Acoustic Materials and Metamaterials
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Lecture - 32
Advantages and Applications of Membrane Type AMM

Hello and welcome to lecture 32 in the week 7 of this course on Acoustic Materials and Metamaterials. In today's course we will discuss about some Advantages and Applications of Membrane Type Acoustic Meta Materials. So, up till now we discussed more about the fundamental principle of working of these membrane type acoustic meta materials.

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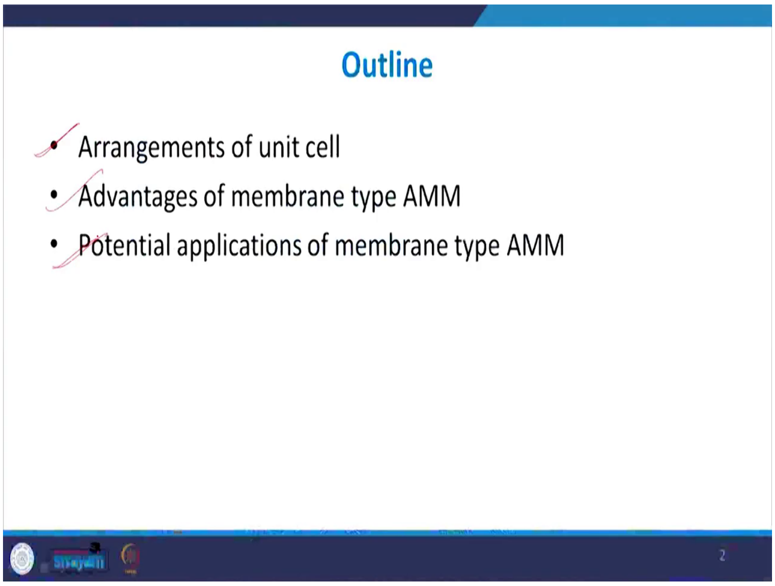

So, we studied how when we have a unit cell with a stretched membrane how does it behave and respond, and how does it how is it able to block the sound. Similarly, we studied how the unit cell, where you have a stretched membrane with some mass attached to it. In that case how does it behave and in what regions these unit cell became to have a negative effective mass density.

And in that region suddenly these seemingly thin membranes are able to not allow any sound waves to pass through. So, we do not get a propagating wave, because rho becomes negative; so which means that, the propagation vector is negative. So, we have studied the basic principles here and in this class we will be more about the applications and the general advantages and disadvantages of these materials.

So, we will begin with how the unit cells are arranged to form a layer of material. So, if you go here, we will begin with how these unit cells are arranged to form the metamaterials, and then what are the advantages and then the potential applications of these membrane type acoustic meta materials. So, here the first arrangement was proposed by Lee et al the source is provided here, Lee et al 2009.

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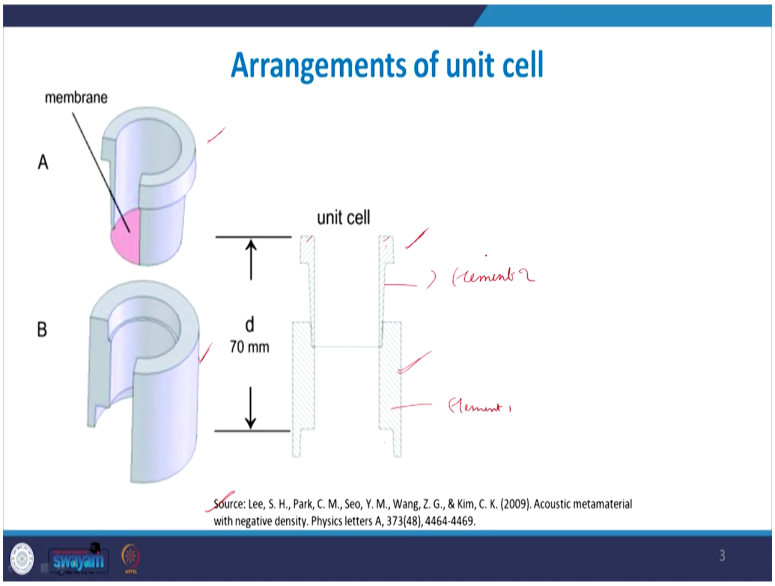

So, here what you have is that, we were discussing about the membrane being a part of a heavy of a long waveguide. So, you have hollow tubes, hollow dense tubes with stretched membrane in between. So, the way he proposed this arrangement is that, you have these are the two sets of waveguide.

