Nanobiophotonics: Touching Our Daily Life
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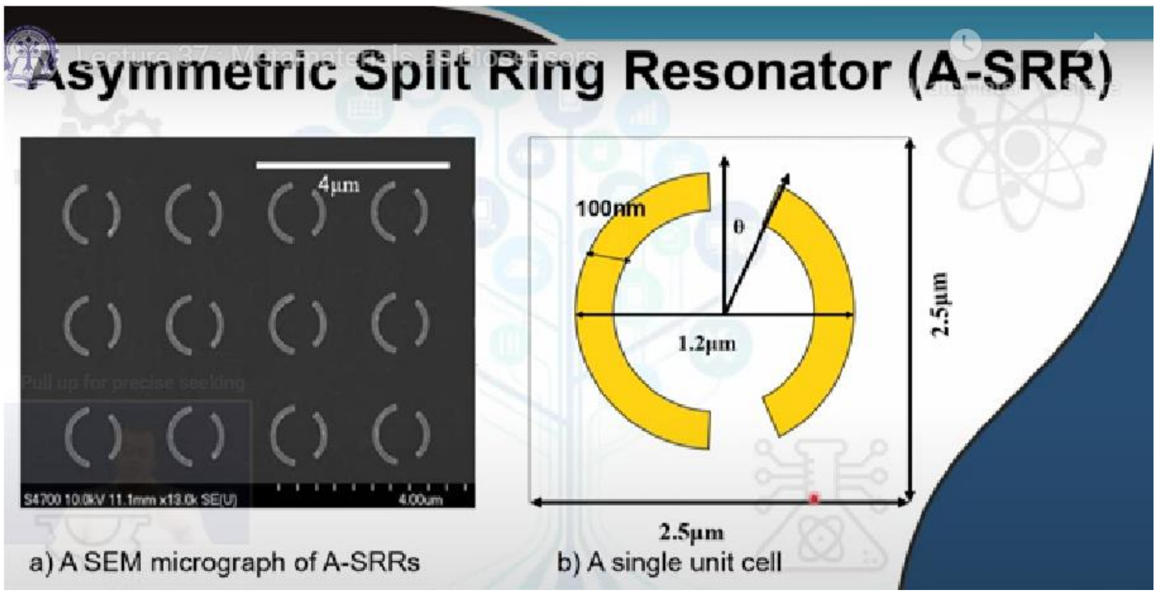
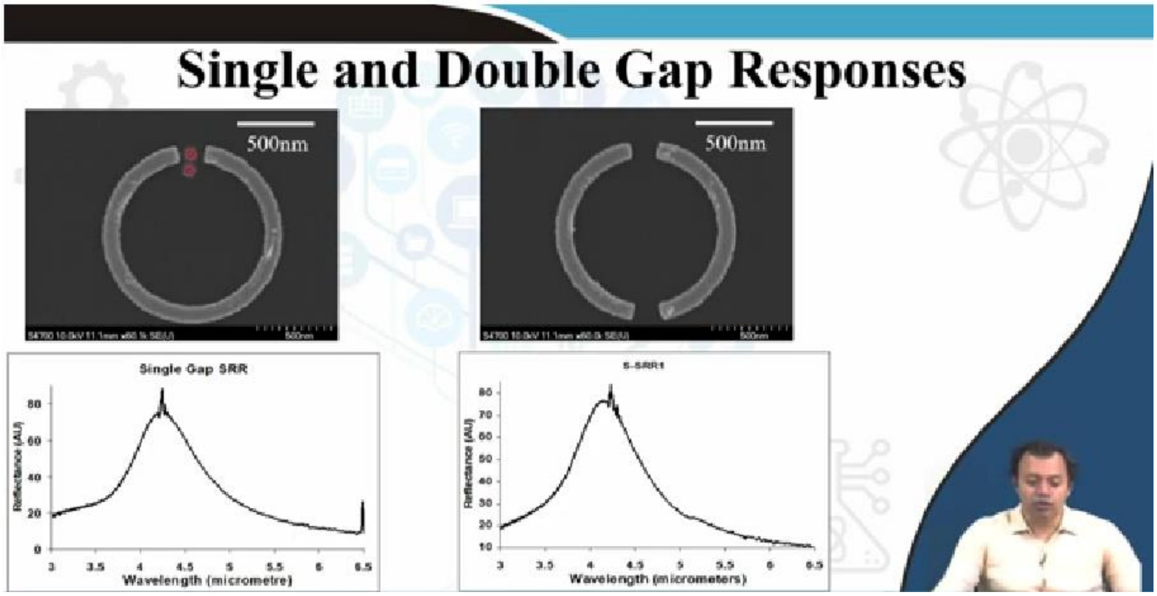
Lecture No. 37
Metamaterials as Biosensors

Welcome back. In the previous class, we have discussed metamaterials, what are they and how they are significantly different from their natural counterpart. Today in the quantum biophotonic series, we are going to discuss how to apply metamaterials as biosensors. We have seen several examples or there exist several examples of metamaterials in different application communication antennas cloaking devices displays, but here in biophotonics we are more or less interested about the applications of metamaterials as biosensors.



