Biophotonics
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Lecture No. 01
Introduction to Biophotonics (Part-I)

Hello and welcome. Thank you for joining. My name is Basudev Lahiri, and I will be your guide as we explore the topic of biophotonics together. Today is an introductory course. Today I am going to deal with the very basic of what biophotonics is and at the same time, I will describe you how this specific course on biophotonics is arranged. Let us start.

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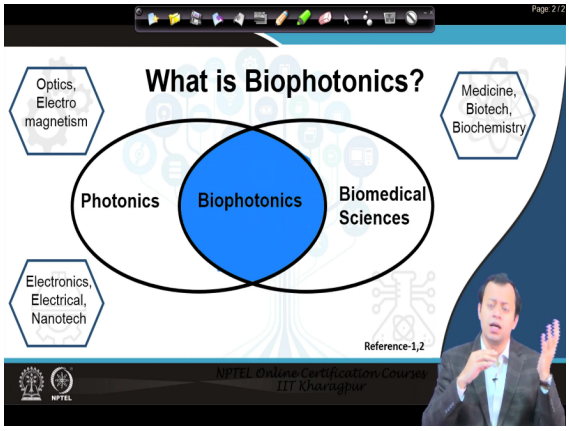

Now, what exactly is biophotonics? If few of you have listened to my introductory video, you will know that I have described biophotonics simply as a technology that deals with the interaction between light and biological material. I gave you two very common example of biophotonics— one being photosynthesis where light reacts with the chlorophyl present in plants and the chemical energy is formed, the by-product of which is oxygen, the same oxygen that we all breathe. Here, light or bunch of photons that are present in light are interacting with biological material.

Another prominent example of biophotonics is our vision, where light falls onto our eyes, the retina acts as a transducer, the optical signals are converted into neural signals, and our visual

cortex in the brain interprets these light signals into our vision, the perception to see this beautiful world. So, biophotonics basically encompasses or fuses together photonics on one hand and life science technologies, biological sciences together. Now, this is a technology, therefore, it has to have some sort of application. What are the applications of biophotonics?

Now, let us see what else biophotonics encompasses, apart from the technology part. Well, first and foremost, biophotonics contain the photonics part. Photonics as we all know is the technology that deals with modification or manipulation of photons. Photons are the quanta of light. Obviously, photonics stems from optics and electromagnetism. We will be discussing, but perhaps you already know that light has a dual nature; it has both wave characteristics as well as particle characteristics.

Photonics, basically deals with the particle nature of light. It deals with the quanta or the packet at the discrete level of basic energies of light which is called photons. And, photonics deals with the manipulation of these light particles, these photons for various applications, applications such as communication, optical fiber communication, - creation of laser, creation of light emitting diodes, several as such.

Electromagnetism is just associated with it, but electromagnetism mostly deals with the wave nature of light. Photonics, therefore, mostly encompasses the photon part, that is the optics part but also electromagnetism. At the same time, photonics encompasses engineering, especially electronics engineering, electrical engineering, these days computer science-based engineering are coming up. I will be discussing a little bit of that as well, but above all, nanotechnology.

You see, 1960s, have been a seminal decade for science or for engineering and technology. Several new technological breakthroughs came forward. During the 1960s, we developed laser; we developed optical fiber; Narinder Singh Kapany developed optical fiber; lasers was developed; Bell labs denoted photonics, they coined the term photonics where they found out that light or photon particles, that is the quanta of light, can be utilized to send information, photonics was developed.

At the same time, a seminal development was taking place in the field of electronics where they began to develop the so called integrated circuit or IC chips where you can miniaturize several different electronic components onto a piece of silicon chip which is hardly bigger than the size

of a coin. So, several of these technological breakthrough, technological development, allowed us to explore the area of photonics; area of nanotechnology; area of laser.

Now, while this thing was happening in the 1960s and the 1970s, biology was also not standing still. The biology was equally moving forward in the 1950s, they have developed the model? as well as understood how DNA and RNA works. They figured out gene, genetic mutation etcetera. Microscopy gave insight into the deepest recessesof cells and biology combined with biotechnology, bio-science, bio-chemistry was taking a quantum jump.

