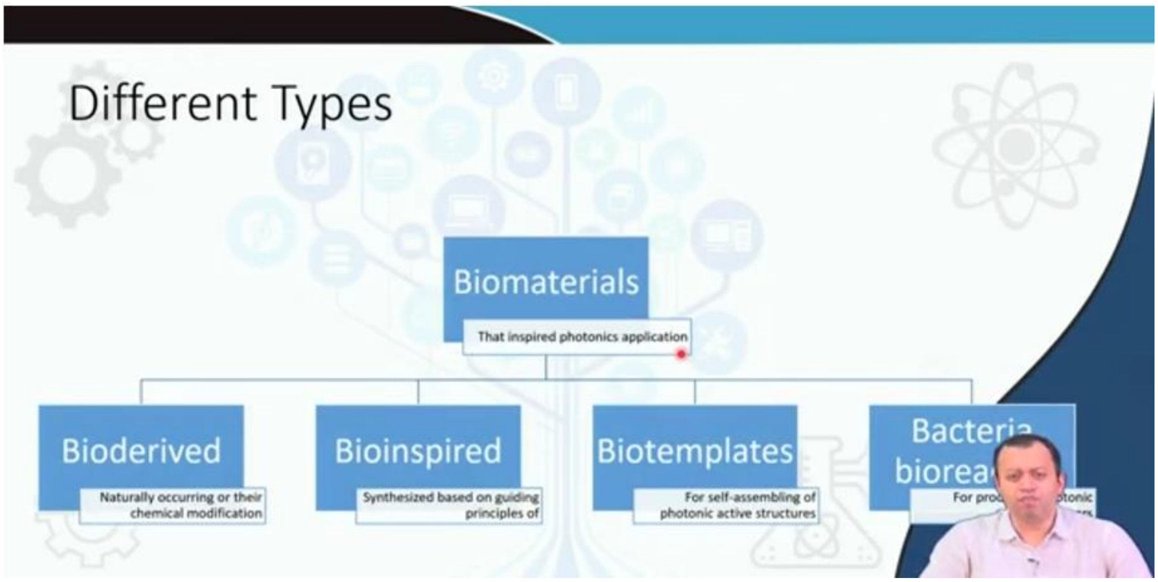
Previously light was there, this is some kind of a biological matter and interaction and we are trying to reveal this particular biological matter. Yes. Now, I have a biological matter, I am now subjecting it to different light and trying to scatter light, trying to localized light, trying to diffract light in a specific manner. Both cases light and matter, light and biological matter are interacting, but here it is slightly reverse. Previously, light was given to image something, brain image, this image, that image.

Now, in this particular case, we are trying to look for specific matters, specific biological matters or biologically inspired matters that interact with light and create some sort of a slightly different phenomena like a different type of interference, different types of refraction pattern. So, basically it agitates the photon in a particular way. So, that is the overall thing and it is slightly different and it is coming up specifically. So, today's topic bio inspired material is are materials that they draw inspirations from structures and properties found in natural world. These materials mimic the design principle of functions of biological structures and they take advantage of the unique feature found in plants and create new opportunities for fields like optics, imaging and sensing.

So, try to understand this. There is a specific morphology of a nucleic acid such as DNA or RNA. They are done in a specific wavy like double helical structure. How many double helixes do you get in a normal life? Similarly, all of you have seen at least the schematic image of a coronavirus, a sphere with spikes, spike proteins around it. So, these are very unique structures, a DNA or a virus or even the proteins with their secondary and tertiary structures molded along with and their size is comparable to the wavelength of light.

