Biomedical Ultrasound: Fundamentals of Imaging and Micromachined Transducers

Prof. Karla P. Mercado-Shekhar, Prof. Himanshu Shekhar, Prof. Hardik Jeetendra Pandya

IIT Gandhinagar, IISc Bangalore

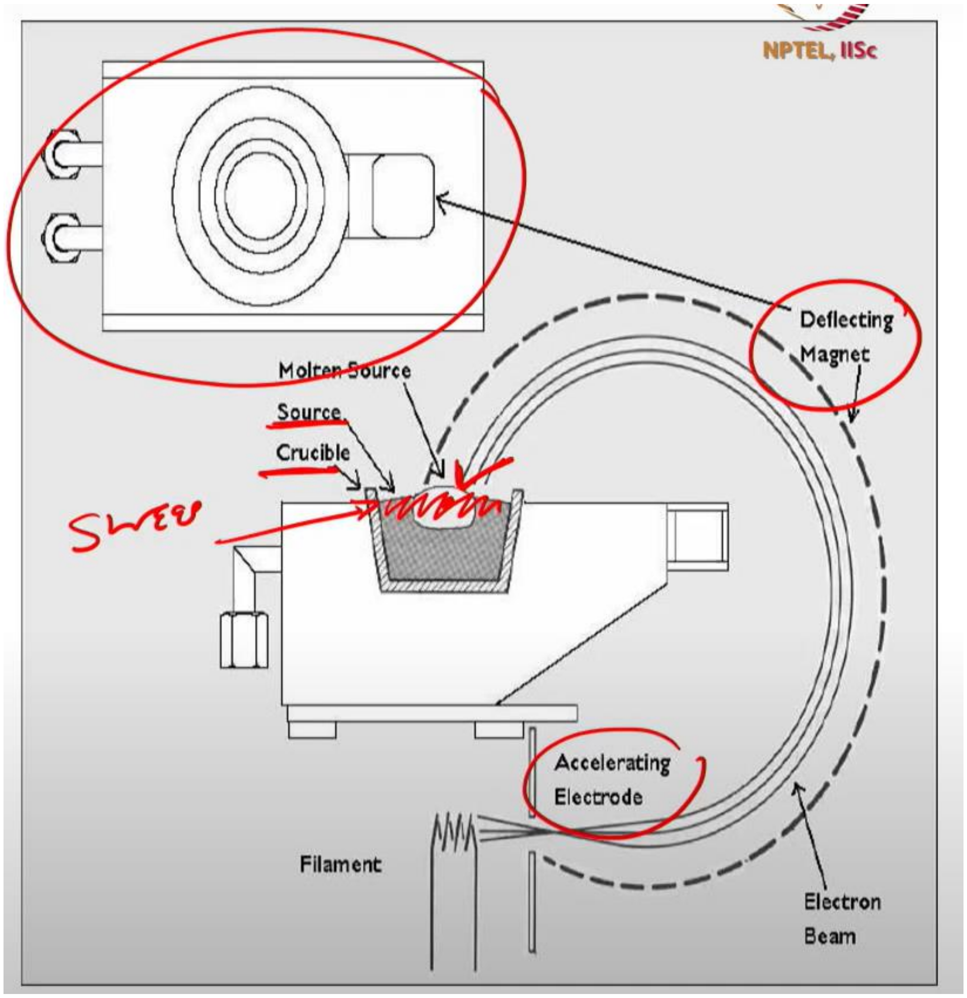
Lecture: 21

E-beam Deposition theory

Hi, welcome to this lecture. In this lecture, we will look at electron beam evaporation. In the last lecture, what we have seen? We have seen thermal evaporation. So, let us see how electron beam evaporation works and how it will overcome the limitation that thermal evaporation poses. That is that if you recall in thermal evaporation technique, the material that we want to evaporate right at that material melting point should be way less than the material that is holding the source material. So, melting point of the material right.