So, this is the shape. So, if you take the side view, this becomes a shape of one particular section of the waveguide and this becomes a section of the another. So, these are the two sections when they are combined together and this part one contains a membrane that is attached on top of it. So, this is just a cut view of this. So, the membrane is attached on top of it and then it is attached to the lower part and it is made into a tight fixed arrangement.

So, you get one unit cell. So, if you do the same process again and again. So, let us say, you have attached this particular element on top of it; but in the bottom also the shape is curved in such a way that this shape will fit it into the bottom also. So, this is the kind of arrangement and this shape is complementary to the above shape.

So, when you arrange this. So, here element 1 element; so let us say this is element 1, and this is element 2. So, element 1 on top of it we have element 2; then on top of it again element 1 is repeated, then element 2 is repeated. So, it is a alternate periodic repetition of element 1 and 2.

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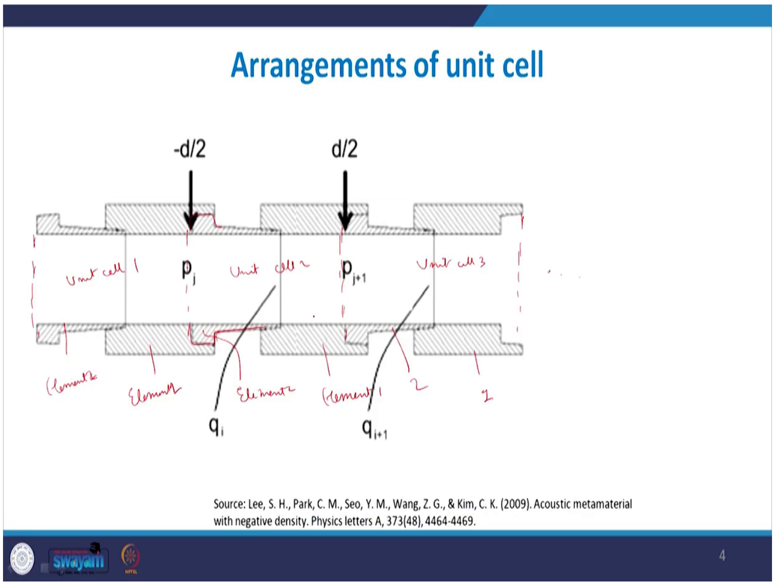

So, you see here, this is element 2 followed by element 1 followed by again element 2. So, as you can see here this is the element 2; it starts somewhere here. So, this is element 2, then we have element 1, 2 and then 1 and so on. So, these two elements they are arranged in series. So, one on top of each other and when you keep connecting them and fixing them together, at the end you will get is a long waveguide and in the waveguide there will be stretched membranes occurring at regular intervals.

So, the stretched membranes will be occurring at regular intervals. So, you get such unit cells. So, all of this, so here from here till here becomes one unit cell and similarly from here till here becomes another unit cell, and from here till here becomes another unit cell. So, this is unit cell 1, unit cell 2, unit cell 3 and so on and so forth.

So, you have such long wave guides attached and the unit cell is being repeated again and again by repeating alternating between two main elements; and where here element 2 contains a stretched membrane and is fixed inside element 1 and so on.

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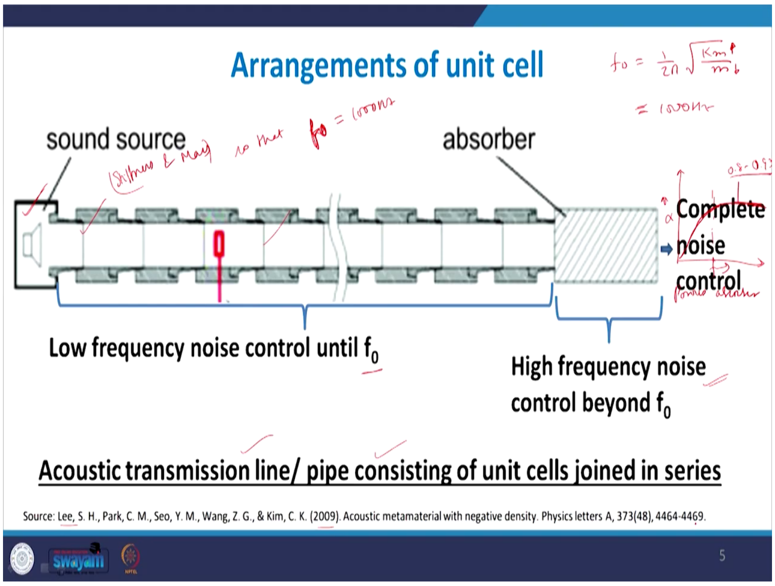

So, how does it, how does these help. So, this is a series connection of these unit cells. And it was proposed as I said by Lee et al 2009 and this is the resource here. So, if you have such long series of elements, this can be like an acoustic transmission line or a pipe. So, if you have some noise source here.

