Smart Materials and Intelligent System Design

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Lecture – 04

Welcome to the MOOC course on Smart Materials and Intelligent System Design in the last few lectures, I have talked about piezoelectric materials and magnetostrictive materials. Now, today we will be taking up a new material.

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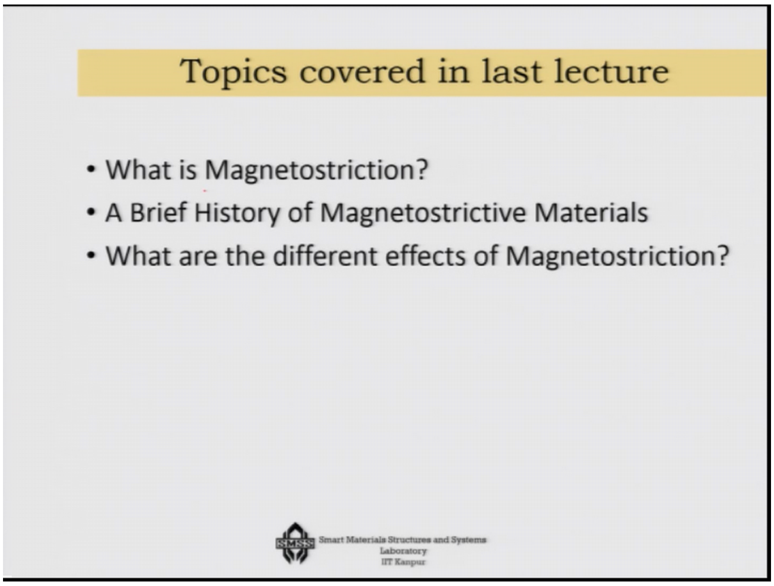

So, just in the last lecture if you remember we have talked about. What is magnetostriction? We have told you about a brief history of magnetostictive material. So, that you know how such materials have evolved and we have discussed about different effects of magnetostrictive material. So, in this lecture we will take up a new material now which is active smart polymers. So, we will talk about that what are these group of active smart polymers.

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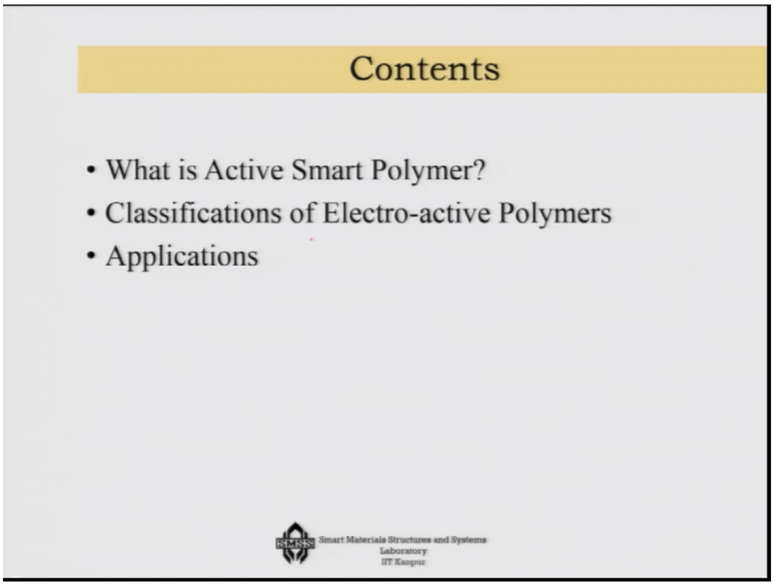

And what are the different classifications of these electro active polymers, a particular group of it and what are the applications of it. Now, what is the reason for us to go for this active polymers?

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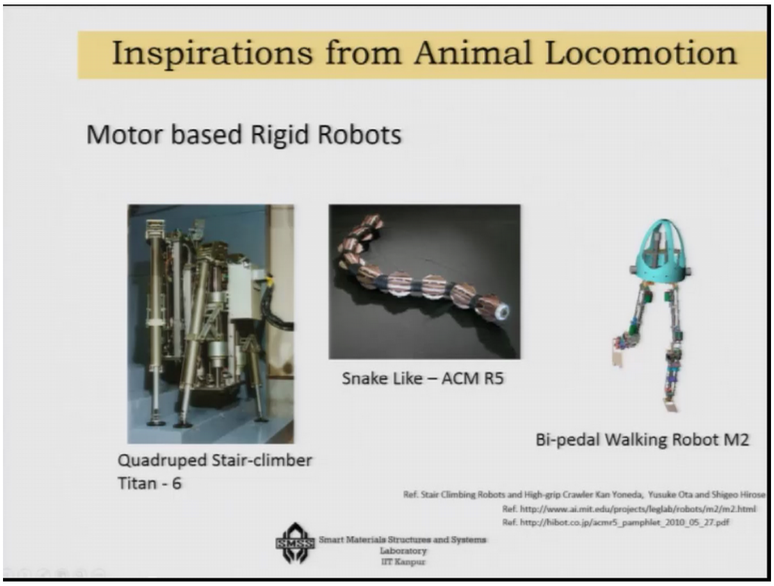

One of the important inspiration came actually while we know we tried to simulate the emulate so, to say the animal locomotion systems ok. So, the first you know series of rigid robots, if you look at it that there were this robots of like quadruped stair climbers they are quadruped, but they are not good like the animal to mimic the animal behavior, because they were not like the real legs.

People get somewhat more towards the real system, when they could develop something like a snake like motion in ACM R5 one of the examples and even more sophisticated when they could develop actually a bipedal walking robot M 2 or other robots are such examples, but one of the thing is that in all this robots the locomotion was achieved, from actually motor based rigid robots, they were not muscle based on the other hand animal based systems are muscle based.