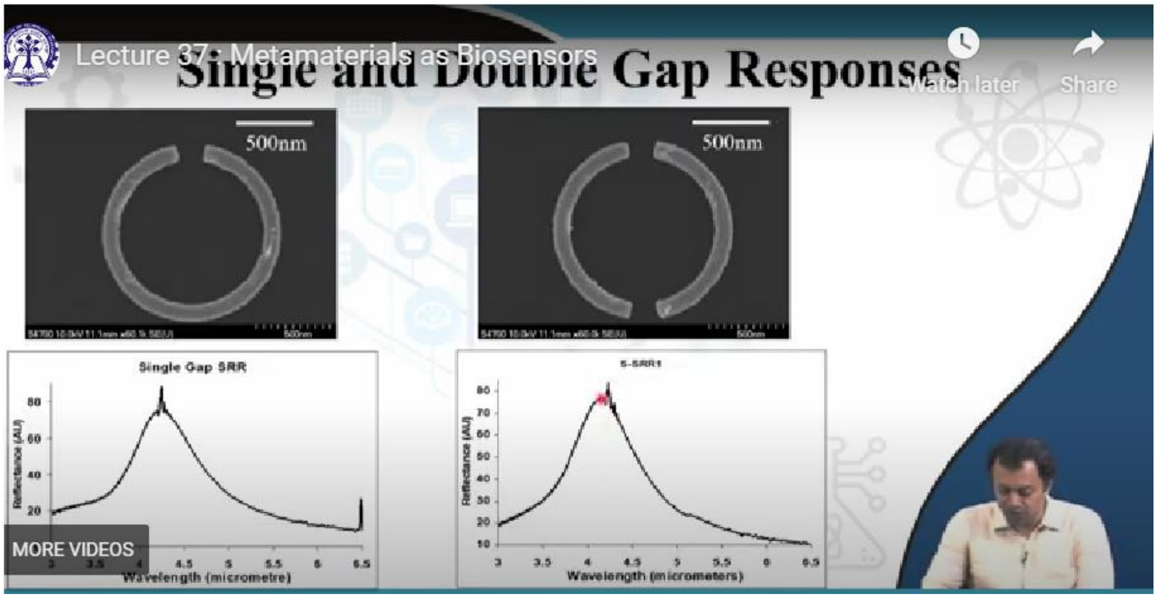
So, let us go on with it. What we try to do? We try to modify the shape of the splittering resonator into making something which we call as the asymmetric splittering resonator ASRR. What is an ASRR or asymmetric splittering resonator? It contains not one U or she shaped structure, it contains two. So, two arcs that have the same center of curvature that has the same center, but asymmetric length. So, the left-hand arc is little bit bigger and the right-hand arc is little bit smaller and they are separated by an angle theta between them. This is the unit cell the schematic and this is the scanning electron microscope image.



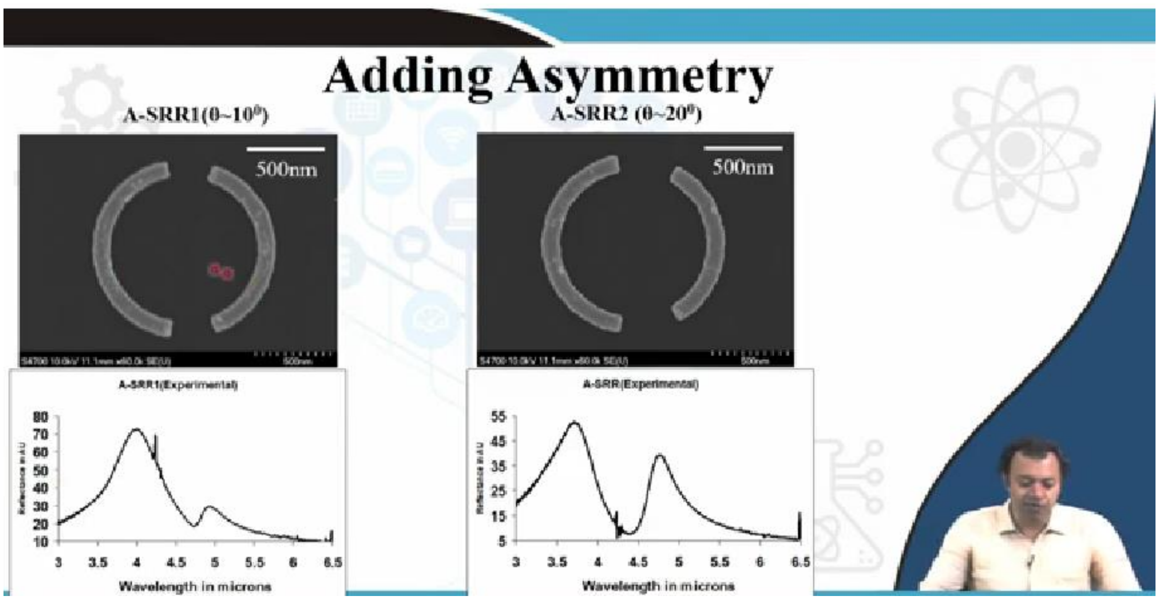
The scale is given from which you can understand what are the size, the length, breadth and dimension they are made up of gold on top of a glass substrate using electron beam lithography system. So, what is the significance of these structures? I told you that the resonance response of these kinds of U shaped or C shaped structure this is split ring remember this is more of a ring which has got splitted it is broken. So, it is a broken ring. The resonance response the magnetic resonance response depends on the size length, breadth and height. So, if you have two C shaped structure two arcs of the exact same structure exact same size right then the response of this left hand arc and the response of the right hand arc will also be same.

