Transducers For Instrumentation
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Lecture - 22
Acoustic Sensors: Surface Acoustic Wave (SAW) type

Hello, welcome to the course Transducers for Instrumentation. Last lectures we were discussing about the acoustic waves, how the acoustic wave travels, what are their general properties and the modes of their travel, how they travel in the material or on the surface of the material. So, today we are going to discuss about the sensors, how do we make sensors out of these properties of materials and we will be using these piezoelectric materials for making these acoustic sensors. So, depending upon the mode of propagation of these waves, these acoustic waves we can classify these sensors into two types, one is the surface acoustic wave sensor or we call it SAW sensor as say WSAW and the second is the BAW sensor or bulk acoustic wave sensor where these waves travel within the bulk of the material. So, in surface acoustic wave the wave acoustic wave travels actually on the surface of these piezoelectric material and in BAW sensor the wave travels in the material from one end to another into the bulk of this piezoelectric material and we call it BAW sensor. So, we have two types of sensors for these acoustic sensors. These acoustic wave devices are described by the mode of wave propagation. True or on a piezoelectric substrate. And as we saw we have two types of sensors, one is the surface acoustic wave and the other is the surface acoustic wave. The surface of the wave propagates on the sub surface of the substrate on the surface of the substrate it is known as SAW sensor.

And the second is BAW sensor or bulk acoustic wave sensor. If the wave propagates through the substrate. It is known as BAW sensor. So, we have two types of acoustic sensors, one is SAW sensor where the wave travels on the top of substrate it does not go beneath the material and the second is BAW sensor where this wave actually travels into the substrate from one end to another. So, let us discuss SAW sensor first. So, SAW sensor is we take a piezoelectric material which is must for these acoustic device and we generate the acoustic wave on surface of this piezoelectric material and this wave will travel from one end to another on this piezoelectric material and in between whatever is the sensing zone is that sensing zone is in between the transmitter and the receiver. So, transmitter is the one which generate these acoustic wave from some electrical wave and this acoustic wave travels on that this piezoelectric material in between there is a sensing happening which is called the sensing zone and then at the receiver end we have some structure which convert this acoustic wave into an electrical signal back. So, that we can measure this electrical response which is generated by the sensing zone. So, let us consider this circumnus acoustic wave sensors first. So, first we need to generate this acoustic wave and that we generate this acoustic wave and that we generate using some structures called IDT or inter digital transducers. We call them IDT in short. So, this consists of two interlocking comb type shapes. They are called metallic coatings. They are applied to a piezoelectric substrate. These IDTs are used to convert electrical signal into acoustic waves.

They are used to convert electrical signal into surface acoustic waves. And we can by changing the length width position of these IDTs. So, this is the position and thickness of the IDTs. The performance of sensor can be optimized. So, in saw sensors the surface acoustic wave sensor we need to generate a acoustic wave on the surface of the material. So, how to generate this surface wave? We put a IDT structure which is inter digital transducer. This IDT structure is nothing but a comb like structure. The comb like we have multiple fins from one side and the multiple fins from other side and they are kind of interlocked to each other without touching the different electrodes. So, this consists of interlocking comb type structure which is called IDT structure and we apply a electrical signal to this IDT structure and this structure generates the surface wave on the surface of piezoelectric material. So, this has two electrodes one from the left one from the right and they are interlocked and we generate we apply the electrical signal on these two electrodes and accordingly surface wave will be generated.

The performance of this surface wave or the sensor in general this can be optimized by adjusting the length, width and the position of this IDT structure. So, let us see how this IDT structure look like. So, we have a IDT structure which is placed on top of piezoelectric substrate and generally this is photolithographically printed. So, let us say we use gold as a material. This is one comb structure and the second one is in between this interlocked. So, this another terminal is. Something like this. So, we can even put some color here. This is first terminal. So, this is the second terminal. This is terminal number one. And this is terminal number two. So, this is terminal number three. So, this is the second terminal. So, this is the IDT structure. We have comb like structures from both the sides one from the top one from the bottom and they are like interlicked without touching each other. These two act like a electrical poles and we apply the electrical signal which is let us say sinusoid wave across these two terminals. Now the spacing of this IDT structure determines for which frequency this IDT structure is the optimized and convert to acoustic wave effectively. This spacing is the spacing between these two IDT structures as well as the spacing in between these two IDT structure as well as the thickness of each and every fin. So let us say we have this distance as in terms of lambda.