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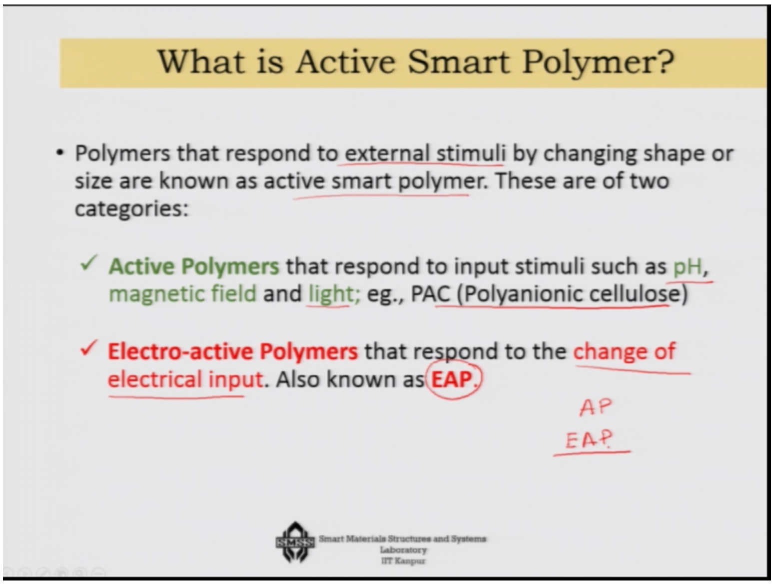

So, the point is that can we develop a muscle based locomotion system. Now, active smart polymer can actually do that, this type of polymers can respond to external stimuli by changing shape or size and that change of shape is really very high.

I will show you later on and this are known as active smart polymer. Now, this type of polymers are generally we divide them into two categories, one is simply active polymer in which these you know these inputs stimuli that, we apply can need not be just an electric field it can be pH, it can be magnetic field or it can be light it for example, Poly Anionic Cellulose PACs ok, they are you know one of the groups, I will show you some of the groups which can be activated by using light photo strictures.

So, active polymers can take basically any inputs and it is not a electrical input non electrical inputs chemical inputs magnetic inputs, or light as an input. Electro active polymers on the other hand respond to the change of electrical input and that is why they are known as EAP. So, we have active polymer AP and we have a special group which is EAP, which actually gets activated with the help of electric field input.

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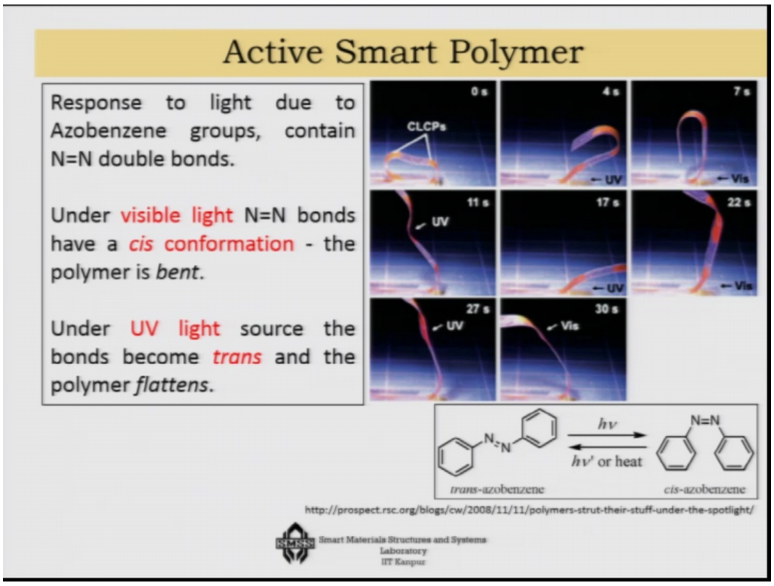

Now, one example of active polymer if you look at this that, in this particular system you actually have this is based on Azobenzens ok, Asobenzene group which contains this double bonds of nitrogen and the moment, you apply you know a visible light say for example, then this double bond reacts in a manner that it actually bends. So, there is a cis conformation in it.

And when you apply the UV light source not the visible light then it goes to the trans mode so, by varying the UV and light source. So, for example, in plain light you can see that there is this bend there and you apply UV you see that the bends are opening up it is getting flat flattened. Again you apply light again it is bending actually so, bend flat bend flat sequence can actually generate some kind of inchworm motion. So, this is a light actuated motion that you can generate in such a system.

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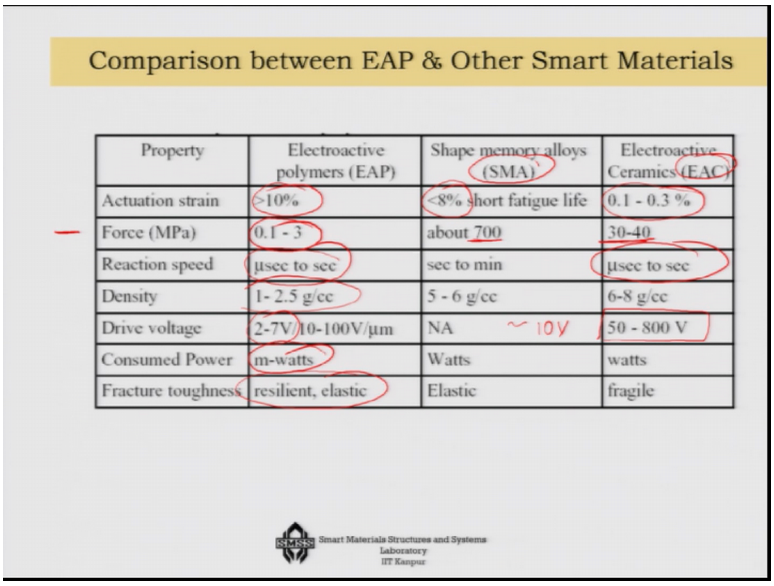

Comparison between EAP & Other Smart Materials

Property	Electroactive polymers (EAP)	Shape memory alloys (SMA)	Electroactive Ceramics (EAC)
Actuation strain	>10%	<8% short fatigue life	0.1 - 0.3 %
Force (MPa)	0.1 - 3	about 700	30-40
Reaction speed	μsec to sec	sec to min	μsec to sec
Density	1- 2.5 g/cc	5 - 6 g/cc	6-8 g/cc
Drive voltage	2-7V/10-100V/μm	NA ~ 10V	50 - 800 V
Consumed Power	m-watts	Watts	watts
Fracture toughness	resilient, elastic	Elastic	fragile

Now, if you compare between the inelectroactive polymer that the other activation, but electric energy has an input. So, if you compare the performance of that forces other piezoelectric materials, you know that are generally used like a shape memory alloys, or like say electroactive ceramics, you would see that the actuations strain inelctroactive polymers is about 10 percent, which is much higher than the shape memory alloy is 8 percent and much higher than any of the electroactive ceramics which is only 0.1 to 0.3 percent 10 percent remember is some kind of a change you will be able to see even, you know simply with your eyes itself. So, it will be very much visible I will show you examples when you will see you will be able to see that.

