Selection of Nanomaterials for Energy Harvesting and Storage Applications

Prof. Kaushik Pal
Department of Mechanical and Industrial Engineering
Indian Institute of Science, Roorkee

Lecture – 12
Nanogenerators: Triboelectric Nanogenerators

Hello, so in this particular lecture, we are going about the Nanogenerators about the Triboelectric Nanogenerators, because from this title itself you can understand that we are going to discuss about the so many types of nanogenerators in which second lecture we are going to conduct on triboelectric nanogenerator.

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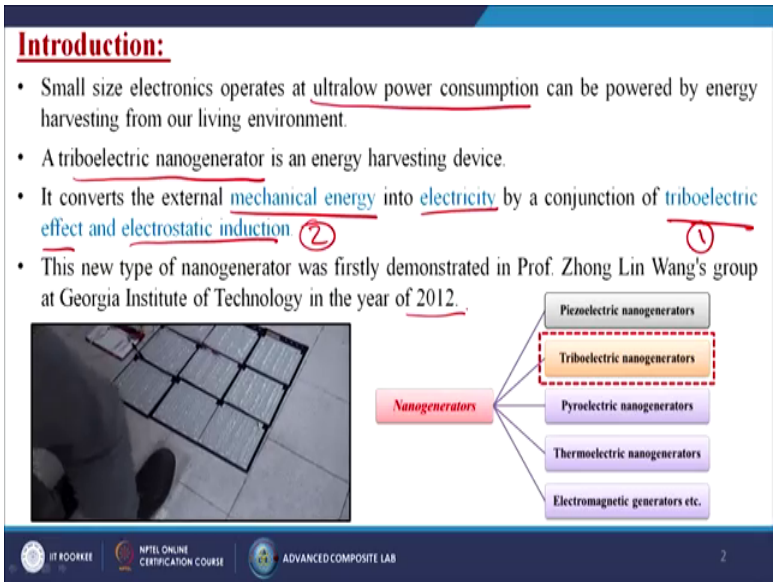

So, basically before going to start about the introductions, so what is the triboelectric nanogenerator? So, basically this triboelectric nanogenerator is a small size electronics operates at ultralow power. So, you can see from here that ultralow power consumption can be powered by energy harvesting from our living environment. So, basically what we are going to do? Either we are going to do any kind of load, or maybe pressure or maybe frictions, and then we are going to generate the electricity from that.

So, basically a triboelectric nanogenerator is an energy harvesting device of course, because we are generating the electricity from that particular equipment, or maybe the device. How it is working? Basically it converts the external mechanical energy into electricity by a conjunction of triboelectric effect and the electrostatic induction, so that

is a combination of two. One is called the triboelectric effect that is the number 1, and the electrostatic induction that is number 2.

So, this new type of generator was firstly developed by Prof. Zhong Lin Wang. He is working basically in Georgia Institute of Technology, he is very famous in this particular area, and he has published lots of publications and patents and the books. And he has invented the technology in the year of 2012. So, as I told already, so there are some nanogenerators based on their applications. So, one is called the piezoelectric nanogenerators, then triboelectric nanogenerators, pyroelectric nanogenerators, thermoelectric nanogenerators and the electromagnetic generator. So, now today actually we are going to discuss about the triboelectric nanogenerators.

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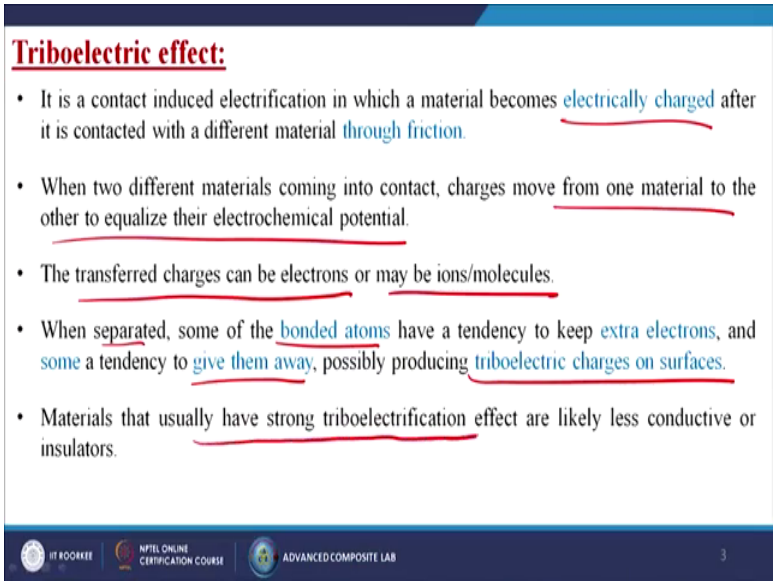

So, what is triboelectric effect? Because as I told already this triboelectric nanogenerators is working on the triboelectric effect and some electrostatic induction. So, first let us know that what is triboelectric effect. So, basically it is a contact induced electrification in which a material becomes electrically charged after it is contacted with the different material through fiction. So, basically the best example is that in our hand. So, if I rub my hand or maybe if anybody can rub their hands, so automatically what will happen after certain time, by rubbing the friction will be generated in between the two contact surface, and then that friction is converting into the electric energy. So, like this way basically this concept has come.

So, when two different materials coming into contact, charges move from one material to the other to equalize their electrochemical potential. Another best example I can see that sometimes it may happen that we are using the comb for to our hair and then if you rub that comb for particular certain time to our hair, then you can find that our hair is attracting towards the comb. So, that means, and also some little bit sound you can find it out. That means what? Some kind of electronic transfer or maybe the charge transfer is taking place in between the comb and the hair.

So, the transport charges can be electrons or maybe ions or maybe the molecules. When separated, some of the bonded atoms have a tendency to keep extra electrons, and some a tendency to give them away, possibly producing the triboelectric charge on surfaces, so that means, there is a electron differences in between the surfaces. Materials that usually have strong triboelectrification effects are likely less conductive or maybe acts as a insulators.