So, the response will superimpose the response of this is equal to the response of this and they have superimposed upon each other and has produced an overall resonance response that is showing a peak at 4 to 4.5 micrometer wavelength. This wavelength is specific from biosensing point of view because all the proteins the lipids fats etcetera more or less vibrate in this particular area you will soon know why it is such. What we did we kept the left-hand arc constant the size of it is kept constant and the right-hand arc size start getting reduced we started reducing the size thereby increasing the angular gap between the left-hand arc and the right-hand arc. Previously the left-hand arc and the right-hand arc were the same in the next case the left-hand arc were kept constant we did not touch it we simply started reducing the size of the right-hand arc.

So, what happens now previously previously I told you the resonance depends on the size if the size is same the resonance is same. So, the resonance of left and resonance of right were also same because their size was same and they are superimposing. Now the left-hand arc is slightly bigger than the right hand arc their resonances are closer to one another closer to one another, but not the same not the same. So, the big peak that you

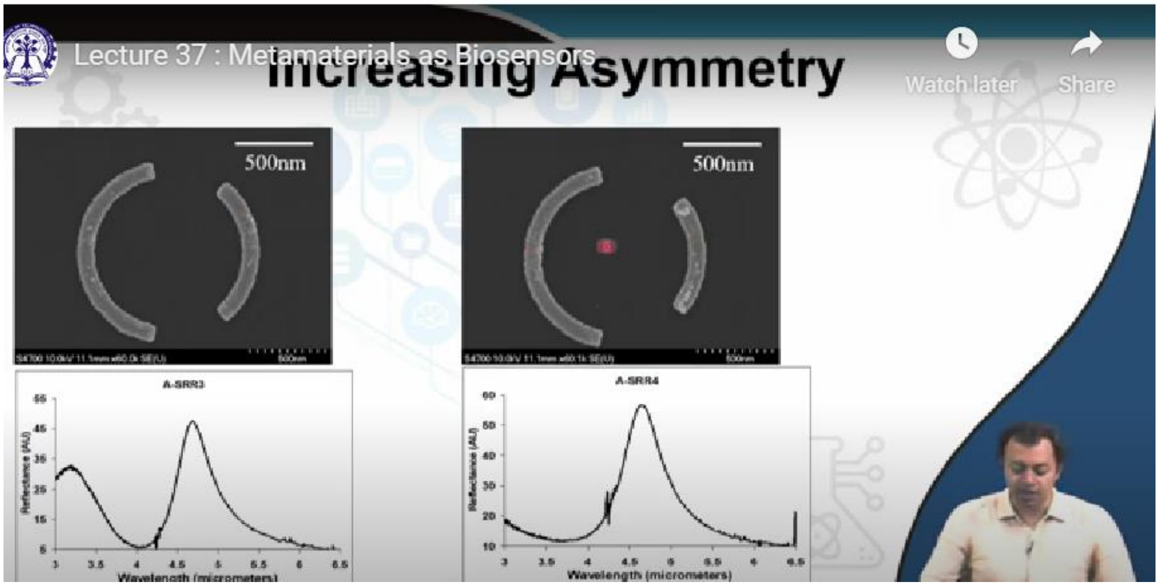


see here the big peak that you see here starts bifurcating and the difference in the resonance of the two peak starts coming up difference in the resonance of the two peaks