But what is the flip side of it deformation is very large, but the force is actually quite less it is about 0.1 to 3 Megapascal, where as SMA you get a much higher force and considerably high force in electroactive ceramics. The reaction speed is also moderate or at least comparable to the electroactive ceramics, density wise they are very light driving voltage vise it is low driving voltage which is good because electroactive ceramics need much higher voltage, shape memory alloy whereas, need a some kind of voltage of the range of 10 volt or so it is actually a given process.

And the power it consumes is about milliwatt range and it has a good fracture toughness resilience etcetera. So, only the negative side is the force development that is the minus side of it and to some extent the reaction speed, otherwise this is full of positive things which are worth of actually venturing that is what is our motivation to study the electroactive polymers.

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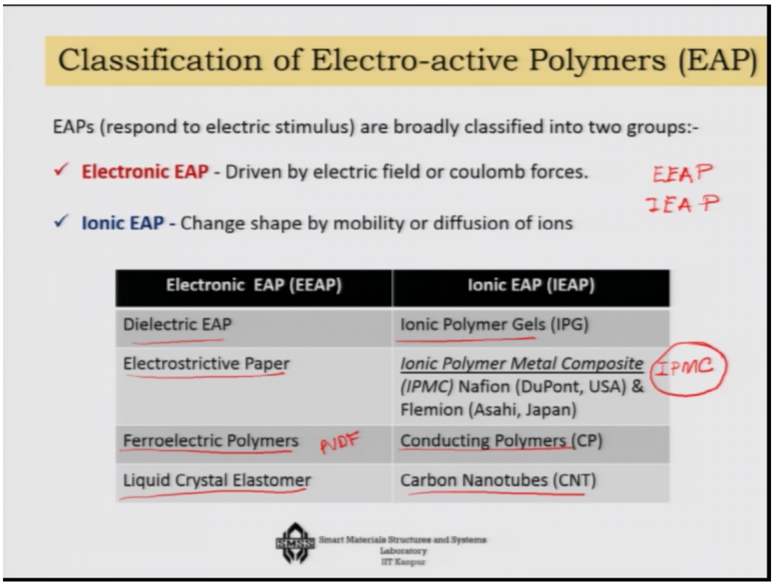

Now, among the electroactive polymers are EAPs. We have two groups one is called EEAP that is Electronic Electroactive Polymer and another is called IEAP that is Ionic Electroactive Polymer. If you look at EEAP there are typical examples are like dielectrics or electrostictive papers, ferroelectric polymers, like PVDF for example, I have shown you in one of the RDR classes liquid crystal elastomers these are all EAPs, if you look at IEAPs ionic polymeric gels, IPMC Ionic Polymer Metal Somposite also known as IPMC, this is what is very popular I will mainly focus on this today conducting polymers and even carbon nanotubes.

So, these are the group ionic electroactive polymer now naturally the one of the important aspect is that here the phenomena is at the you know at the electron level. So, it is a electronic movement or changes so, to say which generates this effect on the other hand here, it is at the ionic level. So, the speed is a little slower in comparison to the electronic electroactive polymer.

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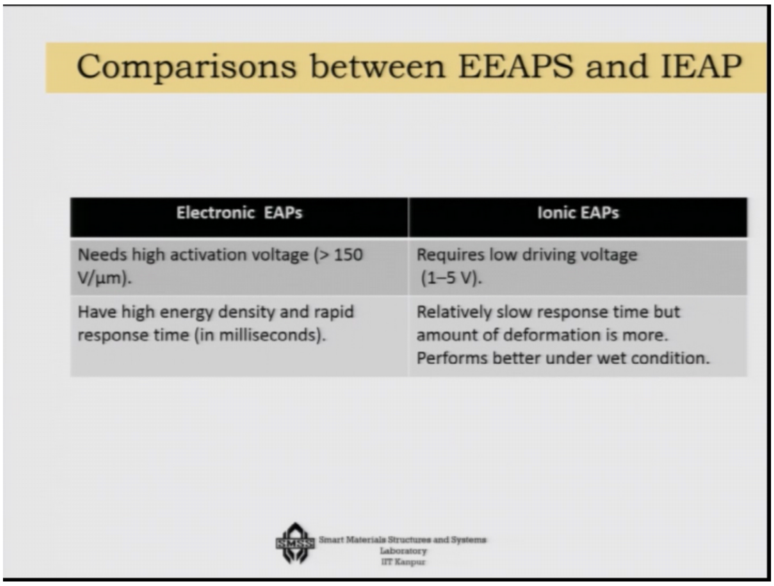

So, if you look at the comparison between the two, electronic activation of course needs a higher actuation voltage, but here you need a low driving voltage, but here the energy density is high and rapid response time.

Whereas ionic electroactive polymer it will have a little less you know slower response time that of course, the amount of deformation will be much more because a particularly under wet condition, because large scale ionic movement in the form in fact, movement of water jetting out will create a huge change in the shape of the system.

