Biophotonics
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Lecture No. 51
Introduction to Nanotechnology

Hello, and welcome. So, we are almost at the end of this course this topic on bionanophotonics or biophotonics per se. I hope some of you are still with me. I hope I was able to teach you something that you had already forgotten. I have been able to revise or refresh some of the long-forgotten concepts and topics. At the same time, I believe I was able to tell you something new.

So, continuing that process, we are at our penultimate lecture. We are at module number 11 from a total 12 modules. And today is an equally interesting topic. Today, we are going to discuss about nanotechnology, nanotechnology for biophotonics. And today I am going to introduce you or giving you a brief glimpse peek at the wonderful world of nanotechnology.

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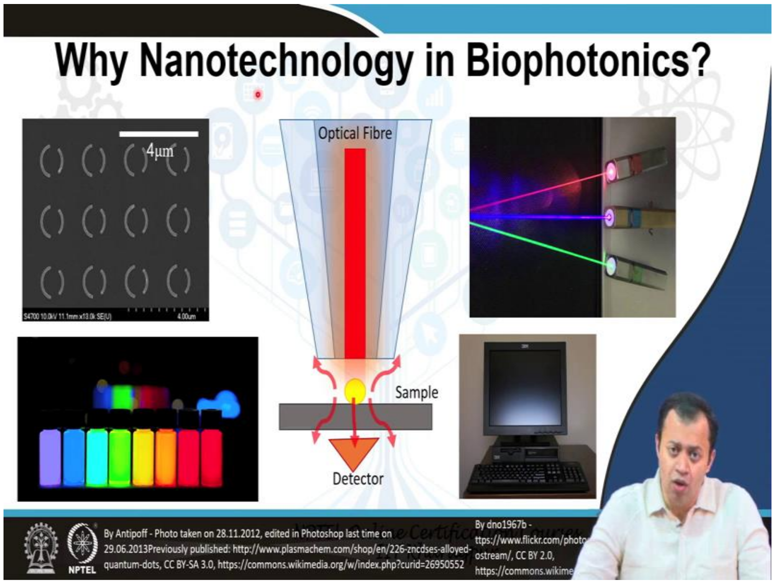

Now, obviously the question comes that why do nanotechnology and biophotonics. It is biophotonics, not necessarily bio-nanophotonic or nano biophotonics as I discussed previously as I mentioned earlier in the beginning. Well, the fact of the matter remains that I hope you are able to understand or remember few of these images from your previous lectures. And all of these equipments are possible to a large extent because of the technological advances made in the field of nanotechnology.

Frankly speaking, biophotonics or for that matter, with that regard, photonics itself would not be where it is now without the advent of nanotechnology. You remember this, these were the bio-nanosensors, the Nano sensors, which when coated with either DNA strands or some kind of an organic compound shows a different response, so these are basically optical, resonator acting as optical transducers. The fabrication of this was entirely made by nanotechnology tools. Basically, these are metamaterials.

Remember, this was the bioimaging, imaging in the near field where your sample and the distance between the sample and the optical fiber were very, very close to one another around less than 100 or 500 nanometers. So, this optical fiber tip as well as these very highly sensitive detectors, all were being possible to make with the help of nanotechnology. What about lasers? Throughout this lecture, I think more than one module, several modules we have discussed how lasers are applicable in surgery, medicine, cancer research, whatnot, eye surgery, etcetera.

All lasers, almost all lasers, these rays that you found has something or the other, created or fabricated using nanotechnology tools. These are quantum dots or these are fluorophores or chromophores that you use in either PDT or maybe fluorescence tagging, where you want to tag a particular part of a molecule with some kind of an exogenous fluorophore. Was it exogenous or endogenous? Let me know if you know. I have forgotten.

And the ubiquitous computer. The processor that you have in your mobile phone, that you have in your tablet, that you have in your humble desktop computer or laptop computer, everything, everything has been made because of the information, because of the technological leap, because of the knowledge, because of the skill that we have generated via nanotechnology.