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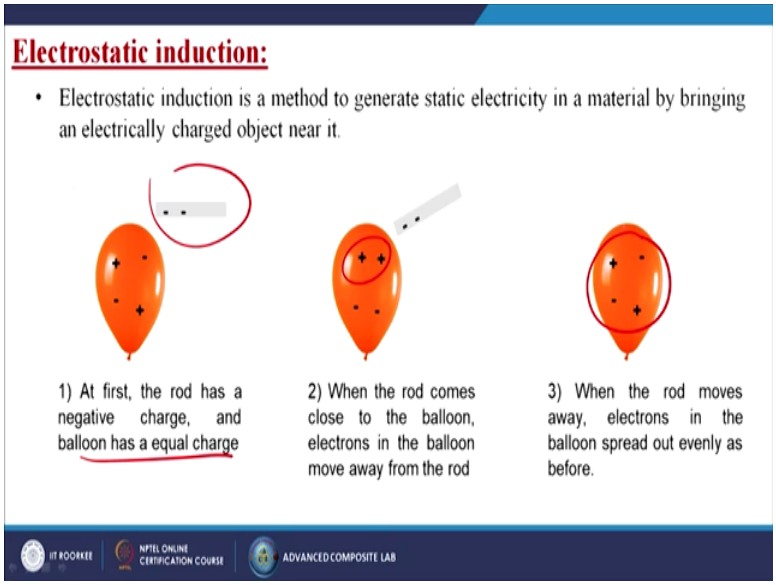

So, now we are going to discuss about the electrostatic induction in this particular slide. So, what is electrostatic induction? So, electrostatic induction is a method to generate the static electricity in a material by bringing an electrically charged object near to it. So, now, I can give an example, so that you can better understand. Suppose I am having one balloon, so in that particular balloon, first it is almost into the balance conditions. Now, I am bringing one negatively charged rod towards it. So, first what you are doing? The rod

has a negative charge and balloon has a equal charge or maybe the balance charged. Now, when the rod comes close to the balloon, electrons in the balloon move away from the rod itself. When the rod moves away, electrons in the balloons spread out evenly as before.

So, what is happening? When I am taking out the rod, so that time plus and minus were equally distributed. When I am bring that minus that means more electron charged rod to that particular balloon, so all the positive ions is going towards it. But again when I am taking out the rod nearer to the balloon, so automatically again it is equally distributed in the system itself. So, that means, by any charged rod or maybe any charged material, if we come to take to a particular material, so automatically the opposite ions will be attracted by that particular material itself. Now, how we can achieve this kind of results?

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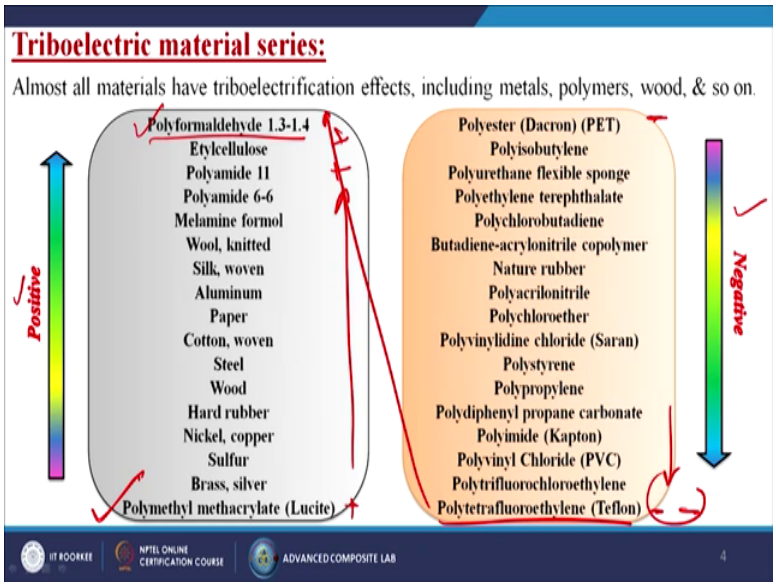

So, of course, depending upon their triboelectrifications, so basically it has been divided into two parts; one is called the positive and other one is called the negative. So, almost all materials have the triboelectrification effects including the metal, polymers, woods and so many. So, basically if I talk about the positive one, so first is called the poly formaldehyde 1.3 to 1.4. And then slowly, slowly it is coming down to poly methyl methacrylate that is called the Lucite. And if I talk about the negativity of that particular materials, so first top side is called the polyester or maybe the Dacron or maybe

sometimes we are calling it is a PET. And the last one is called the polytetrafluoroethylene or maybe the Teflon, PTFE.

So, basically in this way we can subdivided the materials into two parts; one is called the positive ion, and another one is called the negative ion. So, in these particular tables, I can tell you another interesting thing was that, here this polymethyl methacrylate which I am talking about is the positive ion, but of course, the positivity is increasing tremendously to the top. So, now, if I take this poly formaldehyde, and then I can compare the materials with the right hand side, here you can see that negativity is here for the polyester. Of course, it is there, but when I am coming to the down, so here the negativity is tremendous.

So, if I take this polytetrafluoroethylene with the poly formaldehyde, the highest positive and the highest negative one so automatically it will give you the maximum electricity if I rub these two kinds of materials. Now, we are going to discuss about the Triboelectric Nanogenerators in short form generally sometimes you are calling it has a TENG, T E N G.

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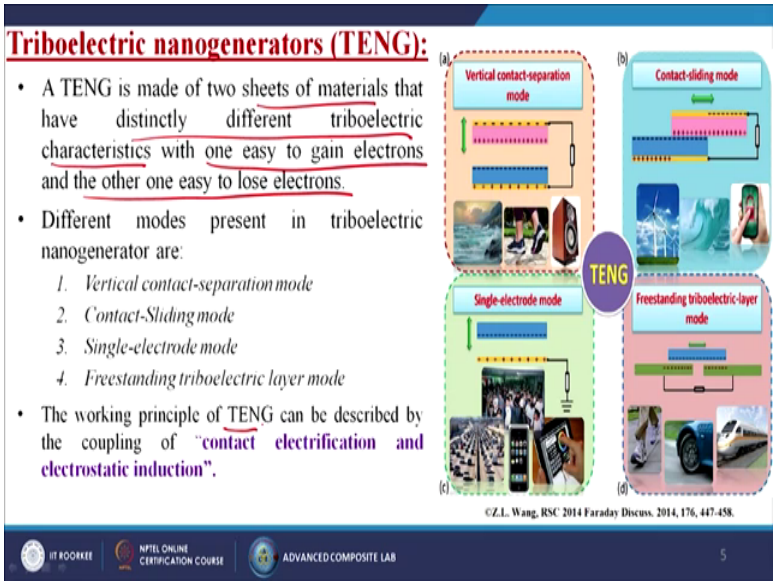

So, a TENG is made of two sheets of material that have distinctly different triboelectric characteristics with one easy to gain electrons and other one easy to lose electrons. How you are going to select that particular materials? From the previous slides, because one is the positive, another one is the negative. So, automatically from that particular table, you

can easily choose your materials. And then after that how we are going to do? There are different modes on may be the methods available to generate electricity through this triboelectric nanogenerators.