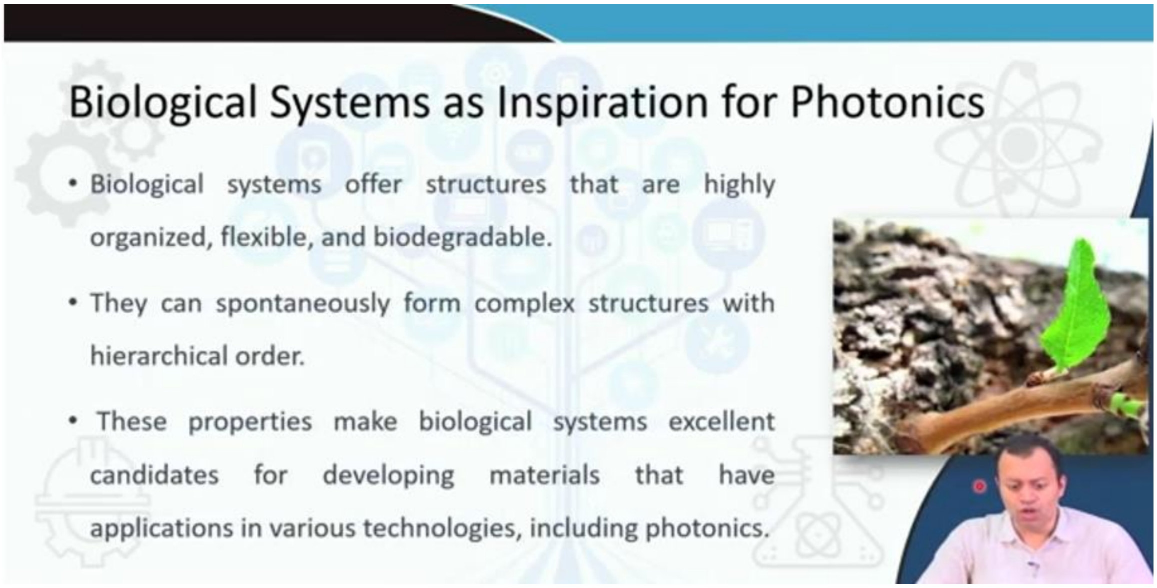
So, yes light can be made to interact with them and understand them and even modify them granted, but is the opposite possible that when they themselves are interacting with light when these type of smaller structures interacting with light, the reflected light the transmitted light has a slightly different relationship phase wise, energy wise, frequency wise with respect to what the input is and thereby this defracted, this reflected, this refracted light could be utilized for fields such as non-linearity or imaging or sensing right. So, here instead of trying to reveal these biological matters, we are utilizing these biological matters to modify the light that is falling onto them. The modified light is then being used for some other purposes which may not be biology at all. For example, laser can we create laser light, can we create laser by using DNA as an active material? We have discussed DNA, we have also discussed laser, laser requires an active material where the electron go from lower level to upper level and then there is spontaneous emission and 2 photons instead of 1 photon get emitted we have discussed that. So, the active material can it be some sort of a protein or some sort of a DNA nucleic acid, can that be utilized? Can we utilize these kinds of biological matters nucleic acids, proteins etcetera as some kind of a fluorescent material specific kind of fluorescent material which will be like a fluorophore which we will then tag it attach it with something else that we want to see.

Think about it? So, that is the overall idea such slightly reversing the concept from light interacting with matter to matter interacting with light. At the end of the day both are the same, but overall this is a new way of looking at similar problems. So, that is basically bio inspired material. So, biomaterials or the biological materials that is specifically pertaining towards photonics application can be roughly divided into 4 different categories.

