Nature and Properties of Materials
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Lecture 26
Smart Materials 4

Today, I am going to talk about a new group of smart polymers and these are active smart polymers. So there are many such polymers which behave very similar to the piezo ceramics or magnetostrictive materials that we have seen in the sense of both from direct effect as well as from the reverse effect point of view and these polymers are very useful for us. Why because the elastic modulus of a polymer is much less in comparison to the ceramic or the metallic counterparts, so as a result they are more compliant.

So you can give actually very flexible shapes by these polymers and then you can use them as integrated sensors or as integrated actuators. So, our intention is to look into the polymers the subgroup of polymers, which shows some amount of smartness that is both in terms of the direct as well as in terms of the reverse effect. Now, IVMCs of this group of active polymers are especially important because of the demand of developing new robotic locomotion system, which would simulate the animal locomotion.

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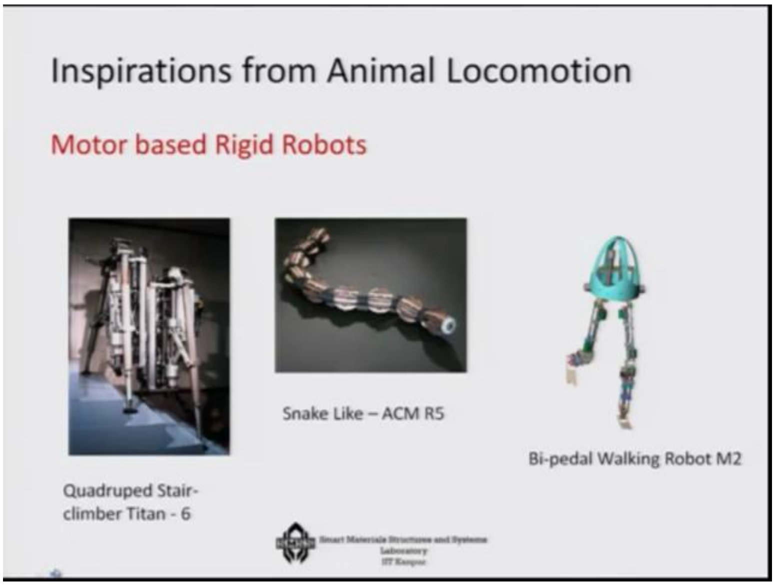

In fact, if you look at the robot development of robotics with respect to various types of robots which can simulate or bio mimic the animal locomotion, then the 1^{st} in the group something like the quadruped stair climber titans, so these are actually many leg kind of a robot and then there is this snake like robot ACM R5. And also later on people developed Bi-pedal walking robot. The important thing is that in all these robots, the actuation for example, this bi-pedal is achieved through the use of conventional motors.

But motors are heavy, motors are more power consuming and they have backlashes and other problems, so people started thinking can we not replace these motors by something like artificial muscles. So replacing motors by artificial muscles is something that triggered actually the development of active polymers by artificial muscles. Like this region you develop muscle system with the help of polymers, which can substitute the motor based system, so hence today we will talk about some of the smart polymers.

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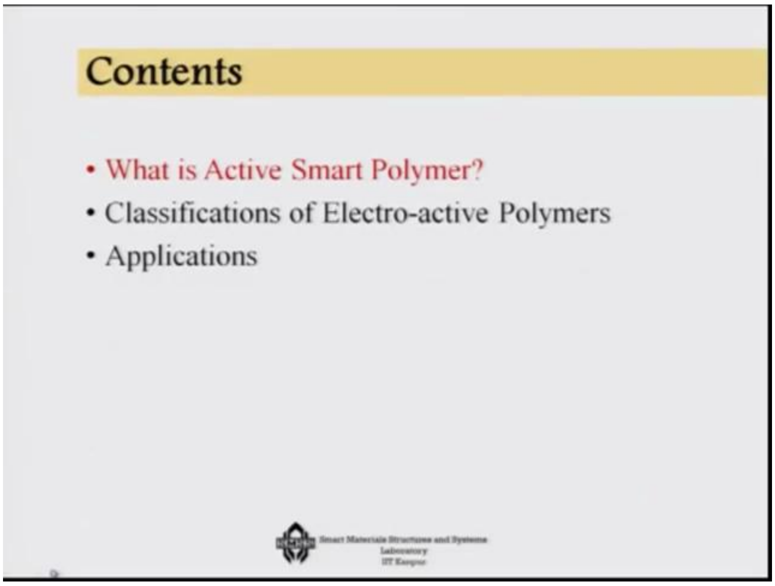

First we will define ourselves that what an active smart polymer is. We will then talk about the classification of these electro-active polymers and then we will mostly talk about the applications of these smart polymers. So the 1st thing is that what an active smart polymer is.

