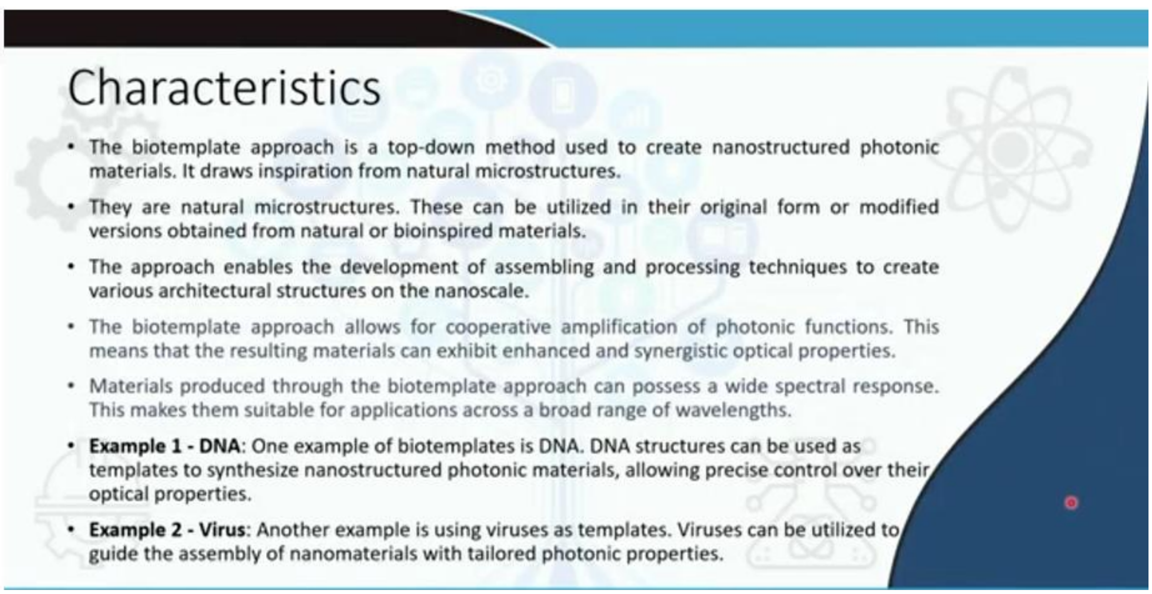
Nanobiophotonics: Touching Our Daily Life
Professor. Basudev Lahiri
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Lecture No. 59
BIOTEMPLATES

Hello and welcome. We are at the so-called home run. This is the penultimate lecture of the last module and we are at the end of our course on nanobiophotonics. I do feel slightly melancholic, but at the same time I feel good that a substantial amount of knowledge I was able to transfer to you spanning from biology to physics to medicine to brains to optics and photonics and what not. So, this is the penultimate lecture. So, let us talk about biotemplates.

I told you in this topic that we utilize biological materials naturally existing nature created biological materials as some sort of a mold, as some sort of a template and then put some sort of polymers or nanoparticles in the specific sort of arrangement that this template allows us to do right.



So, what exactly are those bio templates? So, a biotemplate approach is a top down by this time you should know what is top down versus bottom of approach in nanotechnology. It is a top down method used to create nanostructured photonic materials. It obviously, draws inspiration from natural microstructures.

They are natural microstructure. These can be utilized in their original form or modified version. The approach enables the development of assembling and processing techniques.