So, again, let me repeat photonics for that matter in generally and biophotonics in particularly would not have been possible where it is now without having a proper knowledge, without having the required development of nanotechnology per se. Many of you know already what nanotechnology is.

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But the standard definition, according to the National Nanotechnology Initiative, is that nanotechnology is defined as manipulation of matter with at least one dimension sized from 1 to 100 nanometers. So, if there is an object with a length, breadth and height, at least one of that parameters, either length or breadth or height has to be between 1 to 100 nanometers. All three can be, two of them can be, but at least one of that has to fall in a nanometer scale range. And since it is a technology, it needs to have a specific application.

Again, since it is a technology, we usually will deal with artificially created material. We will manipulate things. We, so let us be honest, there are viruses and bacteria etcetera. that are already in nanoscale. A virus is not a nanotechnology. A virus is a naturally organic assemble or a bacterium or a swell is a naturally existing organism or something of that matter. What we are talking about in nanotechnology is either a material that we have created ourselves artificially in lab or at least if there is a naturally existing material, say for example, a virus or a cell of similar dimension, we are able to manipulate it according to our own will to a large extent.

So, all the matter the nanomaterial part, the material part comes in as well as the technology to change, modify, manipulate is also within the overview, within the purview, within the ambit of nanotechnology. So, thereby imaging comes up, where you are able to take near-field imaging, so imaging or bioimaging or near-field imaging are also part of nanotechnology. And not only just the imaging concept, but everything associated with it, the detector, the stage, the measurement device that brings in very close to the surface, all of that comes up over, under the overall ambit of nanotechnology.

And most importantly, it needs to have a specific application. Without any application, without any viable application, without real life purpose there is no point of having a technology. What is the point of having a technology which is only for academic purposes, which does not solve any real-life problem. What real life problem? Well, as you by this time now, in biophotonics, we are looking to cure human diseases. Several human diseases are being cured. So, we will utilize the same thing here that nanotechnology is also being used for several practical real-life application.

Many of you might have heard about nanomedicine. Many of you used nanotechnology-based product, like as I said, your computer, your laptop, your mobile phone, your tablet. Many of you see that is happening in some kind of a GPS navigation system. The overall network that I am talking about happens to be because of nanotechnology. Nowadays, they are making these drones, these very small flying objects.

Well, very small as compared to a large aircraft for that matter, different types of processor, different, automobile, self cleaning glasses or the glasses that changes its color upon excitement by light, LCD displays, all of these things. You name it. You cannot escape nanotechnology around you. Several materials, several equipments, several technologies, if you take a look around is because of nanotechnology. And nanotechnology utilizes usually either makes materials of a size in the nanoscale or manipulates material of the size of the nanoscale.

Curious incidence why nanotechnology is used in biophotonics, because this particular size 1 to 100 nanometer or even 1 to 1000 nanometer, 1 nanometer to 1000 nanometer that is 1 micrometer is where several of your biological compounds already exist. So, for example, a virus is 100 to 200 nanometers, you already know, DNA is a 10 nanometer, hemoglobin is somehow smaller 5 nanometer. This is a large chain of DNA, whereas hemoglobin this is a single part of DNA. Then bacteria are 1 micrometer, little bit bigger are 10 micrometers are these red blood cells etcetera.

So, several biological materials, several biological matter, for example, cells, organelles, viruses, nucleic acids, all of these things, say for example, glucose molecule here all of them, liposome, all of these falls in similar ranges as where nanotechnology mostly deals with. So, it makes sense that if we are able to have a technology, if we are able to use a technology that already manipulates object of that particular dimension or if that technology exists that can make something artificial of a size that is comparable to something of a, already naturally existing and their interaction could overall result in some kind of modification.

Say for example, you make a nanomedicine or a nanodrug whose size is similar to that of a virus and that is preventing the virus from doing its work. That is preventing is the virus either from infecting, by preventing it from hooking on to the cell membranes or preventing the virus from replicating inside the cell or preventing the virus from hijacking the cellular machinery, cellular reproductive machinery. So, there already exists certain matter or certain technologies by which they can interact and thereby your purpose in this particular case in biophotonics curing or detecting human diseases could be done.