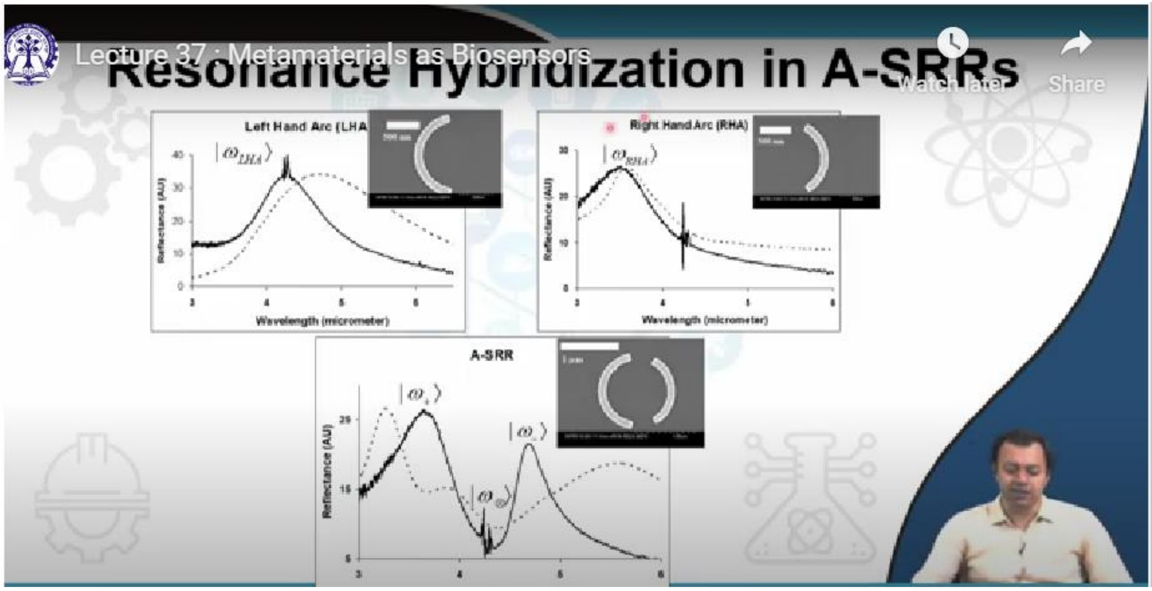


start coming up when the big peak bifurcates into two peak and one trough bifurcates any divides it simply opens up. This peak is because of this this resonance is because of this and what is in between in between is the most important part where the resonance response of this and the resonance response of this is same, but opposite and they have cancelled each other.

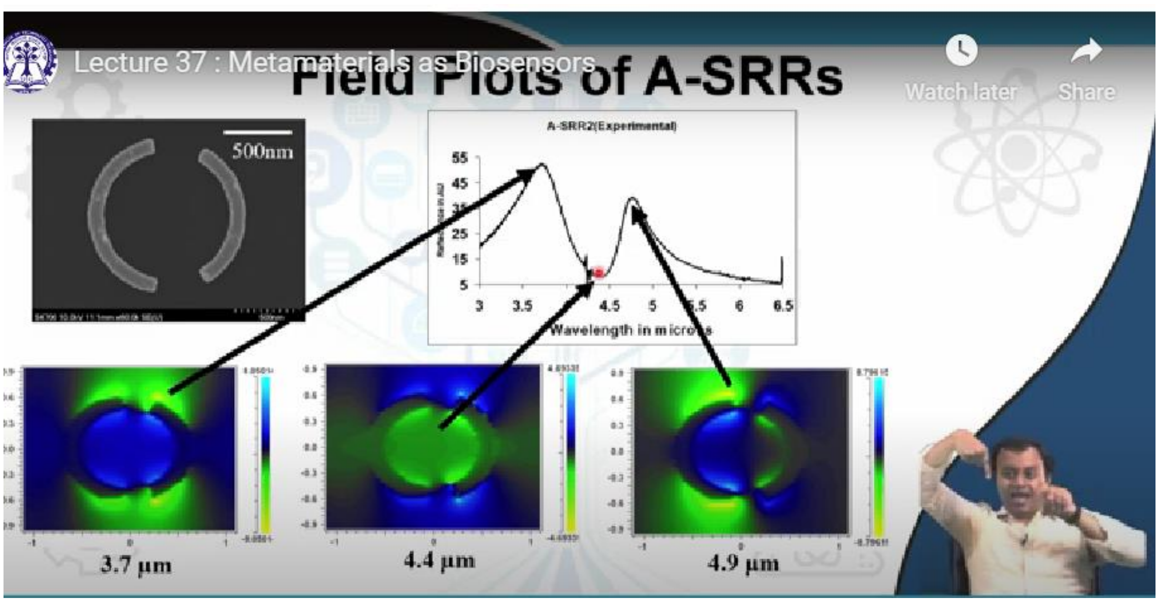
Imagine two wires two coils containing electric current they are brought very close to one another a mutual current flows to one another in both of them and the strength of the mutual current is so much. So, it does not happen in electric current per say, but the strength of the mutual current thinks it like that it opposes the flow of the normal current flowing through it so much so that it cancels each other.