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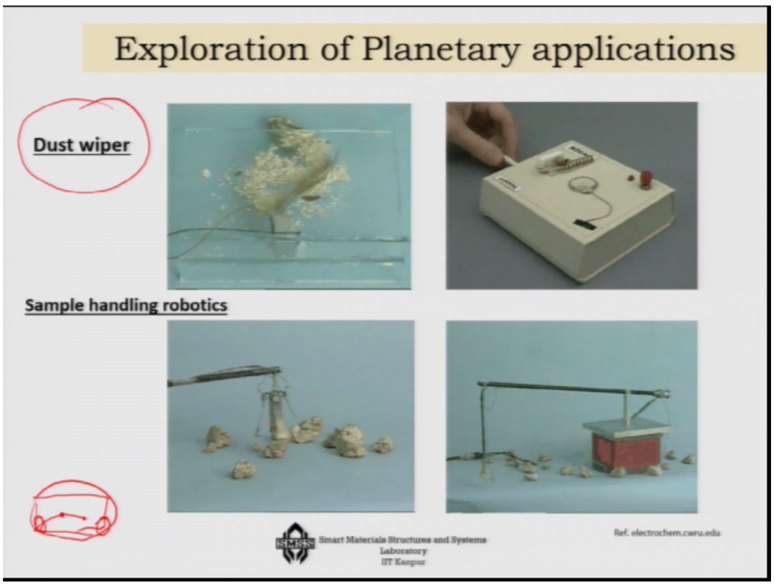

So, here is one of the very popular application that is particularly for space applications that you can use these things for creating dust wipers, because you know that many of the rigid body wipers, they always have some of the blind spots which they cannot clean.

That is because the links are of fixed geometry, they cannot change on the other hand for electroactive polymers you can change the length of the wiper so; that means, you know, if you take a rectangular spot in a rectangular block, you can clean the entire rectangular block whereas, with your so called if you look at the car wipers with this type of a system, there will be always some corners say for example, this type of corners which you will never be able to clean properly are this corners. So, that is why I said dust wiper particularly for space shuttles, this is a very good use. The other use is in terms of sample only you can use these things to actually, you know use like fingers like artificial fingers.

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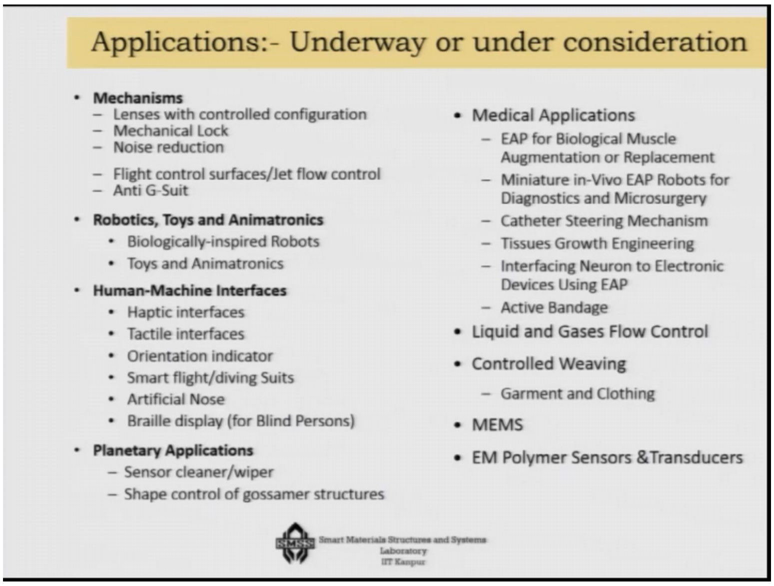

There are plenty of applications of such a system in mechanisms in lenses, mechanical clock, or noise reductions etcetera just to mention if you the list is in front you robotics in terms of toys animations, there is something called you know biologically inspired animations ok, mechanical animations or mechaanimals.

So, where you can animate the object in a way which is almost like a real world situation and that you can do with the help of electroactive polymers, because you can achieve large deflection in a compliant surface. So, that is why it is used at a very high rate in animations.

It is also used in various human machine interfaces like for touching tactile interface of our orientation of our you know diving suits etcetera, planetary applications I already talked about medical applications particularly one application is becoming very you know active in the research (Refer Time: 11:24) that is in terms of developing drug actually injections. So, controlled drug release in a system can be done with the help of electroactive polymers. Also it is used in liquid and gas flow control controlled weaving MEMS based systems and various other sensors and transducers.

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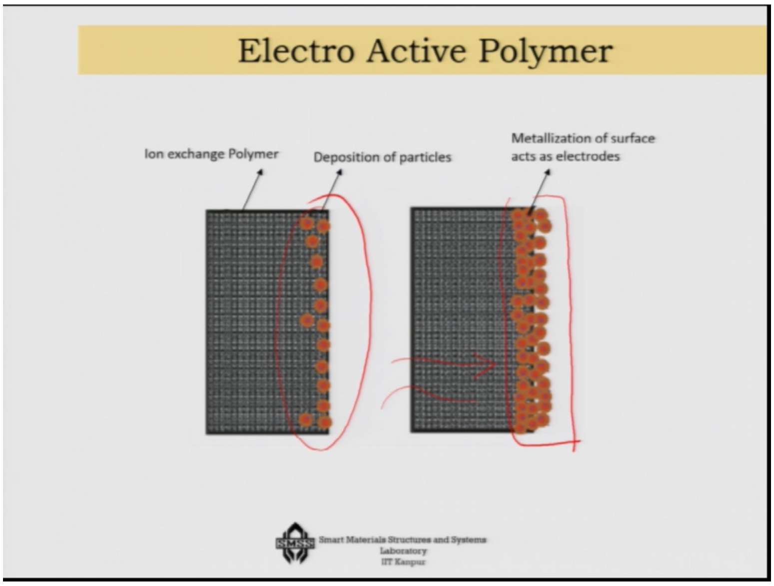

Now, if you look at a one of the most popular electroactive polymers, which is I told you the IPMCs, then it works like ion exchange polymer and if you have deposition of particles here ok, you can actually make a metallization of them. So, you can make a polymer in such a manner that it is partially metalized ok. So, this kind of a thing will actually help to develop cathode or anodic terminals in a polymer.

As I told you that they we have to at the end look for a high, you know movement of water inside the system going in or going out. So, towards that direction to control that high cationic movement you know metallization is very much necessary to see the elctroactive effect.