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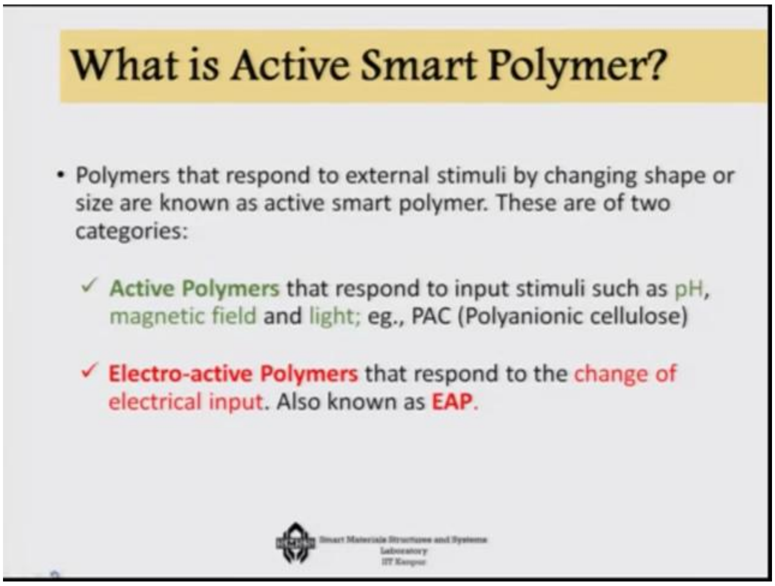

The polymers that would respond to external stimuli by changing shape or size are known as active smart polymers, so which means that it is mostly the reverse effect that has been kept in mind that you are giving some external stimuli and the polymer is changing its shape or size. Of course, the other way direct effect is also available in some of these polymers and we will talk about it whenever these polymers will come into the discussion.

Now active polymers can be divided into 2 subs, in one group the response can be anything other than electrical or and of course mechanical. So for example, if it is pH, if it is magnetic field or light for that matter okay like Polly anionic cellulose PACs and there are many such active polymers, I will show one example. So these polymers are known as active polymers, simply active polymers as the respond to input stimuli which are generally non-electric in nature.

Now, electro active polymers on the other hand as the name suggests that they respond to the change of electrical input and hence they are known as EAP or Electro active polymer. Now given a choice, which one would be prefer? Of course, we prefer the electorate active polymers because it is easier to control such a system. To control the movement of a system with the help of a magnetic field generation or with the help of pH change chemically or with the help of light intensity is still not the technology has not developed up to that extend. On the other hand, to control it electrically it is much better.

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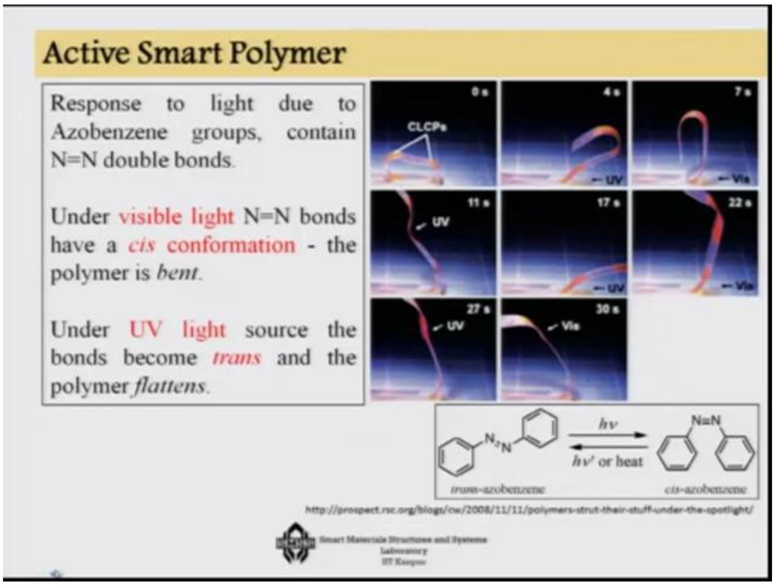

So one of the examples I told you in the terms of only active polymer is this light based response of the Azobenzene groups, this Azobenzene groups actually contain this double bond of nitrogen. Now what happens under visible light as you can see that this is the double bond of nitrogen here as you can see. Now under visible light this double bond go to a cis configuration, so the moment you put light on this, they to go to a cis configuration something like an angular configuration.

That is why we say that it gets bent and under UV light, this goes to the Trans configuration, so this is under UV light which means they remain straight, so it is straight under UV light and under natural light it is bent. Now, if you develop a system like that as you can see and then successively you apply the UV light and plane light, then what you can do is that you can bend it, you can straight it, bend it and like that the bending and straightening sequence you can actually use it in terms of locomotion of a system. So this is one of the supposed to be a very active smart polymer which is coming up, so this is one of the uses of an active smart polymer.

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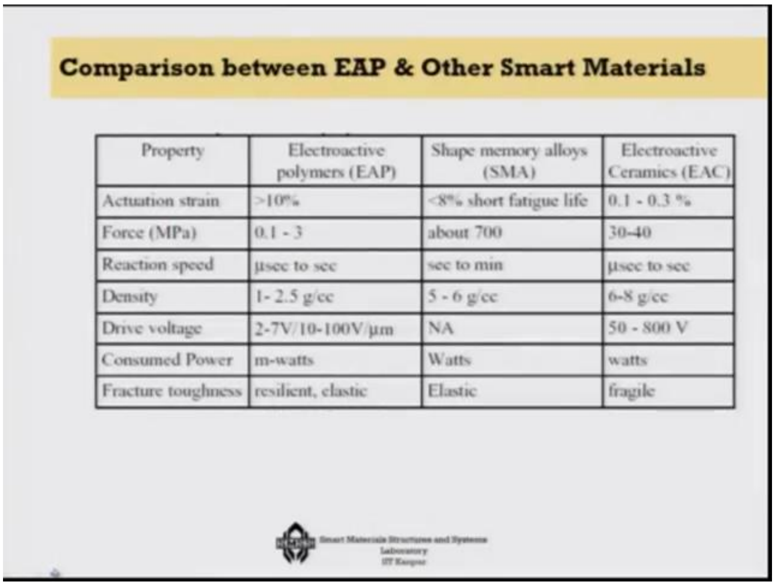