You have made a material based on nanotechnology whose size is relative to the size of say a single virus or a single protein or a single bacteria, which upon contact with the virus, upon proximity, upon closeness with the virus, with the pathogen, say its property changes, for example, a fluorophore, which usually emits light upon contact with a virus, upon having a biochemical reaction with the virus, it is gets quenched and it stopped emitting fluorescent light.

And thereby, you can see a before or after image, you can have some sort of a detection or if the light gets emitted at a different wavelength. Previously it was emitting something green. Now, it is emitting something at red and this can only happen when the fluorophore has undergone a biochemical reaction and you can make this reaction very, very specific. This reaction can only happen upon its contact with a specific viral protein. So, you are thereby detecting a virus and thereby, there is early detection and what not.

You can look at DNase, for example, we have made probes which can look into DNA. I told you about it in my metamaterial, biosensor, where we can have an artificial sequencer. We can have a sequencer which behaves differently depending on the different type of ATCG sequence of the base pairs in a particular DNA molecule. So, several of these technologies, several of these mechanisms, several of this equipment, several of these tools can be done using nanotechnology.

How do you think we are able to use optical tweezers? How do you think we are able to do optical tweezers? You have to perform it under certain kind of a, you are manipulating a material of a very small size, a nanoscale size. You are lifting it up. You are trapping it. You are drilling through it. What not, remember previous class. All of this thing is possible because of nanotechnology.

So, how did this come? I mean, how were we able to come to this technology? Where was this present or where did it arrive from? Well, no matter what the physics people tell you. Let me give you categorical answer that the advent of nanotechnology can directly be claimed by us guys from the electronics engineering department from the field of electronics, basically microelectronics. Microelectronics or microfabrication or nanofabrication were the precursor of nanotechnology.

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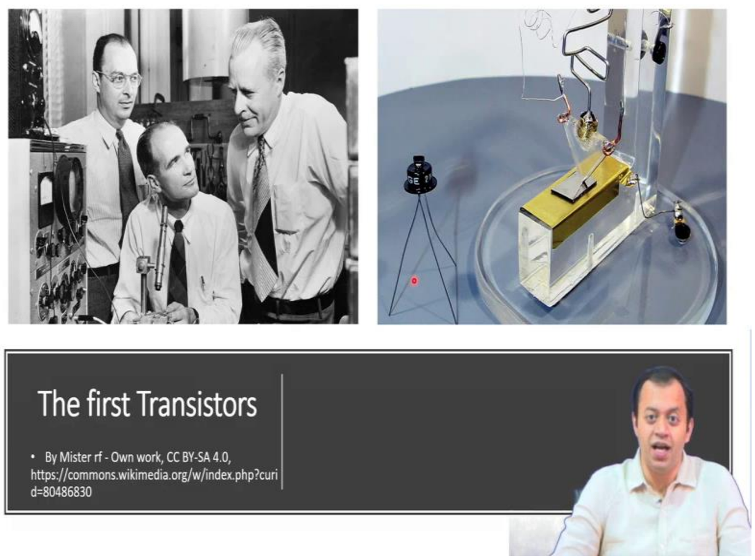

So, if a physics guys say that it was their work, you need to tell them that no it was our work. I know I previously said that we should not have this division in science, but I take pride that I belong to the category which these geniuses were. These were the people Shockley, Bardeen and Brattain, who made the first transistor, the first point contract transistor in 1947. And then they made, this is a replica of the original one. This is the replica that they made in Bell Laboratory. This is the first bipolar junction transistor.

Electronics students now be chuckling they know all about bipolar junction transistor, I mean, that is their bread and butter, bipolar junction transistor, field effect transistor. For those of you who had forgotten, it is basically a PNP or NPN transistor. So, this was the very first replica of the very first transistor that they made, before this, 1948, this was made in 1948, before this, it used to be valves. You do not need to know about valves, because they are extinct like dinosaurs have stopped existing. Similarly, valves in electronics have stopped existing.