So, let us say we have some heavy noise source at one end, and it is emitting loud sounds at almost all the frequencies. So, you have a general loud noise source. Then you can attach this transmission line and at the other end you have attached a porous material, a porous absorber; so this particular we know that, this is a unit cell which is containing a stretched membrane.

And we know that this particular type of unit cell it behaves in such a way that, from 0 till it is natural frequency it has negative density and therefore, from 0 till a particular frequency limit, it does not allow wave to propagate through. And this natural frequency depends upon the stiffness of the membrane and the mass of the membrane. So, if we can manipulate the stiffness and the mass.

So, let us say we can manipulate the stiffness and mass, so that the natural frequency f naught becomes let us say up to 1000 Hertz; because up to 1000 Hertz is the region where noise control is very difficult. So, if we can manipulate these membranes in such a way that, their stiffness and their masses, so that; because f naught will be 1 upon 2 pi under root of K m by m. So, we can increase the stiffness value, decrease the mass value and so on that it comes to about 1000 Hertz or so on.

So, we can make it in this way. So, when the noise source is incident, it cuts the first part cuts all the frequencies, it does not allow any content between 0 to 1000 Hertz and then only the high frequency content is was through. And then at the other end we have a porous absorber and we already studied what is the feature of a porous absorber. A porous absorber typically. So, this is for a porous absorber, it typically allows; this is the typical kind of an alpha versus frequency.

So, usually at low frequencies up to 1000 Hertz or so; the performance is low, they are not able to block the sounds, they are not able to dissipate the sounds. But suddenly beyond this they have a performance of 0.82 to around 0.95 or so on, a good absorber. So, at high frequencies they are able to absorb well.

So, what we get effectively is that, this particular portion is responsible for controlling the noise until a certain frequency, so all low frequency noise. And this f naught can be manipulated to be any value of say 500, 1000 and so on. So, the low frequency noise control happens using the first part and then the high frequency noise control happens beyond this range using the porous absorber.

So, at the end what we get. So, if I delete this just to make it clear. So, at the end what we get is, we will get a complete noise control. So, the noise throughout all the frequency, all the audible frequency range is being cut and we get a complete silence. So, this is like sort of proposal where we get a perfect noise reduction material both for low as well as high frequency, ok.

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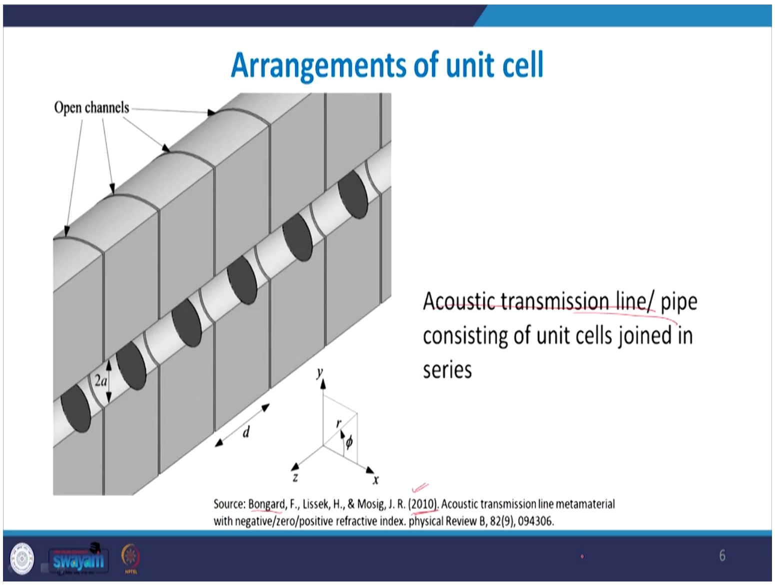

Other such arrangements have been proposed; so here we had two different irregularly shaped elements that were clutched, that were fixed together to make into waveguide in series. We can also have some symmetrical structures, so this shows again a cut view of another acoustic transmission line that was proposed by. So, this was proposed by Bongard et al 2010 a newer version.