What are those? One is called the vertical contact separation mode, second one is called the contact sliding mode, third one is called the single electron mode, and the forth one is called the freestanding triboelectric layer mode. So, I am going to discuss all in one by one in the next subsequent slides.

So, now as I told the working principle of TENG can be described by the coupling of the contract electrifications and the electrostatic induction. So, right-hand side, you can see that we have gathered certain images from the various studies has done by the Prof. Wong, and he has published that paper in these particular journal. So, basically he has done his work on all the modes like vertical contact separation mode, contact sliding-modes, single electron mode and the freestanding triboelectric layer mode.

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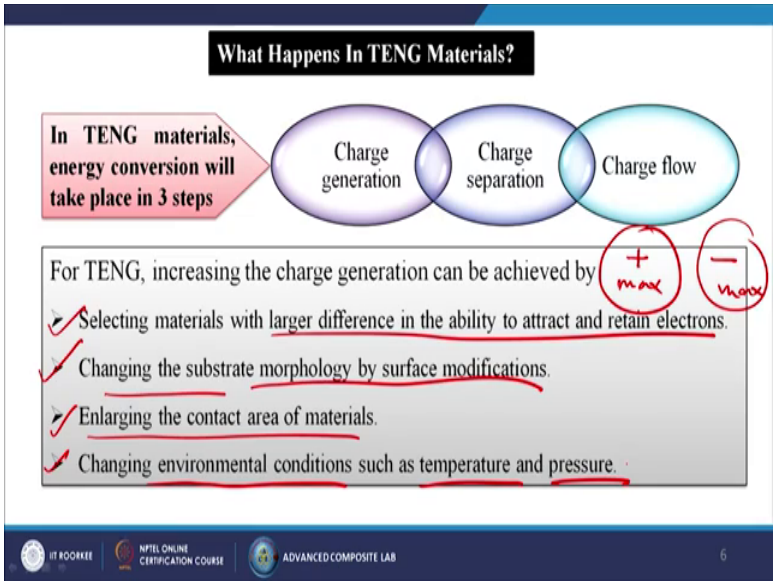

So, now actually what happens the actual mechanism behind the TENG materials, what is happening? In TENG materials energy conversion will takes place in three steps, first one is called the charge generations, and then the charge separations, and then the last one is called the charge flow. So, for TENG increasing the charge generations can be achieved by first one is selecting materials with larger difference in the ability to attract and retain electrons that means the maximum plus and the maximum minus right. Then

second one is the changing the substrate morphology by the surface modification, sometimes it may happen that from the nanomaterials point of be, if I can say that yes of course, I am having that materials which is having the positive charged ions and which is having the negative charged ions.

But still everyday from the society or maybe the from our application point of view or maybe our requirement, we need materials which can give the more electricity. So, now, to get more electricity, what we are going to do? Either whatever the materials is having the more positive ions or more negative ions, either we are doing certain kind of coatings or maybe wrapping or maybe dopings to increase the more positivity or maybe he more negativity of that particular materials, so that get we can get the more amount of electricity. So, thus we can do the changing of the substrate.

Next, enlarging the contact area of materials, we can enlarge the contact surface in between the two substrate. Next, fourth one is the changing the environmental conditions such as temperature and pressure. Of course, because temperature plays a vital role on this particular triboelectric effect as well as the pressure. Now, we are going to discuss one by one that about the different modes.

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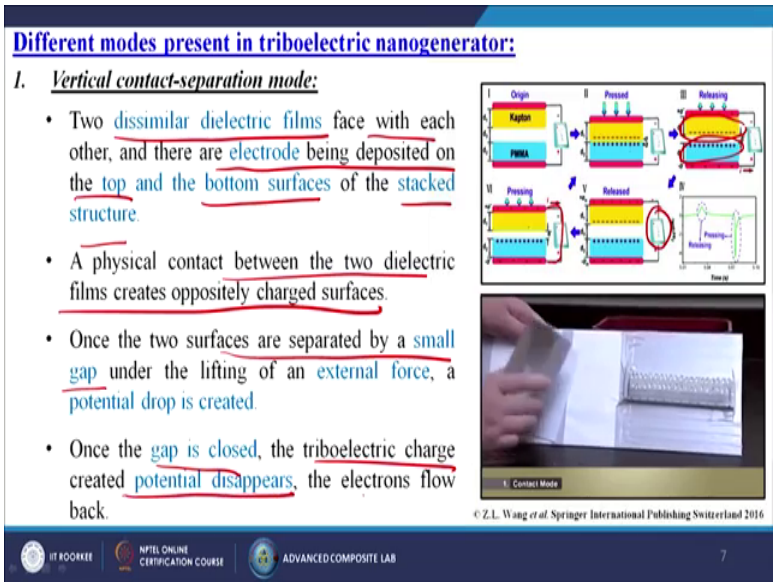

So, first one as I told already it is known as the vertical contact separation mode. In this particular case, two dissimilar dielectric films face with each other and there are electrodes been deposited on the top and the bottom surface of the stacked structure. So,

in this vertical contact separation methods, so basically what we are doing? We are using the captain films in one side another side is the PMMA that is Poly Methyl Methyl Acrylate. So, in this particular case, what happened I am having two electrodes and then simple I am pressing it. So, first I am pressing it, so that the charge is generating at that particular interfaces and then we are releasing it.

So, what will happen? The after that one material will be negatively charged one material will be positively charged. And then after that this negatively charged electron will go these particular things to the opposite electrode over there just to make it compensate. And in this particular case, simple we are taking out the current from this particular region.