Now, it is but natural that two bourgeoning fields of science and technology has to overlap at certain point of time. And that happens in case of biophotonics. Biophotonics merged photonics which itself is an interdisciplinary field combining physics, electromagnetism, electro-optics, optics specifically along with the engineering background of electronics and electrical along with nano-technology with the biomedical sciences of biochemistry, biotechnology, and ,above all, medicine.

As I said, biophotonics is a technology course, it has to have an application, it cannot simply stay as a proof of concept It has to have an application. And the primary application where biophotonics is used, is in medical field. There are, of course, several other different applications of biophotonics which we are also going to explore, but for the time being, let us discuss about where biophotonics could be utilized pertaining to medical field.

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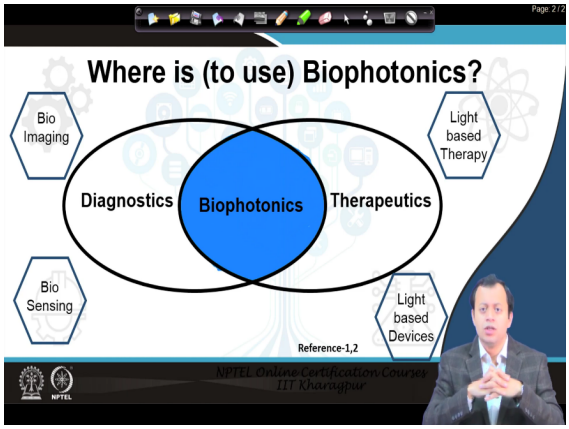

Now, the main application of biophotonics is two-fold. First is Diagnostics. We utilize light and interact it with biological material for early diagnosis. We want to detect diseases as early as possible. These can be diseases such as cancer or diseases such as pandemic, pathogen or vector born disease, like at this present moment, this is, end of the year 2020. And we are in the grip of corona virus pandemic, there is a possibility or there is potential in biophotonics for early and rapid detection of these viruses and the manifestation of these viruses into an infection.

So, biophotonics deals with early diagnostics. We want to detect, we want to sense, we want to identify different types of diseases. The other part of biophotonics is therapeutics. Therapeutics is simply put is cure. You not only want to detect a disease, but you also want to utilize light or photons to cure such diseases. So, both diagnostics as well as therapeutics combined is what biophotonics is applied for. A substantial part of this diagnostics is bio-imaging. In fact, the humble microscope that was discovered, I think in the end of eighteenth century which is still very popular and the most common thing in any of those pathological laboratories, biological laboratories, biotechnological laboratories has increased or has increased its capabilities by leaps and bounds.

That was the first direct evidence where we saw that photonic technologies applies to microscopy can be utilized for clear three-dimensional imaging of biological matter. That was the very first historical instances of biophotonics in action where the humble microscope was

utilized for measuring or sensing or detecting or visualizing what is going inside a cell. The microscope, the humble microscope that had a resolution of say few millimeters, now have resolution up to few micrometers. So, bio-imaging forms a very important part of diagnostics, which is the application of biophotonics in this particular case.

Another example is Biosensing. Now, when you are able to see something, you are obviously able to detect something, right? In vision, I used the term “perception”. So imaging or as the saying goes 'seeing is believing', you want to see, you want to detect, you want to identify and therefore you want to sense. Biophotonics enable us, this particular ability, we are able to see a particular virus present in say a tissue, a cellular structure, and thereby we identify that this infection has started happening.

At the same time, using bio-imaging, not just microscopy, there are several other techniques which we will deal with. With bio-imaging, if we are able to see genetic mutations happening in a particular area of tissue, we may be able to infer that perhaps cancer is setting in. At the same time, there is this topic of therapeutics. Therapeutics deals with curing. We are not only satisfied with simply identifying or detecting the anomaly, detecting the disease, detecting the ailment, but we are also interested to cure it. And we want to cure it using photons. Thereby, we can then have something called light base therapy. Light based therapy or at the same time, we developed light based devices.

