Nanobiophotonics: Touching Our Daily Life
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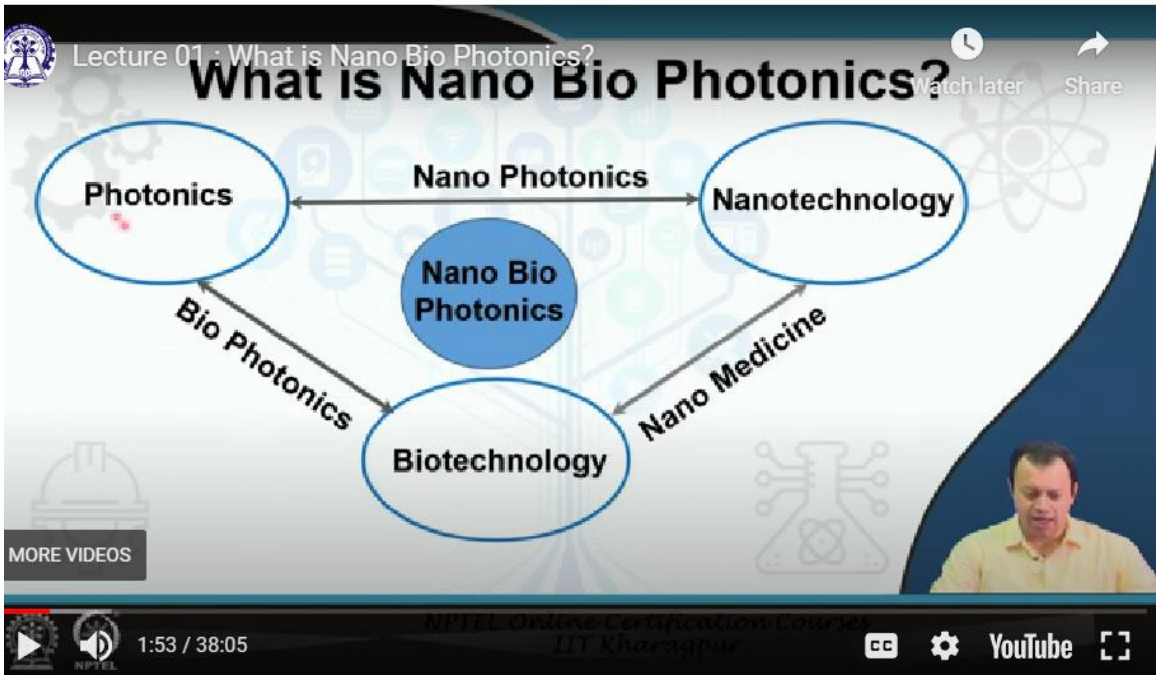
Lecture No. 01
What is Nano Bio Photonics?

Hello and welcome. My name is Dr. Basudev Lahiri. I am an assistant professor at IIT Kharagpur and I am here to discuss about this exciting new topic of nanobiophotonics. If this is something that has captured your imagination then welcome. Nanobiophotonics is a highly highly interdisciplinary field.

It encompasses or fuses concepts from photonics which itself is interdisciplinary, it fuses concepts of nanotechnology which again is interdisciplinary and of course, it fuses concepts from biotechnology or biosciences. So, as you can see by combining all of these three aspects we are going to learn something fundamental at the same time we are going to learn something that is truly state of the art or path breaking or really catapulas to the future. Welcome again let us start. So, what exactly is nanobiophotonics? As I told you that it fuses concept of three main field as the name itself suggest.



It has photonics as the forefront then it has nanotechnology and obviously, it has biotechnology. In itself each three fields are interdisciplinary to begin with. When you combine photonics with nanotechnology that is trying to understand light and its interaction

with matter at a nanoscale level. So, you possibly make materials or structures which has size or features of dimensions in the nanometer scale region and those interact with lights those lights have wavelength of similar nanometer scale levels as well and that is called nanophotonics. Nanophotonics basically is interaction of wavelengths of light in the nanoscale region visible light 400 to 800 nanometer infrared light ultraviolet light with structures artificial engineered structures or naturally occurring structures which are 400 nanometer, 300 nanometer, 200 nanometer as such and their interaction is studied understood and obviously, since it is a technology it has to have a practical application that part is called nanophotonics.