So, a physical contact between the two dielectric films creates oppositely charged surface. Once the two surfaces are separated by a small gap under the lifting of an external force, so here you can see the lifting of the either it is maybe the manually or maybe by some other means. So, simple you are touching and then you are pulling it out, and then again you are touching, and then again you are pulling it out, you can easily see from this particular video.

So, in this particular case, you can see that how the LED is glowing, so that is known as the vertical contact separation mode. Once the gap is closed, the triboelectric charge created potential disappears, the electron flow back. So, when I am keeping it out, electrons is come back to its original positions, then again when we are touching, so again the electron flow is taking place. So, that is why when you are touching the LED is glowing, when we are taking it out, the LED is off. So, now, here just it is an idea that there are different types of basic structures are available for vertical contact separation mode for triboelectric nanogenerators.

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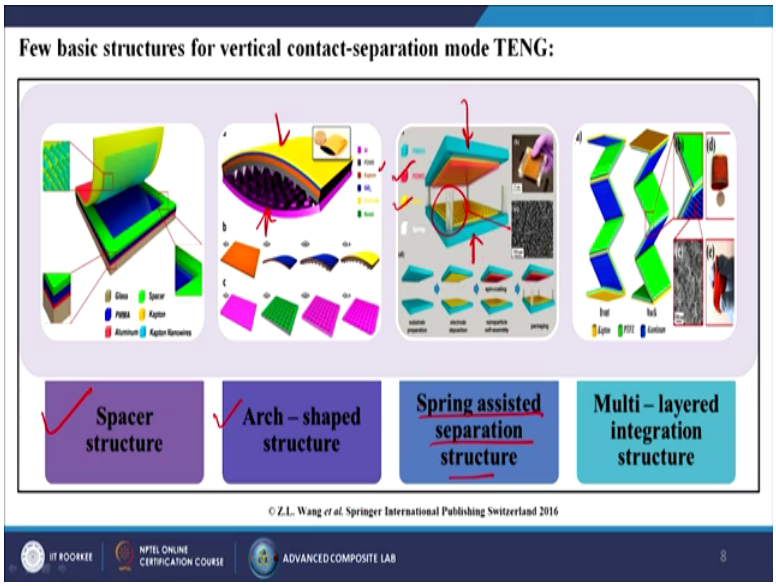

In this particular case, you can see some the glass is the substrate, then top of that we are putting the PMMA - Poly Methyl Methacrylate materials. And then top of that, we are having certain kind of spacers, in this particular case we are using the (Refer Time: 14:22). So, simple we are using the (Refer Time: 14:24), and the poly methyl methyl, and just we are contacting them and we are generating electricity.

In this particular case, you can see that we have used the PDMS, and another side is called the gold particle. So, by this contact generally we are making the electricity. So, here this is called the spacer structure, this is called the arc-shaped structure. So, arc-shaped means you have to press from here and from here then only the contact will be taking place. In this case, it is like a page - book page. So, simple just you are taking out the page and then leave it, so automatically the page will come into its original position.

In this particular case, we are using the spring, so this is known as a spring assisted state separation structure. So, just we have to put the load over there when you release the load operation so automatically it will come to into its original place. Here in this case that is called the multi-layered integration structure. So, it is a one kind of this structure. So, simple one by one you put it like that, and then again pull it like this, and again put it like this, so you can do this kind of vertical contact.

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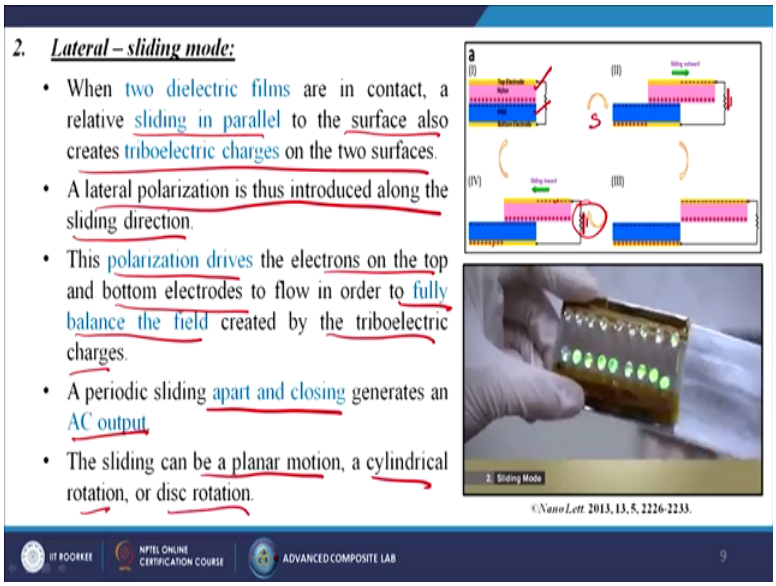

Next one is called the lateral-sliding mode. So, from this particular title, you can understand that we are talking about the vertical, now we are doing it laterally. So, when two dielectric films are in contact, a relative sliding in parallel to the surface also creates the triboelectric charge on the two surfaces. Yes, of course. So, what is that? In this particular case, we are using the nylon, we are having the PTFE, and we are having the two electrodes. So, one is the bottom electrode and the top electric top of that. And then simple this one is the static and this one is the dynamic. So, one is static; another one is dynamic. So, just I am doing the sliding contact like this.

So, in this way simple the charge transfer is taking place from this because it is the positive on, it is the negative on, so automatically the surface, the charge will be the opposite one. So, automatically the electron will flow from this to this, from bottom electrode to the top electrode and we are getting the electricity from here. So, in this particular case, the lateral polarization is thus introduced along the sliding directions. This polarization drive the electrons on the top and bottom electrodes to flow in order to fully balance the field created by the triboelectric charges.

A periodic sliding apart and closing generates an AC output. The sliding can be a planar motions, a cylindrical rations, or maybe the disc rotations, that means, either you can do this or maybe you are having, this you are rotating like this. So, in any directions, you can do the sliding. So, in this particular case also it has been published into some good

journals called Nano Letters, and people have shown the video like this, that when they are doing, the sliding automatically the LED is glowing.