Property	Electroactive polymers (EAP)	Shape memory alloys (SMA)	Electroactive Ceramics (EAC)
Actuation strain	>10%	<8% short fatigue life	0.1 - 0.3 %
Force (MPa)	0.1 - 3	about 700	30-40
Reaction speed	μsec to sec	sec to min	μsec to sec
Density	1- 2.5 g/cc	5 - 6 g/cc	6-8 g/cc
Drive voltage	2-7V/10-100V/μm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

Now let us come back to the focus of electro-active polymers which I said will be more useful EAPs will be more useful in terms of the development of actuators and sensors. So if we compare electro-active polymers with the shape memory alloys which I will be talking about in the next lecture and electro-active ceramics, where are they? The most noticeable thing is that the strain that it deforms is greater than 10%, which is much-much greater than any one of the other 2 categories.

What it means is that you can make actually very large deformation in the system. The force on the other hand, stress for example, 0.1 to 3 MPa which means whereas this is very high, this is very low the force availability. Reaction speed is about microsecond to second, electro active polymers are generally quite fast, but it varies. Density wise once again the density is low, drive voltage is extraordinarily low 2 to 7 volts; compare that with Electro ceramics 50 to 800 Volts.

The power consumption is also very low milliwatts range. Compare that with Electro ceramics or SMAs which is in the watts range. And the fracture toughness is almost absent, it is very resilient and elastic on the other hand, the electro active ceramics are very fragile. So from many such points of views we can see that electro active polymers are going to be much more useful for us in comparison to any other smart material.

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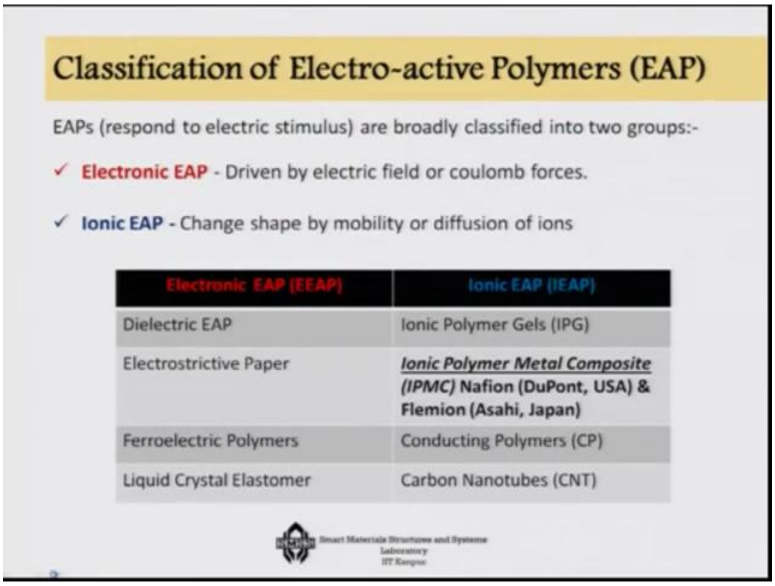

Now, electro active polymers itself can be subdivided into 2 subgroups. One is called Electronic electro active polymers, where the polymer the change in the polymer is driven by the change in the electric field or Coulomb force. For example, you think of the PVDF as I already said, piezo electric material that is one of the electronic electro active polymers or Dielectric EAPs, Electricity papers, Ferroelectric polymers or Liquid crystal elastomers, all of them are they respond by the change of the electric field.

On the other hand, for ionic electro active polymer, this actually responds due to the mobility or the diffusion of the ions. For example, ionic polymer gels or ionic polymer metal composites, we shortly call it IPMCs. There are many IPMCs available like Nafion from DuPont and Flemion from Asahi Japan, and then conducting polymers and carbon nano tubes also come into the category of ionic electro active polymer where the changes happen due to the mobility or diffusion of the ions. Now let us compare between the EEAPs and IEAP that is Electronic electro active polymer and Ionic electro active polymer.

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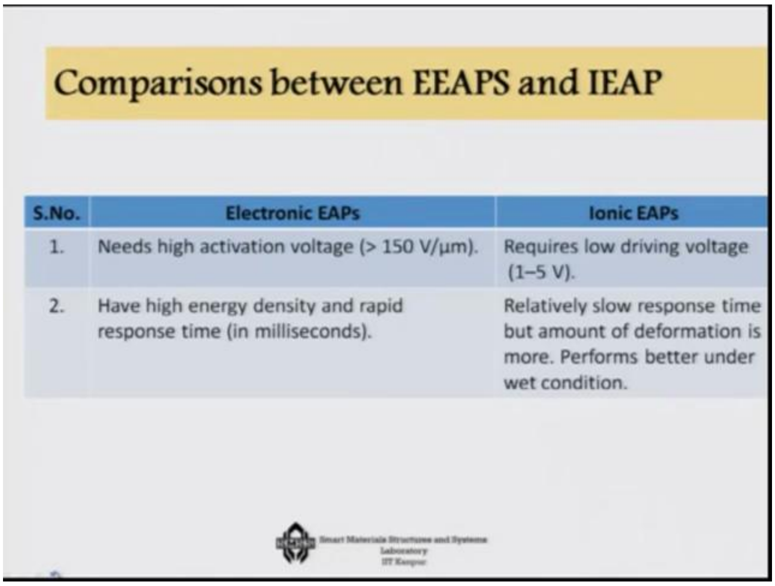
Comparisons between EEAPS and IEAP

S.No.	Electronic EAPs	Ionic EAPs
1.	Needs high activation voltage (> 150 V/μm).	Requires low driving voltage (1–5 V).
2.	Have high energy density and rapid response time (in milliseconds).	Relatively slow response time but amount of deformation is more. Performs better under wet condition.