So this distance is lambda by four which is the thickness of this fin and the spacing between these fins for example this and this. This is the spacing between these two fins overall. This is also lambda by four and the overall from this point to this point is lambda. So depending upon the thickness of the fin and the spacing between these two fins which we can control as lambda by four. Lambda is the wavelength of applied electrical signal which will be converted into acoustic wave. So the frequency of acoustic wave will be the same as the frequency applied as a electrical signal. The electrical signal is let us say coming at one kilohertz accordingly there will be a wavelength. So we design this IDT for that particular one- kilohertz electrical signal and we choose this lambda accordingly. Based on this lambda by four spacings of this IDT structure this is effective for one kilohertz signal if lambda is accordingly for one kilohertz. So for different different frequency we need to optimize this IDT structure to get maximum conversion of electrical to acoustic wave.

So this is one IDT structure and this is also reciprocal in the work because if we apply an electrical signal between electrode one and electrode two, this IDT will generate acoustic wave on the surface. On the far end, when we want to convert this acoustic back to electrical The same IDT structure can be used. So when the acoustic wave will hit this structure a potential will be developed between electrode one and electrode two this will be measured using electrical equipments this voltage is the output of IDT structure. So this IDT structure the same structure can convert electrical to acoustic wave and acoustic wave back to electrical. So to make a saw sensor we need to use two units of this IDT structure on top of a piezoelectric material. So practically we have a surface acoustic wave sensor like this. So we have a piezoelectric substrate this is our piezoelectric material. On top of this piezoelectric substrate we have this IDT structure. This is port one where we are applying electrical signal and then this port one will generate acoustic waves those waves will travel in this direction and when they reach at the far end we have the same IDT structure placed here to convert it back into electrical signal.

This is port two. And this center zone is our sensing zone. So here in this we see we have a piezoelectric substrate on port one we put a IDT structure and port two also is the same IDT structure with same width and length and all the configuration. And when we apply electrical signal on port one there will be a surface acoustic wave generated by this IDT structure which will propagate in both the directions. So on the left we see a boundary so this is not going into that direction on the right side this wave will propagate. In between we have a sensing zone where we will apply different material or we do sensing for example we want to check what material it is so we put that material on this sensing zone accordingly the characteristic of surface wave changes. And this surface acoustic wave we sense it using port two which is again the same IDT structure and it will generate acoustic wave back to electrical wave. This acoustic wave then this electrical wave generated by port two will be compared to the electrical wave we applied on port one and difference will give us what was there in the sensing zone. So this is how these surface acoustic wave or the surface acoustic wave sensors, saw sensor works. So these saw devices are manufactured using the same photolithography process what we use for integrated circuits. So these are the acoustic wave devices are manufactured using the same photolithography process that integrated circuits use.

The only difference is there is no junction actually exists in acoustic wave devices. The only difference is that no junction exists or more precisely no semiconductor junction exists in acoustic wave devices. And typically aluminum is deposited in pattern to make these IDT arrays. So these acoustic wave we manufacture them using the same process what we use for our IC fabrication the silicon based semiconductor fabrication process the same process we use. The only difference in case of acoustic wave devices is there is no semiconductor junction actually we need to make.

We just need to make we just need to deposit a layer of metal on piezoelectric substrate and we need to pattern it photolithographically. We need not to go for the ion implantation or diffusion or other kind of process to make junctions because we do not need a junction. We just simply need IDT structure so we first deposit the metal on surface of piezoelectric material and then photolithographically we pattern the IDT structure on this metal using the masks and the dimensions of these IDT structures are not very small as compared to integrated circuits what we use in those IC fabrication. So a kind of crude mask will also be good enough to pattern these IDT structures. So let us see how a fabrication process or the manufacturing of these acoustic devices looks like. So first, we start with the substrate. So we have a substrate which is our piezoelectric substrate and on top of this we deposit a layer of metal let's say aluminum or gold or anything. This is a thin layer of metal. This is metal frame. And in the second step we use photolithography.