Now, perhaps all of you have heard of this laser eye correction, laser eye surgery, LASIK is one of it. There are several other laser surgeries in which you correct some kind of astigmatism or cataract operation, these are all several times done with the help of lasers. So, we are detecting with a microscope that there is a problem. We are detecting with the help of other biophotonic technologies, not just microscopy, say optical coherence tomography, that there is a problem, there is an anomaly, there is a disease and then, we are using another sets of photons, another sets of technology, light based technology to cure it.

Example, light based therapy, example, laser eye surgery, laser eye correction. There are other such techniques - tissue engineering through light or perhaps you have heard of this laser-based hair removal, laser-based wrinkle removing, these are parts of cosmetic surgeries, strictly they are not curing, but they are modification. At the same time, biophotonics enabled us to develop

light-based devices. These are implants. Implants that can put say, in your eye, that can help you improve your vision.

There is a new term coming up these days called artificial vision where people whose, who are unfortunate enough to get their retina damaged and thereby their vision is severely impaired, we can develop light-based devices, so called artificial retina that will be implanted at the back of your eye, and that will help you interpret the light signals, thereby restoring up to a bit, not exactly, up to a bit, the vision of such a patient,. So, the utilization of biophotonics is both in detection as well as in cure.

Apart from that, apart from that, since biophotonics is a bourgeoning field, it is developing into the areas of biotechnology, it is invading the area of nano-technology, biomaterials, nano-materials for performing modification, genetic mutation, there is a topic which we are going to discuss at the end which is optogenetics or neurophotonics where we will see that not just we are looking for cure, but we are looking to modify, we are looking to modify a biological material using light. But generally, for intent and purpose, biophotonics is mostly applied for detection as well as therapy.

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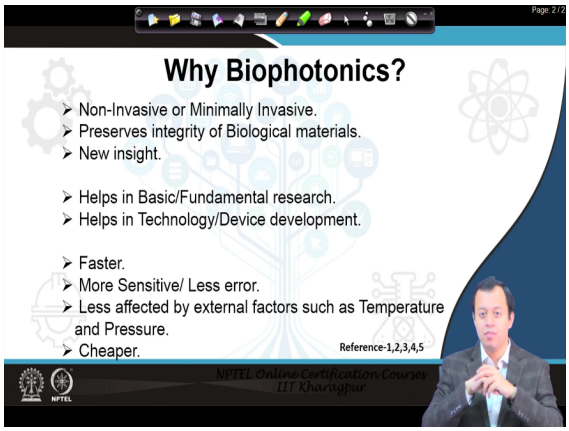

Now, why we need to do biophotonics? There are several other technologies, biophotonics is just one of them but maybe there are certain unique advantages of biophotonics that the other technologies are unable to provide. The most significant, in my opinion, advantage of

biophotonics as compared to any other such techniques, any other such technologies is its non-invasive or minimally invasive nature. You see, if we are trying to understand what is happening inside a cell; how the nucleus works or how different cellular processes takes place, it is a common method to take the cell out, put it in a petri dish and inspect it under the microscope, that is called(so called) the in-vitro studies.

Now, any biologist will tell you that nice as these are, there are certain time nuances of how a cell actually react inside an organism, inside the body of a particular, particular organism. We need to see or we need to detect or we need to image or we need to sense how these different cellular processes, how infection or how genes or all these biological processes works inside the organism. Biophotonics allows us to peek, to probe inside the organism without modifying or modifying very negligibly the overall environment or the overall organism. You see, it makes no sense to change the organism completely from one to another and thereby figuring out what exactly have taken place inside.

Biophotonics preserves the integrity of the biological material, it is no way destroying or taking that molecule or taking that cell out from the living organism in order to study it, though that can be done. Obviously, that can be done but here, the idea is to measure, to detect, to see something in its natural or native environment. And thereby, it provides us new insight, thereby it provides us how exactly a particular, say, cell organelle reacts, a cell organelle works and how it interacts with its neighborhood. Thereby, it helps us in basic and fundamental research.

Now, this is quite important. We need to understand fundamentally, at the atomic level or the molecular level how these materials, how these processes are taking place. Several other technologies fail to give us this insight in a very basic and fundamental level. Since we are not changing the overall environment, we can be absolutely sure through biophotonics that what we are seeing is actually how it is. And obviously, it therefore helps us in technology and device development. If we can understand what is causing a particular cell to mutate, maybe we will be able to reverse it, maybe we will be able to detect as well as cure the specific problem that is happening deep inside a cell of an organism.

