Physics Seminar

April 15, 2019

>>: Okay. Everyone, can I have your attention? I want to introduce our speaker today. This is Ooman Varghese. He is an associate professor at University of Houston and today he's going to be talking about nanomaterials. So I want to give a little bit of his background. He has his Ph.D. in physics from Indian Institute of Technology, which is which is, you know, one of the absolute top science engineering schools in the, you know, whole world. He's currently an associate professor of physics at University of Houston. He's been there for how long?

>>: Six years.

>>: Yeah. And his group is primarily focused on developing nanoscale materials and heterostructures and investigating kind of the unique properties of these materials. And when I say nanomaterials, I mean things beyond carbon nanotubes. But they've made nanotubes out of many different materials, which I'm sure he'll talk about. I think this is your second talk here?

>>: Yes.

>>: It's the second time. He gave a talk a couple years ago when we were back in the old building. So with that, I guess I'll turn it over to our speaker.

>>: Thank you, Professor David. Good evening.

So I would like to talk a little bit about what we are doing in our lab, and in connection with the topic of today's presentation, which is materials at a nanoscale. So before I -- what I'm going to do is to give an overview of why we are doing this study and what are nanomaterials, what are the unique properties we have observed in our research.

So, I hope all of you are in physics -- have a physics background. How many of you are engineering background? All physics? Okay, good.

So then, materials physics is an interdisciplinary area. So there is not only physics but engineering and also other subjects also, like chemistry, biology, and other. So we have a cocktail of everything when we go through the presentation. So stop me anytime if you have a question, and we'll discuss there. And if you are sleepy, also, raise your hand. Then we can have some exercise.

So, we have a remote, David? Remote or just --

>>: Oh, just press the keyboard.

>>: So my lab is a nanomaterials and devices laboratory. They deal with all of the nanomaterials and all of the devices and processes based on these materials. So let me

start with the -- what is the nanostructured material. I know most of you are familiar with most of this nano-- the term nano. But in the field, the broad field of condensed matter physics, and materials as a solid state condensed matter physics and nanomaterials comes under this topic of solid state physics. So what is a nanomaterial? The materials with the dimensions at least one dimension, plus in the range of nanometers or in the nanometer scale. Usually we say the size is (inaudible) nanomaterial.

So depending on how the material is confined in space, we call it a zero, one, or two dimensional. For example, if you take a very thin sheet where the thickness of the layer is in nanomaterial or an angstrom, we call it -- the other two dimensions can be anything. It can be millimeter or kilometers. But still the thickness is less than tenths of millimeters, we call it a nanometer material.

One dimensional material -- so this is an example of a two dimensional material. We will discuss this material in particular later but you can see that this is a sheet, very thin sheet but it is extended in micrometers.

The other structure is one dimensional. The length can be in microns or millimeters or anything but the diameter. For example a wire. If you take the diameter, should be in nanometer. So the example is a nanowire. This is a silicon nanowire and the other is a nanotube. Nanotube is sometimes called a quasi 1 dimensional material because it is a circular shape. It is different from the hollow circular shape which is developed in the nanowire. But generally these are one dimensional nanomaterials. And then finally the zero dimensional, which is the nanocrystal, these are used for the nanoparticle. Generally the dot has a dimension less than 8 nanometers, 10 nanometers. So there it is zero dimension because it is confined in all three dimensions, all three -- especially confined in all three directions. So this is why it is called a zero dimensional material.

So this have only a few -- for example, if you take a nanoparticle or a quantum dot, there's only a few hundred atoms in that. That means we are utilizing some of the unique properties of the atoms. That is the benefit of these nanostructures. We can find some of the properties and exploit it for different applications which we are interested.

So these are the three different types of nanomaterials. So in our lab we utilize these properties for primarily three applications. One is solar fuel generation. There are two things in the fuel generation process we are interested in. One is water splitting, the other is carbon dioxide to fuel conversion.

Then the second project is the hybrid solar cells. This is a recent type of solar cells. And the last application is the sensors for medical diagnosis.

So we will discuss this briefly. I don't want to go into too much details. So I don't want you to be bored with all these research specific things.