So, here you also we have a transmission line and these individual, these are the individual elements where you have the membrane attached in between and so on. And these elements are connected together and a long transmission line can be formed in series, ok.

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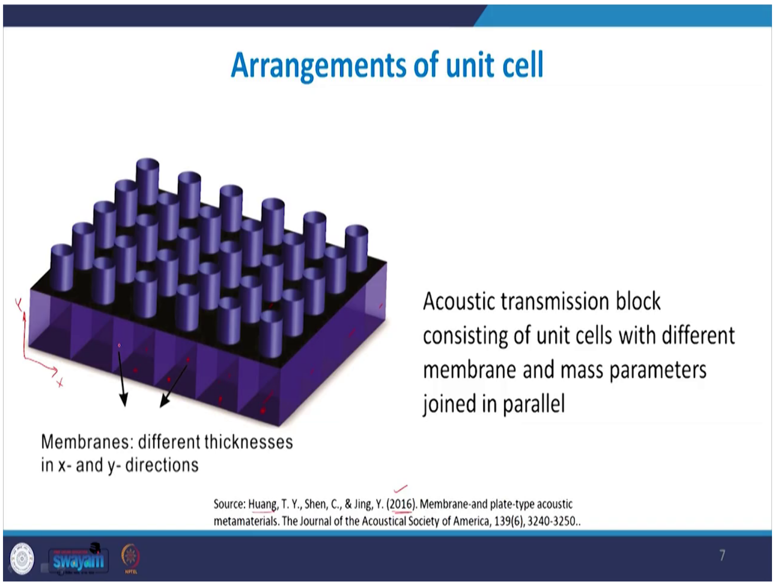

Another arrangement is when they can be attached in parallel; so not necessarily in series, but they can be attached in parallel. And what you get is that here the arrangement is proposed by Huang et al 2016, it is a newer form of arrangement. So, here you have all these corresponds to the different unit cells. So, you have unit cell 1, 2, 3, 4, 5, 6 so on and they are arranged in a parallel structure. And what you have is that, here you have membranes on both the x direction and the y direction. So, this is the membrane, this is let us say the x direction. So, this becomes the x and this becomes the y.

So, normal to x we have the x plane, and normal to y we have the y plane. So, here the membranes along the y plane, so this membrane, this membrane, this membrane and so on; the membranes which are in darker colors. So, here the thickness is going to be different where they have a higher value; and the membranes that are perpendicular to x plane, they have a lower thickness value.

So, the membrane parameters are different for different directions, so that we get different noise control in different direction. So, this is the kind of innovative arrangement that was proposed.

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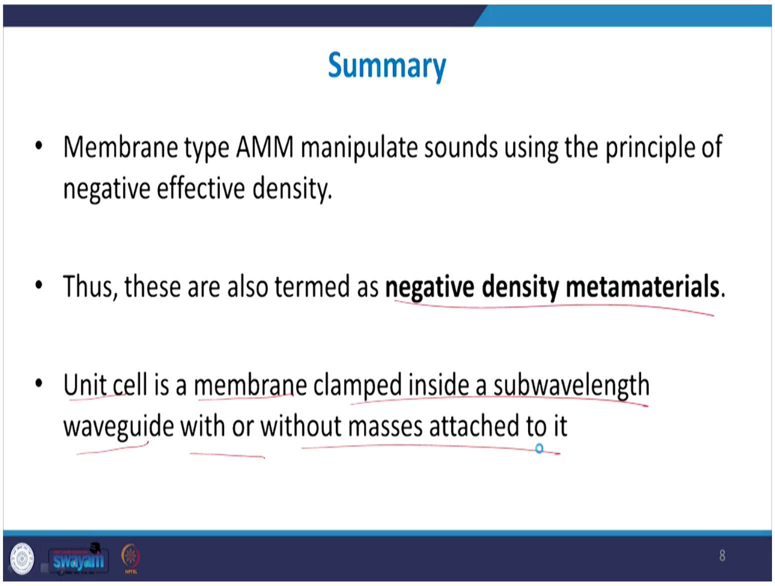

So, a brief summary before we go into the advantages and applications is that; such membrane type of acoustic meta materials they can manipulate the sounds using the principle of negative density. And then that is why they are termed as negative density meta materials. And the unit cell is either a stretched membrane clamped inside a sub wavelength waveguide, either with or without some mass attached to it.