Well, since it is photonics, since it uses photons, it has to be faster. In 1960s, in the Bell laboratories, when they coined the term photonics, they figured out that photons, the vibration of

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photons are much faster than electrons, the frequency in which the electromagnetic wave of a photon can vibrate is several order of magnitude higher than that of electron and photons also contains higher amount of energy. So, it is much easy as well as it is, you can have much more functionality with photon when you are transmitting information.

So, photons or photonic technologies is by definition, quite fast. And it is also more sensitive and less error prone, why? Because unlike electrons, light particles, photons, are less effected or not at all affected by external temperature and pressure. Those of you who come from electronics background know that electronic equipment, diodes, transistors etc fails at extreme environment, fails at say, space on inside extreme environment of mines.

Light has no such dependence on temperature or pressure to the best of my knowledge. And we can utilize light (photons) for very accurate detection of diseases and therefore, it is also much more sensitive. And then there this question comes, I should have put a question mark here, if biophotonic technologies is cheaper or not?

At this present moment, it is not. But it has shown huge potential that perhaps, one day, biophotonic technologies will be much cheaper than other biotechnology based devices, based techniques and it will help us cure human ailments much more easily, much more rapidly and much, at a very cost effective manner. At this present moment, this 'cheaper' term is arguable.I am not going to say that it is cheaper right now, but it has shown enormous potential that it could be quite cheaper in the coming futures.

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So, what are the opportunities for students of various backgrounds in biophotonics? Now, in my introduction video, I said that this is an interdisciplinary field and students from various different backgrounds, physics, chemistry, biology as well as electronics, electrical, mechanical, chemical, computer science engineering can use this elective as a subject at the same time, students or participants from biotechnology field as well as medicine field can utilize biophotonics as an elective subject and try to learn what are the new topics or what are the new tools available.

From a physics point of view, biophotonics will enable you to understand how biology work at a fundamental level. We can go for single molecule detection, we can see how these molecules are forming conjugates and thereby, how these bio molecules are overall giving rise to something we called as life. At the same time, physics can deal with the microscopy, the imaging aspect of biophotonics. Physics students will find it very interesting that how we have utilized light or light-based techniques to prove such deep, though light has a diffraction limit, but we regularly these days, break the so called diffraction limit of light to prove at an atomic or molecular level to understand what is happening at the very basic of all of these materials.

Chemistry students can see how we can go for different drug development, targeted drug delivery, you can from a biochemistry point of view try to understand what is happening inside the cell, inside the tissue, how a disease is manifested. Electronics or electrical or mechanical, chemical engineers can see how these different implants are made, the so called micro

electromechanical system MEMS or nano-electromechanical system, how they can be utilized, how you can make artificial vision. At the same time, how we can develop new techniques, new tools for curing as well as modifying the cellular structure, modifying biological material.

Biomedical and medicine people can obviously utilize biophotonics, to, for, as I said, rapid and early detection of a disease and cure as well as therapy, at the same time, modification of several such ailments. So, as you can see, people or participants from various background can come together and understand what biophotonics has to offer. And as I said in my introduction video, no matter what your background is, if you have the courage to break through your comfort zone of your already familiar subject, biophotonics, you will find in biophotonics something very interesting. It is there for every one of you.

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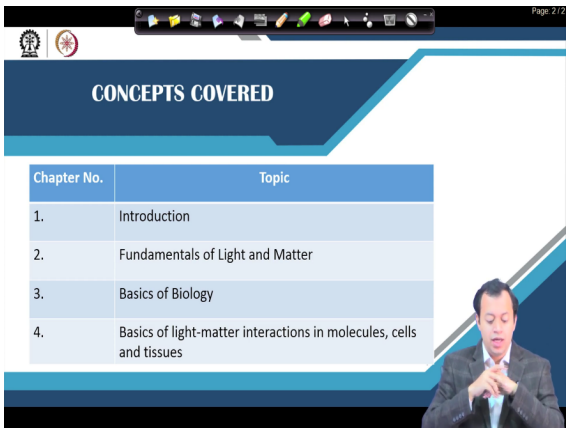

So, what are the concepts that I am going to cover in this topic? We are in the first few classes, this one and the next, I am going to discuss about the very basic of biophotonics; what is it, what it is there, where you can utilize it? And then, chapter 2 and chapter 3, we are going to discuss the fundamentals of light and matter as well as basic of biology.