The 1st important thing is that electronic electro active polymer needs high actuation voltage something like greater than 150 volts per micron meter. On the other hand, IEAPs require low driving voltage something like 1 to 5 volts. Secondly, electronic electro active polymers have high energy density and rapid response time. On the other hand, ionic electro active polymers are slow but the amount of deformation is more and it performs better under wet condition because I told you that it is the mobility of the water in the ionic form that actually creates the deformation.

So if it remains moist, more amounts of ions of water will be going towards particular size and as a result there will be more deformation in the system. So there are many applications of it as you can see that people have thought of using it as the dust wiper particularly for space applications.

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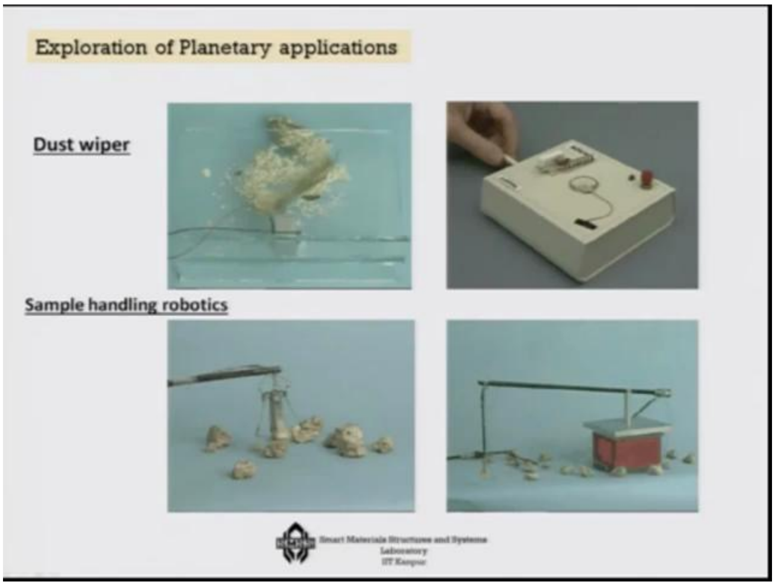

So today's wiper, how does it move? You must have seen that it works like a rigid movement. So because of that rigid movement, it swipes a curve and if you have one more of this type, then that swipes another curve. But then there will be some corners which you will not be able to reach by either of them and those corners if you have on the other hand the dust wiper which can actually vary its length if you use such dust if you use such kind of a long wiper which can vary its length.

Then you can actually go from one corner to the other corner with whatever work volume you wish it can go very nicely, so that is what IPMC is very good for that kind of a system. Also for handling the samples just like our fingers, it can deform to a very high extent for handling of the samples. So if I try to kind of bring all these applications together, we will see that one good application is in terms of mechanisms, it can be used for lens controlling, for mechanical lock, noise reduction, for flight control surfaces or anti-G suit, so for all sorts of mechanisms you can use this.

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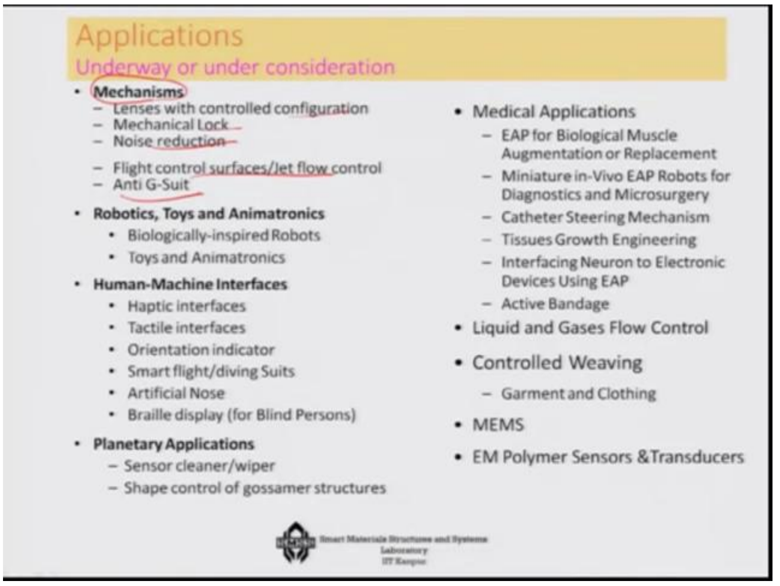

You can use it for robotics like I showed you the example of walking robots, et cetera, biologically inspired robots, toys and animations. You can use it for human machine interfaces towards the end of this lecture I will show you one such application, tactile interface okay artificial nose, things like that. Then you can use it for planetary interfaces like I told you that you can use it for that wiper or gripper or cleaner wiper or shape control of gossamer structures like that.

There is a good use of this material for medical applications for example, it is used for biological muscle augmentation okay that is one, then miniature in Vivo EAP robots for diagnostics and microsurgery, Catheter steering mechanism, tissue growth engineering, interfacing neuron to electronic devices, active bandages, et cetera. You can also use such a system for liquid and gas flow control, control weaving or garments and clothing, then for MEMs and EM polymer sensors and transducers, so it really has a very broad field of application. Now, how does it look like?