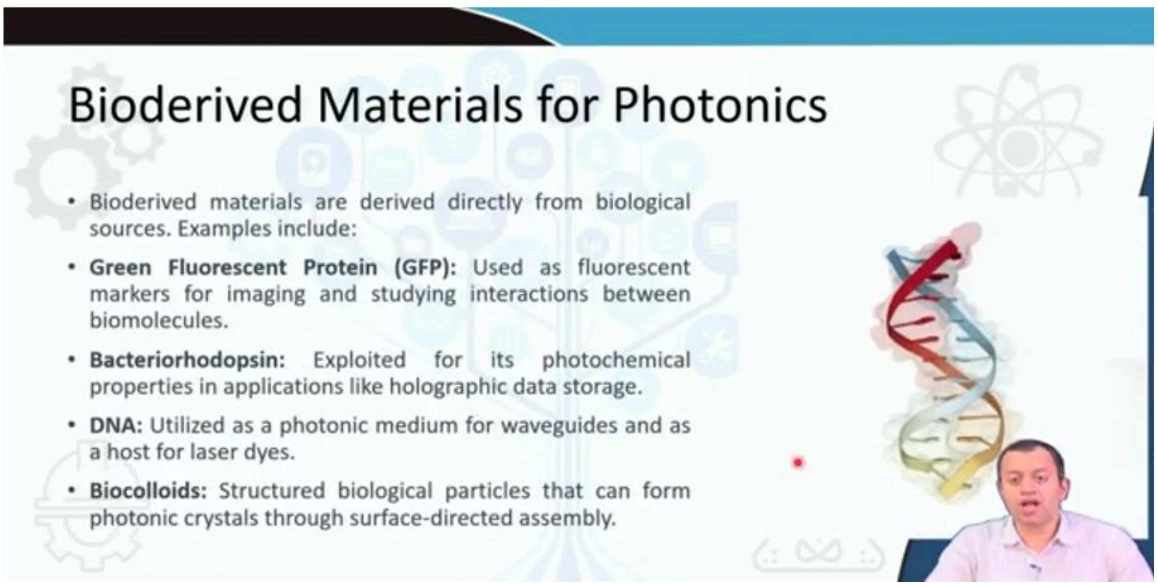


First is bioderived material where they are naturally occurring material nucleic acids, virus's etcetera which you utilize whose unique properties there are 10,000 plethora not 10,000 literally plethora of viruses, plethora of nucleic acids several different structures conformation of proteins. We directly take them interact them with light and utilize them for a specific application. Then there are bio inspired materials bio inspired materials are where we try to look into how biological materials are combining together say for example, the central dogma how is this happening DNA to RNA, RN to protein can we do it for something else. We start with a precursor a chemical reaction a biochemical reaction can we drew can we start with you know compound A that after certain time converts it to compound B and that finally, results in creation of compound C artificially, but inspired inspired by biologically existing materials biochemical reactions. Third is bio templates here there are self assembly photonic structures periodic structures periodic nano structure based on a template based on some kind of a stencil based on some sort of a map based on some sort of an existing design.

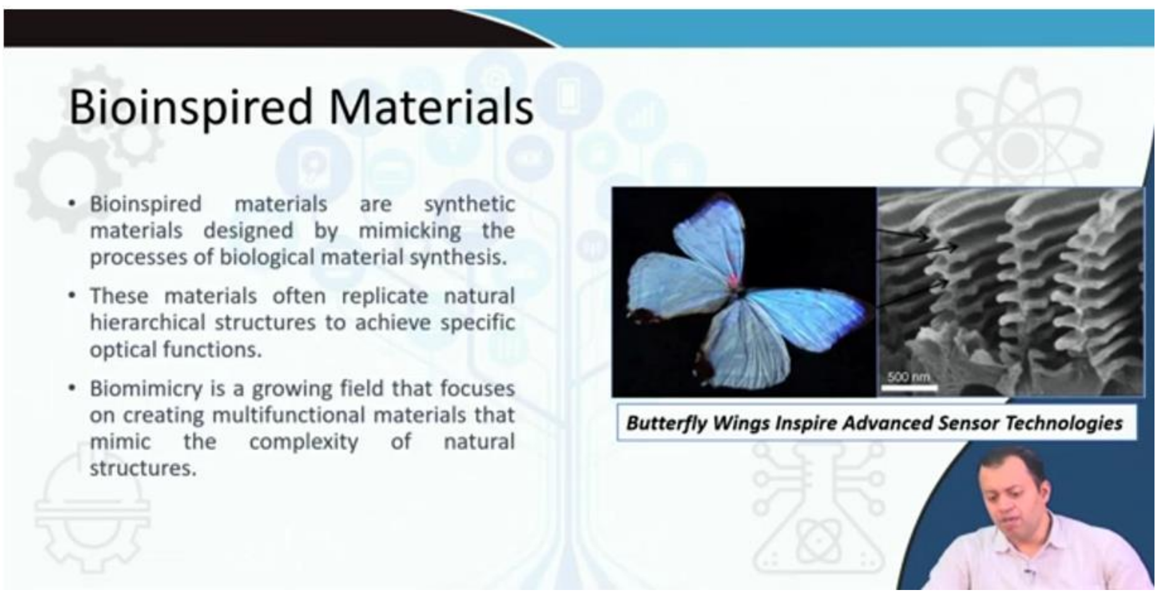
So, you have the virus which spikes around can it be used as a template. So, that the gap the negative structure can be utilized can be utilized at some kind of a periodic photonic crystal periodic photonic material why not they have a periodic structure DNA has a periodic structure it is a wavy like structure a virus has those spikes and it is a periodic structure can we utilize it like you make sculpture like you use stencil you know sculpture you have a mold type of thing on top of which you put clay or cement or something like that and then the mold is taken out and it looks like a looks looks like a statue or your stencil where you write A B C D etcetera there is a already a mold in which the the the blank areas where you put the ink and then a particular stencilized A B C D comes. So, can we utilize the existing biological material as a kind of a mold as a kind of a stencil as a kind of a template on top of which something else will be put and then the virus or the DNA will be taken out and this mold will have a negative structure will have a the opposite structure negative or positive is relative and opposite structure of that and it will it might have slightly different biological properties. Similarly bacteria is a bioreactor we combine couple of bacterias together their interaction produce some kind of a chemical reaction the result is some kind of a biochemical compound because of the mating of bacterias because of the interaction of bacterias and the final product the output of bacterial interaction among each other whatever comes out could be utilized as a thin film the output of bacterial reproduction or output of bacterial interaction with ah with either a similar types similar strain or different strain or different types of of of bacteria. So, that is what biomaterials for a photonic application would be looking like right.