Now, what is the benefit of low dimensional architectures? So if you take this nanotube, the center one is a nanotube. So there, the -- this particle material provides tremendous surface area. What do we mean by that? Surface area? If you take 1 centimeter, (inaudible) say array of nanotubes confined in 1 centimeter square and if you unfold these tubes into sheets, if you cut this to make sheets out of this tubes, the area we get is much,

much more than the 1 centimeter. For example, if you take a nanotube of a length around 20 nanometers and we unfold it, we'll get thousand times the area it occupies, flat area it occupies. That means lot of surface for to observe light or to do the chemical reactions or whatever we want to do, we can use -- we can do with that surface area, if it is surface area related.

The other properties, some of these materials can transport the charges very easily through this material. So for example, if you take light absorbing silicon conductor nanotube, (inaudible) and holds. The electron, some of the materials pass electrons easily through the material, whereas the holes can be supplied to the surrounding for oxidation reaction. So this is what is used in (inaudible). This is the case of one dimensional materials. So the two dimensional material, one example is graphine. I don't know if you know, it's (inaudible) graphite. So we take graphine, and again there are a lot of properties unique to it. We are interested in a lot of these materials in the shape (inaudible) materials.

So these materials also, (inaudible) the quantum dots or nanoparticles, they can Exhibit the charge transfer much faster, or they can show the quantum confinement effect. That means effects will be much, much evident in the case of nanoparticles. A good example is the (inaudible) radiation. If you take a material that involves light up to the (inaudible) region of the spectrum and if you take this bulb material very, very small to the quantum dot, that means it can no longer absorb the red but it can absorb blue or green. So we can tune the light absorption of these materials by just tuning the (inaudible). This is a well known, well-proven fact. So I'm not going to into the details of that.

So this is one example of a nanoparticle. So this nanoparticle, this picture is from -- I don't know how many of you are familiar with solid state physics by Charles Kittel. So probably when you learn solid state physics -- that is one of the (inaudible) books for graduates and undergraduates.

So here you can see (inaudible) the reconstructed images of the atoms. We can see, we can count the atoms from the nanoparticle. Besides maybe a few nanomaterials, but we can count. Nanoparticles can have hundreds or thousands of atoms. Less than that. So that is a unique property.

This is (inaudible) microscope image of the nanoparticle. And why the nanoparticle or a -- an example I can tell, so this particle absorbs light, solar spectrum, then we can use it for water splitting. Of course (inaudible) a few other criteria. Assume that all other criteria are satisfied, but we have a nanoparticle of such material. So we shine light. So what happens is it charges our generator. (inaudible) the electrons in the (inaudible) will be excited by the light to the conduction band. So the electrons can move and across the the reduction process. The positive charge can do the oxidation of the water. The problem is that the (inaudible) is too large.

If you take a micron sized particle, this charges, electrons and holes generated by light can recombine and lost. That means they cannot do any chemical reaction. That is of no use to us. So if you reduce the size to a dot or a nanoparticle similar to this, the charges can immediately get transferred to the surface because the surface is not far from where they are generated. They can move to the surface and the electrons can cause the water to reduce the water and the holes can oxidize the water. So that is how the hydrogen and oxygen are generated. So nanoparticles, this is one of the unique properties of the nanomaterial.

Now, why we are doing all this nanomaterial, just for the curiosity of what is going on in nanomaterial or (inaudible) other recent for investigating these nanoparticles. This is a picture when I went to Los Angeles. This was in the news and this is a picture showing the pollution and the smog in LA. This is not only a problem in LA, but this is a problem all over the world now because of the -- several reasons. One is the particulate admission. Particulate are very small particles. So that kills around 3.3 million people per year, just because of the particulate pollution.

And the particulate PM2.5 is the sides appliance 2.5 micrometers. These are really helpful. So those are the main leading cause of this problem.

Second, atmospheric carbon dioxide is increasing. So, you know, what is the current level of carbon dioxide in the atmosphere?

>>: (inaudible).

>>: It is much more than 300 now. Now it was -- a few years back it was 300. And I think if you take the history of the earth, most of the time it was around -- close to 300, 280 parts per million. And a few years back it was 300. Now it is 410. It is increasing very fast.