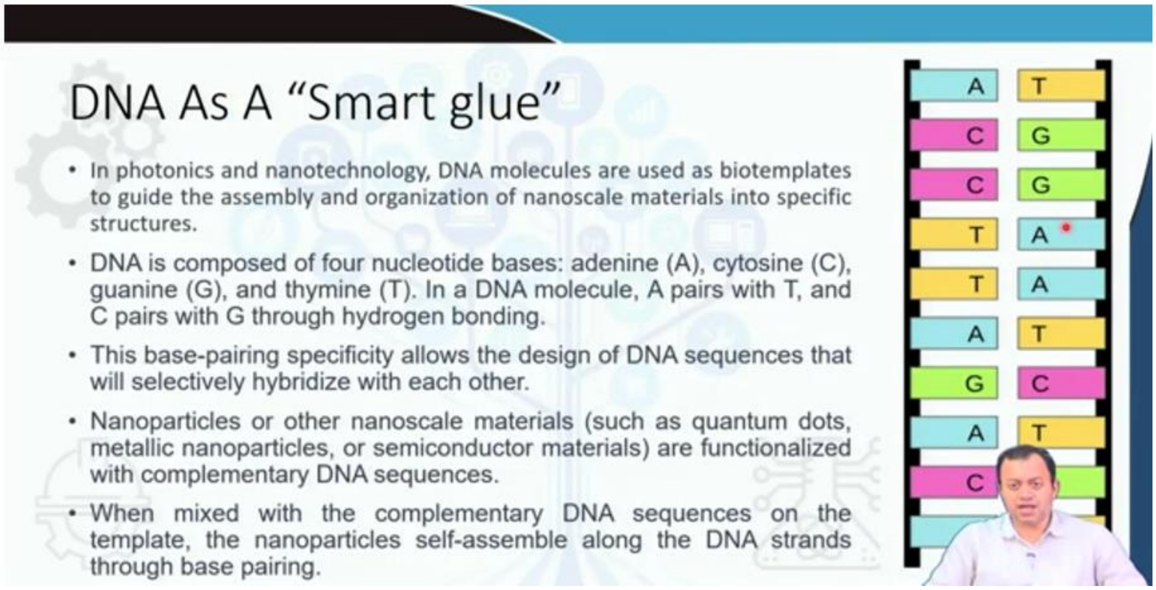
The biotemplate approach allows cooperative amplifications and there is wide range of biological materials have a wide variety, they have wide distribution even in a small 1 micron by 1-micron area of a virus or a DNA or a bacterium. You will see several types of features, several types of nanostructures.

If we use it as a mold and try to create a negative structure, try to create a negative structure by you know putting some sort of a polymer. So, suppose you have a viral structure like this with these being the spike proteins with this is the core spike proteins. You deposit some kind of a glue, some kind of a polymer in between in between this gap in between this gap and then somehow you remove this virus. You either dissolve it in some organic compound or somehow you remove it. So, whatever remains whatever that polymer remains will be a negative structure of the spherical of the spherical virus with spikes in between.

So, it will be an inward structure with you know lots of holes instead of spikes instead of cylinders, you will have lots of gaps, lots of dots, lots of hole in between with a hollow core with a hollow core. So, imagine the coronavirus particle that you have seen all over a negative structure of it a negative structure of it. So, two very important biological materials that we can utilize as a biotemplate number 1 is DNA. One example of biotemplate is DNA. DNA structures can be used as templates to synthesize nanostructured photonic materials allowing precise control over their optical properties and the second being virus as I was saying.

Virus can be utilized to guide the assembly of nanoparticles with tailored photonic properties. So, having that kind of a negative virus structure with holes and hollow cylinder and what not you are thereby periodically varying the refractive index. You are thereby both in virus as well as in DNA you are periodically varying the refractive index with polymer air, polymer air, polymer air and thereby restricting the movement of the photons, restricting the movement of the photons and in essence making some kind of an optically active electromagnetic structure or electromagnetically let us me rephrase it electromagnetically active nanostructure. Electromagnetically active nanostructure can you make picostructure, can you make picostructure with you know different strands of DNA, what would be the length of one single DNA, is it in angstrom, is it in picometer. So, instead of having nanotechnology are we talking about angstrom technology.

I recently had the pleasure of attending a lecture of professor Nikolai Zeludev of University of Southampton and he was talking about Pico optics not nano optics and these were some of the ideas that he provided.