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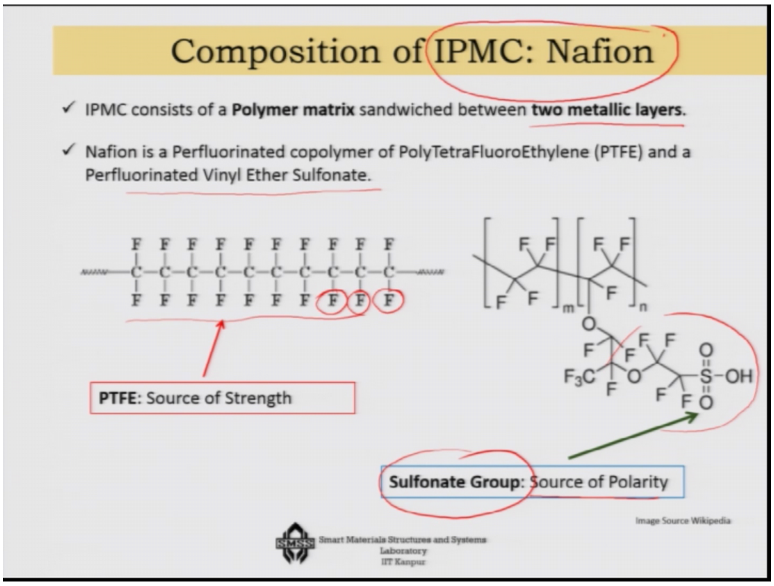

Now, if I focus on one of the most important you know ionic polymer which is known as Nafion, then you would see that it is having actually you know a polymer matrix which is sandwiched between two metallic layers ok.

Like this two electrodes formations that I have shown you and Nafion itself is having actually a PTFE structure, which is also known as perforated copolymer of PTFE. So, you can see the presence of fluorine's and the carbon main chain which actually gives the source of strength to the system in addition to you have a perfluorinated vinyl ether sulphonate which is this part you can see that this vinyl ether sulphonate part, which is the source of polarity in the system the sulphonate group.

So, in a sense you have a polymer which gives you a high strength due to the presence of this perfluorinated system, perfluorination is a process where all the hydrogens that is there say for example, you think of a you know ethane, methanes etcetera.

So, all the hydrogens from these areas are actually completely replaced by fluorine ok, that is what is perfluorination of the system. So, perfluorination gives us a better strength and in addition it gives us a polarity and it can hold actually, this sulphonate groups and that is used in terms of you know picking up this ions that we are talking about.

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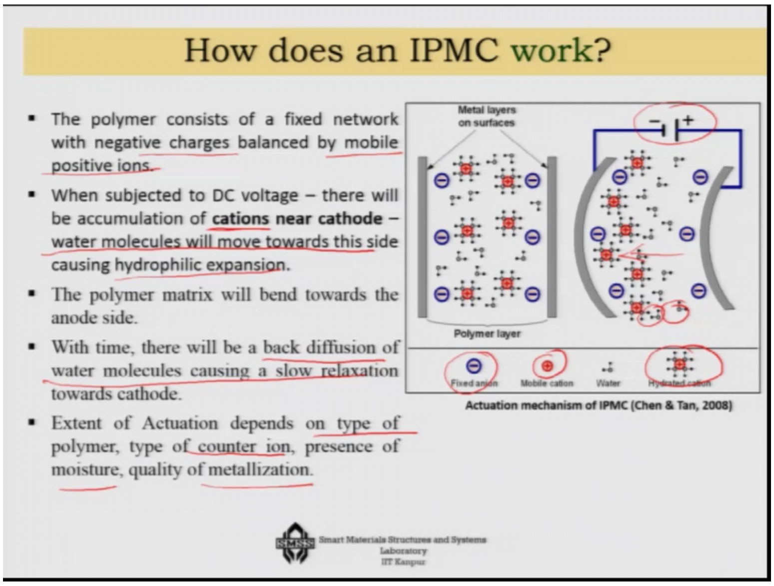

So, how does an IPMC work well first of all it consists of a fixed network with negative charges and that is coming, because of the presence of the sulfonate groups that I we are showing here, and it is balanced by mobile positive ions. So, whenever I am subjecting this system to DC voltage ok I am generating a voltage, what will happen is that, there will be this cations these are the mobile positive ions which will go towards the cathode.

And water molecules which are mostly you know in H plus and OH minus So, water molecules will move then towards this side causing a hydrophilic expansion of one of the sides. So, as you can see here that as we have applied the voltage here, and you can see that, there is a fixed network and you can see the movement of all this water molecules and it causing a hydrophilic you know expansion. So, this is a fixed anion the blue ones, blue ones are all fixed anions and these are the mobile cations as you can see ok.

And you also have waters here ok, along with attached along with the mobile cations and you have this as a hydrated cations. So, as along with this mobile cations the water molecules are also moving towards, this direction to the negative side you are getting you know and expansion in this direction. So, this is something which creates a large change of shape in the system. Now, what will happen if all negative charges go towards one direction, they will gradually start to repel. So, there will be a back diffusion that will happen in the water molecules so, which will cause a slow relaxation towards the cathode.

So, extent of accumulation of these will depend on what is the type of polymer we are using, what is the type of ions presence of moisture and the quality of my metallization, how good is my you know cathode and anode terminals.

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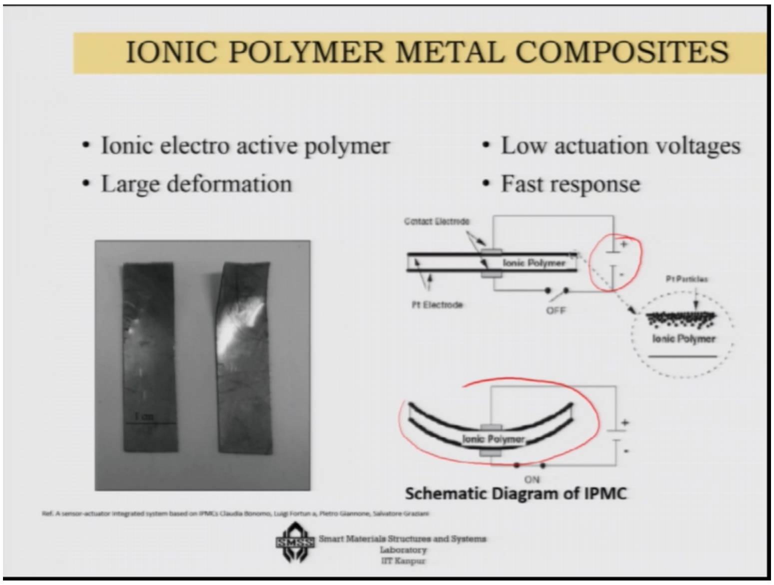

So, this is how then IPMC system works and, if you look at a IPMC composite, then you can see that you know in this particular IPMC system for example, that as I am applying the voltage in this system ok, how these bending is taking place in the system and this is in reality you know how you will be getting it in a same Nafion or Nafion of this type of similar IPMC systems.