Further reduction further reduction makes them two separate resonators meaning they are not talking with among each other the resonances have to be close enough to couple this is coupling. This geometry they are closer to one another they are talking among each other they are producing their characteristic shift, but in this particular case this is a separate arc almost this is a separate arc and here you do not see the response of this at all it has gone somewhere outside and not attaching or not talking among each other right. In the previous case the resonance response were closer not same, but similar there was a time when the response of this was affecting this the response of this was affecting this, but here there is so much dissimilarity in size that they do not talk among each other they do not see each other and produce individual resonances.
So, we are not interested in this or this we are interested in this part the so called asymmetric splitting resonator of a theta of 20 degree. What it does it basically hybridizes the resonance hybridization of resonance means the left-hand arc has a

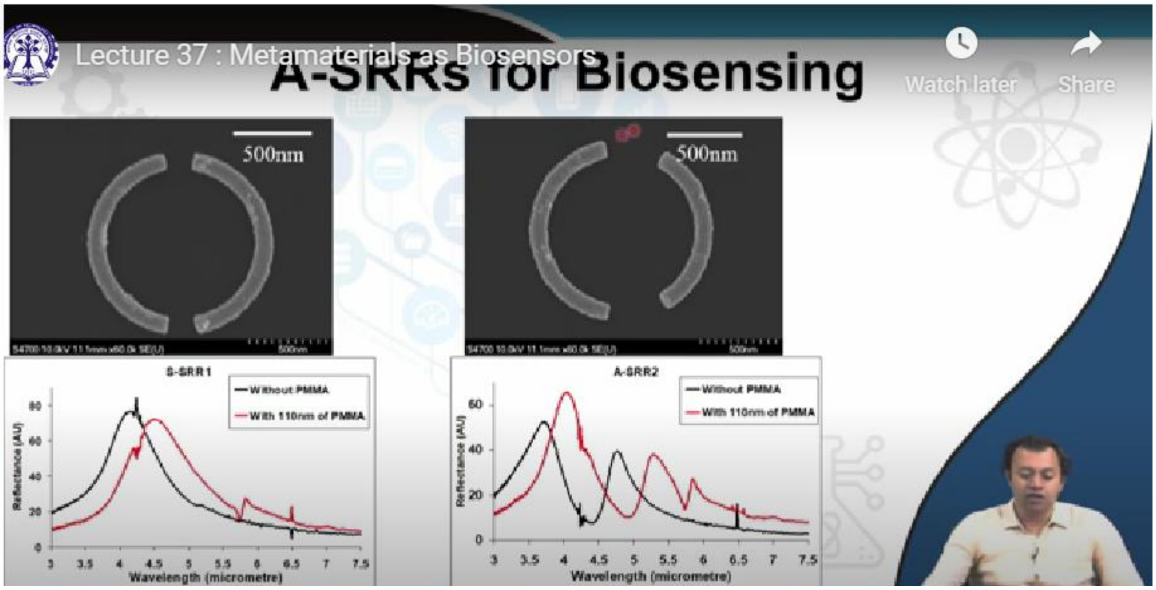


response the right-hand arc has a response, but when they come together when they couple they produce a characteristic response which somewhat belongs with its parent left hand somewhat belongs with the right hand, but somewhat belongs with something that is completely different that is completely unique in its geometry itself. So, it is like children of parents a child will resemble certain things from the father certain things from the mother, but there will be certain property of the child which will be completely unique to her or his own. So, this is something that this geometry is producing where the response of this gets modified by the presence of this the response of this gets modified