Another problem with the pollution is high ozone level. So higher ozone level, in LA that is a big problem. Ozone is created by the reactions of (inaudible) automobiles, countries, and all those. These are real problems, and it is increasing.

This is the particulate -- the map all over the world. So you can see here the particulate based pollution is much smaller in red regions. US is much safer compared to this, but (inaudible). So this is the severity of the pollution.

Now, what we do, this is one of the side work we do. This is in collaboration with (inaudible) university in Japan. What we did is we studied what is the effect of the nanomaterial on the human body or living cells. So we studied the toxicity of this material. So this is a nanotube of titanium dioxide. If you go to the grocery store and get some food and see the ingredients, you can see titanium dioxide on it. That is used as an antifun gal in a lot of things. But when we did the toxicity studies, we found that the nanotubes can penetrate the cell and go into the cell and destroy the nucleus. That means it is genotoxicity. So it can destroy the nucleus. So that much -- that is (inaudible) material in the bulk form when it became a nanomaterial. It has this problem. But there are opportunities. So that means we cannot just inhale all this nanomaterial. Some are very toxic. We have to be very careful. Even if they are benign in the bulk form.

So, but we are thinking of using it for cancer treatment without drugs. So it can kill the nucleus, and we plan to use that property.

Now, coming back to that particulate air problem, coming back to the carbon dioxide problem, so this is the arctic ice coverage. So you can see the line. This is the average over several tens of years. And this is the -- this was the coverage in 2018, a few months back. So this means (inaudible) the coverage, ice coverage is decreasing. And the Antarctic coverage also is not very impressive. There also there's a change in the coverage of the ice coverage in this region. So if you want more details -- so if you see the graph, how the extent of ice is reducing, this is the graph. From 1980 to 2016, almost linear (inaudible).

So now, so if you need more about this, you read this article, it's a very nice article about this. But why do we need to worry about these things? Why physicists need to worry about this?

>>: (inaudible).

>>: Yes a lot of -- there is the main problem, one of the problems (inaudible) arctic ice decides the (inaudible) circulation, the ocean current. The gulf stream going through the Europe to make the (inaudible) that is no more there because there is no ice for the hot water to float to the arctic region. So these are real problems. Earlier it was a matter of debate. Now it is a real problem. It's (inaudible).

So this -- the unit of measurement (inaudible) a panel to report about these problems, and this is -- if you are interested, you can read this report. It's available online. This is IPCC on climate change. In 2015, they said the increase would be around 1.5 degrees Celsius but that is enough to cause a lot of problems, putting a lot of land under water and creating a lot of problems in the whole world.

So I'm not going to into the details of that, but if you see the correlation between the carbon dioxide and the global temperature increase, this is the average -- the temperature that has been there are for centuries or millennia. That is the base level. And from 1980s, it's almost linearly increasing. The average global, average temperature. Now, you think that is maybe just a -- a few years -- it can come back. But if you see the carbon dioxide emission, you can see the correlation.

See, this is the carbon dioxide emission, until around 1950s. Then when we started using coal -- we were using before but started using oil (inaudible), it is increasing. Now you can see the slope of the carbon dioxide. And this matches very well. If you overlay, it matches very well. So that will clearly say what is the effect of burning the hydrocarbon fuels.

So now if you burn the octane, pure octane, there is an oxidation process. So when you burn octane, what do you get? When you burn any hydrocarbon, what do you get? Carbon dioxide and water vapor.

So how much carbon dioxide do you get? Assume that density is one. If you burn it, you will release 2.3kilo grams of carbon dioxide. So my trip from University of Houston to here, at least I did 78kilo grams of carbon dioxide. Just my trip to UH Clear Lake. So you can imagine how much CO_2 emission we are responsible for. If you take the U.S.

emanation, (inaudible) billion tons carbon dioxide. So the petroleum, the natural gas, and the coal.

Since 2010, we have been reducing the emission. But still six million metric tons. (inaudible) which is less carbon and these are some of the -- there are reasons for this but still if you take it all over the world, each person in the world is responsible for around five metric tons of carbon dioxide per year. So, that is the amount you're dumping into the atmosphere. And remember, only 25 percent of this carbon dioxide is absorbed by plants and 25 percent by ocean. That's 50 percent will stay in the atmosphere. Where does it go? It doesn't go anywhere because carbon dioxide is very stable. So that is where the problem comes.