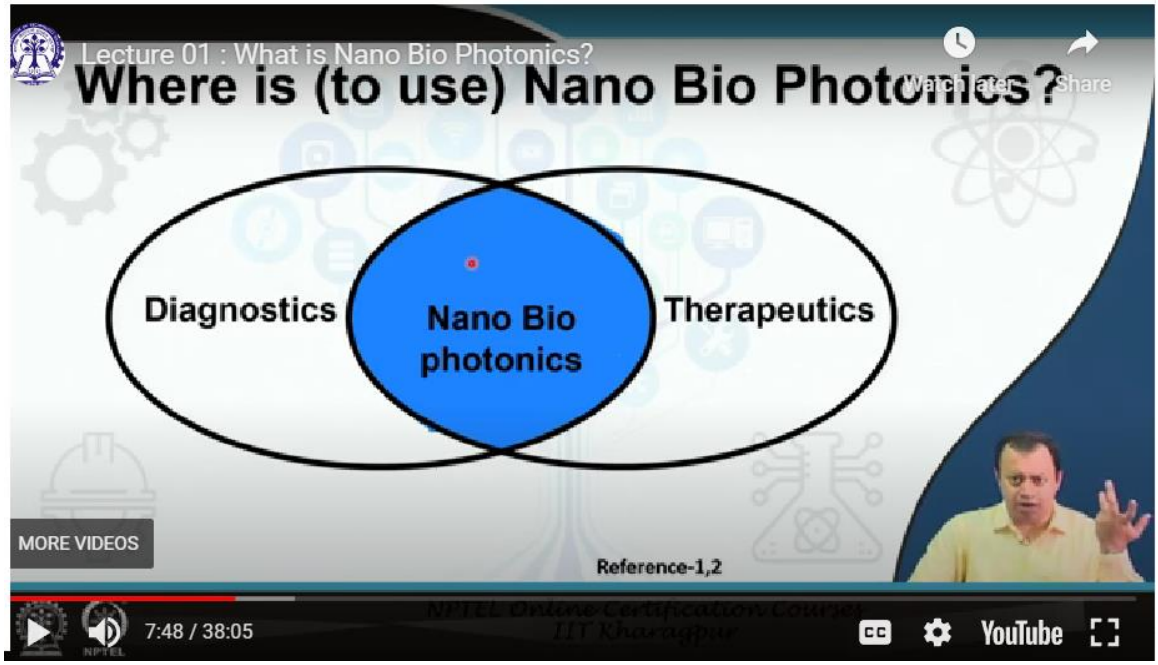
On the other hand when photonics merges or photonics fuses or photonics interacts with biotechnology that is we try to utilize light per say to interact with biological material. Biological material which could be pathogens, bacterias, viruses, fungus etcetera or it can interact with cells sub cellular components nucleus mitochondria etcetera or it can work with nucleic acids proteins those bigger macromolecules. When light is being send to see what kind of interactive effect it is happening it is creating with biological substances biological materials we call it biophotonics. Not only light is sent to these kinds of biological macromolecules to understand or reveal or to image or to see those structures sub cellular structures, but also biophotonics tries to see if we can manipulate or if we can modify those macromolecules by sending light waves. Combination of nanotechnology and biotechnology gives us nanomedicine.

This is a very interesting field in itself as such nanotechnology you know is manipulating is the technology that manipulates matter at a nanoscale level. You have nanoparticles, nanostructures etcetera and they are then been utilized in a biological system to see their interaction some kind of nanoparticle any kind of thing that can attract heat that can be acidic that can be basic that can have something special property are being injected are being introduced into a cellular mechanism I am giving you an example. And then we try to see that this artificial material this artificially created material from nanotechnology how is it interacting with a biological substance. Here light is interacting with biological substance, here a material is interacting with biological system, here light and materials are interacting with each other. Now when you combine all three all three of them you get nanobiophotonics.

Nanotectonics is the is at the interface of photonics, nanotechnology and biotechnology. So, thereby it makes it doubly or dare I say triply exciting right. You have something that is at the forefront of research. We need to understand therefore, the concepts of nanotechnology, the concepts of photonics, optics electromagnetism and of course, basic idea of biology is required. Do not worry there is hardly a person who could say that she or he is a specialist in all three none of us are this is not a specialist course per say after

having this course you cannot I cannot guarantee that you are going to be a specialist in nanotechnology or specialist in biotechnology or specialist in photonics.

What I can guarantee on the other hand is that after going through this course you will have a newfound appreciation for the concepts of all three different fields and depending on your taste, depending on your choice, depending on your inclination of course, you can then further go forward to specialized in any one of them or if you are like me you can sit at this interface and try to get the best of all the three different fields choice is yours. So, let us continue this is just the introduction part and I will give you an overview in this lecture of what you can expect in store for you if you so choose to continue this course on nanobiophotonics.