So, if you want to overcome this limitation, we can use the electron beam evaporation and if you see the slide electron beam evaporation consists of the following one there is a filament then there is a accelerating electrode then there is a deflecting magnet. and then the deflecting magnet can be used to deflect the electron beam on to the source material which is loaded on to the crucible in this case. So, if you understand right from here crucible, crucible here we can or may not use the metal or we can use graphite as a crucible. This is a material which is loaded onto the crucible and the filament generates a high electron beam.

This electron beam travels right because we first generation is because of the electrical current that is applied to the filament, the electron beam comes out and is accelerated through this accelerating electrode, when it accelerates there is a deflecting magnet which deflects this electron beam on to the on to the source which is loaded on to the crucible. When this thing happens if it is a point source that means the electron beam is only at the point it will start melting and evaporating, but if you want to uniformly melt it then you should do a sweep right which is called sweep. This sweeping or point source all things we can use a deflecting magnet which is shown in this particular schematic. So, if you read the paragraph this paragraph the electron beam or e-beam evaporation is a physical evaporation technique. that allows the user to evaporate materials that are difficult or even impossible to process using standard resistive thermal evaporation.



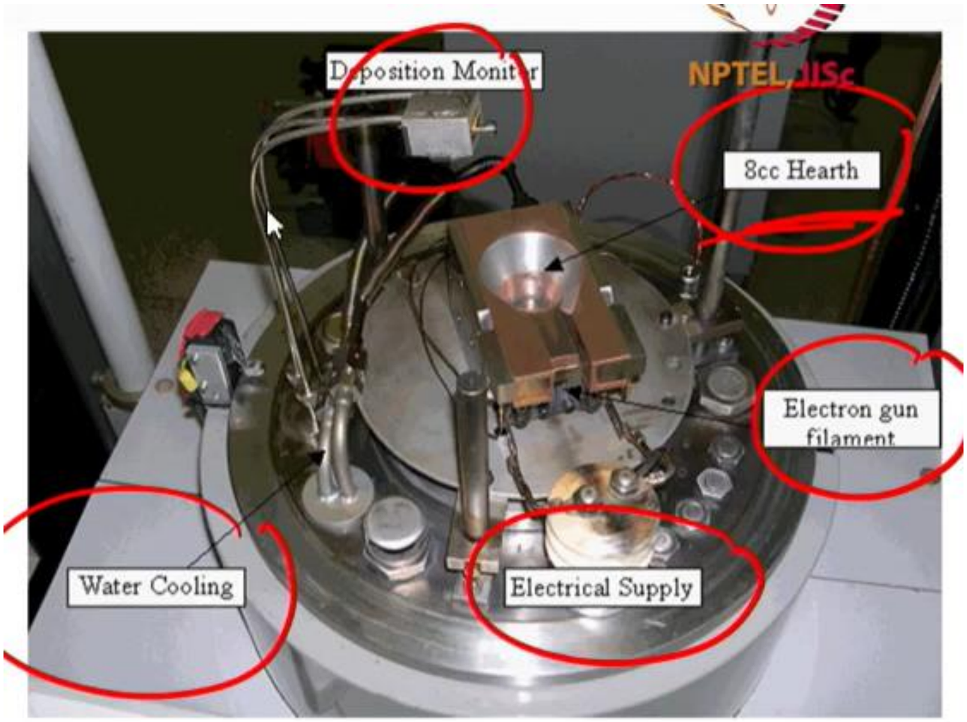
Some of these materials include high temperature materials and some ceramics. To generate an electron beam, an electrical current is applied to the filament which is subjected to a high electric field. This will cause electron in the filament to escape and accelerate away. Electrons are focused by magnets to form a beam directed towards a crucible that contains the material as you have seen here in this case the energy of the electron beam is transferred the material to start evaporation many materials will either melt evaporate or sublimate. Now, because this electron beam will start evaporating if it also generates lot of heat on the backside of this particular crucible, we use cold cool water to keep the crucible cooler compared to the source material. So, in this case there is no heating of crucible there is no heating of your source holder and thus you are not dependent anymore on the melting point of the source holder in this case it is called crucible.