So, biological system why does this basically why do this? So, biological system of a structures that are highly organized flexible and biodegradable obviously biological material. So, they have to biodegradable they are flexible imagine how flexible your body is not just from a gymnastic purpose, but I am talking about the amount of you know ah stress and strain it goes through its immune system how flexibility is the pain management system how how how how cool or flexibility is every single day your sense organs are bombarded by different types of signals auditory signal visual signal touch signal smell signals all of that needs to be processed. So, how beautiful and how many variety it has can we mimic it can we mimic it an organization if you ever get a chance to say ah have a microscope and look underneath ah something trivial like the wings of a butterfly under the microscope wings of any any any insect like dragonfly you know the insect dragonfly ah any any anything similar even mosquito maybe if you can if you can manage to you know extract the wings of a mosquito and look it under the microscope you will see incredible complexity and tremendous amount of organization of different structures nanostructures or microstructures variety of them large number of them and in a organized way none of the internal structures present in you know insects or moths or you know anthropods etcetera are random they are organized they are nano and there is a variety of them. So, can we mimic that in real life they can spontaneously form complex structure will hierarchical order you know central dogma to you know cell to tissue tissue to organ organ to organ system and finally, the very very complicated organism. These properties make biological system excellent candidates for developing materials that are application in various technologies including photonics specifically photonics.