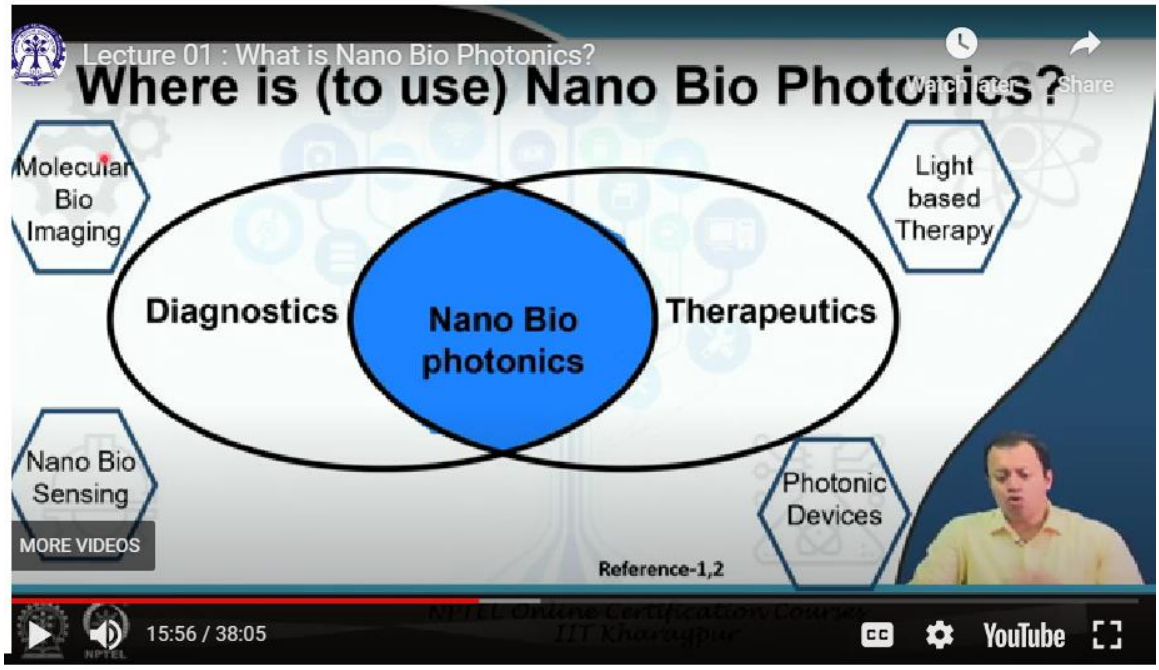


So, where exactly do we need to use nanobiophotonics I have given you the what part what is nanobiophotonics, but let us now come to the heart of the matter is why nanobiophotonics is there I mean what is in there for you why should you study nanobiophotonics or most importantly why should the world in general care about nanobiophotonics why do we need to study that. Well nanobiophotonics have two fundamental applications and these applications make them very attractive they are utilized for detection of diseases at the same time they could be utilized for curing of diseases right. So, when you are trying to utilize some nanobiophotonics technologies technologies that you utilize photonic concepts with biotechnology concepts with that of nanotechnology concepts there is a paradigm which is directly affecting our daily lives and this daily lives which part of daily lives. If you ask is it affecting it is affecting mostly the health paradigm.

It is mostly affecting our day to day well being our health our environment our day to day lives per say. Nanobiophotonics has certain advantages that you will discover in the coming days that very few other technologies can provide, nanobiophotonics have two direct manifestation on disease, the same technology the same nanobiophotonic technology can be utilized for both detection of disease as well as its cure right and this is something that is happening at a nano scale level at a molecular scale level, meaning you are not just detecting the disease when it has manifested into a full blown crisis when the entire part of the body is affected, but nanotechnology or nanobiophotonics provides you provides you with the tools with the equipment with the knowledge with the concept to detect disease when it has just manifested itself in a cellular or sub cellular level i.e. just one or a couple or few hundred cells are affected it has not gone any further. Early detection of disease and it not just you are detecting it early you are creating avenues you are creating further technologies that has the capacity to reverse, reverse this manifestation of a disease at these affected regions which is few cells few hundred cells which is basically at a nano scale level, without affecting any other part of the body. That is at least the aim the goal how much we are successful in it you will discover as the course progresses. So, the different aspects in diagnostics as well as therapeutics for nanobiophotonics happens to be molecular bio imaging and nano bio sensing.

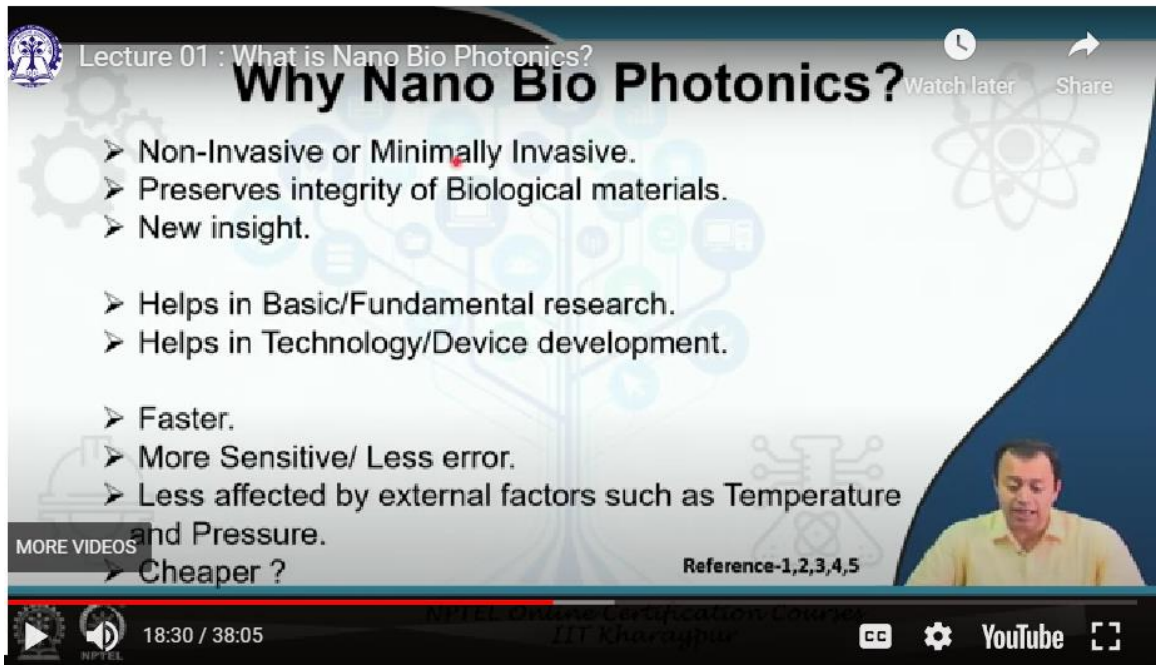
So, imaging sensing and detection more or less come under the umbrella of diagnostics we want to detect, we want to classify, we want to understand, we need to understand where the disease is and what exactly is the disease. There are different types of disease some of them are communicable i.e. some of them are created because of the presence of an external agent, pathogens or some kind of pollutants or some other materials that has simply affected it. So, you need to understand you need to see, you need to thereby come to an analysis, you need to sense, you need to detect, you need to image, at the same time there are certain diseases which are non-communicable and that happens because something has gone wrong somewhere very specific and very particular inside your body i.e. cancer. Your body is creating a tumor your body is creating a bad gene is creating bad proteins and this bad proteins is manifested in the form of tumor somewhere in the body and it has not been triggered not necessarily though obviously, there are carcinogens that can trigger this, but several times it can happen inside your body by your own bodies mechanism failing, not just cancer there are other diseases such as Alzheimer's or Parkinson's diseases, neurodegenerative diseases which we fully do not understand and they are created not necessarily by some external agent, though it could be smoking is a leading cause of cancer, but you all know some people somewhere who had never smoked, never drank, never went in front of a nuclear reactor, but still developed full blown cancer right. We need to understand we need to differentiate, we need to sense, we need to classify, we need to detect these areas these manifestation of the disease at a cellular or sub cellular level at an early stage the diagnostic aspect of nano bio photonic technology allows you, provides