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So, here also the some basic structures for the lateral sliding mode of the TENG. So, basically it is called the plane sliding structure, so simple your sliding like this. Here the rotation disk, so that means, two disc and one is rotating on top of that. Here the rotation cylinder structure, so I am having a piston kind of things in which I am having the rotor and the rotor is rotating in this particular manner. And in this particular case, it is called the case encapsulated structure. So, simple the thing is that what will be the structure or maybe the modes? Simple your material is subbing onto your material, either into the circular motions or maybe the cylindrical motions or maybe the sliding way, so that is the thing.

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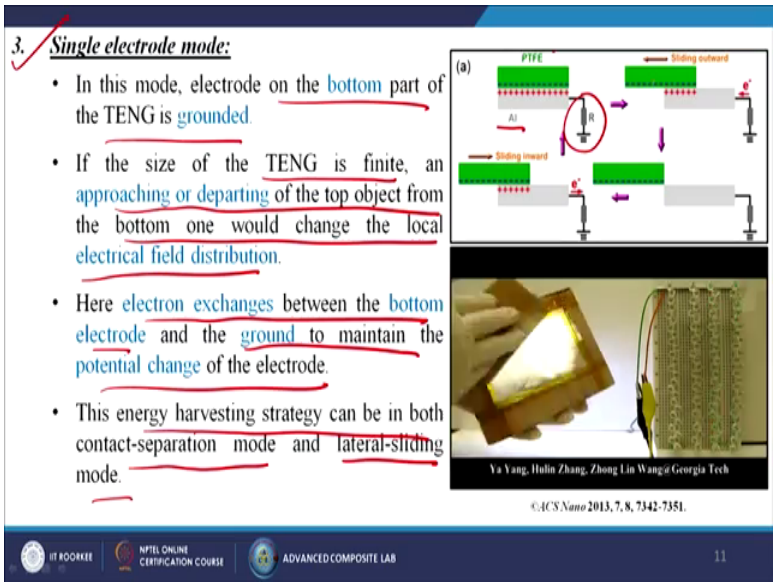

Next 3rd one is called the single electrode mode. So, in this particular case, in this mode, electrode on the bottom part of TENG is grounded. So, you are doing the grounding over there. So, in this particular place, you are taking the aluminum and the PTFE. If the size of the TENG is finite and approaching or departing of the top object from the bottom one would change the local electric field distribution. Here electron exchanges between the bottom electrode and the ground to maintain the potential change of the electrode itself.

This energy harvesting strategy can be in both contact or maybe the separation mode or maybe the lateral sliding mode. So, simple in this particular case, you are doing the one kind of sliding inward and outward and when this is coming out, so automatically you are getting the electricity. So, you see after rubbing, when it is leaving from the particular substrate, then automatically the light is glowing. So, this has been also published by the Prof. Wong group and in a very good reputed journal.

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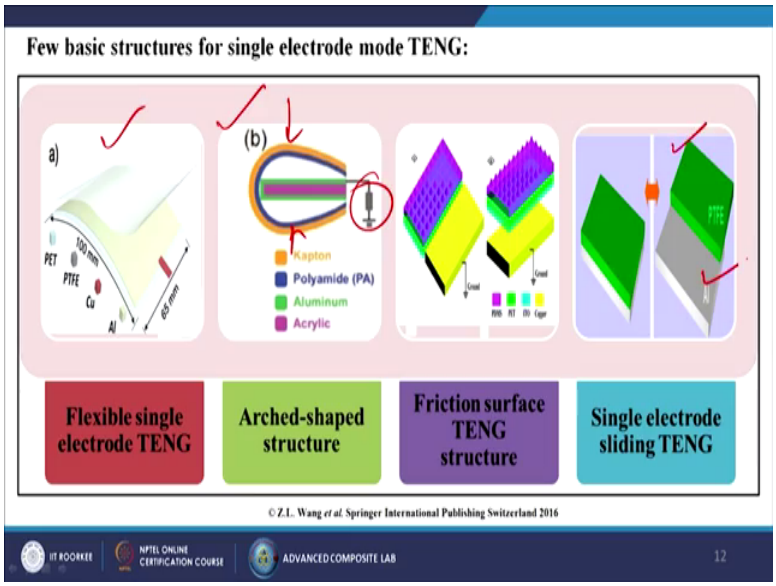

So, here is also the same thing that is called the flexible single electrode TENG. So, flexibility nowadays people are working extensively on the flexibility of that particular materials, because you can wear it on your body or maybe on your jackets or maybe as a clothes or maybe on shoes, socks any anywhere, so that is why we are trying to do the work and flexible materials. So, that it can bend it is having a very high good life and then we are having some kind of arc-shaped structure also. In this particular arc-shaped structure, just you are pressing the materials from here and then you are releasing it and you are getting the electricity.

This one is the friction surface TENG structure. So, simple either you are putting it vertically or maybe vertically putting, and then sliding, and then you are taking out. So, it is a combinations of other methods. Here is called the single electrode sliding TENG. So, I am having only the PTFE and only the aluminium and just I am rubbing both the materials, and I am getting the electricity.

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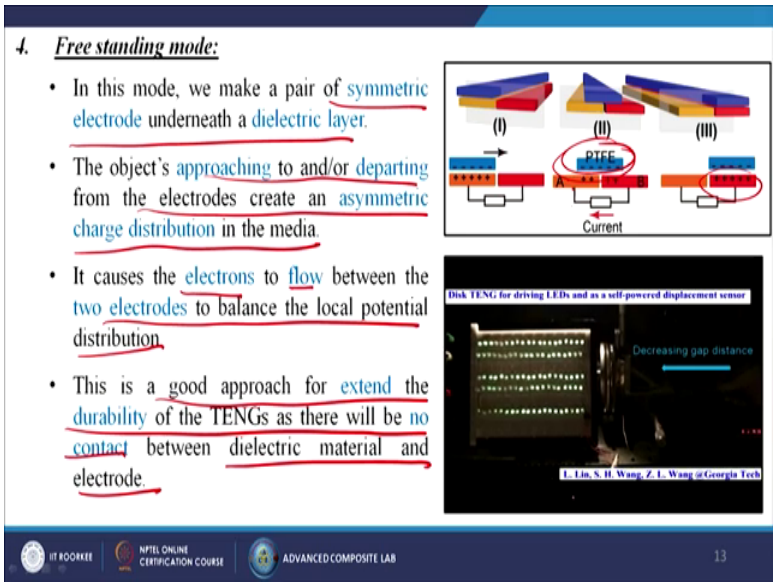

Next last one is freestanding mode. So, in this particular mode, we make a pair of symmetric electrode underneath a dielectric layer. The object's approaching to and or departing from the electrodes create an asymmetric charge distribution in the media itself. It causes the electrons to flow between the two electrons to balance the local potential distributions. So, in this particular case, what happened? The material, in this particular case, PTFE is only the single one, but we are having two electrodes one in A, another one is B, and they are attached together. Now, I am PTFE is have being the more negative ions and A and B is having more positive ions.