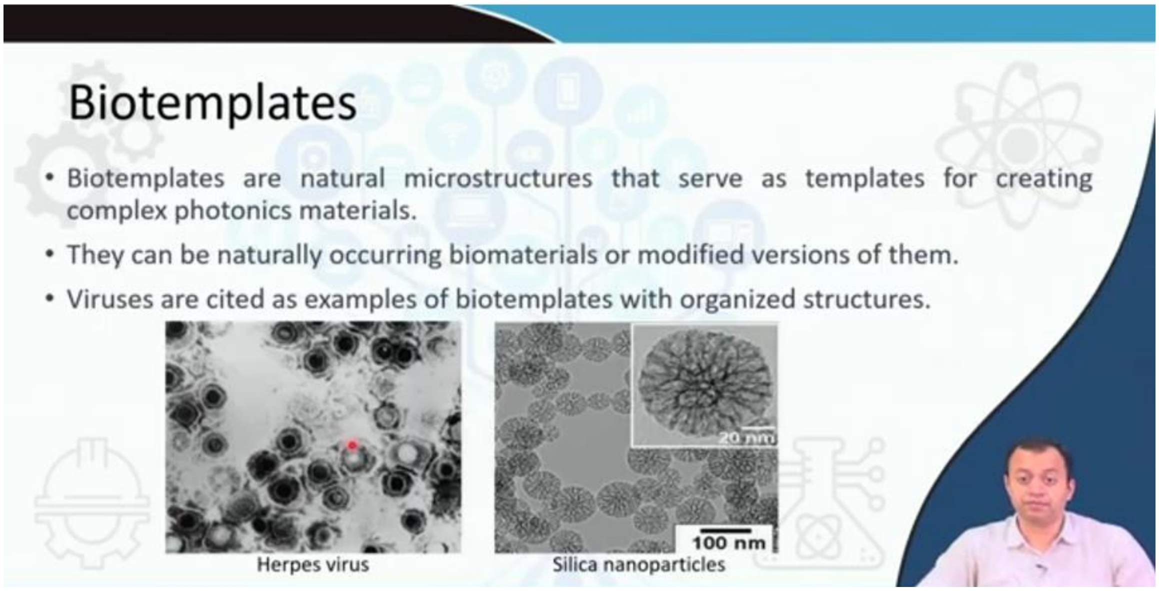
So, what are bio derived materials? Bio derived materials are derived directly from biological sources several of them you already know the number one being green fluorescent protein this protein has existed in jellyfish we have extracted it we have put it as a DNA template inside different animals' mice's chemically and try to see in vivo in life different areas you shine light on them they emit green light. We have bacteria rhodopsin we have discussed rhodopsin quite a lot exploited for its photo chemical properties like holographic data storage GFP is used for studying interaction between biomolecules DNA as I was saying it could be utilized as a waveguide as well as laser dies it can be utilized for lasers and also thin film waveguides they can be utilized to guide light from point A to point B with minimum amount of diffraction or any loss just like you have an optical fiber waveguide yeah. Similarly DNA based waveguide think where science is going and of course, biocolloids structured biological particles that can form photonic crystal through surface directed assembly photonic crystals are the photonic equivalent of semiconductors like semiconductors restrict the flow of electrons in a semiconductor electrons can only exist in valence band and conduction band it cannot exist in the forbidden band gap photonic crystals are similar where there are bands of energy like valence band and conduction band photonic crystals have bands of energy allowed band and disallowed band in allowed band photons can exist in disallowed bands photon cannot exist like we have the electronic band gap the difference between valence band and the conduction band band gap we have the photonic band gap PBG between existing lower level energy lower energy level of photonic crystal versus higher energy level equivalent of conduction band of photonic crystal in between is the gap where photon cannot exist just like you dope in semiconductor to create some extra energy levels inside the band gap and thereby increase the conductivity photonic band gaps photonic crystals could also be utilized for exactly similar purposes where defects can be put where some extra energy channels could be created in between the photonic band gap and thereby it could be utilized for various purposes for example, optoelectronic devices optical filters photonic filters etcetera etcetera. So, we can create those kinds of photonic crystals using biological colloids biological colloids combination of solid and liquid together and it can be used as an assembly.



So, this is exactly what I was talking about this is the beautiful butterfly wing and they are not dyes they are not chemicals if you look into the wing under a microscope you will see they have this incredibly organized nanostructure that all reflect a specific amount of light by interference by diffraction pattern that allows other frequencies to cancel each other, but only one or two frequency to survive and that frequency happens to be blue or this different shades of blue thereby the butterfly looks this beautiful.