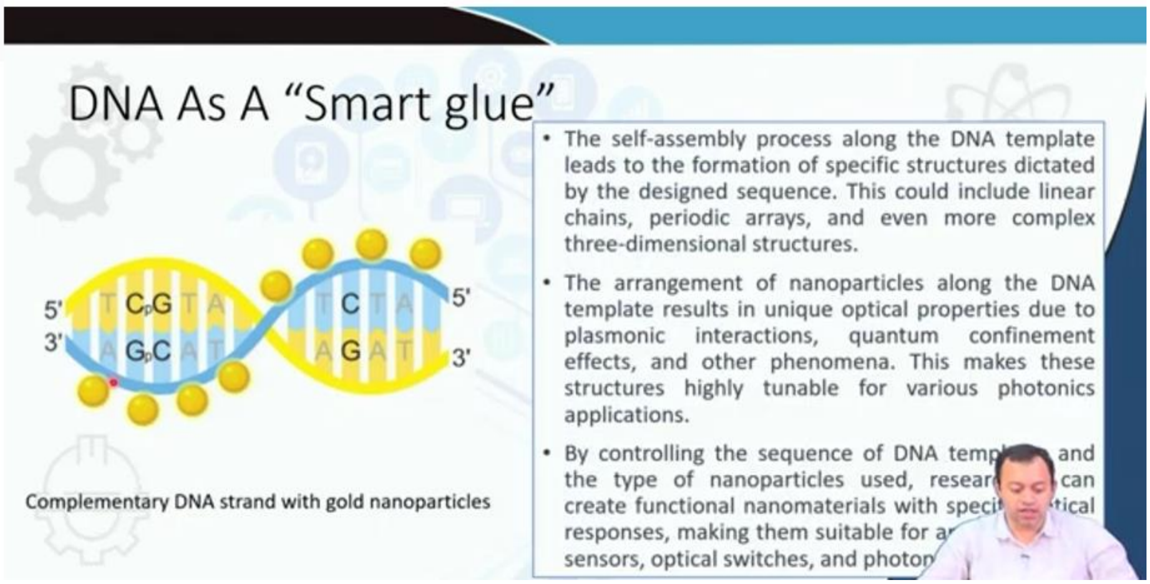


So, let us let us try to discuss a little bit more about deoxyribonucleic acid DNA as a smart glue. So, as I was mentioning in photonics as well as in nanotechnology DNA molecules are used as bio templates to guide the assembly and organization of nanoscale materials into specific structure. You know that DNA has 4 nucleotides 4 nucleotide bases A C T G and they are all paired A with respect to C and G with respect to T. So, if you have C here you almost always able to say the complementary pair being G.

On the other hand if there is T here you know that the complementary pair will be A there is no other process there is no other well couple of exception always exist, but 99.9999 percent case if you know one set of bases one particular sequence you can immediately calculate the other sequence. So, nanoparticles or other nanoscale materials such as quantum dots metallic nanoparticles or semiconductor materials are functionalized with complementary DNA sequences. So, you can put your negative structure or you can put your polymer or quantum dots either in the gap region either in the gap region make some sort of a negative ladder structure consider it as a ladder in between the space you have put some sort of a nanoparticle polymer or nano polymer quantum dot and what not or you can put it alongside in certain of the bases and then try to try to create another complementary pair and combine them together and later remove it later remove it. So, that you have a negative structure this white spaces where I having my cursor the white the laser pointer you can have some kind of a nanostructure with this precise precise location and if you are clever enough.