So, what I am going to do, just I am rubbing my this negativity on top of that A and B. So, what will happen, just to balance that electronics charges, so automatically the B is getting the more potential difference over there and that potential difference just we are collecting. This is a good approach for extend and durability of the TENGs as there will be no contact between dielectric material and the electrode. So, in this particular case, what happened here the Prof. Wong group has also done the same thing decreasing the gap distance if you minutely see from this particular image. So, when we are decreasing the gap, so automatically the LED is glowing.

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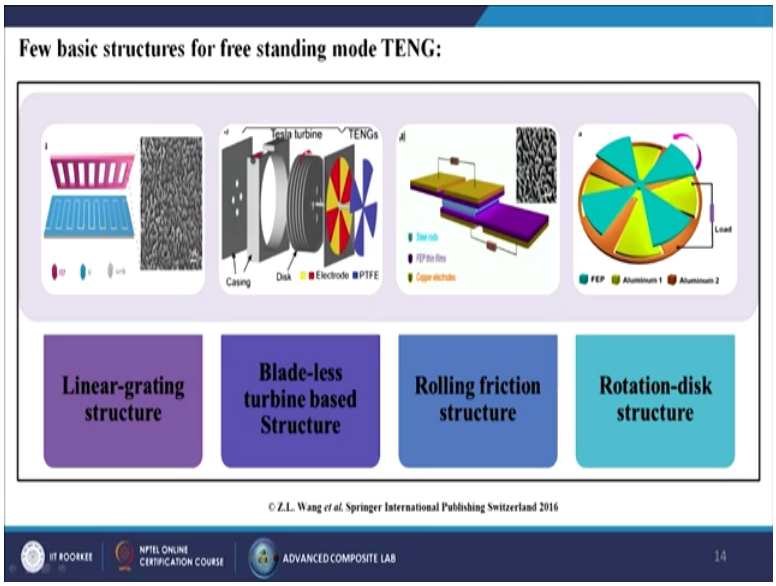

So, now here the few basic structure for free standing mode TENG is called the linear grating structure, so this is the case. Here the blade-less turbine based structure, here is called the rolling friction structure and the rotation-disk structure. So, this is the examples of the freestanding mode triboelectric nanogenerators.

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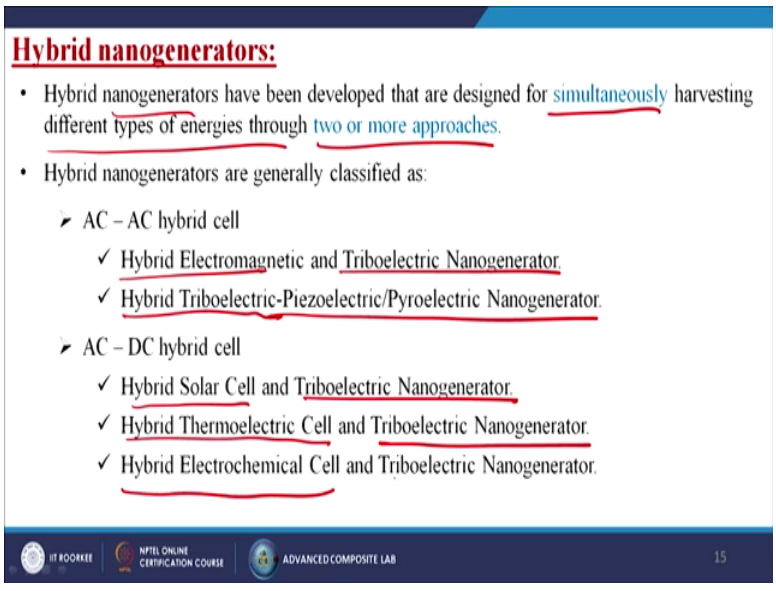

Now, come to hybrid nanogenerators. So, from the name itself hybrid means you are using different modes and combining both modes together and then you are generating the electricity. So, hybrid nanogenerators have been developed a design for

simultaneously harvesting different types of energies through two or more approaches. Now, you are combining the modes.

So, what is hybrid generators? Like AC - AC hybrid cells in where you are doing hybrid electromagnetic and the triboelectric nanogenerator, this both you are combining. Hybrid triboelectric and or piezoelectric maybe the pyroelectric nanogenerator this concepts you are combining. If we talk about the AC-DC hybrid cell, so in this particular case hybrid solar cell and the triboelectric nanogenerator you are combining. Hybrid thermoelectric cell and triboelectric nanogenerators you are combining or maybe hybrid electrochemical cell and the triboelectric nanogenerators you are combining.

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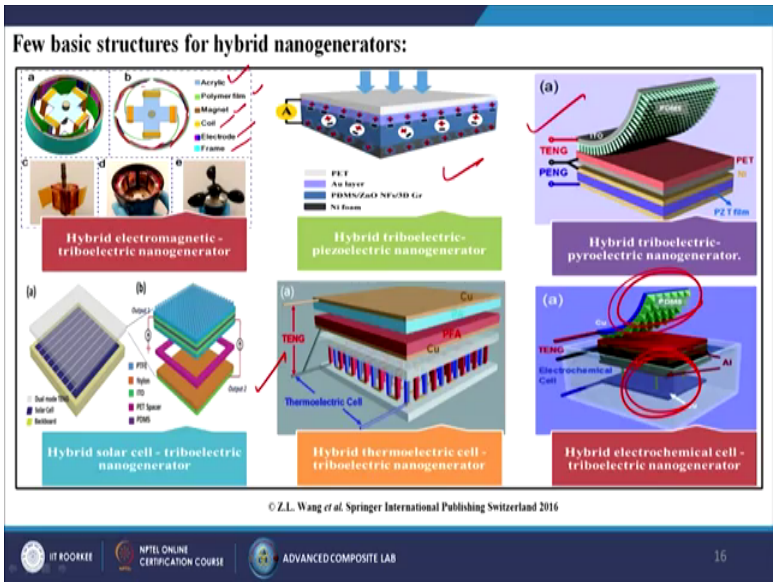

So, now also the same thing, here also the few basic structures of the hybrid nanogenerators. So, you can see in this particular image, hybrid electromagnetic triboelectric nanogenerator case, they are using the acrylic, polymer film, magnet coil electrode and the frame. So, by this way, when this magnet or maybe the coil is rotating, and then it is generating the electricity in this particular points, and you are getting.