This is a bipolar junction transistor. This part is a plastic. This part is simply a plastic. So, do not worry about that. They have a germanium semiconductor here. The germanium semiconductor is glued to a plastic. They have shouldered some point contact gold here and here at the two sides of the triangle. And the base, this base part is also somewhat of a gold. This is the germanium PNP junction, so different parts, different types of doping. This part to the best of my knowledge is emitter, this part is collector and this part is base, and they are the strings that are connected together.

So, this was the first bipolar junction transistor. It exists in the museum. This is a replica, but there are most museums have replica of famous thing. I think the original work actually got destroyed. And see how they have shouldered it and these are the springs and inductors and whatnot that has been connected. The first semiconductor device was first semiconductor-based transistors were actually germanium-based. It is only after the knowledge of silicon came into fourfold that electronics industry boomed and with that microfabrication boomed.

And finally, with microfabrication, the tools and the techniques that were developed in basically IC design, integrated circuit design, chip design combine it with different aspects of chemistry, different aspects of physics, different aspects of somewhat of an architecture, yes, even architecture, mechanical engineering, i.e., microfluidics, nanofluidic, optofluidic, the physics part that this microfabrication tool, microfabrication technique started growing to what nanotechnology these days are.

But never forget it started by these guys who were trying to make a transistor in their laboratory, in Bell Laboratories and this is the copy, replica of the very first transistor that they made around 1948-49 as such. But obviously you will not have a transistor in itself. You need to make a circuit out of it. You need to have a circuit out of it. A transistor needs to amplify particular signal or some sort of a network needs to be made.

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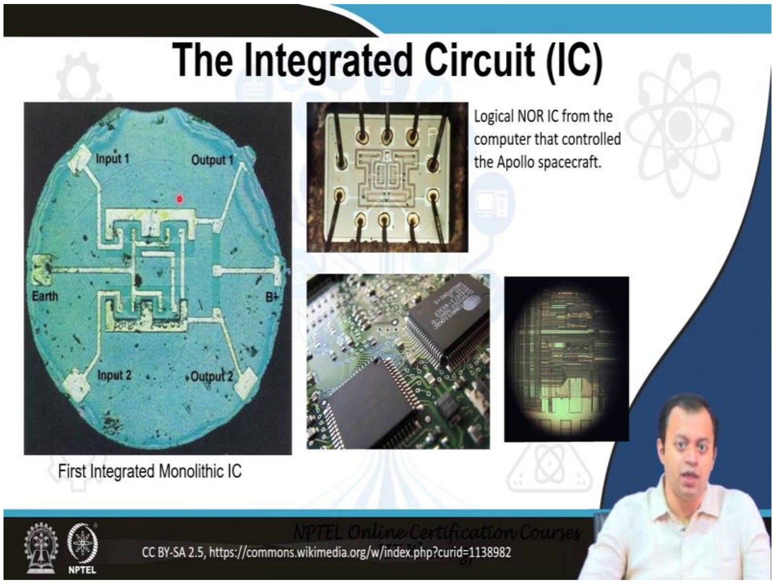

So, thereby, came the advent of the integrated circuit or IC. All of you know what ICs are. You find it everywhere from festival lighting that happens to your mobile phones to your sophisticated camera. Any electronic equipment these days, any single electronic equipment these days uses an IC. And this happens to be the first IC I think patented by Noyce in 1960, - 1961. See how many components are there. These shiny parts are merely aluminum connect. And this entire piece used to be something like a coin, the currency, the coin that we have, a dollar coin or a few cents that used to be the size and he called it integrated monolithic IC, i.e., all the elements were put in one single chip, one single element.

Previously, you have to have different things here. This was the semiconductor. But you are connecting the base separately, the emitter separately, the collector separately. Here the transistor, along with the resistor part, along with the resistors that interconnect all of them were put in the same lumped element, all of them were monolithic, monolithic means single stone, in one single chip. So, a same part of the chip is acting as a transistor, a slightly different part of the same chip of the same piece of the same block of the same piece basically is working as a resistor, is working as an inductor, is working as an interconnect.