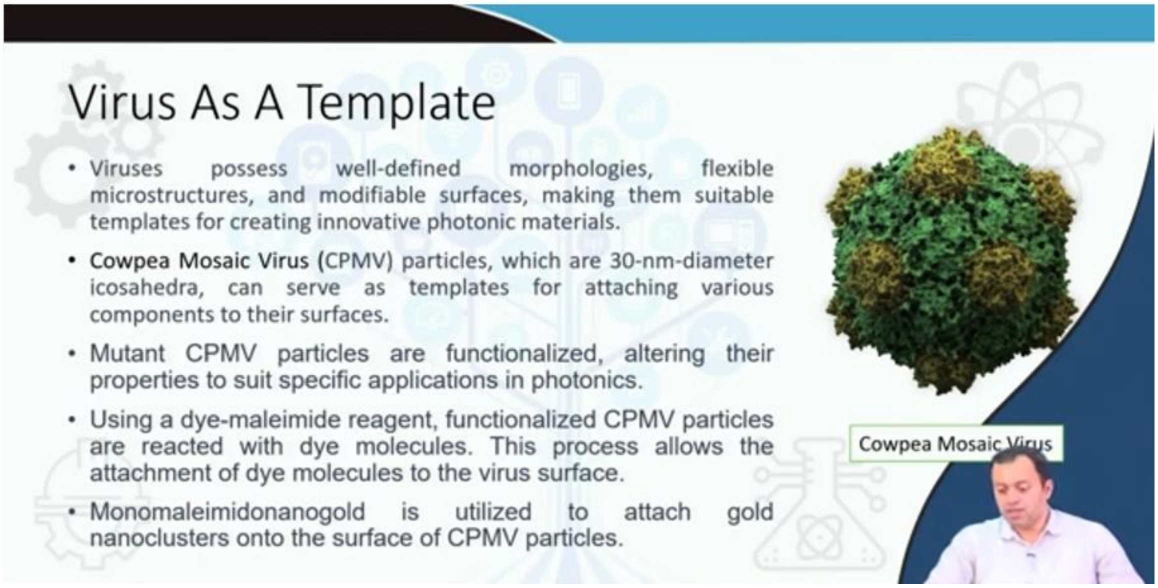
So, that you have made some kind of a quantum dot a specialized quantum dot specialized nanoparticle which will only attach with C which will only attach with T which will only attach with G and A then by this you will have a complementary nanoparticle based you know periodic structure periodic structure with particle A B B C C D and so on and so forth in that arrangement. So, nanoparticles or other nanoscale materials are functionalized with complementary DNA sequences when mixed with the complementary DNA sequence on the template the nanoparticle same assemble along the DNA strands through base pairing. So, through base pairing C matches with G you have created a nanoparticle x that is specific to C and nanoparticle with y specific to G. Now you have arranged them together you have arranged a particular one together and have tried to meet C and G by definition x and y will also meet right. So, if the refractive index of x is said 2 and the refractive index of y is 2.

5 you will have 2 2.5 2 2.5 2 2.5 or mix and match. So, all of these things are available where we utilize DNA as a template and imagine the resolution imagine the how small it is going to be.



So, nanotechnology probably is passé now, now you have to look into Pico technology or angstrom technology. So, as I was saying you can you can have this gold nanoparticles complementary strands then can either be attached with the base pairs or you can have it with the you know phosphate base the the the the the the backbone. So, the self-assembly process along the DNA template leads to formation of specific structures dictated by the design sequence. So, this allows you the this this controls it. So, that the nanoparticle is arranged in a specific pattern a particular pattern is maintained this could include linear chains periodic arrays and even more complex 3-dimensional nanostructures.