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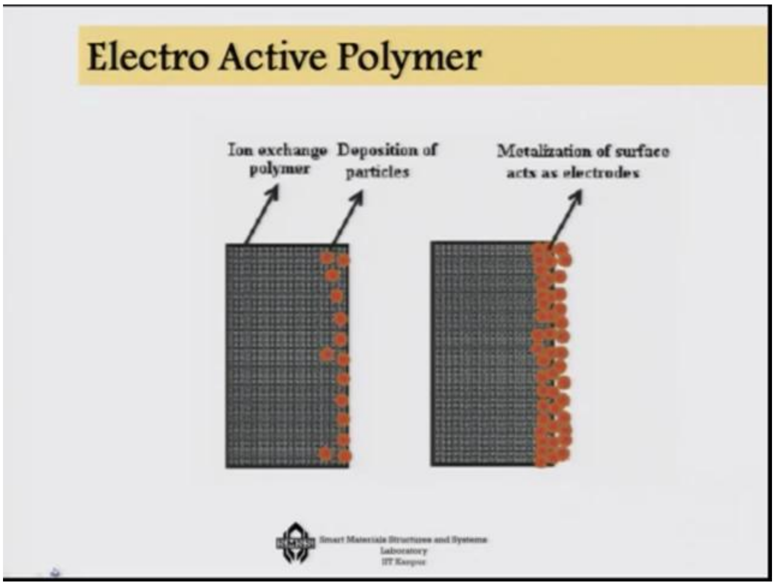

This is typically an ionic I should say this is an ionic electro active polymer that is IEAP. So what you have here is typically Nafion for example would be like this Nafion. So you have this polymer here, the ion exchange polymer and there are these depositions of particles on it. Now, these particles you can actually metalize this surface with the help of an electrode you can metalize this surface so that you can apply the voltage to generate a polarity like cathode or anodes.

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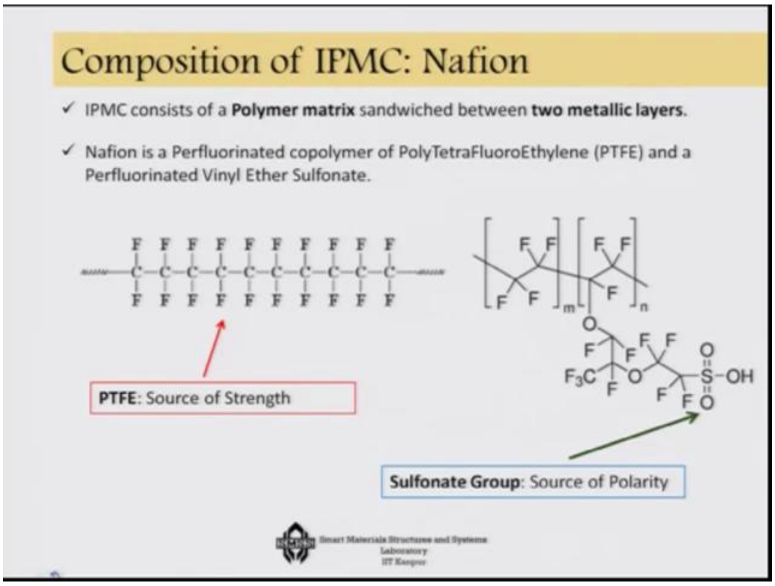

Now, if you look at one of the ionic electro active polymer which IPMC, so IPMC is Ionic polymer matrix composite, short form is IPMC. If I look at the structure of IPMC, what I am going to see is that the main chain is actually PTFEs and that is the source of its strength.

PTFE is something that is used even for your applications like non-stick or things like that, it is very very strong. And on the other hand, it has some additional groups which are like sulfonate group which is its source of polarity.

So, IPMC is basically or Nafion is actually Per fluorinated copolymer of PTFE and a Per fluorinated Vinyl Ether Sulfonate, so there are 2 copolymers that are used for developing this polymer, one gives it the strength in the backbone and the other gives it the source of polarity. Now, how does this system would work?

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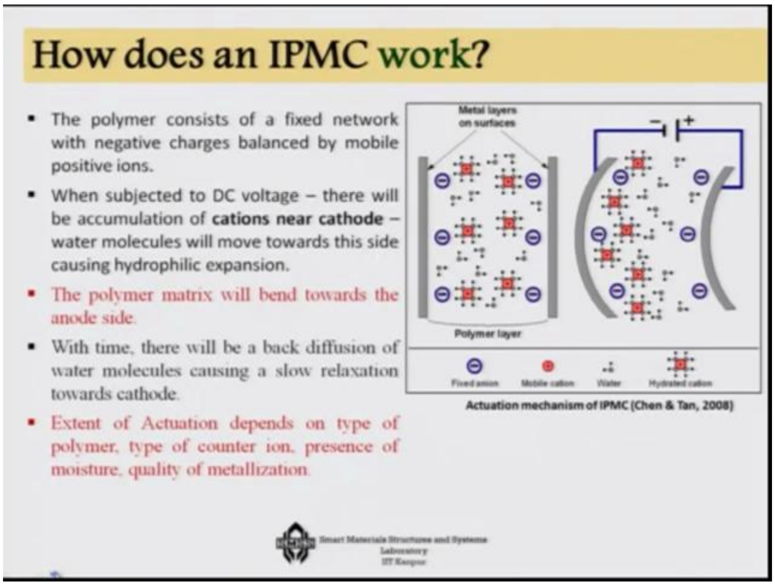

This polymer consists of a fixed network with negative charges balanced by mobile positive ions, this is important. It has a fixed network and in that fixed network there are these negative charges as you can see and this negative charges are balanced by positive ions around them, mobile positive ions are just fixed to it. When it is subjected to DC voltage like this, what do you expect to happen? There will be then that accumulation of all the cations near the cathode, so as a result you can see that all the cations are coming close to the cathode so that kind of a migration that is taking place.