We are not dependent on the melting point of the crucible. So, that is why this technique can be used for evaporating material that has a higher melting point which will not be easy for us to evaporate in the thermal evaporation technique. Now, you have this socket in this you can say it is a copper hearth in which you can load the crucible and we can the electron will come and will be focused on to the particular source material, you can see shutter here right you can also see the shutter here right you can see how the source is loaded right source material is loaded on to the crucible. Electron beam will come from here and it will hit here, it will sweep here. You have multiple sources.

Now this is covered with the help of a shield. So, the electron beam will come as I have shown here right and the it will start evaporating right it will start evaporating when it starts evaporating it should not get deposited on to the second or third or fourth source holder right the material that is loaded on to the source holder this material that we are evaporating should not get deposited on to either of these another source materials. Thus there is a shield which will help us not to deposit the material on to these particular sources. I do not have anything else to show to you in this slide. So, let us go to the next slide.

In this slide you can see a QCM, Quas-Crystal Monitor or Deposition Monitor. There is a hearth as I told you earlier also in which you can place the substrate holder which is our crucible. There is a electron film filament, electron gun filament, electrical supply which is applied or filament to generate the electron beam. There is a water cooling here and there is a magnet on the back side. So, thermal evaporation suffers from contamination by evaporation of crucible materials and this process is not sufficient to evaporate high melting point materials.

E-beam evaporation is used to overcome these problems, and it uses water cooled crucible in the depression of water-cooled copper hearth as you can see in this particular case. The electrons are thermionically emitted from the heated filament but are shielded from direct line of sights. The filament cathode assembly potential is biased negatively with respect to nearby grounded anode or trans magnetic field which serves to reflect the electron beam 270 degree arc and focus is on the source right evaporate which is at ground potential there is very nice video again it is on YouTube. So, I am not playing here, but what you can do is you can just see this link and you copy it in your YouTube. So, that you can watch it at home I am not playing here just because it is there on YouTube.



Now, the question is the power densities. Power densities of about 10 kilo Watt per centimeter square are utilized in melting metals, but dielectric requires less power 1 to 2 kilo Watt per centimeter square. The contamination level of deposited film using E-beam is less compared to thermal other PVDs that is a advantage. However, electron beam also creates an X-ray. So, that is a disadvantage because X-ray may damage the devices.

The electron dense current density J_e leaving the hot filament is due to thermionic emission we already know that, and it is given by Richardson equation which is given here.