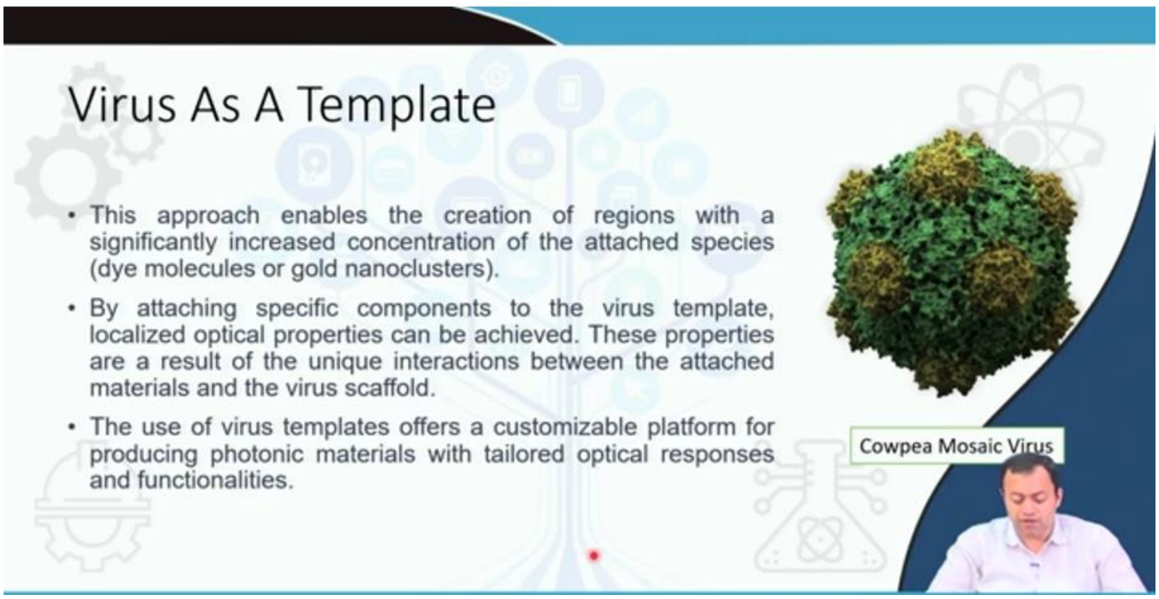
The arrangement of nanoparticles along the DNA template results in unique optical properties due to plasmonic interaction quantum confinement what not. So, there will be a combine effect between them they will have individual plasmonic resonances plasmonic resonances is because of the localized electrons I told you the electron that comes to oppose incoming light radiation. But if you have arranged the plasmonic nanostructures in such a such a way with each nanoparticle identical exactly same as the other one then the localized surface plasmon resonance the the the the electron cloud here versus electron cloud here versus the electron cloud here are all same because they are identical particles. And when you have the same electron cloud combining together they will talk and they will resonate and the result the output result is creation of a huge you know LSPR signal resonance surface plasmon localized resonance surface plasmon signal that could be utilized as a sensor because these signals these signals that are generated by the free electron present in this gold nanoparticles they are very very susceptible to any change in the local refractive index. So, you just cover one of them one of them with some amount of a molecule a biomolecule something something is just attaching it the entire structure will get disturbed the resonance of the entire structure will get disturbed because previously they were just identical to one another now one of them is non-identical i.e. you have introduced defect you have introduced effect. So, there is a small red shift small red shift and that could be utilized to detect the presence or absence of any particular molecular species meaning you are going into so called single molecule detection single molecule detection. So, the arrangement of nanoparticles along the DNA template results in unique optical properties due to plasmonic interaction quantum confinement this makes the structures highly tunable for various photonic application and by controlling the sequence of DNA templates and the type of nanoparticle used researchers can create functional nanomaterials with specific optical responses that can be used as I said as sensors optical switches and other photonic devices.