So, what can we do? This is one of the projects which we are doing, how to address these pollution problem, carbon dioxide problem. We'll come back to that later, but let us see why we are -- how we are making the nanomaterials. One example is oxide nanotubes. This is just one of the materials we prepare. This is not carbon nanotube, but we can make similar to carbon nanotube, we can make nanotubes out of a lot of different materials. We are interested in oxide semiconductors. Now, why oxide? Oxides are stable. We are not worried about oxidation problem. Silicon, if you take, it can oxidize immediately. But these oxides are very stable, and they can -- they can show -- they have semiconductive properties, also. So we are interested in making nanotubes of these materials.

This is the nanotube of titanium dioxide, which I was developing in the beginning of 2000. This is the titanium dioxide. The length of the nanotube was around .5 micrometer, but the diameter can vary from around 15 to 20 nanometers. A lot of range. We can (inaudible). This is a nanotube sample, this region is covered in the nanotube and the tops are the substrate, which is the titanium foil.

So this is different images of the nanotube structure. You can see the -- from the this image you can see the hollow inner region of the nanotube.

So now, if you look at the transduction, you can see what is there in the walls of the nanotube. I don't know if you can see clearly. You can see the crystal lattice. So these are amorphous. That means a lot of (inaudible) electrons and holes can be combined. So we can reduce it for applications like (inaudible) or solar cells. So we want to make it crystal in. Then this is how the crystals are formed inside the walls of the nanotubes. So this is one crystallized region. These will merge to form a single network of the crystallize. That is how the whole nanotube become crystallize. Because of the nanotube wall, it can be -- it can vary from just 2 nanometers to a few tenths of nanometers. So that we can (inaudible) the thickness of the walls.

This is another image of the nanotube area. These are grown by the (inaudible) and where these nanotubes are spontaneously (inaudible) automatically in the test tube like. So the bottom is closed and the top is open.

So these are different types of nanotubes. These are long nanotubes. We can go to even millimeter length.

And depending on the application, we grow the nanotubes either on glass or (inaudible). This is nanotube area grown on wire, titanium wire. So the tubes are grown outward. So this is used for an application called a force probably (inaudible) to separate the phosphorylated (inaudible). So this is for the study of (inaudible).

So this is -- so far we just pass through the titanium dioxide nanostructure. This is another structure we developed, zinc oxide. You can see the (inaudible). We'll discuss the application later.

Now, why we are interested, in the nanotube structure rather than other structures, one reason is that these nanotubes can be attached to a surface. Not like particles. Particles can fly away unless we make (inaudible). But these nanotubes can be attached to substrates. So these do not fly away and cause environmental problems. That is one thing. But for these applications, these nanotubes provide us very high surface area, as we discussed earlier. And more than that, the thickness of the nanotubes, here you can see, the thickness of the nanotube is in the few nanometer range. So if it absorbs the light, the charging area is in the wall, and these electrons and holes, the charges can easily come to the surface before getting recombined. So the largest surface area (inaudible) the charges to come to the surface for the production of oxidation reaction.

Now, with these nanomaterials, these are developed for different applications. Not just like we develop a lot of nanomaterials and find applications. It's not like that. They are developed for the application.

So sometimes we get (inaudible). Nanotube growth was like that. We were aiming at making (inaudible) structure of high surface area but (inaudible) so our research can go completely in unexpected ways.

So now we do the studies of the nanotubes. You can see this is a four probe structure. I don't know how many of you are familiar with the (inaudible) using four probe. This has four probes and this is a single nanotube of titanium dioxide. And this can be heated on one side. You can see (inaudible) and we can study the electrical properties, thermal properties, of the same nanotube. This is a microdevice.

So these are the nanotubes we study. What we observed was that the nanotubes in the (inaudible) form, that means one titanium and the (inaudible) IO2. Now, there is (inaudible) conductivity. But if you are (inaudible) hydrogen, we can remove from the oxygen from the lattice. If you reduce the lattice, the thermal properties are now completely different. Thermal property is now very low. It has gone down here. The black and the green.