you the avenue to do exactly that. At the same time there is this therapeutics part, therapeutics part deal with either photonic technologies or nano photonic technologies in which light interacts with external materials which are nano scale level and these interaction of an artificial material some artificial nano particle along with light combining together inside your body results in destruction of the pathogens, which you have detected earlier, which you have detected imaged classified earlier and or detects the bad cell detects the bad tumor. Here you are creating light-based therapy. Now make no mistake here when I talk about light-based therapy I mean scientific, scientifically proven mathematically verifiable technologies. This has a capacity to go in a very weird direction as soon as I take light-based therapy name they take it, they run it with something that I should not be discussing. These are mathematically viable mathematically provable 10 people will get this therapy and 9 people will show exactly the same effect. The 10th person might have slightly different effect just like any other medicine any other paracetamol or any other kind of medicine. So, light based therapy and photonic devices encompasses in itself nanotechnology and photonics and create some kind of an environment that can be utilized to target affected cells affected tissues affected parts of the cells and pinpoint it locate it and modify it modification could be destruction modification could be overall reversal destruction as you can understand is far easier than trying to reverse, but those things are coming very strongly in future.



So, why nanobiophotonics is interesting because it takes you to a sub cellular level it lets you image it lets you detect it, lets you sense, it lets you classify it, differentiate it with other type of diseases classify it by classification, but definition of classification has to be differentiation you differentiate into different groups different boxes different levels and

then when you have done you are not simply staying there. You are trying to reverse it if you think that this classification or this manifestation that has come up is harmful for the body. So, nano bio photonics since the name bio is there, has a direct impact on health if I had been teaching you nano photonics I would have been discussing about communication and cryptography and quantum computing and what not. If I had been talking about bio photonics, which I previously have done I would have been mostly dealing with interaction of biological material with light, but nano bio photonics is specific with a nanotechnological aspect where most of the manifestation is at a nano scale level.



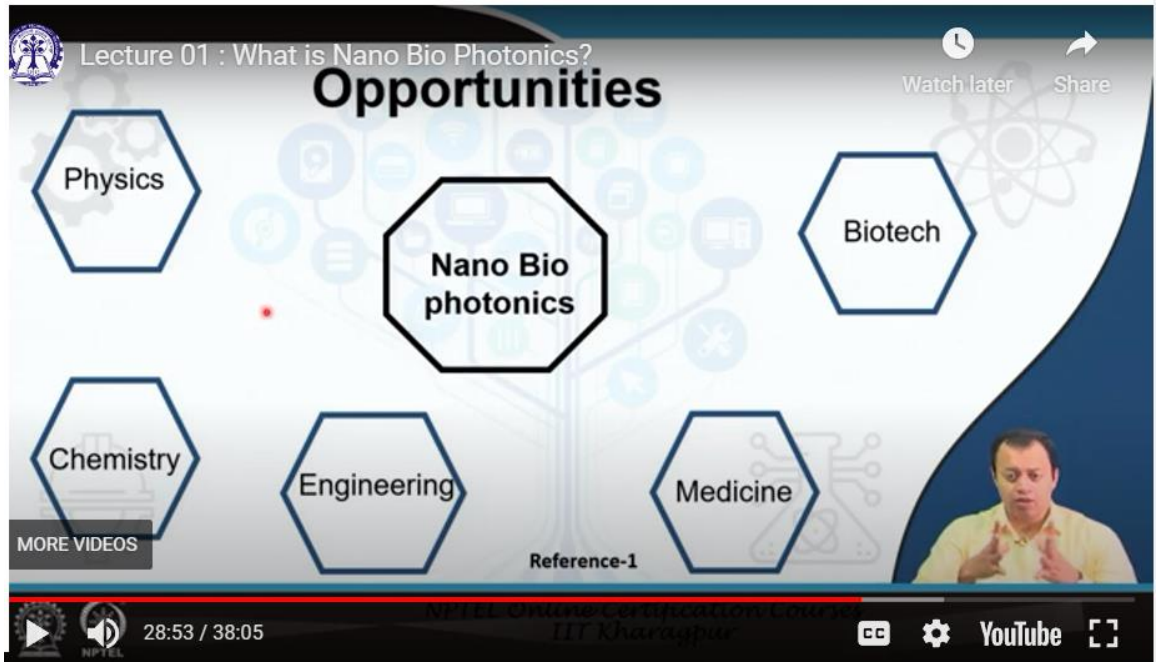
Why do you need this, I told you that it has several other technological aspects that very few other competing technological field can provide, but there are certain advantages that you get when you combine the best of three worlds, first and foremost it is non-invasive or minimally invasive since it is nano level, you are trying to minimize the side effects, you are trying to minimize the effect in the whole body, you know there are several medicines that you take and that may cure you from a particular ailment a particular problem that you are facing, but it creates several other manifestations several other headaches, several other you know side effects that goes worse with time. So, nanotechnology or nano bio photonics have the capacity to reduce this side effect to a large extent. Since we are utilizing mostly light and not electric current or some kind of a chemical agent it has the capacity to preserve the integrity of biological material. You are not passing high voltage current through part of your body or some cellular structure. You are sending light visible light we all go out and we all take visible light and it has obviously, some direct effect on our body our body creates skin specifically creates vitamin D and what not, but to a large extent if we are not exposing our self to ultraviolet or very harmful