And how or where did this idea come from? They came to know that when you have an electronic device and electronic circuit, there is some sort of an energy dissipation in these connecting wires. Electrical and electronics engineering student know when they draw circuit diagrams, you make a small wire, you make an interconnection and you think that the voltage drop across them is nil, because the wire, the resistor is connected with a emitter or a base or a collector, it is the voltage drop is only across the resistor and the straight line that you are drawing instead of the zigzag resistor, the straight line that you are drawing, it has no resistance.

In fact, it is considered as a short circuit if you forgot to put resistance in your circuit diagram. Your teacher might scold you that this has short circuited itself. But in real life these wires have a particular finite amount of resistance. And if there is a resistance, there is a voltage drop, some amount of energy dissipation.

So, people thought that if we can lump all together, we have silicon, different areas of doping of silicon, make it different conductive, and you can make different conductivity. We require different conductivity when it is a PNP or NPN transistor, base, emitter, collector, are of different resistivity, different conductivity, remember that. We can increase or decrease the resistances of a semiconductor by doping and manipulate it. That is the whole point of semiconductor.

Silicon started getting very cheap, because we developed the technologies to make ultrapure silicon. And silicon is, I think, the second most abundant material on earth crust. So, everything came together and we started making more and more monolithic chips were in the same piece, in the same element, you can have multiple amount of electronic devices. The same piece, different areas can act as a resistor, an inductor, maybe a capacitor, maybe some sort of a transistor, maybe a diode, whatnot. And this was the IC that controlled the Apollo spacecraft. Think about it.

This was the IC that controlled the Apollo spacecraft, but now the humble mobile phone that you use in your day to day life has more technology, more processing power, more technology, more number of transistors, more number of circuits than the entire computer set that was able to send a man to the moon and return them back. Let that sink in. The mobile phone that you have in your pocket right now has more processing power, has more circuitry, has more, can store more amount of information than the entire computer or entire sets of computers that were used in Apollo spacecraft in the year 1969 that took Neil Armstrong and their friends to moon and return them back safely.

This is your humble circuit that you see in any motherboard. This is your humble nanotechnology-based processor. And if you take away the package and look through it, you will see these millions and billions of this transistor. So, from 1960 to 1990 or 2000, we have taken a quantum leap. We have taken a jump. And this was all IC design. Previously, there used to be 4 or 5 elements in an IC. Now, you have couple of billions of circuits in one single chip.

And I do not think anyone of you do not know the Moore’s law. This has been used in t-shirts to everywhere, popular culture. Moore, Gordon Moore said that, every 18 months, one and a half year, the total number of devices, total number of circuits, the total number of elements within a chip doubles and its size half. But it is not a mathematical law. It is more or like a forecast type of thing. People swear by its veracity. But when he started it, it was more of a prediction, like you predict weather. So, he tried to predict in the future. It is not an absolute law that this thing can happen only in 18 month or up till 18 month this will happen something like that.

So, you all know what Moore's law is. If you do not know what Moore’s law is or if you have forgotten, just make an Internet search. I do not want to discuss Moore’s law in this particular case. But you understand that the precursor was integrated circuit. We were able to develop technologies that was packing more and more functional materials in a very small area. That was packing, that was fabricating, that was making, that was creating functional devices of very, very small sizes, yet they were powerful.

How big is your mobile phone as compared to the previous computers? Do you know, previously in 1950s or 1960s the computers used to take up an entire room? Now, you have I think 100 or 1000 times more power than the computer's processor in your pocket, in your mobile phone. So, that is what all of us need to acknowledge that where it has come and where are these things made.