So now, we studied more into the -- the details of this property and then we found that electrical conductivity is higher for this material because the hydrogen reduces the oxygen and these oxygen vacancies are donors, electron donors. So they have high electrical conductivity. But at the same time, when we studied the (inaudible) coefficient, we found that the changes from negative -- sorry, the negative to the positive. Negative (inaudible) means the material is (inaudible) semiconductor.

But after reducing, but when you reduce the temperature, so you can see that when you reduce the temperature to around 175 Kelvin, the (inaudible) becomes positive. That means the material becomes in all holes are reached in that material. So that had never been observed. So (inaudible) low temperature in single energy. But the bulk materials, nobody observed this.

But the temperature, when we increase the temperature, about 175, material transfers back to the intake. So these materials are (inaudible). These are (inaudible) many applications, thermoelectrics. Just (inaudible) the application.

So, this is the thermal (inaudible) coefficient, and around 75 it becomes positive. So that transition was (inaudible) at that temperature.

Now, what we think was that the oxygen vacancies, they create -- those are different stage in the gap of the titanium dioxide. Those are dormant until the temperature is low. When the temperature is low, they act the electrons and they (inaudible) that means hole rich material, electron rich material.

So this is just an example of the unique properties exhibited by the nanomaterials.

So I don't want to go to the different fundamental properties. Let's go to the applications. Three applications I'm going to discuss briefly. The solar cell. So the first one is solar cell. So we -- we used this material to the titanium nanotube to make the solar cell. But for solar cells, we know light has to go (inaudible) on this material so that it can absorb. So there are two problems. One, we were using it -- you saw the picture of the nanotube sample. The substrate was a foil. It is opaque. So that material, that substrate could not admit light into the titanium dioxide. So we had to put that on glass. That was a big challenge but we overcome that.

So we deposited it on the glass and then we did the oxidation process and then we heated. So this is the metal filling and here is the nanotubes grown on the top of the glass. So this is the -- these are the images of the nanotube. Because of the porous nature, these (inaudible) had very low (inaudible). You can see this. We transferred turns increased when a (inaudible) of nanotube was quartered on the top of the glass. So the transfer was 90 percent around because of the nanotube.

Now, the other problem was that this material, to be used in a solar cell, titanium dioxide is transferred. It has a gap of around two to three electron. So it cannot absorb solar radiation. So we had to use something else. (inaudible) solar cells based on this material. So we stained the high surface area nanotube, titanium dioxide nanotube with a dye. We can use even natural dye also but some are not very efficient so we used commercial dye. But we found the (inaudible) was high for that dye. This shows the quantum efficiency. Quantum efficiency means it tells you how many electrons (inaudible) are generated or driven to the external section per (inaudible). That means one electron -- if you are shining the material with a hundred photons, how many are converted that are falling through the (inaudible).

So that is one of the earlier work we did, that demonstrated this material (inaudible) nanotubes in (inaudible) form, they can (inaudible) in a very large range, usually in a desensitized solar field, people use large particles to scatter light and increase efficiency. But in the case of nanotubes being able to do that, nanotubes (inaudible) is reabsorbed by the dye, that (inaudible) efficiency is really high. So this was the work we did, and now very recent work is on (inaudible) material has a structure of A, B, or three. That's the structure. Strontium titanate, these are all (inaudible) materials.

But very recently, there are organic (inaudible) of this structure has been developed. (inaudible) is one example. (inaudible) so this material, people found that this material is very good, but the problem was that this material is, organic material is very unstable. If it sees water vapor or humidity, it's gone. Changes in property, no more (inaudible) for solar cell. Or oxygen, it can be (inaudible) material.

So stability has been a problem with the solar cells. If it is not stable, what is the use in we cannot manufacture (inaudible). But when we use the nanotubes filled with this material, (inaudible) doesn't absorb light. But what it does is that it transferred charges from the (inaudible) to the that's what the titanium dioxide nanotube does.