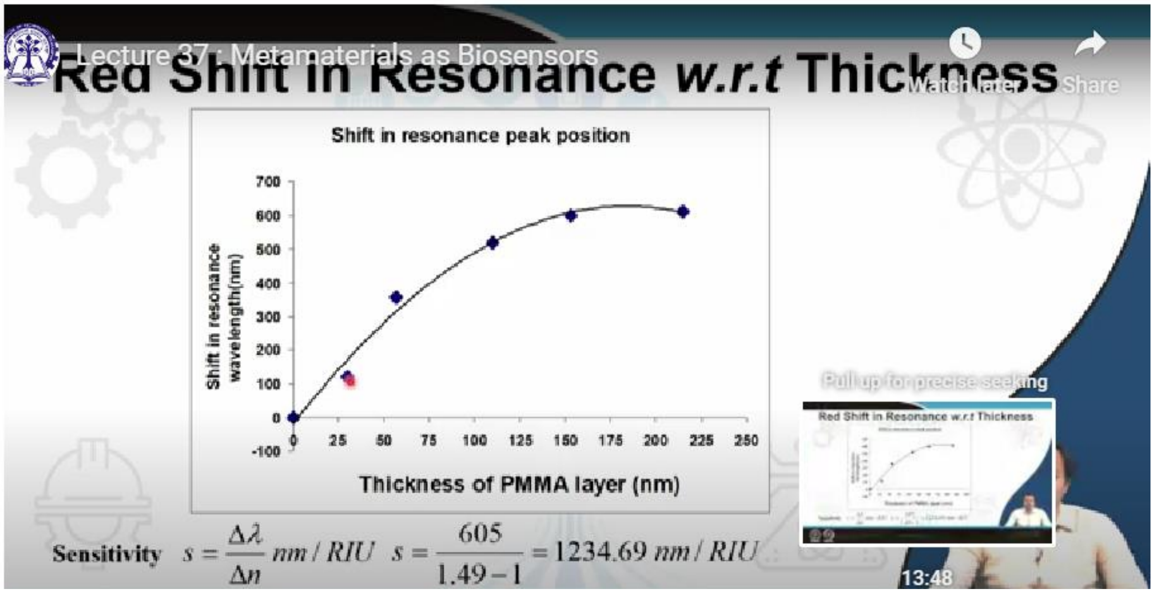


by the presence of this and this creates the so called trapped mode or the dark mode or these days they call it bound state in continuum different meaning and there is a slight amount of difference between all of them I ask you to figure it out yourself because they are simply for me semantics overall what happens is that this is the peak where the response this one is resonating the dominance the resonance of this is dominating the entire system this is the peak where the resonance of the bigger arc is dominating the system this on the other hand the trough the dip is the one where the resonance of both are equal and opposite and they cancel each other the resonance response cancel each other meaning meaning the light that is given to shine on it cannot transmit cannot reflect they are simply cancelling each other electric field and magnetic field of this is equal and opposite to the electric and magnetic field of this and they have almost neutralized each other cancelled each other and thereby there is no movement of light you have trapped light like you can trap water in a bottle if you have trapped water in a bottle the water cannot evaporate cannot leak out here the optoelectric field is trapped within the contours of these nanostructures I give you the size of this if the entire scale is 500 nanometer how thick these are so you are sending infrared light of 5 micrometer compare this with 500 nanometer or 100 nanometer I told you this has to be much much smaller than that so you can produce this unique unique properties of light where light is simply dissipated or absorbed at a particular frequency depending on the size of the structure that you have created these structures were all created by me if I can create you can create yourself these are all experimental result I am not showing you any theory these are all experimental results made by created by my own hand and I can help you create it if you so choose. So, think about it what purpose you will use this for you have trapped light or you have resonated light at a particular frequency at a particular wavelength in previous class you have seen in the visible frequency range here we are doing it in a infrared frequency range mid infrared frequency range if you want to go into detail please go through this paper is quite popular these days in this paper.

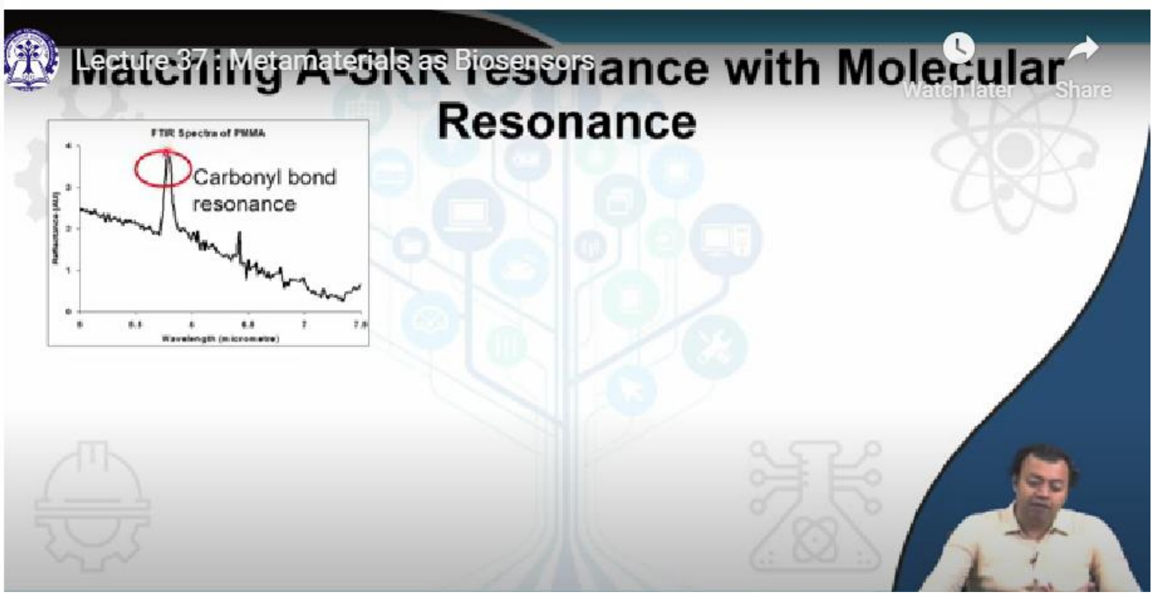
So, we utilized it for bio sensing this electromagnetic hot spot this this this area is called electromagnetic hot spot because most of the electromagnetic field is concentrating on specific specific areas concentrating on specific specific areas right there are less amount of electromagnetic field here they are concentrating at the edge of the arcs inside etcetera. So, you can call it electromagnetic hot spots heterogeneous distribution of electromagnetic field electromagnetic field is not uniformly distributed it is closer to certain areas they are metallic structure. So, you know antenna effect you have those tridents like thing in very tall buildings which attract the lightning falling into that particular place and it discharges it. So, same thing electromagnetic field will be concentrating at the end of the arcs or near the metallic metallic plates or the metallic nano structures. So, they can be considered as electromagnetic hot spot the property of this electromagnetic hot spots are they are very very susceptible to any refractive index change remember the formula of metamaterial from previous case the epsilon c it depends on epsilon c any change in epsilon c the response the response this resonance response will change.