So, simple this kind of configuration you can see in our fan. So, when the rotor is rotating there is some magnetic field generation is taking place, and due to that from that particular point they are generating the electricity. So, concept is something like this. This is called the hybrid solar cell tabulating nanogenerators. So, simple we are having that solar cell as well as I am combining the triboelectric effect over there. In this

particular case, we are having the hybrid triboelectric and the piezoelectric generator. So, I am using some piezoelectric materials as and with the some triboelectric materials.

In this particular case, we are using the hybrid triboelectric pyroelectric nanogenerator. So, some kind of pyroelectric effect materials with the triboelectric materials I am combining. If you talk about some kind of AC-DC combinations, then hybrid thermoelectric cell with the triboelectric nanogenerator we are doing with hybrid chemical cell and the triboelectric nanogenerators, that means, what? The chemical reactions is taking place over there. So, automatically one charge will be transferred, and then the opposite change materials I am putting over there and then they are generating the electricity.

So, by any virtue of means either your material is having that capability to generate the electric ions or maybe some other means I am generating the electric irons, or maybe that ions in between it whether it is positive and negative, and the opposite materials just I am using as a triboelectric materials and I am generating the electricity.

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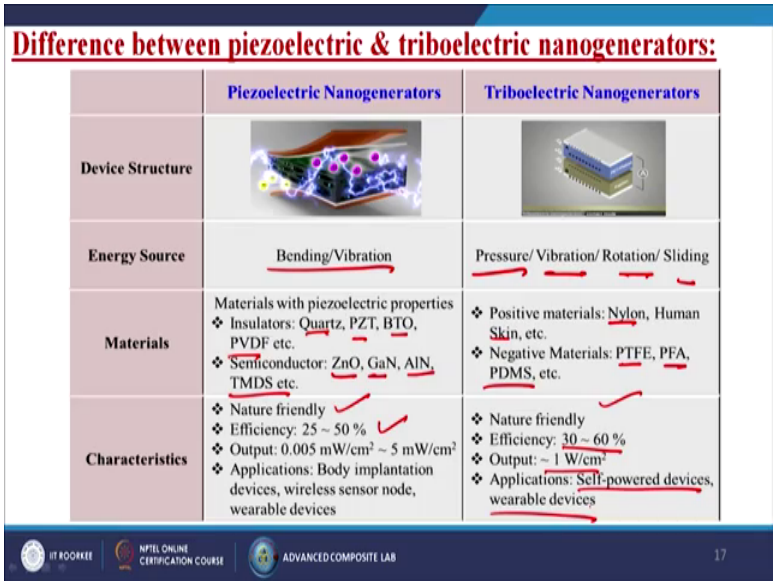

So, now the basic difference between the piezoelectric and the triboelectric nanogenerators. If I talk about the device structure, so you can see that there are two distinct image; one is called the piezoelectric nanogenerators, another one is called the triboelectric nanogenerators. So, the term tribo; tribo means it has come from the tribology. So, what is tribology? Tribo means actually the friction, it is a Greek word. So,

from friction means anyhow we are generating the friction in between the two surface and we are generating the electricity.

Piezoelectric, it is a intrinsic property of that materials that if I put any load or pressure onto that particular materials, automatically it will generate the electricity that means, the mechanical energy is converting into the electricity. And in this case by friction, it is converting into the electrical energy. So, energy source, it is like bending and vibrations, as I told already. In this particular case, either it is pressure, vibration, rotation or maybe the sliding.

If you talk about the materials, materials with piezoelectric properties like insulators like quartz, PZT, BTO, PVDF, Polyvinylidene Difluoride, and semiconductor like zinc oxide, gallium nitride, aluminium nitride, TMDS. And if we talk about the triboeletric nanogenerators positive materials like nylon, human skin, I have given the examples right. So, negative materials like PTFE, PFA and the PDMS.

Characteristics about the piezoelectric nanogenerators it is nature friendly, efficiency is generally 25 to 50 percent. Output is 0.005 milli watt per centimeter square to 5 milli watt per centimeter square. Applications, body implantations devices, wireless sensor node, or maybe the wearable devices in this particular case triboelectric nanogenerator is also nature friendly efficiency is 30 to 60 percent. Output is almost more or less 1 watt per centimeter square. So, in this particular case you can understand the output energy is more. Applications generally self-powered devices, wearable devices in this particular case generally we are using.

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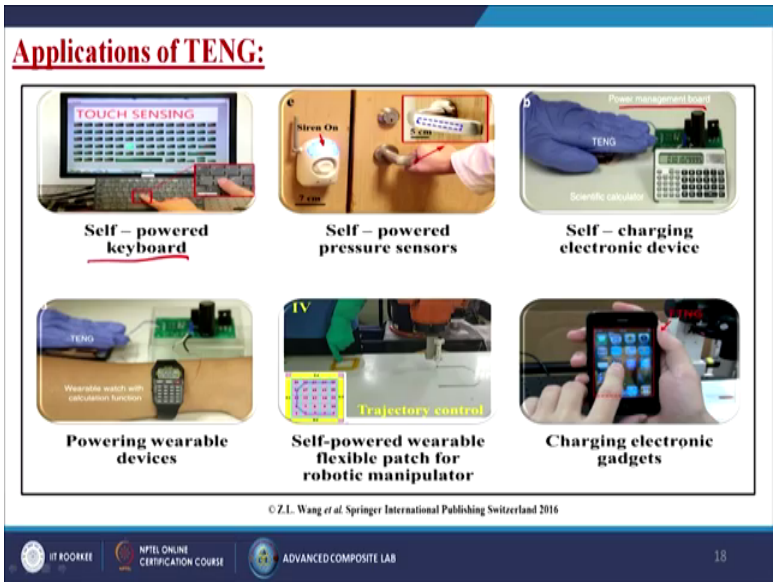

Next we are going to discuss about the applications of TENG. So, basically some kind of self-powered key board. So, when we are pressing that keyboard, so if we put any kind of triboelectric materials just below your keyboards, so automatically when we are going to type anything in our keyboards, so automatically it will generate the electricity. Till now we are using the keyboard to typing something on my computer, but simultaneously if I will get the electricity and then that electricity if I store into some device so later I can use it, so that is an extra added advantage.