So what we found, we got an efficiency of 15 percent, that means 15 percent is converted into electric energy. The (inaudible) we observe very high stability in this nanotubes. Normally this should be encapsulated but we tried it without encapslation and found that these solar cells made of titanium dioxide are much more stable than those made of the other material. So what we -- the reason is that you can see the nanotubes. The nanotubes spacing, we cannot just the -- these are nanotubes on the glass with the -- widely spaced. Now, these, when we fill this with the (inaudible) light absorbing material, this acts as a template -- sorry, the scaffold for protecting the organic materials, which is unstable. So this oxide covers the encaps lates the (inaudible) and gives stability to that material.

So earlier we were talking about the surface area, high surface area for transfer.

So this is one of the -- this is one application which we are studying, how this material can be used for solar cell application. The.

The other one is the solar fuel generation. We can generate the fuel, like water. We can split water and generate hydrogen and oxygen. If you give energy to that. The sun light is the -- the sustainable way of producing or generating energy for our needs. So we use a process called photo electrochemical conversion of the water. So what we do is we disperse the nanoparticles or nanotubes or two dimensional nanostructures in water and shine light. And we can -- the electrons and holes are generated, as I explained before. These are not far away from the surface. They can cause the reduction and oxidation.

But the problem is that this is not sustainable. After some time, these particles can lose surface properties and they can reduce the activity. So what we do is that we use the photo electric chemical ways to generate hydrogen. That means we have a structure, we place small electric (inaudible) so that the charges, the electrons generated can flow to the other electron. For example, this is the anode, this is the catode. So here the light absorption (inaudible) but the electrons are driven through the (inaudible) to the catode. So thereto (inaudible) is generated. And here the anode (inaudible) water plus light is hydrogen plus oxygen. Now, we need at least 1.23 electron volt for this to happen, the water splitting to happen.

Other process is carbon dioxide to fuel conversion. So it's the same way. Reducing and oxidizings water. Here the carbon dioxide is converted into fuel. So if you mix (inaudible) water vapor, you'll get methane out of that. And we can burn that or put it in a fuel cell to generate power. But the byproduct are again carbon dioxide and water vapor. So this can be again sent to the recycler to convert back to the methane. So that means the recycling process, it can be (inaudible) using such process because we are not reducing it the carbon dioxide as free gas into the atmosphere.

I'm not going to into the details of this but let me tell you, we have the solar spectrum ranging around 218 nanometers to 225 nanometers. Out of that, because we can use only 1.23 electron volt per electron, we can use up to (inaudible). But because of the particular reasons, the harvestable (inaudible) ranges to around 800 nanometers. So we (inaudible) to convert, to absorb light and do the fuel generation process.

So this is the conduction of semiconductor diagram. We can shine light and excite the charges to the conduction band. And these electrons can be used for the reduction. All the electrons, (inaudible) this can go really to the high in the conduction band where the energy can be lost due to (inaudible) and it can come back to the bottom of the band and make it transfer. So here we are losing some energy, high photon area. So we are trying to utilize this also so that we can improve the efficiency of the process.

So the ideal efficiency of the process is around 31 percent. That means we can convert, using a single material we can convert sun light to fuels around 31 percent. That is the idea. But if you -- particularly the efficiency goes down to around 15 percent. That is the expected efficiency when we develop the process for carbon dioxide conversion out of water splitting.

So when we use titanium dioxide for water splitting, we found that the quantum efficiency is very high in the ultraviolet region. But if you go to (inaudible) that means there's no fuel generation. There is no chemical (inaudible) generated. That means the process is very inefficient. Only ultraviolet light is around (inaudible) of the totally solar (inaudible).

Now, what we do is we do different strategies. Let me explain one strategy that is (inaudible). We put (inaudible) inside the (inaudible) titanium dioxide and make it absorb light. That is one strategy. So here is (inaudible) with nitrogen. So nitrogen will be shifted to around 2.4 electron (inaudible). That means the green region of the solar spectrum. So this we utilize for converting the carbon dioxide into water vapor and methane. We shine light, we fill the chamber with the carbon dioxide and water vapor, (inaudible) and then the carbon dioxide reacts with the water vapor and generate methane or even other alkanes. Are generated.

So very recently, we changed the strategy from (inaudible) had its own problems so we changed the strategy. Now we work on (inaudible) the titanium dioxide with two dimensional materials. So they can absorb light and transfer the charge to the titanium dioxide nanotube. So that way we can use very inexpensive light absorbing material. For example, (inaudible) can be used as a -- if you can make a 2D material of (inaudible), very cheap (inaudible) and generate fuel out of that.