So this is our substrate. On top of this we have metal. On top of this metal we put something like photoresist which is a light sensitive material. So this is photoresist. This is the metal and this is substrate. Now we use mask which we use in integrated circuits.

So we have a mask here. The certain portion of this mask is opaque and certain portion is kind of transparent. So we have this mask. The IDT structure is patterned on this mask. This is the pattern which is put on this mask. This depends on what design you have. So when you put a mask on top of it and you shine a UV light on the top. This is UV light. The light will pass when this mask is transparent leaving a pattern on the photoresist and photoresist will harden and accordingly the pattern will come on the substrate on the photoresist and the metal. So when we use this mask we are transferring the pattern on the mask to the photoresist and photoresist will harden where the pattern is formed. Then we use chemicals to remove this photoresist and the same pattern will be transferred to the metal. So in part C as a step C we have this pattern transform to onto the photoresist. This is our substrate and then we have this metal. And on top of this photoresist is patterned now as per our mask. This is substrate and this is photoresist.

This is step C. Now we use chemical to wash away the extra metal which is exposed now to the outside environment and some of the metal which is shielded by this photoresist that metal will not go away by the chemical treatment. So when we do this chemical treatment now our pattern is transferred on the metal. So in this step D we have this substrate and our metal is patterned now. This is the metal or IDT structure. So as we can see we start with substrate put the metal on top of it by deposition. Then we use photolithography using the mask we transfer the pattern on the mask to the photoresist and that photoresist will be hardened in that area as well. Then we do the chemical treatment we do etching of this photoresist which is not hardened that will go away and then we etch the metal which is now the portion of that metal which is exposed to environment that will be washed away. Then we remove the portion of metal which is isolated using this photoresist that will remain there and later on we remove this hardened photoresist as well. So at the last we get a substrate where on top of it only the metal is there which is already patterned so we get this IDT structure.

Now let us see how this IDT structure works. So we have this IDT structure one side. This is port one. We sometime call it short device and we connect electrical signal to this. This IDT will generate acoustic waves and on that far side as well we have the same IDT structure. Yeah, and in the middle, we have this sensing zone where we will sense. Now this surface acoustic wave will be generated using this first IDT. This electrical signal which is here shown by this red element. This electrical signal is applied on this short device and acoustic wave will generate. What acoustic wave is? The atoms of this piezoelectric material which is the substrate here those atoms will oscillate. So we will have let us say these are the atoms. These atoms when acoustic wave is applied here. These atoms will oscillate back and forth up and down and will propagate this acoustic wave from one side to another. So this is the sensing zone where this acoustic wave is travelling and at the receiving end this port two this acoustic wave will be converted back into electrical signal which we measure using some volt meter or we can apply a load across it. It can be a volt meter or some electrical instrument to measure this output voltage. So this is a typical saw sensor with bias circuit.

Some points about this saw devices are the displacements. They decay exponentially away from the surface so that most of the wave energy almost 90 or 95% is confined within a depth equal to one wavelength. The width of the electrodes usually equal to the width of IDT gaps. The breadth of inter electrode gaps. Giving the maximum conversion of maximum conversion of electrical to mechanical energy. So, here we have this saw sensor IDT1 converts into the electrical signal into acoustic wave. Accordingly, according to this acoustic wave the atoms of isoelectric material they oscillate top and down and this happens in the sensing zone if there is any other material in this sensing zone this motion of these atoms actually changes compared to the we do not have that material which actually changes the velocity of acoustic waves. So accordingly port two will generate electrical signal which is lagging or leading behind compared to the original signal and this change we can detect using this saw device. Some property of this saw device is this surface wave which is travelling on top most of the energy is confined only on the surface and this decays exponentially within one wavelength of the signal. So almost 95% of the energy remains on the surface of the material.

So this is saw device and usually when we design these IDT structures the gap between the two comb-like structures the gap between them is equal to generally the width of the electrode so that the conversion efficiency is much higher. If we keep that gap equal to the width of electrode which is lambda by 4 as we saw last slide. If we keep them lambda by 4 lambda by 4 so the conversion efficiency of the electrical signal to acoustic wave is much higher for a IDT structure.

So, that is all for today.

Thank you.