See, the idea for this course is to encompass students from various background. I have to therefore, give you a refresher course on what you already know, as well as, if you are going to a new field, the very basic of that new field. So, the fundamentals of light and matter is mostly catered for students from a biology background, biotechnology background, medicine

background and the basic or biology is catered towards students from physics or engineering background. And then we will combine these two in chapter number 4, where we will try to see how light reacts with molecules and cells and tissues.

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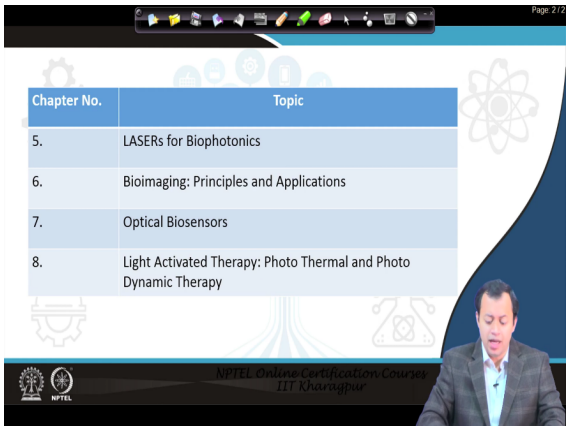

In the next part, we are going to start with the imaging, bio-imaging in chapter 6, chapter 5 is of course lasers for biophotonics. Development of lasers have tremendously helped us in the advancement of this particular field, photonics in general, biophotonics as well. The manifestation of imaging goes directly into optical bio-sensors where we not only are satisfied with seeing but we also want to detect and sense. So, optical biosensors are such a, such materials, optical bio-sensors are such a device by which we are going to sense what is wrong inside that organism.

Then, we are going into the cure part, the therapeutic part of biophotonics where we will discuss about light activated therapy, how you can utilize light to cure photothermal therapy and photodynamic therapy.

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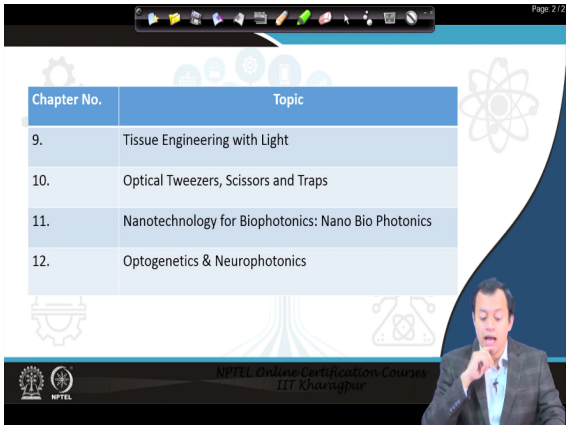

We are also going to see how tissue engineering can be done with light, how light can be used as a trap as a scissor, so light-based surgery. This will probably be very interesting for the surgeons and the students coming from medicine or dental background.

The last two chapters, nano-technology for biophotonics and optogenetics and neurophotonics, these are very specialized topics. This will show you what is in the future of biophotonics, where it will go in future. Previously, we were satisfied just with seeing what is inside a cell. Then we started detecting what is inside the cell. Then we started curing what is wrong with cell. Now, we are modifying what is inside cell and not just in cell but in tissues, inside DNA, inside RNA, nucleic acids, proteins, what not. So, these two things will be discussed in chapter 11 and 12.

We will also be trying to discuss about this bio-nano materials, these new materials that has come up, they get activated by light and they help you modify as well as cure several human ailments. That we are going to discuss in chapter number 11 and 12.