So here blue things are the fixed anions as you can see, these are the fixed anions and these are the mobile cations. So all these mobile cations as you can see, they have migrated towards one side right, towards this the negative side. And as they have migrated what will happen is that the water molecules will move towards this side and it will create a hydrophilic expansion that is why the whole thing has got bent. So the polymer matrix will bent towards the end outside, this is your anode side so as the cations will be moving, we are going to get the bent towards the anode side.

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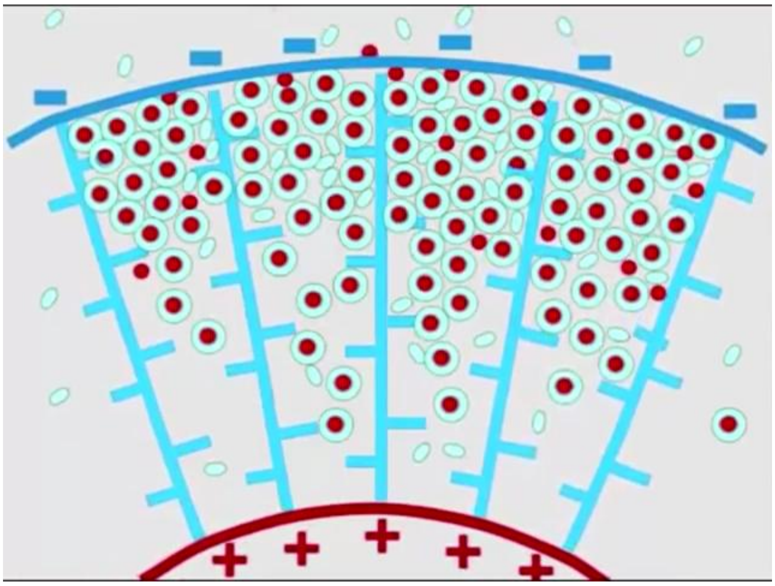

However what will happen is, after amount of substantial this thing have there to neutralize, you will get a back diffusion of water molecules which will cause a slow relaxation towards the cathode. That means not everything will remain attached, little bit after of after some time back scattering would start to happen. Now the extent of this actuation of course depends on the type of the polymer, type of counter ions, presence of moisture, quality of metallization, et cetera, but that is the basic principle of how an IPMC will work.

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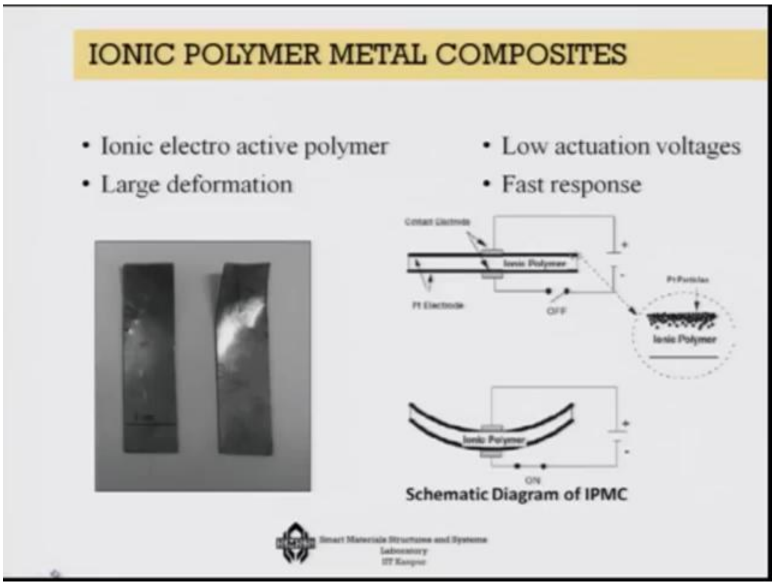

Now these IPMCs are having several characteristics, one is that large deformation, low actuation voltage and fast response. So here, what we can see is that if you build up these 2 electrodes and you pass a current, you are going to get this kind of a bent shape in the system, so it will change its shape as you are going to apply electric voltage, something similar you can see on the Nafions on here. Now, can we get only one type of curvature only in one direction?

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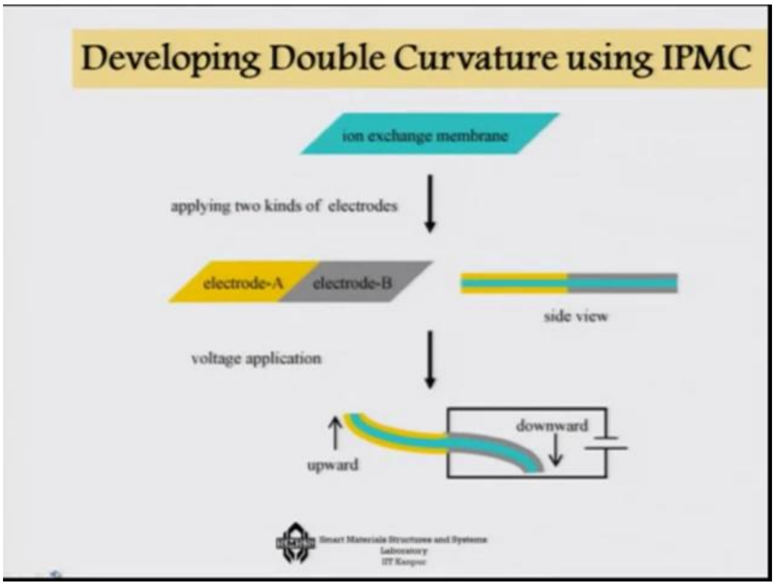