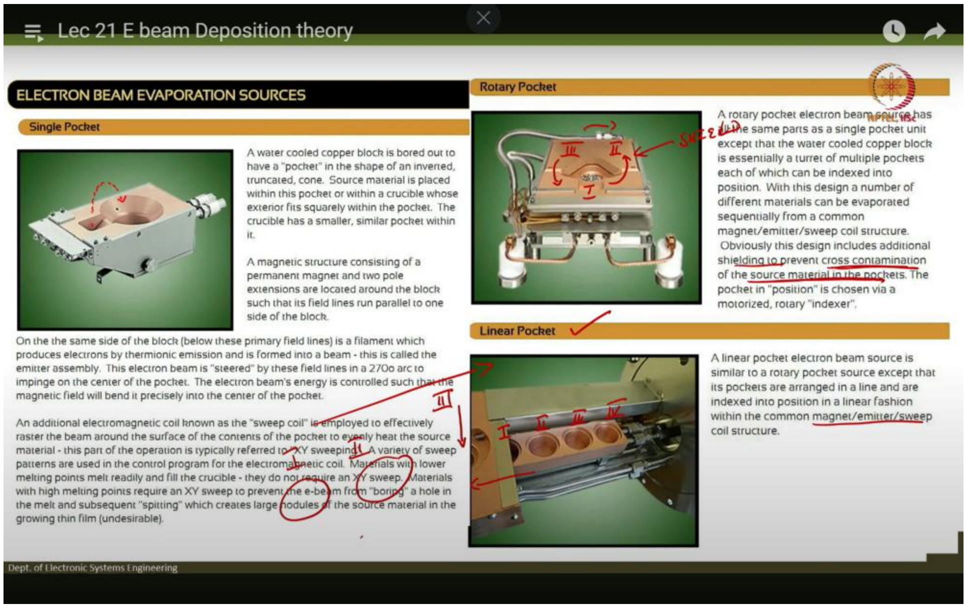
$$j_e = AT^2 \exp(\frac{-q\Phi}{kT})$$

Next near to the evaporation surface or evaporate surface the evaporate flux shows a laminar flow uniformity of thickness can be described by cosine law and I discussed little bit about cosine law on the when we were looking at the thermal evaporation topic. So, the electron beam evaporation sources can be of three types, one is single pocket source, one is rotary pocket source, and one is linear pocket source. So, in a single pocket as you can see this particular figure here, water cooled copper bore block is bored out to have a pocket in shape of inverted truncated cone. Source material is placed within this pocket and the crucible has a smaller similar pocket within it.

The magnetic structure consists of permanent magnet and two pole extensions are located around the block such that the field lines parallel to one side of the block. One of the same sides of the block is filament which produces electrons, and it is this one electron and that electrons will hit here. This electron beam is steered with the help of these magnetic field lines and electron beam is beam synergies control such that magnetic field will bend it precisely into the center of the pocket. So, the beauty of these magnetic field lines magnets is to control the way the electron can be incident on to the centre of the surface. And like I said we can change it from the point source to sweep source with the help of a sweep coil.

You see an additional electromagnetic coil called sweep coil called sweep coil is employed to effectively raster the beam around the surface of the content of the pocket to even evenly heat the source material. I have told you that if you want to heat there is no source holder here or a source material here. If I go back to this is the area this one and I go one more slide back, then you will see that this is the area that we are talking about where the source is loaded. Here we can sweep it uniformly so that we can have a better deposition and uniform deposition. Materials with a lower melting point melt readily and fill the crucible.

They do not require XY sweep. Materials with high melting point require an XY sweep to prevent E-beam from breaking a hole in a metal. That means that if you have a crucible and you have the material loaded on to the crucible it is a high melting point material then we have to uniformly like sweep it. If you do not do that and if you just put a point source what will happen is you just put a point source like this one only one point here then this will not melt because it is a high melting point it will start forming a bore into the crucible and that is not is advisable that is why for the high melting point material we have to go for sweeping. The next pocket is rotary pocket and in rotary pocket electron beam source has all the same parts as single pocket except that the water-cooled copper block is essential a turret of multiple pockets each of which can be indexed into a particular position.



That is easy to again understand, and we have already discussed that there are multiple pockets. So, this is an open one right now. Let us say this is one, then there can be second one, there can be third one and so on. This is in a rotary fashion like this, or it can be like this, or it can be in opposite direction clockwise, anticlockwise does not matter. But the point is here we can hold multiple sources and with this design a number of different materials can be operated sequentially from a magnet.

Obviously, this design includes additional shielding which is this shield to prevent cross contamination of the source material in the pockets. Finally, is a linear pocket. In linear pocket, electron beam source is similar to rotary pocket source except that its pockets are arranged in a line. It goes like this when this is in the electron beam, this material deposited. So, let us say this is 1, this is 2, this is 3 and this is 4.

First 1 will come, then 1 will come here, then here it will be 2, when 1 will come here and 2 will come here, this will become 3 and so on so forth and then it can go back also. So, this is a linear fashion that is why it is called linear pocket. So, linear pocket beam source is like rotary pocket except that its pockets are in a line and are indexed into position in a linear fashion within common magnet emitter sweep coil structure right. So, I think this is enough for you to understand that there is a E-beam evaporation technique and e beam evaporation technique can overcome the limitation of the thermal evaporation technique. So, I hope you understood what we discussed in this lecture and in particular what I wanted to teach you is that in evaporation techniques there are thermal and EMV evaporation, but we go for one more technique which is sputtering in the next lecture where we will see that why we have to go for sputtering and what kind of sputtering techniques are there.

There are DC sputtering techniques, RF sputtering technique, there is a magnetron sputtering technique. So, we can use DC magnetron, RF magnetron, reactive sputtering. So, we will cover that in the next lecture. For each of these tools, you can see the video, lab video, and you will probably understand a bit more than what we have taken in the theory course. If you have again any question, feel free to ask through the forum.

Till then you take care. I will see you in the next class. Bye.