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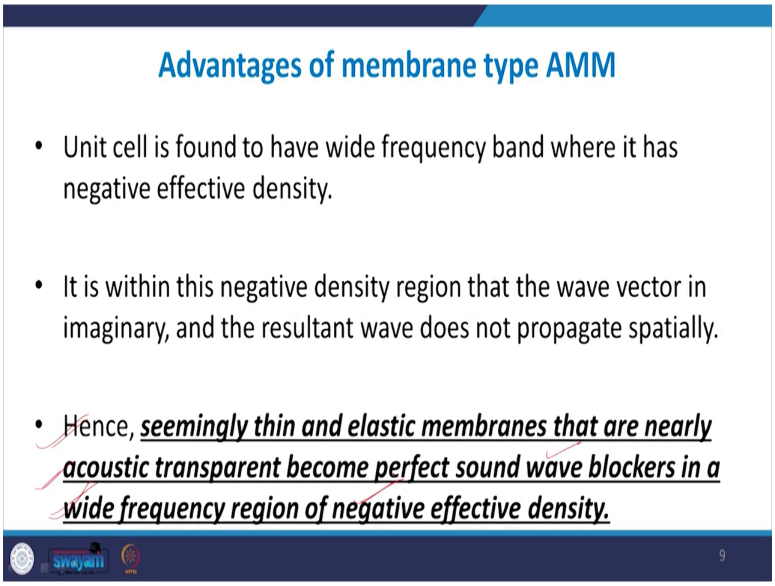

So, what are some of their advantages? The first advantage we already studied was that, you are getting a negative effective density in a wide region. So, you do not get a negative effective density in the small region like only at certain frequencies; you get a broadband range of frequencies. So, for the first type of unit cell, you get a negative density between 0 to its natural frequency; for the second part type you get between f naught to f naught under root of m plus capital M by m.

So, we are getting some broad range of regions where the density is becoming negative. So, the resultant is that, these seemingly thin and elastic membranes that are nearly acoustically transparent. So, if you see our membrane stretched, you will see that it is very thin and light structure; it seems it is almost acoustically transparent.

But the beauty of physics is that, such kind of transparent structures they become perfect wave blockers or perfect sound wave blockers in a wide band of its negative effective density. So, you now get a broadband noise control in low frequency region.

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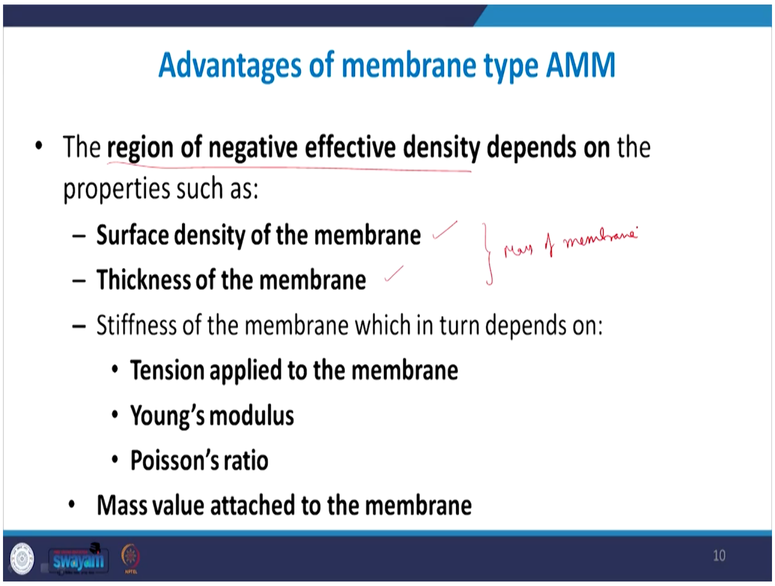

So, the region of negative effective density now depends on. So, we found that, in the wide range of negative density they will be able to block the sound perfectly. And what does this region or the range of frequency depend on; it depends on the surface density of the membrane and the thickness of the membrane, so this gives you the mass of the membrane.

In the same way, so it depends on the surface density and the thickness of the membrane; in the same way it also depends upon what is the tension that is applied to the membrane. So, overall it depends upon the stiffness of the membrane and the mass of the membrane, and the stiffness in turn depends on the tension applied to the membrane, the Young's modulus, and the Poisson's ratio of the material used for the membrane.

And similarly it will also depend upon the density of the attached mass. So, what you see here. So, this is the third quantity which is the mass value which is being attached to the membrane. So, these are the various parameters that are used to govern the response of such structures.