radiation of very high intensity etcetera to a large extent visible light could be utilized or we are let us put it this way we are habituated to have visible light in our body. The 400 to 800 spectrums. Obviously, it has its effect, but these visible lights effect on our body is far less comparatively harmful than ultraviolet, gamma ray, x ray etcetera. At the same time, it does not damage our tissue like infrared which is direct heat and if you go into terahertz and microwave the effect of in our bodies also though not I mean the jury is still out, but it might have some unwanted consequences. By utilizing light and when I talk about light I usually mean visible light technically everything is electromagnetic spectrum granted everything is electromagnetic spectrum.

So, by that definition everything is light, but when specifically, I talk about light I am talking about the visible spectrum. Visible spectrum is more or less with an underline on the term more or less it depends on the intensity, it depends on you know what particular wavelength which part of the body you are getting it affected by how much of it for what duration, but overall it has the capacity to preserve the integrity of biological material if we are clever enough. If we are utilizing particular measures or particular health and safety rules. It helps in basic and fundamental research we need to understand how light is interacting with a biological matter which is at a nano scale level and of course, this helps us in development of technology development of devices implantable devices, devices that could be used to remotely affect your body with as I said minimal harmful effect. Of course, since it is light it is far more faster and more sensitive and it is since light far less affected by temperature and pressure as you know light has very little bearing to this, but word of caution though temperature and pressure has very little bearing on light per say, it does have bearing on the nanotechnological it may have bearing on the nanotechnological material that you are utilizing So, overall the effect is minimum, but not 0. So, overall there is some amount of effect and all of this we are going to understand.

The cheaper part I have specifically put a question mark simply to understand or simply to know or simply to ask this question that it could be made cheaper, light is available everywhere. I am not talking about solar can we utilize this fast amount of light visible light that we are getting for disease detection and for curing of disease can this be manifested or can this be actually seen in a cost-effective manner. So, you have a technology beautiful granted, but this technology would not be popular unless and until it is cost effective meaning it is cheaper internet is popular not because not just because internet is all over the world, but because it can be cheaply it can be very cheaply assessed internet existed since I think 1960s, but very few people at that time could afford a computer, or a smart phone, several of these devices have had not yet been developed, not yet been created and if they have been created they used to be extraordinarily costly. At one time perhaps, none of my audience will remember this, but since I am old enough at one time when India, my country started having mobile phone introduced, I think late 90s,