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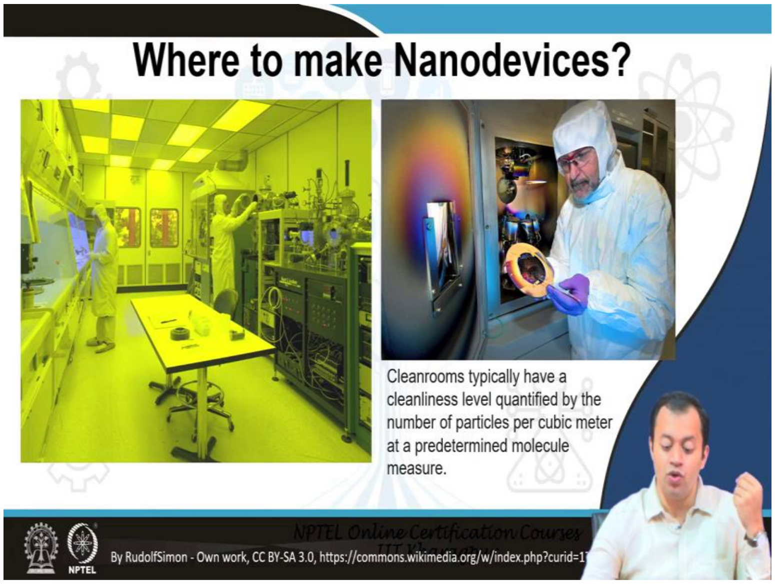

Where exactly are these nanodevices made? The nanodevices are made in specific rooms, specific laboratories, specific environmentally controlled areas, which we call as clean rooms. They typically have a cleanliness level quantified by the number of particles per cubic meter. So, the total number of dust particle per cubic meter of this air at any time gives you the class of this material and you wear these sophisticated suits. Nowadays, we call it PPE, personal protective equipment.

You have probably seen people wearing it for, in biology to prevent themselves from some kind of a viral outbreak, but this has been used for a long time in microelectronics industry, nanoelectronics industry, and they use this sophisticated equipment. The light is yellowish. I will tell you precisely why the light is yellowish, because it helps in lithography. In printing these devices, they make this silicon chips, silicon wafers. Each of these wafers contains circuits, processor circuits, which then go a piece of this, a small piece, few millimeters by few millimeters goes and makes part of this kind of chip, which when looked internally looks like this.

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So, this was the basic introduction to nanotechnology. Actually, I am telling you about microfabrication, microelectronics, but we will build upon this and we will see that how nanotechnology came to know, came with the help of microelectronics per se.

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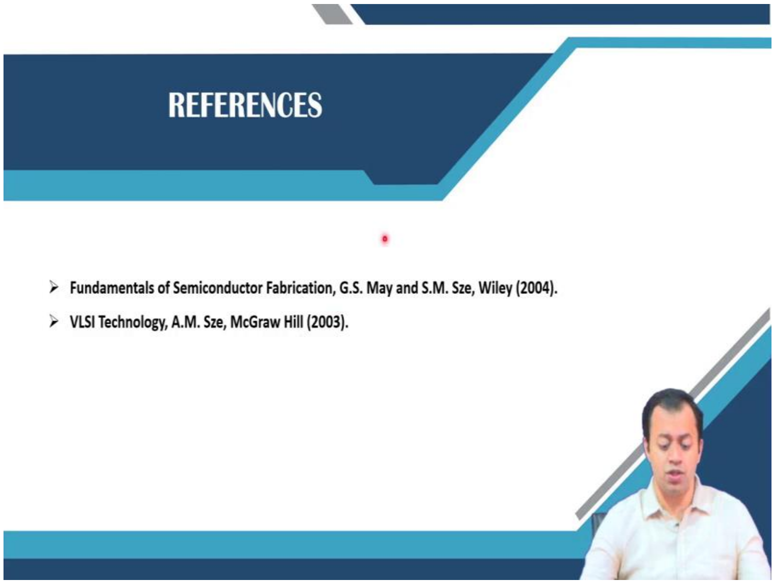

So, these were some of the fantastic books that I am referring to. But these are mostly towards VLSI, very large-scale integration. Maybe the electronics students already know. They have already utilized them, maybe even the physics people. So, try to look into them. They have beautiful, beautiful pictures of this chip making processes.

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So, I will see you in your next class. Thank you.