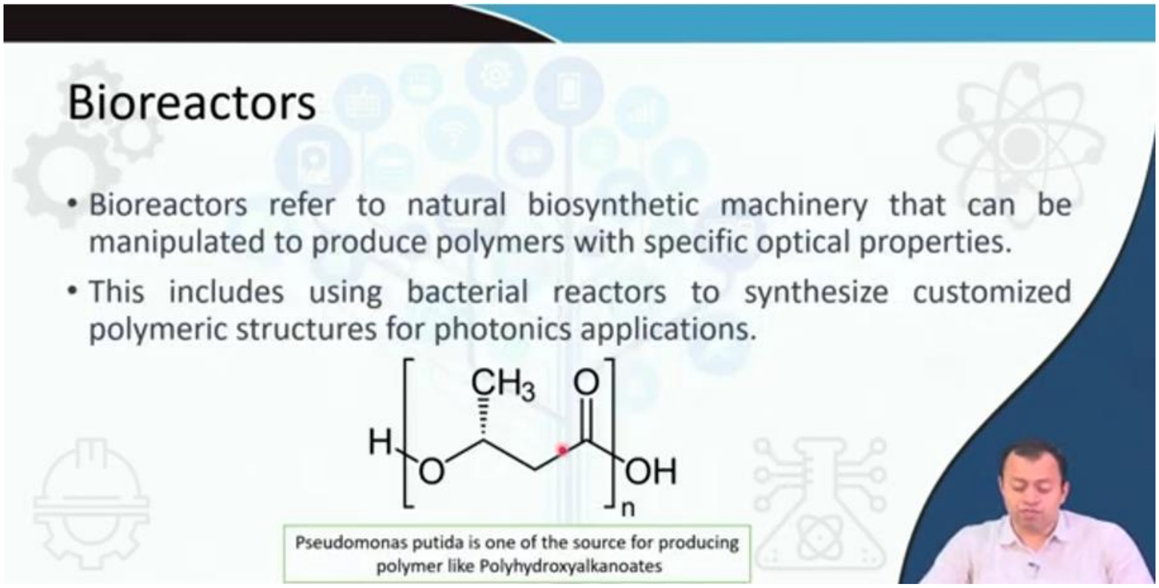
It is not a chemical process it is a physical process under the microscope the butterfly wing does not look blue green why blue green yellow it looks like this gray ash nanostructure type of thing. It simply that when sunlight falls into it all the five all the seven colors by in interference only one color survives rest of the colors are removed. Slight defect here and there changes the color perception and you have you know dark blue light blue brownish yellow or something like that. So, bio inspired materials are synthetic materials designed by mimicking the process of biological material. So, if we have this coming from ah butterfly wing can we not in lab create an artificial structure such as this create an artificial structure such as this and instead of putting in you know ah butterfly wing we put it in our clothes in our apparels at this present moment the color of your cloth is because it is dyed yes you have put different types of chemicals you have painted etcetera etcetera and after certain one year two year of continuous washing and putting it into the sun it fades the color fades color of your clothes fade, but if the structure if they have a nanostructure the cotton or the wool have inherent nanostructure like this then there is something which we call as structural color.

Color because of structure not because of chemical reaction color because of structure and this structural colored cloth can stay for a far longer period of time durable and they can be you know anytime customizable the same cloth slightly by using some sort of a electric current if you are able to change the nanostructure a little bit the same blue green color shirt after passing electric current through it say I am just giving you an analogy ah could look like red and yellow think how cool that would be they are actually doing it this not science fiction look into ah structural colors in textile it is bio inspired. So, these materials often replicate natural hierarchical structure, hierarchical structure to achieve specific optical functions and biomimicry where you mimic where you copy the biological ah phenomena the biological design is a growing field that focuses on creating multifunctional materials that mimic the complexity of natural structures. Then you have biotemplates based on the existing template as I was telling.