No, you can actually depending on the type of electrodes, okay you can actually get 2 different types of electrodes like here and then if you apply the voltage you may get upward bending in one side and downward in the other side and as a result, you can get a bidirectional curvature. If you have more such combinations of electrodes, so you have a beam let us say which has more combination of electrodes this is the top few of it. So what I am going to see, I am going to see a wiggly niggly motion of the system somewhat similar to the motion of the snakes. So you see the double curvature is really very-very beneficial for this kind of a system.

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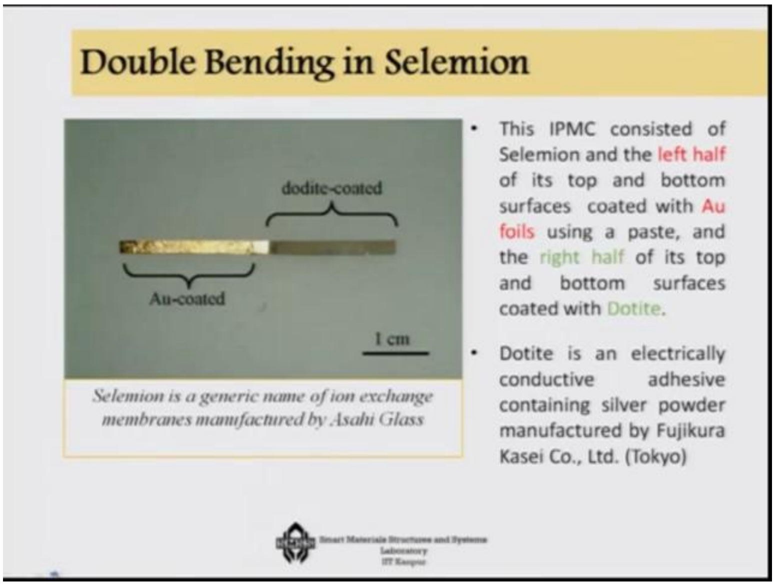

Now, double bending in one of the typical materials like Selemion which is the generic name of ion-exchange membrane of Asahi glass, you will see that it consist of selemion and the left half of its top and bottom surfaces are coated with gold foils. Whereas, the right half of its top and bottom are coated with something called dodite. Now, dodite is an electrically conductive adhesive containing silver powder manufactured by Fujikura, so as a result you will get a double curvature in the system. So these are some of the strategies like you coat with two different materials and then you get a double curvature out of the system.

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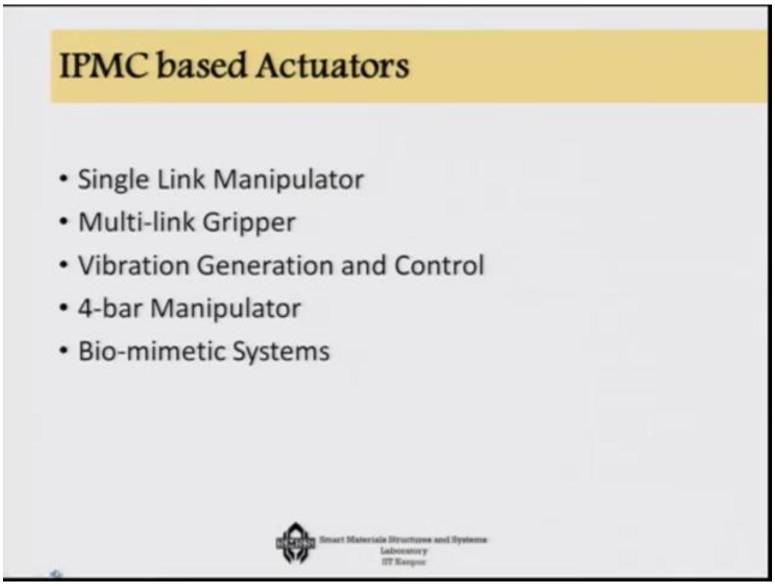

IPMC based actuators have many applications but the major applications are in terms of single link manipulators that means when only link, one single link you have and using that itself, you need to bend it enough in order to hold something and in order to transfer this thing at some other location, so that is single link manipulation. You can of course then use it for Multi -link grippers, for vibration generation and control, for 4 bar manipulation and for bio-mimetic systems, IPMCs thus have versatile applications.