So in collaboration with Rice University and (inaudible) University in India, we developed a process for that. So we exfoliated hematite into a new 2D material called hematene. Like graphine. So this is a D material of iron oxide. So you can see the external lattice. These are the atomic -- the reconstruction of the lattice atomic arrangement of (inaudible). So this is the (inaudible) and then ore of the (inaudible) is hematite. We subject the ore to (inaudible) and then these structures are (inaudible). These are exfoliated out of the ores. It becomes brick like. That is the color of the anoxide.

Then we coat the (inaudible) with this material and we found that the nanotube had only the efficiency of (inaudible). After coating it with the hematene, we could extend the efficiency to 500-nanometer. So that means we are now broadening the efficiency. (inaudible) with this material. But still it is -- it shows that we can broaden the light absorption using this approach.

But what is remarkable was that the quantum (inaudible) alignment of the conduction band and the (inaudible) are not matched. There's no way they can transfer. But we observe through (inaudible) that indeed it was happening. So the only way it can happen is that the high enough photons can excite the electrons to the upper energy levels of the conduction band where it can transfer to the titanium dioxide band. That's similar to the (inaudible) electron transfer. The (inaudible) are transferred to the (inaudible) that is how we got the quantum efficiency in the light region.

Another material we tried very recently is the quantum dot. This is a particle of (inaudible) it's called boron nitride. So we (inaudible) boron nitride. When (inaudible) it created (inaudible) and that made it absorb light. So it is now -- in the fluorinated quantum can absorb light. And again, we studied the quantum efficiency. This time the quantum efficiency was much higher. Earlier it was 12 percent. With this material we could go to around (inaudible) around green and yellow region, and the quantum efficiency ended up around 25 percent. So this is (inaudible) we have now with the new materials. Can we get a quantum efficiency of 80 percent in the light region? In that case, we'll get (inaudible) that's what we are initiating right now.

So this is the hydrogen (inaudible) which shows a dramatic increase in the (inaudible) with respect to the titanium dioxide nanotube and the boron nitride.

The last application is the medical diagnosis. (inaudible) sensors using the (inaudible) for medical applications. Here, this is (inaudible) the Lancet, which is a very high profile American journal. So it came in 1989 that a woman, a 44-year-old woman came to their clinic and what they -- she complained that there was (inaudible) on her left thigh. So she said, she noticed that because her dog constantly sniffed at it. Even though she was covering, it coming again and to the exact location. So she was suspicious about that and she went to this clinic to check it. And they took the sample and they did the biopsy and found out that it was cancer. So they communicated that to the journal. This shows that dogs has the ability to sniff the cancer.

So now, (inaudible) there are many people reported similar things. And now the dogs are being trained for cancer detection, especially the breast cancer, skin cancer, and all of those things. (inaudible) now the dogs are being trained for this, but it's an expensive process. But can we do that artificially and in a very cheap way? That's what we are trying to do, to initiate.

So what we -- the idea is to take the (inaudible) samples and see if that can be connected to the (inaudible). The dogs can smell something. That's why they are attracted to the tumor. So that means there must be some odor or gas coming out of the body that is a signature of the diseased state of the body. So the gas analysis has been used since ancient Greece, and where the people used to test the water and the diagnose the diseases, the physicians.

So this is one of the (inaudible) used in 1898 for the breath analysis. A very good system.

(inaudible) was a big supporter of this exhaled gas analysis. So this is a gas chromatogram from one of his papers, Linus Pauling's papers. So now there are (inaudible) especially for asthma, diabetes, all these things. But our intention was to see whether we can detect cancer in the early stage. So we did -- we developed the zinc oxide nanotube for that applications.

You can see this is a (inaudible) oxidation process. Initially these wires are formed but after some time, these wires (inaudible) you can see the small indents on the top and the hole is drilled but the nanotube. Not (inaudible) but (inaudible). So these tubes are formed. This is very high surface area material. So it can be checked, parts per billion or million level of the gases. So our intention was to detect the (inaudible) organic compound coming out of the breath. So people are recently -- (mic cut out).

(End of class)