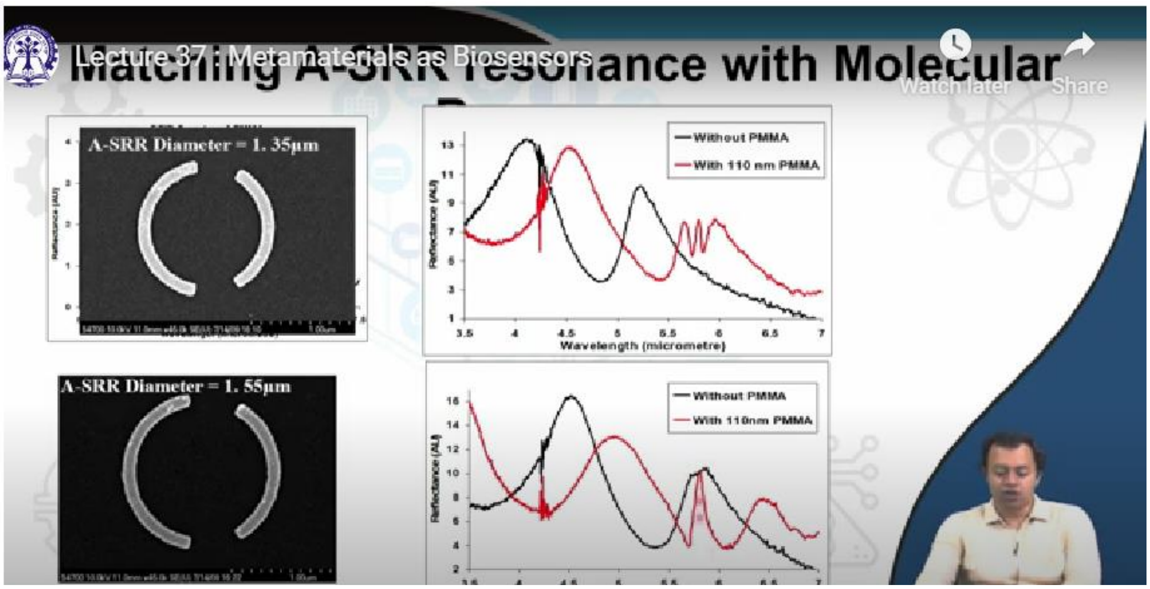
What we did we tried to cover the entire material with very very thin layers of organic compound like poly methyl methacrylate this produced more hot spots than it is symmetric counterpart symmetric counterparts hardly produces any hot spots, but this produces two peaks and one trough. Now, you cover the entire structure with thin layer thin as in 110 nanometer of PMMA that is enough to disturb that is enough to create a refractive index change of 0.49 or 0.4 which results in redshift this amount of redshift how much the response have changed because of the presence of PMMA can be corroborated with the amount of PMMA present that is your biosensing remember previous lectures what exactly is biosensing with analyte without analyte how the transducer will change its property we are changing the transducers property where this is your transducer it was previously resonating at say blue light now you have covered with something else the refractive index changes happen previously light was coming from air and hitting that material now light is coming from air to the analyte and then hitting the material. So, there is a loss for the light that results in redshift redshift means loss of energy that is exactly what it is.



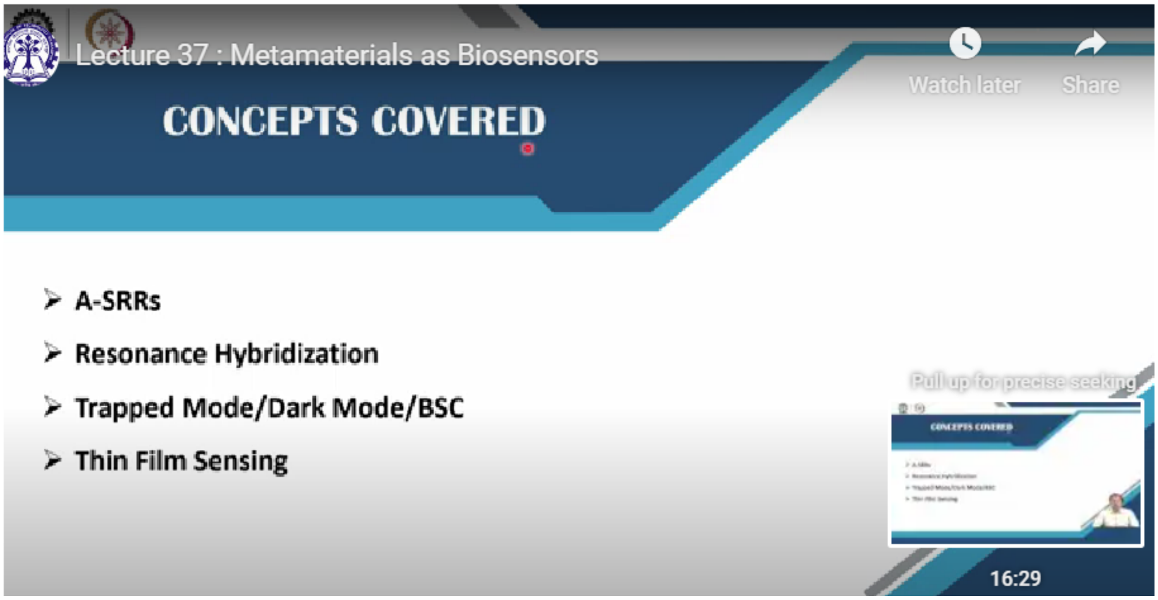
So, this is the redshift of resonance with respect to thickness we were able to measure up till I think 30 nanometer of thin films 30 nanometer can you imagine the width of human hair is around less than few millimeters. So, around 800 microns 200 to 800 microns is the width of a human hair 10 to the power minus 6 30 nanometer is 13 to 10 to the power minus 9 how many of them can be detected can be seen can be understood we were able to see it with poly methyl methacrylate, but same material can have