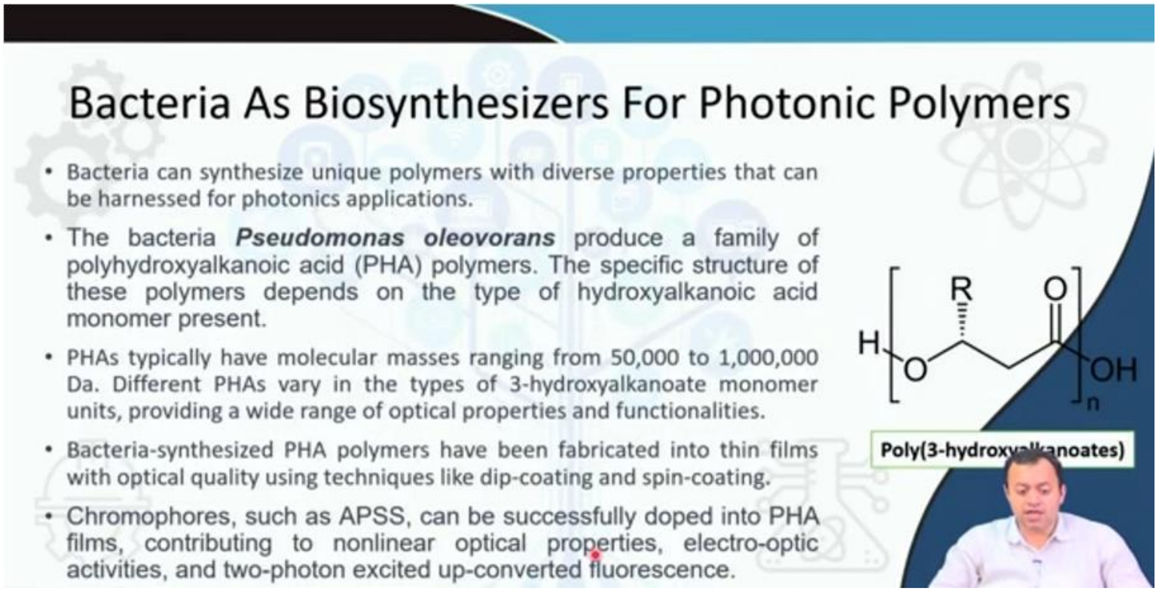
Similarly, you can have virus as a template. So, this is a typical example of a virus now see how these holes inside this cap along with this capsid along with this viral body is arranged now imagine a negative structure i.e. the holes you will fill it with some sort of a polymer some sort of a nanoparticle and the rest as it is and then the nanoparticle is removed. So, what kind of a unique photonic nanostructure you will get by having nanoparticle arranged in this particular pattern please do not think that they are random these holes this pattern this yellowish versus greenish these are not randomly arranged just like you see the colors in butterfly wing or in peacock feather they are not randomly arranged. Similarly, these holes this crest and trough along the body of the virus is not randomly arranged they have a particular purpose combinedly individually you may not find a particular purpose, but when you combine them together probably this makes this thermodynamically stable probably it helps it to protect the nuclear material that is inside the RNA or DNA material which is holding inside or probably it has some kind of a spike proteins associated with it which can be used to attack a particular cellular receptor somewhere in in in a particular cell and thereby open it up it is just like lock and key mechanism I I told you it is just like lock and key mechanism those spike proteins acts as key those those those those things that you saw in the coronavirus they act as a key which attaches attaches with a specific opening of the semi porous cell membrane opens it up and inserts the DNA or RNA presents inside the virus into the nucleus into through the cell through the cytoplasm into the nucleus of the cell hijacking it is reproductive property reproductive machinery and the cell reproductive machinery is no longer utilizing to create copies of the cell, but the cell reproductive reproductive machinery is being used to produce copies of the virus instead. So, the first process comes when the cell membranes particular door particular lock is opened by a specific key and these these these spikes more so in coronavirus you have seen that red color spikes are keys right. So, viruses possess well defined morphology flexible microstructure and micro defiable surfaces making them suitable template for creating innovative photonic materials.