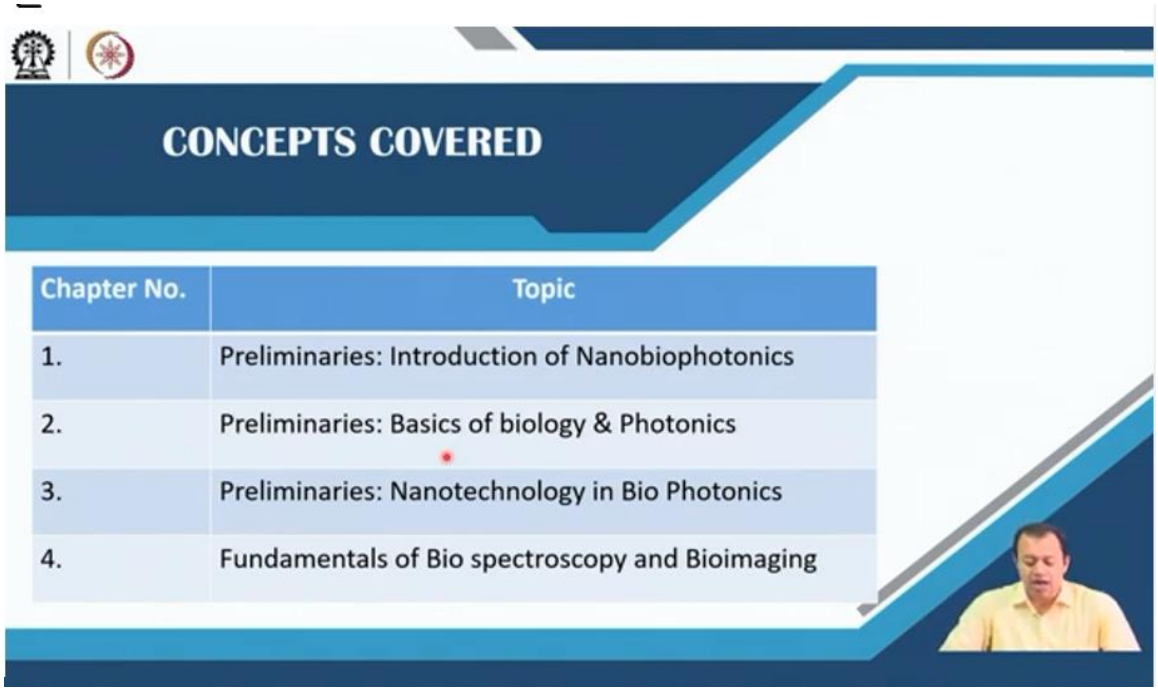
you used to have, you used to pay for both making a phone call and receiving a phone call, you cannot even imagine this. Why do I need to pay to receive a phone call? At one time I remember this clearly, mobile phones were some sort of a status symbol, only the ultra-rich people could afford mobile phones and even there were some tax raids income tax raided those people who used to have mobile phones just to see the source of their income, because this was this costly. Think five years later mid 2000s or now how the manifestation of mobile phone and internet have had happened. Do you know anyone these days around you who does not have a mobile phone? or who does not know how to use internet? my grandfather, he these days is using internet. Why this has happened? of course, this is popular of course, this gives us knowledge, but overall aspect is it is cheaper. So, nano bio photonics has to be cheaper in order for it to succeed no matter how beautiful the technology is if you are not able to benefit the common person in a cost-effective manner none of this matter. I am hoping that some of you may come up after reading this course after going through this course some innovative and cost-effective way. So, that this technology can be you know spread across the world.



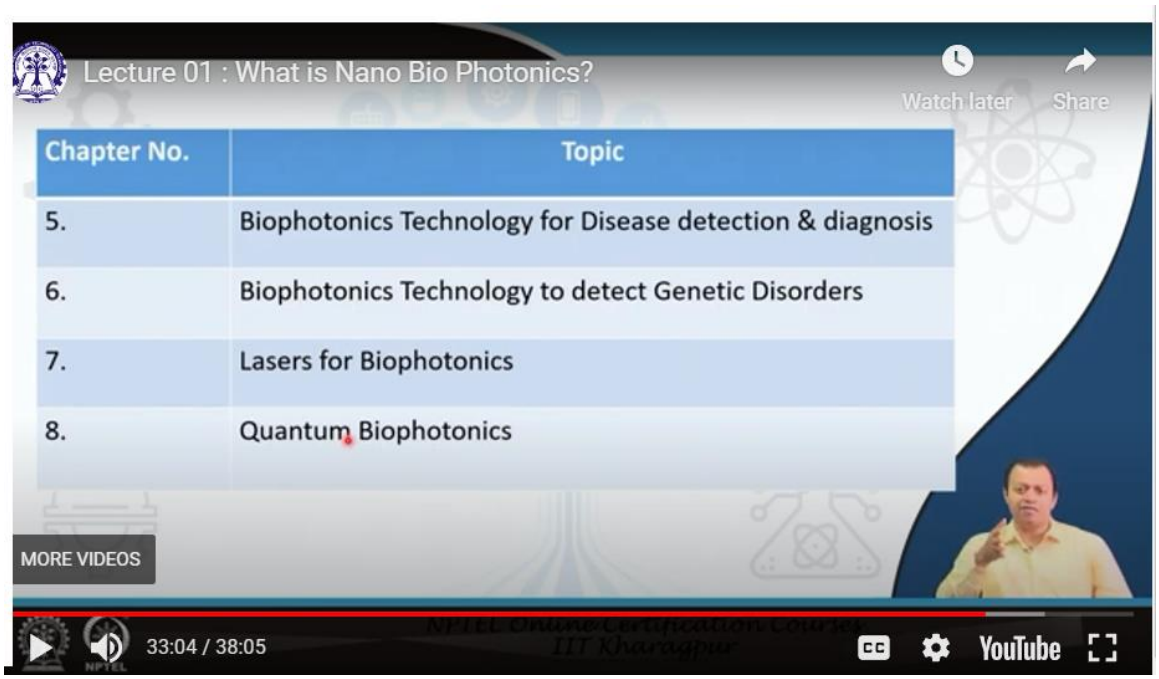
So, opportunities are everywhere since it is a nano interdisciplinary field it is not just for people from medical background or biotechnology background who needs to be interested in nano bio photonics, but people from physics and engineering will find this field fascinating in my opinion to understand how light and how nanotechnology could be utilized together to breach a frontier breach a frontier that engineers or physics or chemistry people chemistry most definitely, but not so much so in physics or engineering who generally think of. You know most of the time most of the time not always when someone is from engineering background electronics and communication engineering