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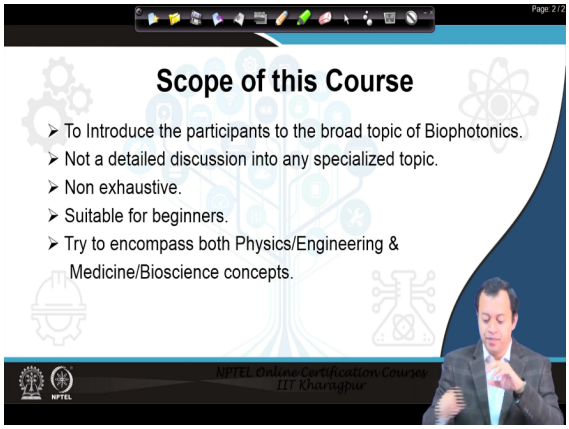

Now, very quickly let us discuss what is the scope of this course. This topic, biophotonics is an introduction. This is no way an exhaustive course. No way I can say that everything that is covered in biophotonics will be covered in this particular course and the main aim, as I am repeating myself, is to encompass or assemble participants from various different background and give them a peek of what biophotonics can be for them. This is a beginner's course and it is suitable for people who have lost touch with either physics or biology for a very long time.

Now, here I, since I have been doing this for a pretty long time, let me tell you the two most common complains that I receive on this particular course. And that is quite amusing. The number one complain I receive from the physics background students is, there is too much of biology. The same course get complain from biology background students that there is too much of physics. For the same course, physics students complain too much of biology, for the same course, biology students complain there is too much of physics.

Complain number 2 - physics students claim - there is very little amount of physics here. And biology students claim - there is very little amount of biology being discussed. Now, understand this. This is a default position. Every human being tries to stay in their familiar comfort zone. So, interdisciplinary subject by definition, you have to breach the boundary, you have to see what the other person or what the other field is going to offer.

These two complain come from this default position, this familiarity with something that I have done for long time and I want to carry on this forward and I want to have very little of the other topic into me. And that is not going to happen. We have to have the appropriate amount of both physics as well as biology to understand biophotonics.

Here, it is my intension to give you, in this particular course, a conceptual idea of various topics. This course is not going to be mathematics intensive; I will be mostly interested to deal with the concepts. If mathematics comes, it will be when it is strictly necessary. At the same time, the amount of biology and the amount of physics that I will be discussing will be basic level; I will start from high school because that is where you have probably last studied physics or biology if you are from medicine or engineering physics background.

We are going to start from that, make no mistake, we will not stay there. I am not going to just discuss class 12 or high school biology or physics, we will start from there and I will manifest or I will take it forward for an undergraduate or even post graduate level which will be, which it is my intension is for you to make sense for this particular topic. So, please be aware that I will be taking you out of your comfort zone and I urge you to help me out to resist staying in your familiar silos and come out to see how beautiful it is at the other side as well.

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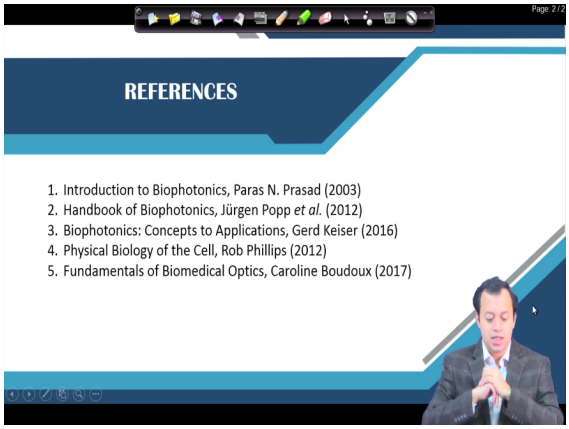

So, there are these 5 references, reference number 1, introduction to biophotonics by Professor Prasad is a wonderful book that I very much recommend. We all learnt from here. But there are

several other textbooks I would recommend you to read through some of them but it is my intension to keep the lecture notes or the lectures that I am going to teach, sufficient enough for you to complete your studies, to complete this course and pass your exam with flying colors.

I will be giving you assignments after 1 or 2 chapters which you need to follow. At the same time, we will have after every 4r week perhaps, live discussion. So, with this, I bid you farewell. Hopefully, we will see each other in the next class and let us explore the wonderful topic of biophotonics together. Thank you, thank you very much.