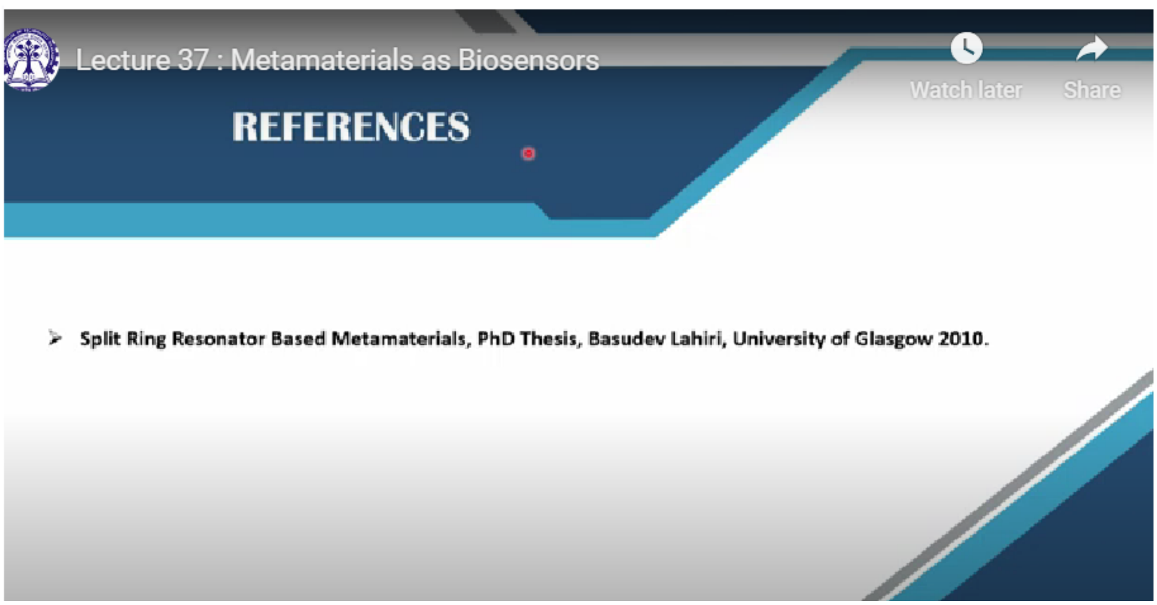
different refractive index depending on its thickness different material can have the same refractive index. So, how do you know simply by refractive index how do you detect something well fact of matter remains that most nanomaterials most organic compounds have their own molecular resonance at particular frequency I told you this before most molecular material have their vibrational frequency in the infrared region and that is what is determined by spectroscopic methods you cannot change that that is fingerprint that is signature, but with your metamaterials you can change the size shape etcetera of your split ring resonator and you can match those two the molecules are resonating at this frequency the metallic nanostructures the split ring resonators are resonating at this frequency you combine them together you get a huge frequency you get a combined



resonance frequency and this is exactly what we did we change the size the diameter of the split ring resonators and we started showing this characteristic feature this this this carbonyl bonds the previous carbonyl bond which was at 5.5 got enhanced by the presence of this peak we can put it either in the peak or in the trough. So, this this this particular peak is the signature of the material this redshift this delta lambda the gap between black and red shows how much it is this is what it is this peak is unique to poly methyl methacrylate this shows how much of poly methyl methacrylate is not only you need to know what is present you also need to know how much of that substance is present we were able to do the same thing.



So, these are basically the concepts that I tried to cover for today asymmetric split ring resonators resonance hybridization trapped mode and thin film sensing I will discuss this in the next class as well those of you are who are interested please go through this



doctoral thesis of mine that is available free of cost online and there are beautiful pictures and if you are interested you can read a bit more about it. Thank you very much.