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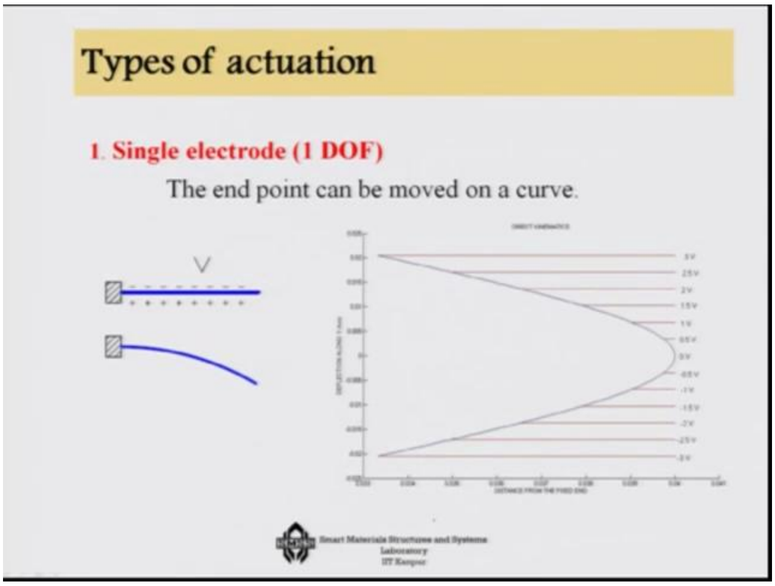

Like as a single electrode, if you use only one electrode then you can actually you you will see that you can actually go through this kind of an works space, so that is the maximum that you can cover with this type of a system.

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On the other hand, if you have 3 or 4 of them then you can use it for holding something some material okay from space, so you can use in the form of developing a gripper system.

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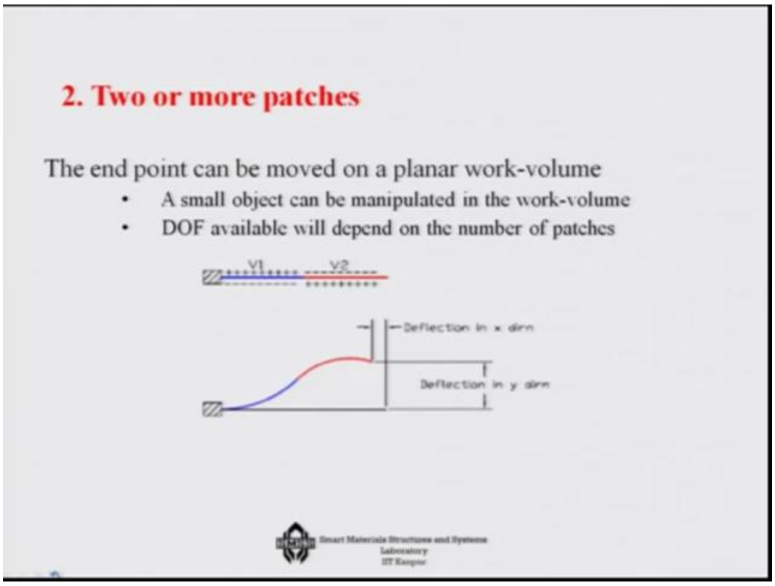

If you use 2 or more patches, then in fact you can actually manipulate a small object in the work volume and the degree of freedom available will depend on the number of such patches like one patch and then you have a 2nd patch, so you can easily make this kind of shapes, et cetera. Not only that, you can also a 4 bar mechanism using active polymer like IPMC.

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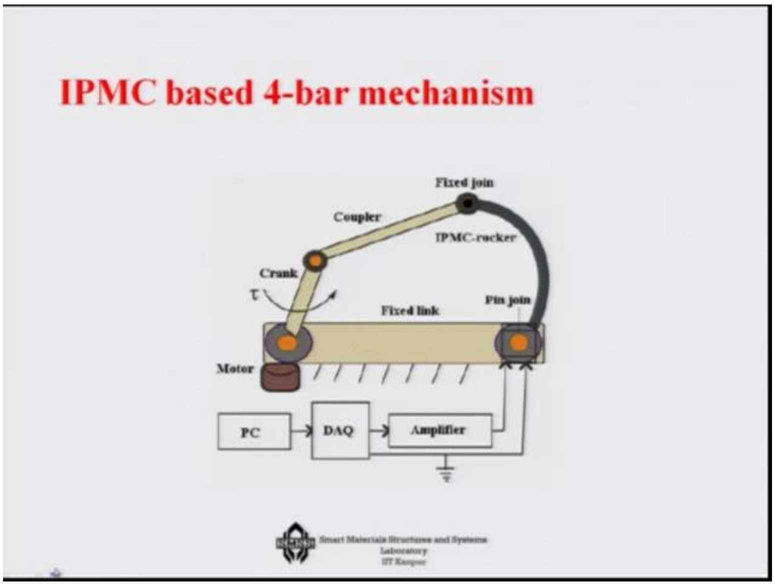

As you can see here, this is a 4 bar mechanism, so 1 2 3 and that is the 4th ring, so with this 4 bar mechanism as you are moving this rocker part of it, then the coupler transfers of the motion and you get this part of course become flexible, you get a kind of a motion due to the bending of this ring. Now that workspace of course you can control by applying voltage in the system in an active manner so that you can control the workspace that it can generate.

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One of thy IPMCs which is coming up in a big way is known as a Gold Polypyrrole IPMCs, so that is good in terms of the lightness, anticorrosive properties, et cetera.

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This is what I told you is a fascinating example of tomorrow that this robot here has artificial lips, which is made of IPMCs. What it does is that through its vision it is carrying the lips of this person and then what it is going to do is that it is going to, so it is scanning the lips here and it is going to change the shape of this lip, so that it can mimic the Master system, so tomorrow's animations can be based on this kind of Biomimetic systems.

So this is where we will end today's lecture and in the next lecture we will talk about shape memory alloys, we will give an introduction. Also we will talk about one and two way shape memory effects. Thank you.