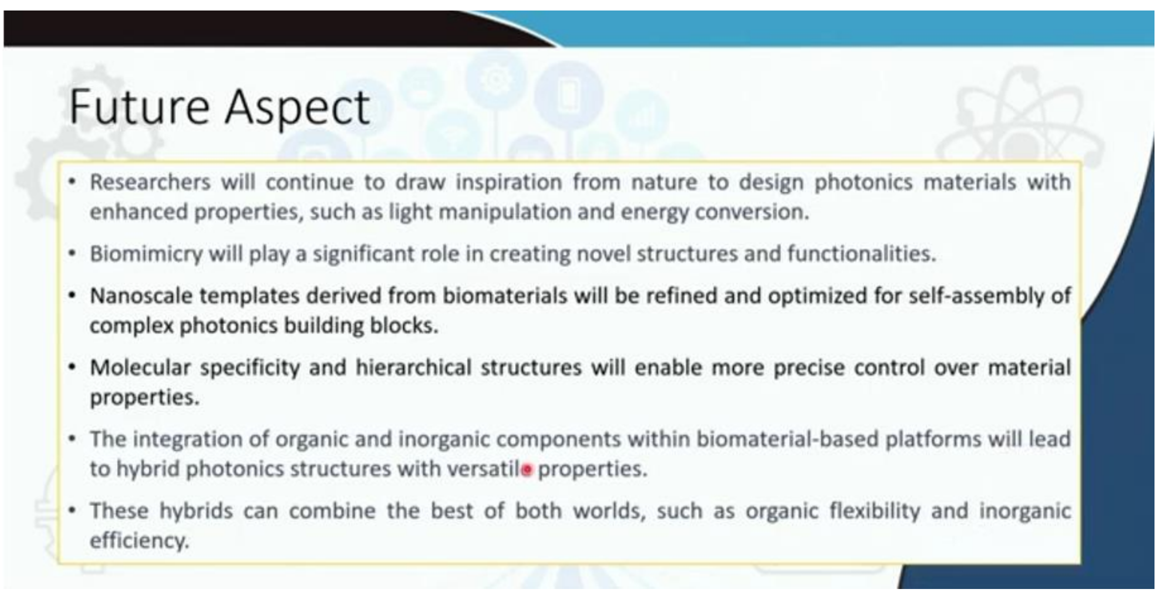


So, biotemplates are natural microstructure that serve as templates for creating complex photonic material they can be naturally occurring biomaterials or modified version of them, viruses are excellent examples of biotemplates. So, this is how the herpes virus organize itself based on these structure this organization some of you may heard of fractal yes mathematical students or student from physics or electronics engineering might have heard of this thing called fractal this is how you know a small design is repeated several times outside and you create a pattern a self repeating pattern.

So, we can based on this kind of a pattern structure this 4 by 4 or 3 by 3 we can create silica nanoparticles of similar nature and then their interaction of light is then seen ah to see if they could produce some sort of a photonic crystal effect, metamaterial effect any kind of interference or diffraction in a in a in a specific manner right. Of course,



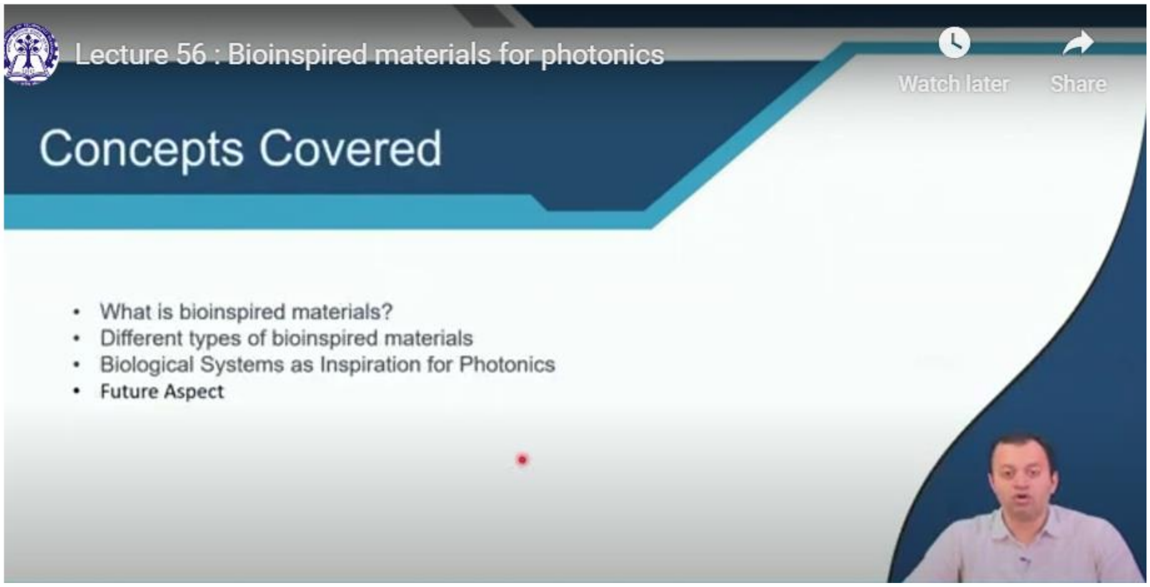
bioreactors as I was saying bioreactors refer to natural biosynthetic machinery that can be manipulated to produce polymers with specific optical properties 2 bacterias combine their output turns out to be some sort of their excretion their output could be considered some sort of a nanomaterial that have a specific optical property this include bacterial reactor to synthesize customized polymeric structure for photonic application. Pseudomonas putida this is the bacteria is one of the sources for producing this polymer polyhydroxyalkanates ah chemistry people can tell me that this is some kind of a thermopolymer that I have heard a polymer that ah is very very that is properties changes with heat.