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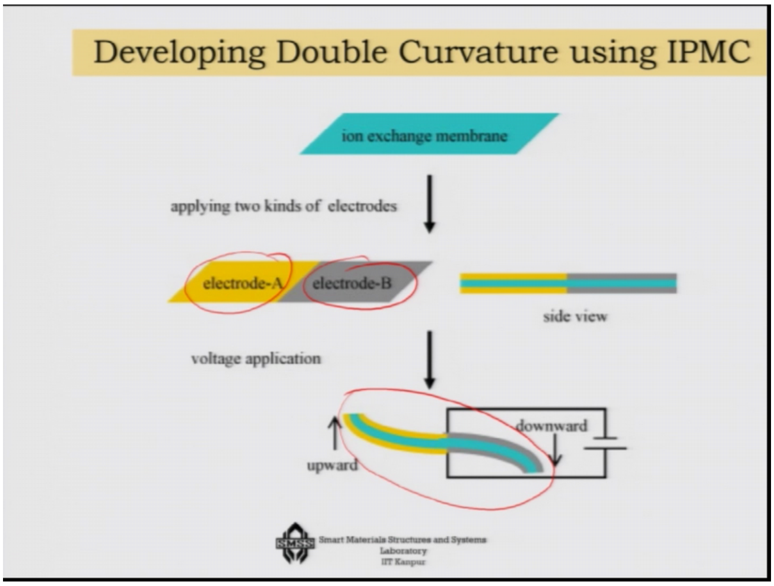

We can actually by selectively choosing this electrodes we can actually make a double bending system also. That means two different types of electrodes so, that the cations change you know the polarities, then you can actually get deflections in two different sides. So, you can generate actually both directional bidirectional bending in the system by choosing electrodes suitably. So, that is the strategy that many a times is used. So, that is you know one of the strategy of developing the double curvature using IPMCs.

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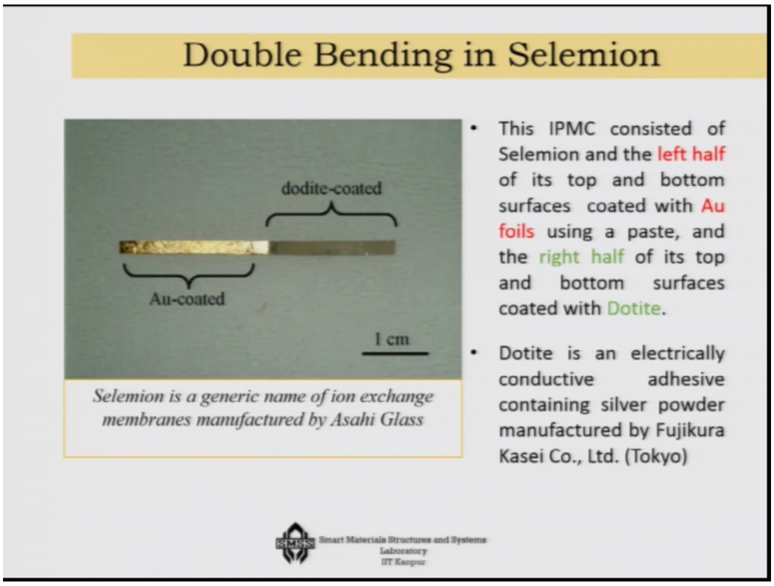

Now, the way it is done is that suppose you put Au coated part in one of the electrodes and the other part is dodite coated ok. So, this is the material here inside is Selemion instead of Nafion it is selemion, which is an ion chain membrane and it is manufactured by Asahi Glass is very popular. So, you apply gold in electrode in one side and dodite in the other side and what you are going to get is actually a bidirectional bending exactly what I have shown you in this case. So, with the materials selemion you can achieve this ok, this is one of the strategy of double bending in selemion.

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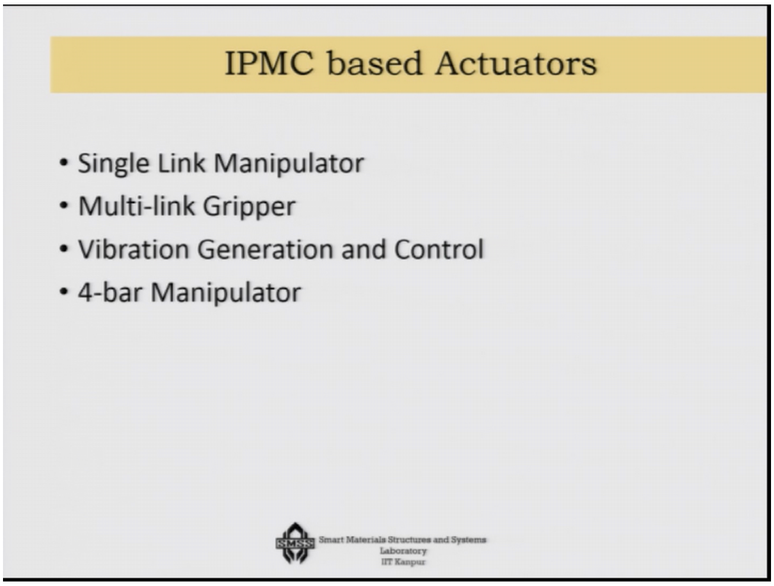

Now, IPMC based actuator specifically they are used for various purpose like single link manipulation like multiple link grippers, vibration generation and control and for 4-bar manipulations.