Here is the self-powered pressure sensor. So, when I am opening any door, so latch, so I am giving certain kind of pressures onto the handle. So, if I utilize that pressure to convert that electrical energy, so that is also the another added TENG. Here is the self-charging electronic devices. So, when I am doing certain kind of pressing on this particular materials, so automatically the power management board is there which is generating the electricity by which you can run the scientific calculators.

Powering the wearable the devices. So, directly I am having certain kind of watch which needs the energy, and directly I am developing or maybe investigating that energy, and I am directly using onto the watch itself. Some kind of self-powered wearable flexible patch for the robotic manipulators some charging electronic gadgets.

So, these all are the n number of applications that generally where we are using this kind of technology nowadays, because it is a very convenient one, nature friendly, it is easily

available and simple something we are doing. But from that particular applications if we generate the electricity, so that is the added advantage, because automatically the cost wise it will be very less, we no need to make any kind of high end device or may be the high end instruments. But certainly from our normal day to day life procedure we can make the electricity.

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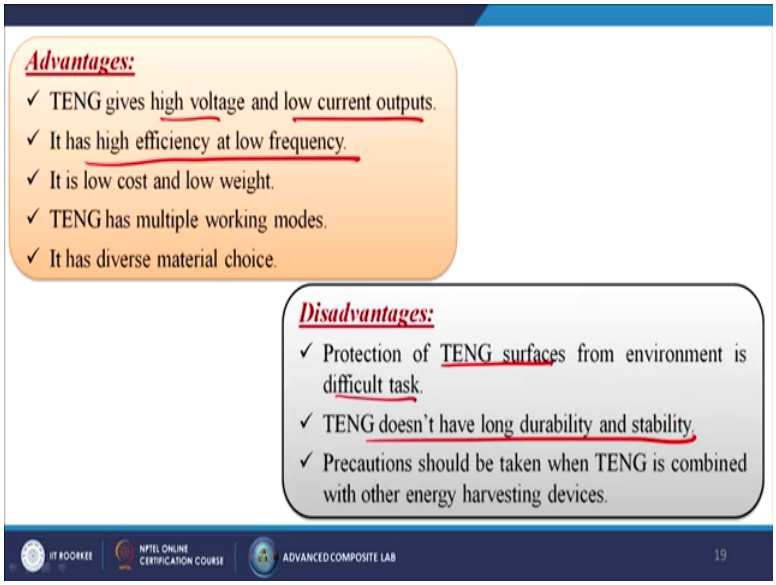

So, advantages, TENG gives the high voltage and low current outputs. It has high efficiency at low frequency. It is low cost and low weight. TENG has multiple working modes. It has diverse material choice.

Disadvantages, of course, there is certain disadvantages. What are those? Protection of TENG surfaces from environment is difficult task, because we have to clean it otherwise what will happen some contaminants will come. So, automatically the charge discharging in between the two surface will be reduced. TENG does not have long durability and stability, because it is based on some material properties. So, after certain time the material may degrade or maybe lose certain physical or maybe the chemical properties. Due to that it can be degraded and it can lose its certain properties.

Precautions should be taken when TENG is combined with other energy harvesting device, that means, the material should be compactable with other materials or maybe the other device, so that is also another kind of disadvantages. But there are plenty of research are going on to overcome this kind of disadvantages, so that we can get constant

energy that is a one kind of you can say some kind of renewable or maybe the green energy in where we do not need any coal or may be any thermal power or maybe anything. Simple from our day to day life working style, we can get the electricity from that.

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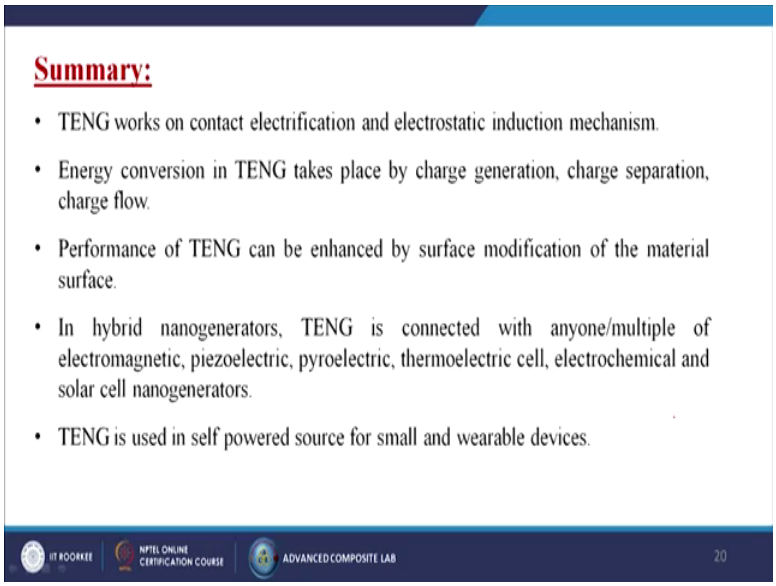

So, now, we have come to the last slide of this particular lecture. So, in summary, we can say that TENG work on contact electrification and the electrostatic induction mechanism which I have already discussed. Energy conversion in TENG takes place by charge generation, charge separations and the charge flow. Performance of TENG can be enhanced by surface modifications of the material surface. As I told already we can do the doping, we can do the rapping, we can add some kind immunity, so that the material can be more active to generate electricity.

In hybrid nanogenerators, TENG is connected with anyone or maybe the multiple of electromagnetic, piezoelectric, pyroelectric, thermoelectric cell, electrochemical and solar cell nanogenerators. And last that TENG is used in self-powered source for small and the wearable devices.

Thank you, thank you very much for listening the lecture.