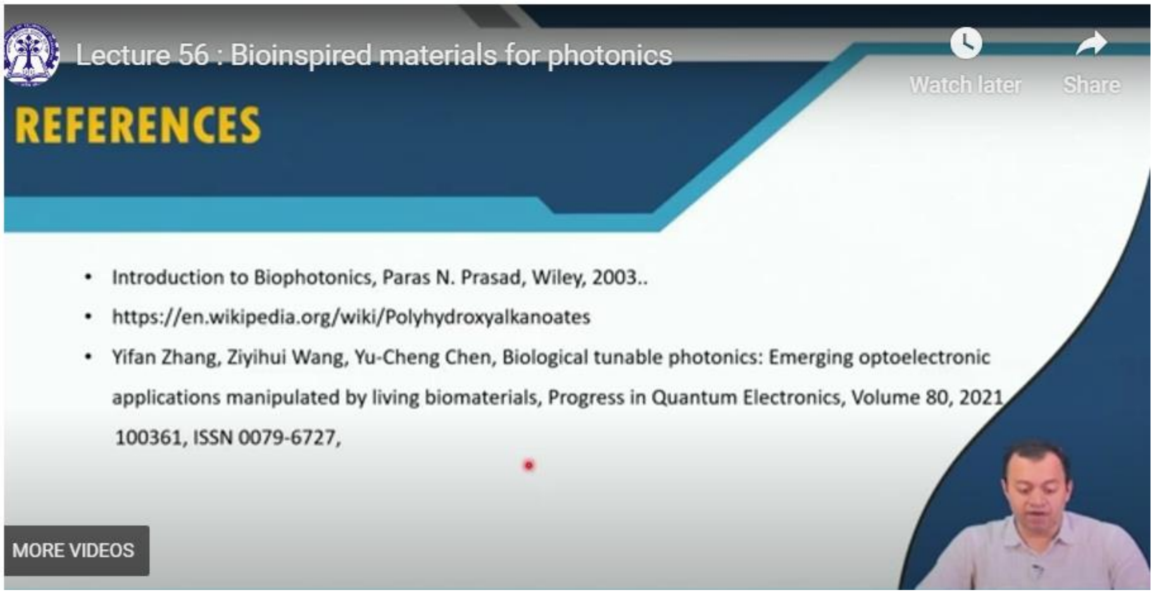


So, what are the future aspect researchers will continue to draw inspiration from nature to design photonic materials biomimicry will play a significant role in creating novel structures molecular specificity and hierarchical structure will enable more precise control

DNA based structures will be explored at photonic devices biomaterials biodegradability and eco friendliness will contribute to the development of suitable photonic solutions UER basically trying to create the so called biochip you have integrated circuits IC electronics engineers you know what if we create an integrated circuits made up of purely biological material think about it they call it the biochip right. So, in conclusion biomaterials offers a rich source of inspiration for photonic innovation the integration of organic and inorganic compounds within biomaterial-based platform

will yield multifunctional structures and their eco friendliness and biodegradability is of course, tremendous advantages as compared to purely silicon based or inorganic material based photonic structures nanostructures.





So, these are the concepts covered and these are my references. Thank you very much.