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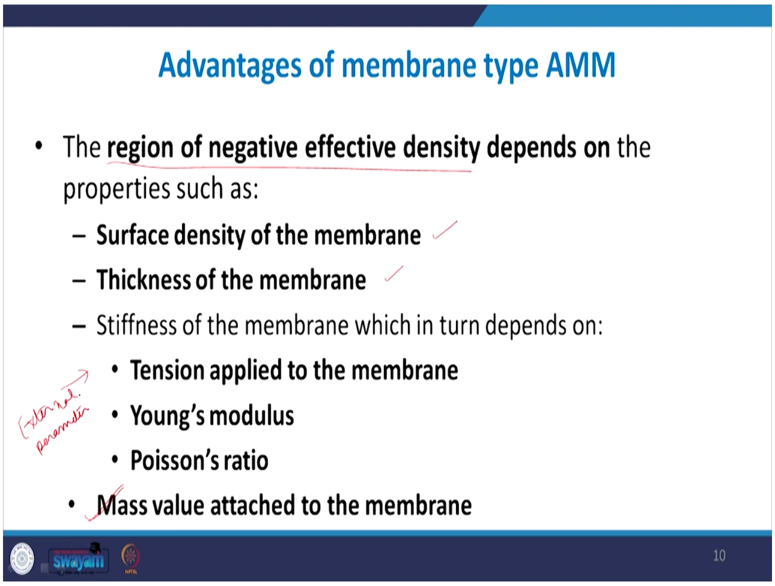

And as you can see this is one of the external parameter, which is not intrinsic to the membrane construction.

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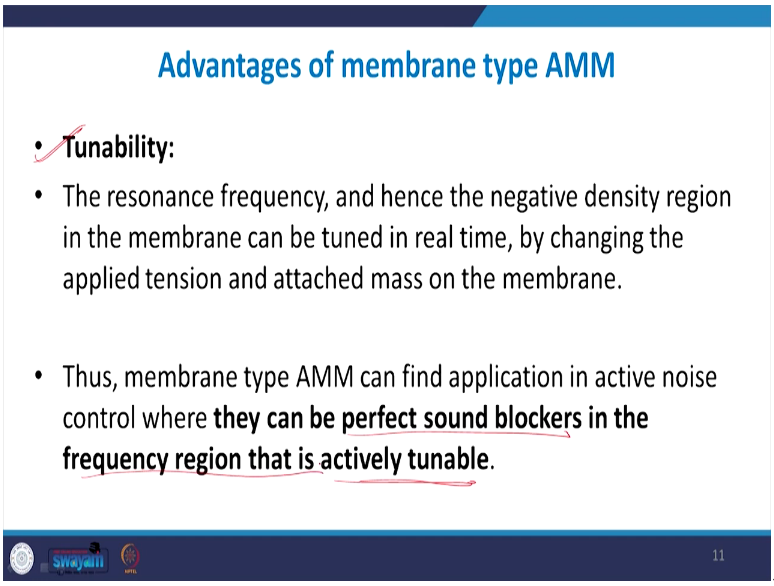

So, that is why they offer something called tunability. So, which means that, in such cases what happens is that the resonance frequency. So, tunability is the characteristic where you can tune the response of a structure in real time based on what is the incoming noise. So, if we have this kind of material and you have some feedback control; so you can do it, you can use it for active noise control where suppose this the sound incident it varies and the frequency response of the sound that is being incident it varies.

Then you have some measurement mechanism through which you can know what is the frequency content and then the there could be a mechanism attached to the membrane which can stretch and de stretch the membrane. So, this will increase and decrease the tension in the membrane. So, once you have, once you can tune the you have some external mechanism to or some external actuator to tune these membranes, so that their tension can be varied in real time.

The response of the membrane will change accordingly and hence you will be able to get perfect sound blockers, which are at whose response are tunable in real time, they can be changed using some external mechanism. So, that is another advantage that is tunability or adaptive noise control.