Copia mosaic virus CPMV particles which are 30 nanometer diameters can serve as template for attaching various components to their surface. Mutants CPMV particles are functionalized altering their properties to suit specific application and using a dimethylamine reagent functional CPMV particles are reacted with dye molecules and you can utilize it to attach gold nano clusters onto the surface of CPMV and thereby can create some kind of a resonating plasmonic nanostructure that will have their own effect. So, instead of designing some sort of a sensor using nanoparticles from your own imagination just look into nature just look into nature they have a huge variety just look into them and if you can copy or mimic that utilize those design already existing because nature has got like few billion years to do permutation combination and finally, it has come to the most efficient design you know about evolution you know about survival of the fittest natural selection. So, the final product after 1 billion years of evolution is something that is most efficient right. So, instead of you trying to make trial and error designs of nanoparticles which may or may not work why do not you look into already existing design present in the nature which nature did over a period nature experimented over a period of 1 billion years since since life form existed in this planet and it has already have come to the fittest the most efficient the best result simply copy it right.

So, this approach enables the creation of regions within a significantly increased concentration of attached species by attaching specific components to the virus template localized optical properties can be achieved and the use of virus template utilized for tailored optical response and function functionalities. So, this is a very cutting-edge technique these are topic of hot topic of research you keep on asking can you give me some hot topic I see it in the forum can you give me some hot topic for research in biophotonics nanobiophotonics. So, this is it utilize your viral particle as some sort of a template and create unique photonic nanostructure electromagnetically active nanostructure even pico structure if you so can and see how it is able to localized light diffract light in a in an unprecedented manner who knows what new phenomena of light

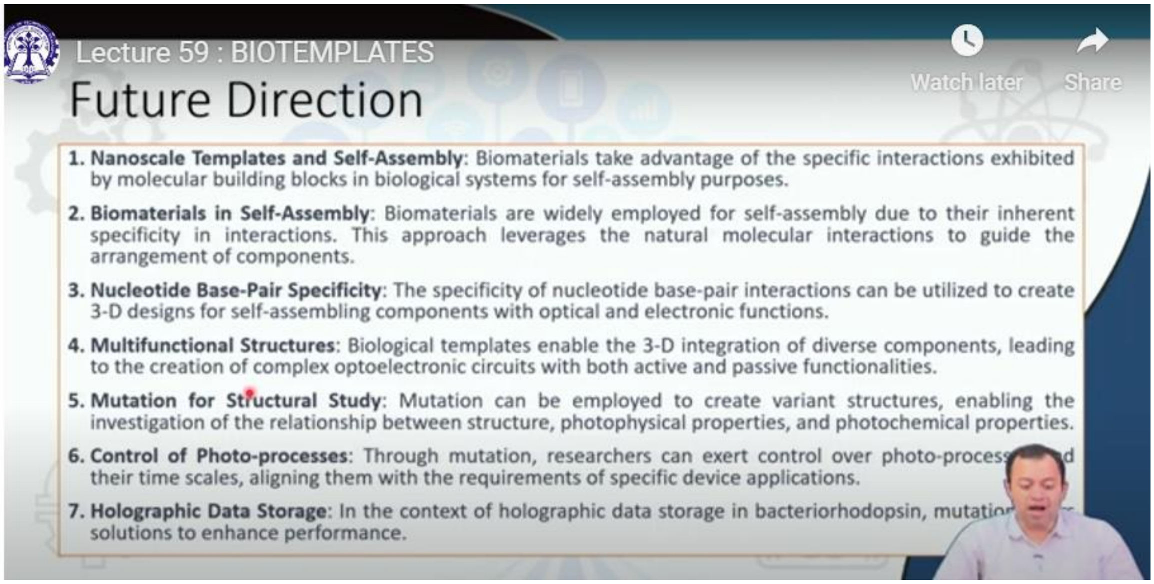


you might come up negative refraction is already their switchable negative refraction there is something called slow light where the group velocity of the light is tremendously reduced you should know what is the difference between group velocity and phase velocity by them now. So, obviously, this is something of a very hot topic at the same time you can utilize bacteria as a biosynthesizer for photonic polymers ah.