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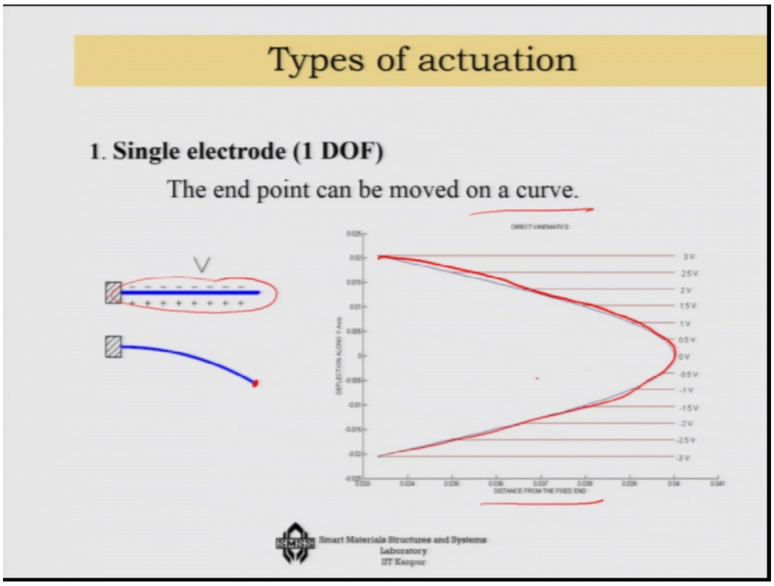

So, if you look at one of the applications like single electrode you know flexible manipulator. So, in this case what you have is that you have a cantilever beam and you apply the voltage, accordingly you will see the tip point getting displaced ok. So, depending on the direction of the voltage, in this case you will see the reversible changes and as a result you will see.

If you start to plot you will see that you know the distance from the fixed end you will see will be actually increasing and the deflection along the y axis that, if you start to measure you will get a kind of a workspace so, to say or the end point movement. So, that gives is you know what is the range in which you can actually manipulate such a system so, this is and you see that the endpoints can be moved in a curve by controlling the voltage in the system.

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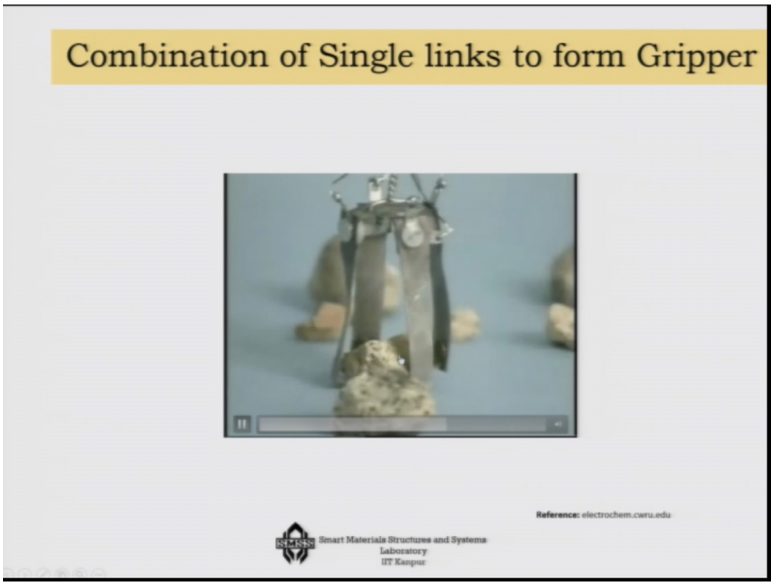

Now, I can show you how you can use it in the form of you know gripper by controlling this. So, if you look at this is used for you know planetary missions by NASA. So, you can see controlling the voltage from this ends, you are controlling this bending and how you are actually using that in terms of gripping a particular system. So, like that you know if you have to pick up a different geometry you can actually change the voltage and it is pretty much you know reverse and robust and programmable. So, that is one of the examples in which you can use such a system.

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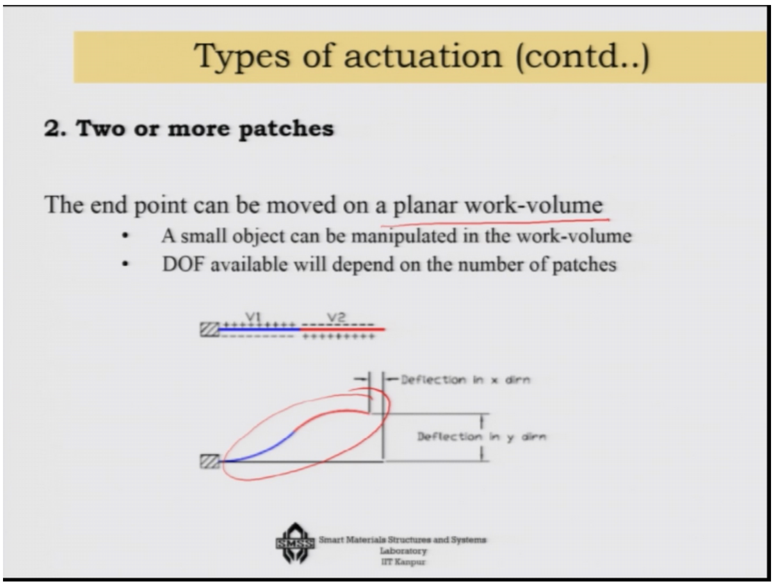

Now, we would like to talk about some of the other you know actuations like, what if I use two or more patches. Well two patches I had already shown you that you can develop a bidirectional deflection in a two patch system and, this can be then used for a planar work volume generation. So, that is something in which you can use this strategy of that selemion with gold and dodite.