computer science electrical engineering mechanical engineering their direct thought of applying their you know engineering craft is not necessarily towards medicine and biology. Electronics and communication whenever they are asked where you are going to utilize your skills your engineering skills I do not suppose that the very first list the very first name on your list is biology, but it could be. It could be and if you give me a chance I can show you I can show you how you can utilize your engineering crafts in medicine and biotechnology. Similarly, physics when you are searching for Higgs boson or you know Andromeda galaxies maybe something that have you have utilized to image black holes similar technologies can be imaged, can be utilized to image single cell or a single nucleus or a single DNA strand, DNA base pair, proteins protein fragments. If we can utilize in telescope can we not utilize that technology in microscope think about it. Similarly, for chemistry people you have been dealing with thermodynamics you have been dealing with different aspects of you know socio chemistry different aspects of materials chemistry, can your skills be borrowed utilized to create some sort of a nano material that is ephemeral how to say that that will evaporate or that has a time bound meaning this particular material will do its work inside the body and then it will be gone, it will vanish, it will evaporate, it will merge or it will be discharged from the body. Can those materials from the chemistry background be utilized to create some kind of a therapeutic solution? some kind of a solution a therapeutic cure for your for-disease manifestation to stop the disease from progressing. So, these aspects are available.

So, what are the concept that we are covering now I understand that few of you have come directly from ah my biophotonics course and few of you are curious about what needs to be what sort of things are different, is this the same course is it a different course. Let me tell you on the offset this is a completely new course this is a completely new course and there are certain aspects like everything else which is going to be similar, but then there are several aspects which are completely new and I think you are going to enjoy it. Those of you who are coming for the very first time welcome you do not need to know any previous courses of mine. this is a standalone course in itself I will be taking you from the basics. These are the three basic chapters I will start with ah in which I will be discussing preliminaries of biology preliminaries of photonics preliminaries of nanotechnology and thereby we will go further. thereby I will take you step by step. Those of you who have already done my biophotonics course and are interested and thereby have returned to this nanobiophotonics course I know exactly what you are thinking, yes I have gone fat it is just that I love cakes and I got invited to so many birthday parties you know after the lockdown there were so many birthday parties and I got invited to several of them and I did lot of cakes, but I will be doing exercise pretty soon.



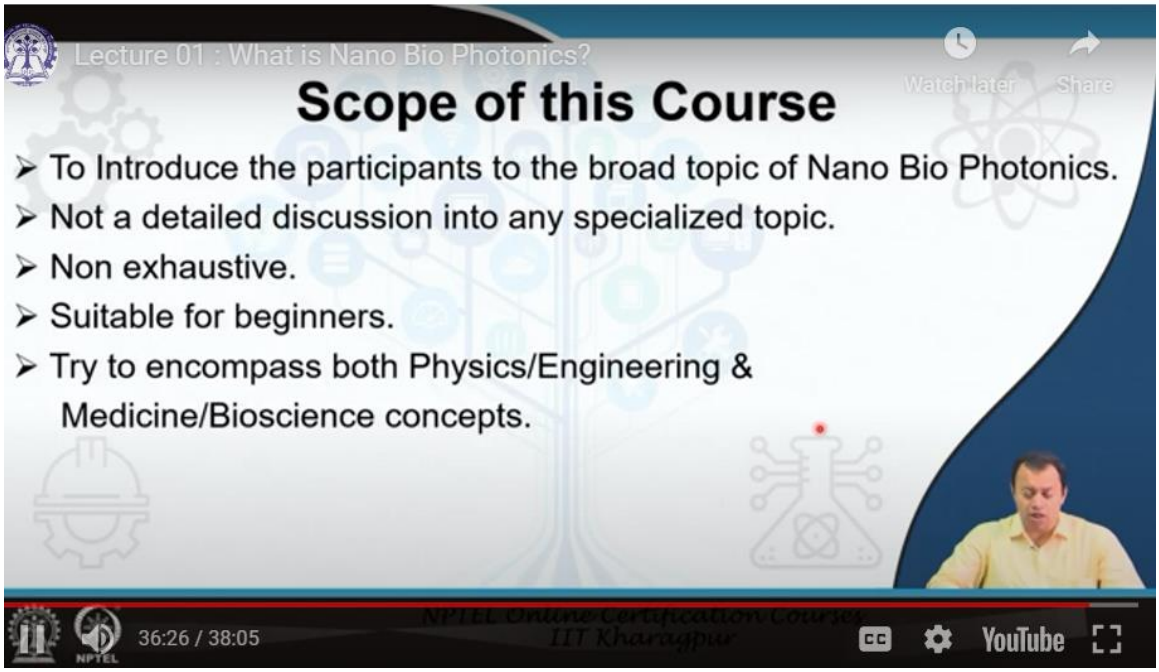
So, yeah so what are the new things if you ask so first three chapters are preliminaries I will be discussing the basics of biology, basics of electromagnetism, basics of nanotechnology. If you think you are too good for it, if you think that you know it by all means, skip the first three chapters let us go from fourth chapter onwards. Here we will be talking about imaging and spectroscopy, but the heart of the matter will be in 5, 6, 7, 8 chapters in this chapter we will be delving into the heart of the technology and we will see how nanobiophotonics or biophotonics technologies can be utilized for direct disease detection and not just any diseases specifically genetic disorders and how we can utilize lasers, but what I am particularly interested in is chapter number 8 which discuss with quantum biophotonics. Now several of you might be amazed to see what they are quantum photonics has been monopolized by the physics groups physics department physics field whereas, quantum mechanics happens to be one of the greatest achievements of humankind and it should not be restricted toward one specific field.