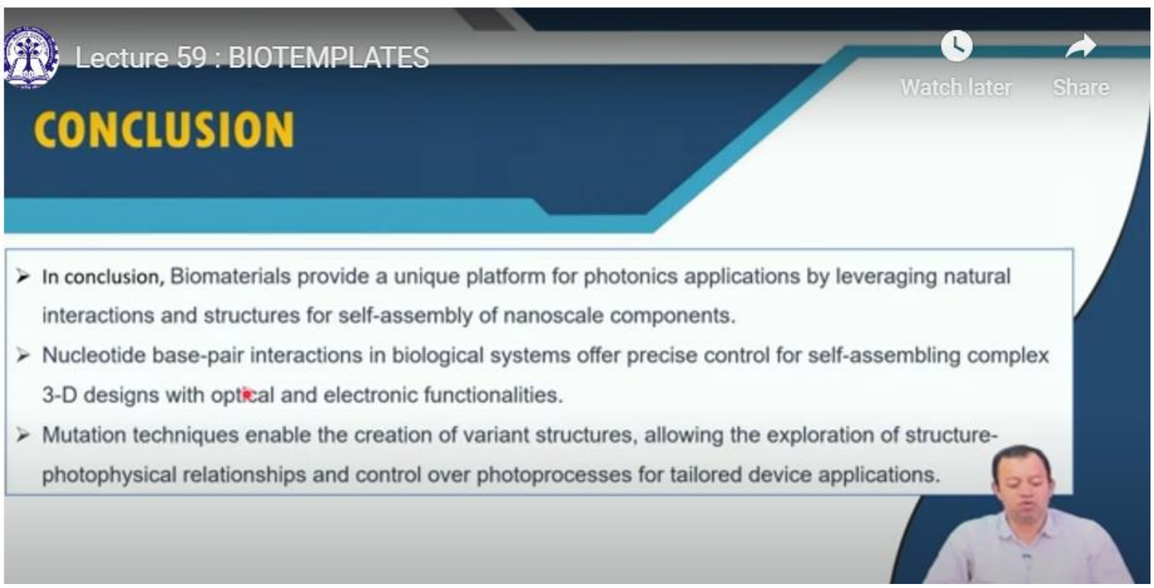


Pseudomonas bacteria produces a family of this alkalonic acid polymers thermo polymer for example, this alkalonic acids p h s typically have a molecular mass from 50000 to 100000 daltons d a is dalton this is the same Dalton that gave the idea of atom something that cannot be divided atom cannot indivisible, but now even a school child knows atoms can be divided into what not.

So, bacteria synthesized PHA polymers have been fabricated into thin films chromophores such as APSS can be successfully doped into this polymer making fluorescent material. So, the output the byproduct of bacterial reaction bacterial mating bacterial reproduction is this thermo polymer which reacts differently with respect to different temperature being put into it and thereby you can try to see some kind of a thermo optic effect where the refractive index change of a particular material because based on the temperature and if you have divided the temperature gradient somehow you can change the refractive index and thereby change how light gets localized. Sometimes opposite is also true by photo thermal heating by absorbing light at specific areas of that polymer localized heating can be achieved and then that localized heating hot cold hot cold hot cold periodicity can be utilized for several different purposes something that I use for making sensors. Certain species will have an affiliation for a particular temperature in certain chemical molecule will have an affiliation towards a particular temperature every chemical reaction has an optimum temperature. So, the particular chemical species particular virus will like to go will to a specific temperature area and by that if the refractive index changes we can also utilize it for the detection.



So, what is the future? We go for nano scale template and self assembly, we go for biomaterial based self assembly, we have multifunctional structure, we have control of photo processes and obviously, holographic data storage.



So, that brings me to the conclusion biomaterial provides a unique platform for photonic applications nucleotide base pair interaction in biological system offers precise control and mutation techniques enable the creation of variant and tunable structures that can be utilized for several different application.

So, these are the concepts that I tried to cover for today and this were my reference I

will see you in the last class. Thank you.