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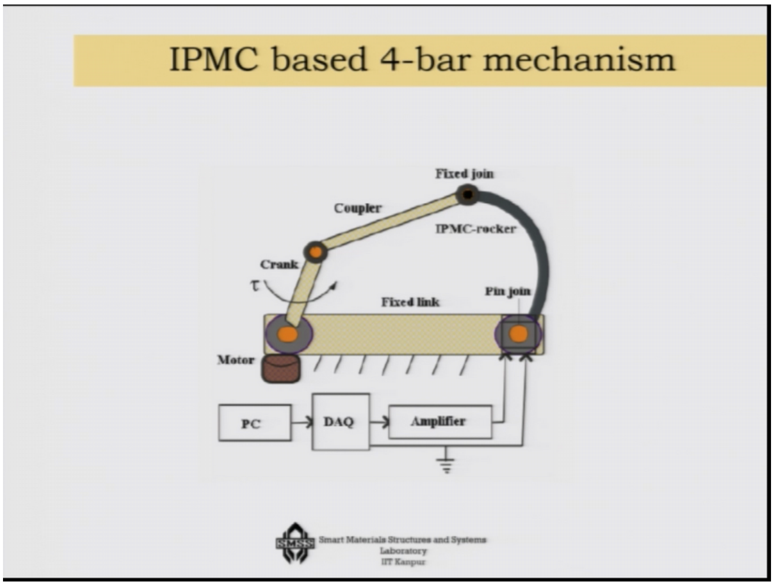

Another interesting thing that can be done is if you develop a 4 bar system in which one of the link is actually flexible. So, then what you can do is that you can use it as a manipulator. So, this is a crank side this is a coupler and this part, if you can change the length of it you can actually use it in terms of developing various different work surfaces.

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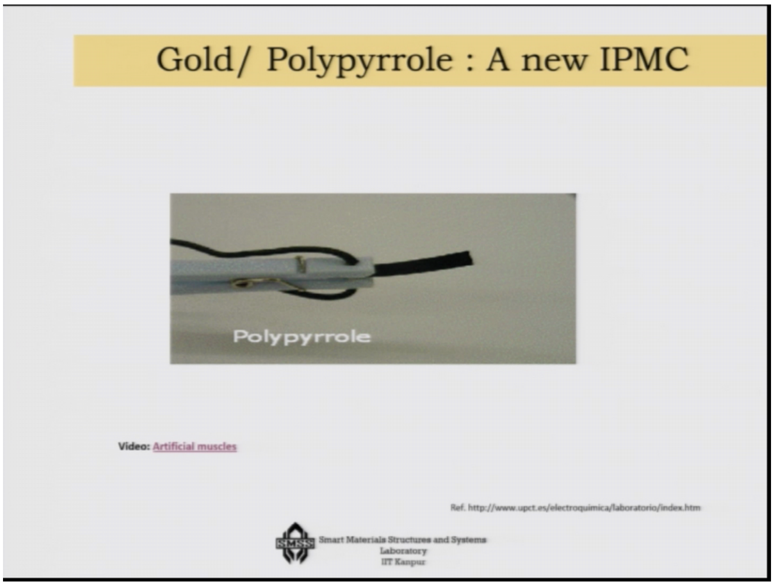

I can show you one examples where this kind of systems can be used for actually developing artificial muscles, this is a polypyrrole which has gold based system you know of electroding.

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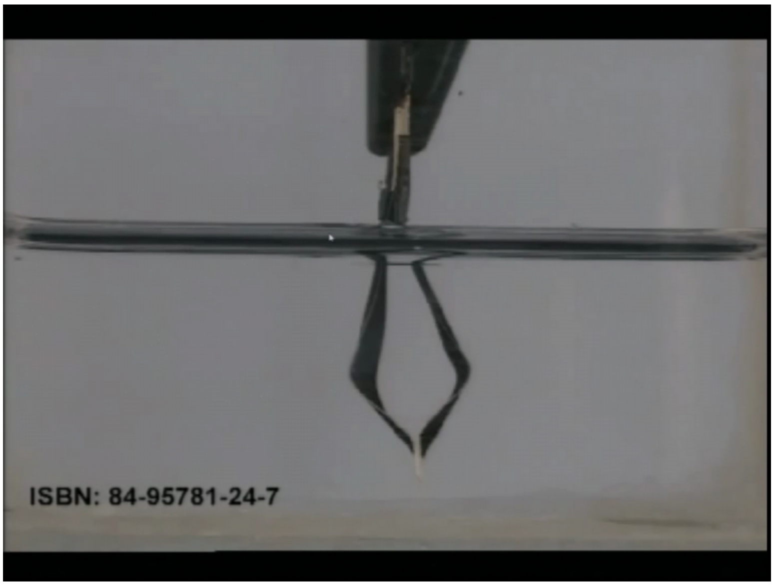

So, if you look at it that how much you are able to change the shape of the system. So, you imagine I was telling you about drug release that, if you cannot joint this much of reflections at the end point release the drugs from a system by using this particular type of you know actuation strategy.

So, the IPMCs this can be used in various cases where you can actually generate in a large deflections and as a result of that you can manipulate an object, you can you know do a pick and place of an object at a location for, you can use it for flow controls and purposes like that. So, this is what I like to give as an overview for IPMCs. In the next lecture we will talk about shape memory alloys we will give an introduction to shape memory alloys.

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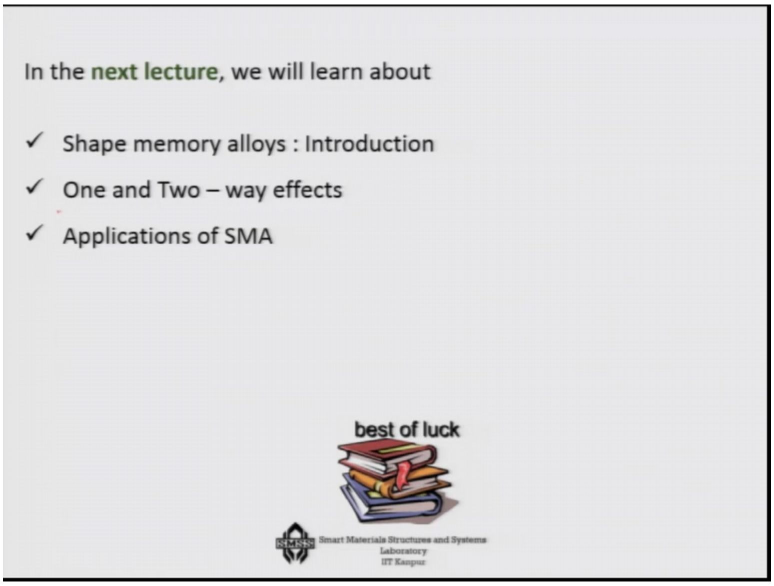

And we will also talk about relevant things like one and two effects of shape memory alloy and applications of such shape memory alloy.

Thank you.