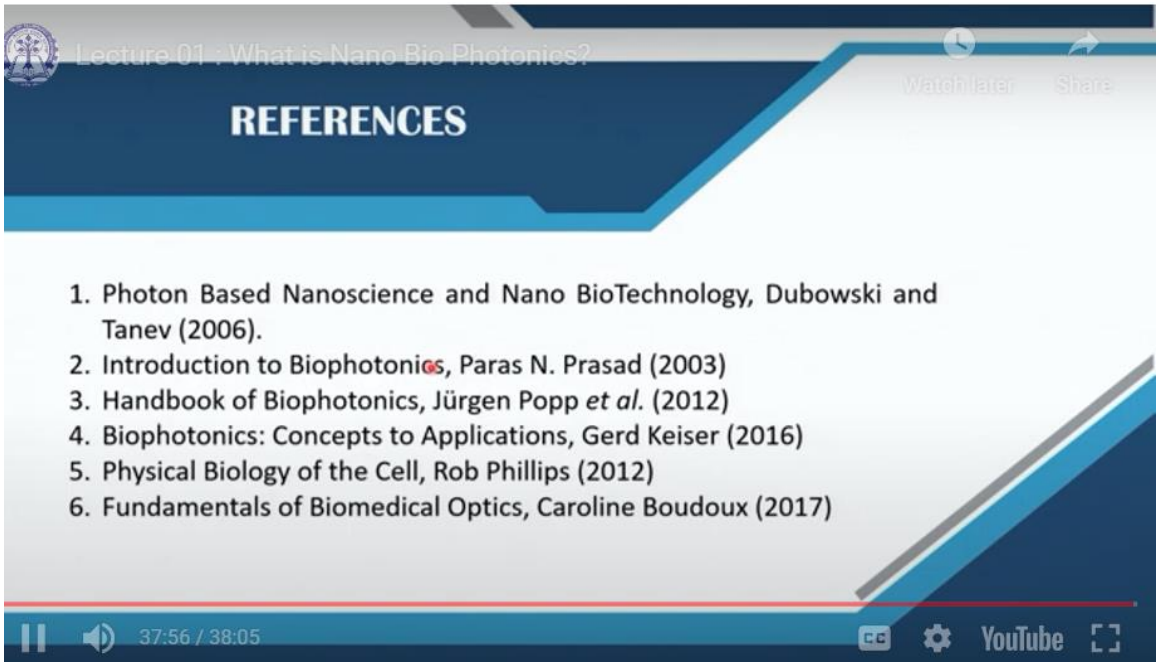
Usually just like engineering when you talk about quantum mechanics you do not necessarily intuitively think that quantum mechanics is going to have a direct bearing a direct consequence on biology, but trust me it does. Whenever you go into a nano scale level quantum effect starts becoming more prominent and thereby we need to borrow we need to ask the physics guys to help us understand what is happening in biological materials when we are at a single DNA single protein strand sub cellular level inside the nucleus. And there is a huge debate going on between the biology and the physics community of why or should we allow quantum mechanics to come in and what sort of quantum mechanics complications it will create in biological aspect because apparently these two do not talk among each other.

My idea here is to bridge that gap I am firmly on that area on that group which believes that any manifestation any advancement in a particular area of science needs to be translated into all other areas of science whatever affects us or one person directly affects everyone indirectly. So, quantum biophotonics is something that I am very interested in that I have to teach you I have to teach you genetic disorders and how you can detect I have to teach you disease and diagnostics and of course, I have to teach you about lasers. If this sound exciting to you let us go to the last four chapters here I will be delving into the human brain yeah, I will be delving deeper into the human brain. Human brain is the most complex material the most complex object the most complex thing humanity has encountered in this universe. There is nothing more complicated than human brain. Humanity is puzzled by its own brain we are going to delve deeper into neuroscience we are going deeper into this specific area of neuroscience which is called neuro photonics and optogenetics.

This is specifically how to understand how to image how to manipulate how to modify brain functions at a neuronal level using nanobiotechnology using nanobiophotonic technology using light using biological materials biological understanding and using nanotechnological materials. So, I am very excited to go deeper than I have previously been into neuro photonics and optogenetics. In previous courses those who are coming from biophotonics this was just merely I have touched upon optogenetics and neuro photonics as promised here I will be give going far deeper Those of you who are new do not worry I will start from the beginning I will tell you how exactly a brain works as much as I know and then we will go deeper into all three aspects. And then finally, we will be going on what is beyond the state of art what is the future overview and future direction.



I hope you will stay with me during the entire course we get to learn from each other trust me it is not a one way traffic it is very much suitable for beginners and a word of caution this course is not exhaustive I do not promise to make anyone a specialist in any specific field interdisciplinary fields are not there to make you specialist interdisciplinary field are there to teach you that what could be achieved, what could be achieved when you go out of your comfort zone. I will try to encompass concepts of both physics engineering medicine and bioscience none of us have a complete knowledge of all. So, do not worry whichever background you are from science you are welcome and if you know this is not going to be a mathematically intense course we will flow we will take a logical flow we will utilize mathematics when required, but it is not going to be mathematically intensive I will not be doing you know 5, 6, 7 slides of calculation mathematical calculations to prove a particular point. I will be utilizing analytical skills or I will be utilizing the flow of logic to give you a concept.



So, that brings me to the end of today's lecture I have merely touched upon the surface or give you an overview of what is required and ah I hope to see you some in the next lecture as well. Thank you very much.