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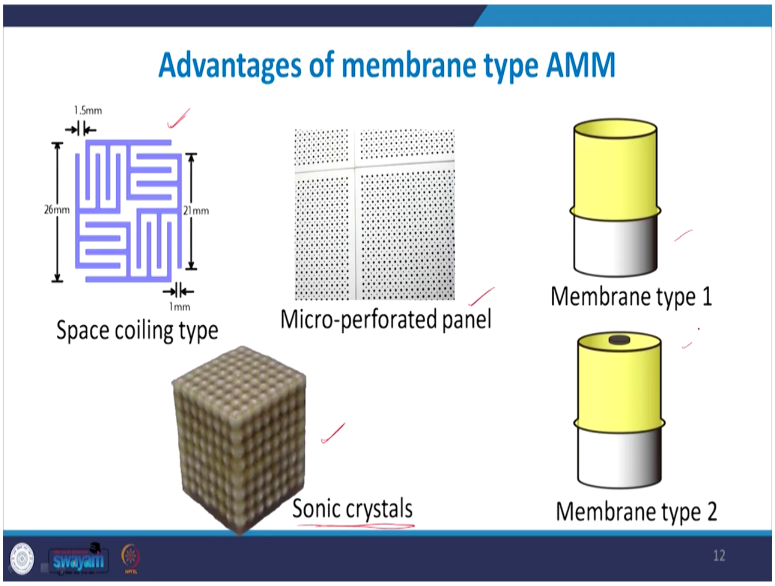

Now some other advantages are. So, if you see here, will after this lecture when we will began and we will began our discussion on another type of acoustic meta material which is called as the sonic crystals. And they are made up of hard lead balls which are grouped together into a cuboidal periodic structure. And similarly some other meta materials were proposed which have some complex configuration space coiling type; then we also have an advanced material like micro perforated panel.

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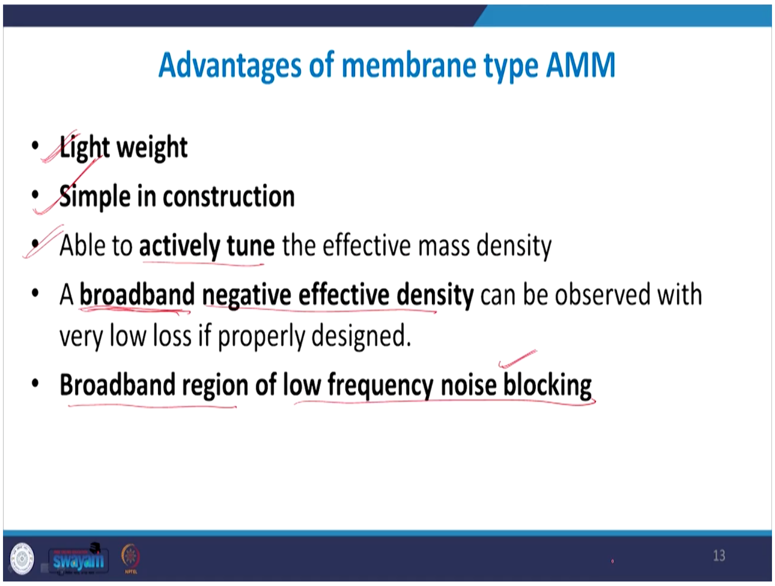

So, if you compare it with some other advanced materials, what you see is that; first of all the membranes they are lightweight, much much simpler in construction, you do not need to use some high end micromachining or some high end machines to do this microbe holes or pores and some high end kind of configuration to get this kind of space coiling structure rather you can do a very simple construction, lightweight.

And we already studied about it that, it can be actively tuned by having some external mechanism which can stretch and de stretch the membrane. So, we can actively tune it to vary it is response in real time. And the most important one is that it offers a wide range or a broadband range, where the density becomes negative and therefore, a broadband region of low frequency noise blocking.

So, this is where it is much better than the traditional materials, because traditional materials they are unable to perform at low frequencies. And here we have a material that can perform at a broadband range and that behaves as a perfect barrier material, which does not allow any wave propagation in this low frequency range.

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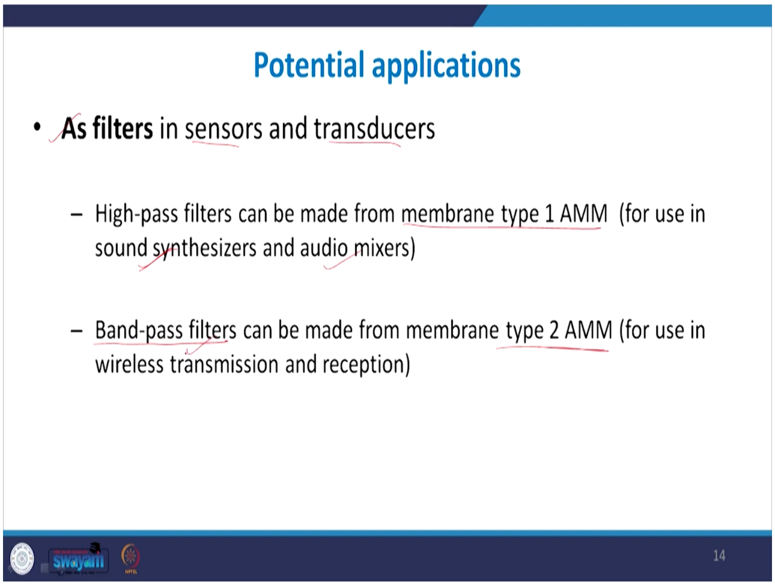

So, what could be the potential applications; one application is that it could be used as filters and sensors and transducers. So, it going to be used as a high pass filter first and high pass filters are the filters which does not allow the frequencies beyond a certain value, so which only allows the frequencies beyond a certain value to pass through. So, you have some cutoff frequency and frequencies above that they can pass through.

And that can be made using the first type of membrane acoustic metamaterial, so where you only have a membrane. So, you know that it will block all the sounds up till a frequency f naught, beyond which it can allow the sounds to pass through. And this can be used for the sound synthesizers and audio mixers; especially in the music industry, usually the bar signals they are separated from the high pitch signals and then they can be remixed together to get a better sound quality.

In the same wave band pass filters can be made, where frequencies within a certain range can be allowed to pass through or not pass through. And this can be done with type 2 and they are used in wireless transmission and reception, ok.

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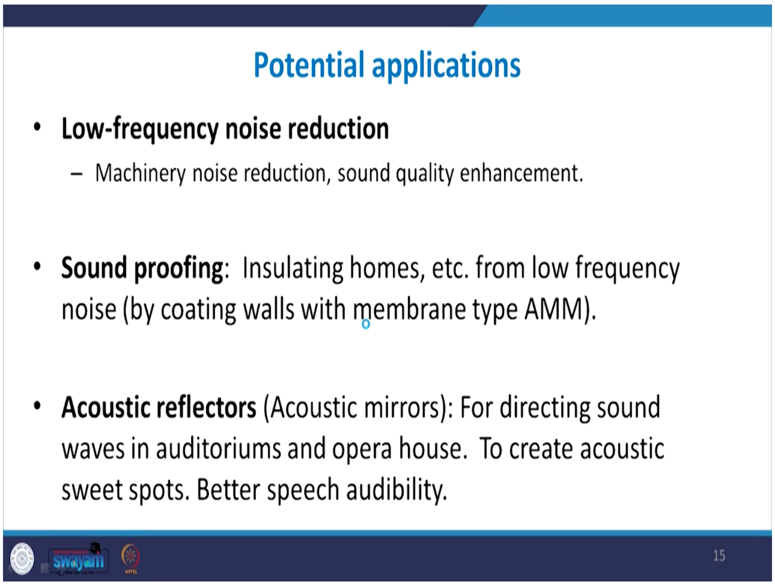

And the other applications that I have already discussed is the low frequency noise reduction. So, here low frequency noise reduction is mainly common in machinery noise reduction. So, machinery noise they are low frequency sounds, their coarse; whereas, the human speech, the whistles etcetera they are high frequency. So, usually low frequency noise reduction is done to curve down all these sounds and make this speech or the communication better, so to reduce this speech interference level. So, low frequency noise reduction or machinery noise reduction.

Similarly sound quality enhancement can be done. Low frequency noise also to a human ear, they perceive such low frequency noise as very rough or coarse sounding. So, the coarseness can be reduced by reducing it is low frequency content and then it can be used for soundproofing. So, if you have, suppose you coat the walls of the homes with such membrane type AMM; then they will not allow propagation of the low frequency sounds.

And hence they can insulate the homes from such machine outside machinery or construction noise. And lastly we have acoustic reflectors. So, as you know that, these materials they act as perfect blocking material. So, whatever sound is hitting, it is not able to propagate; which means it will reflect back. So, they can act as reflectors or mirrors, and specially used in auditoriums or opera house where you have some musician or singers performing.

So, you can have these patches of materials lined around in the auditoriums and when the sound hits it, they can be redirected based on the angle of the material and sweet spots can be created. So, even if some musician or some opera singer is performing on the stage, sounds can be heard at the back also equally well compare just like it is heard at the front seats. Why? Because now the sounds can be redirected to the back seats, so this is how it can be used.

So, with this I would like to end this lecture on advantages and applications.

Thank you.