Fabrication Techniques for Mems-based Sensors: Clinical Perspective

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Lecture – 54
Simulation: Electro- Thermo- Mechanical Properties of Micro-heater using COMSOL Multiphysics

Hi, so, we have seen lot of process flow followed of devices right and if you see for each device when you fabricate it, it requires several things. First is of course, the process flow, second is a recipe, third is the mask because we require mask right. And, then we do the characterization that how the device is operating to understand the efficacy of the device or to understand the performance of the device or in another time to evaluate the performance of device.

So, now micro fabrication or micro engineering requires certain set of tools or equipment that we need use to fabricate those devices and to name few we have seen we use litho-photography. It is also called mask aligner right, we use e beam lithography, we use thermal evaporation, then we go for wet etching, we go for dry etching; again dry etching we have seen RIE, which is Reactive Ion Etching, DRI Deep Reactive Ion etching and then we also go for PECVD, LPCVD, APCVD.

So, the point is that all this equipment, the usage is costly. When you make devices in bulk it becomes cheaper ok. So, before we fabricate the device is always good to perform simulation and the simulation will help us that for the given design or for the design that we have chosen for a particular device how it will work; that means, let us take an example of strain gauge.

If I apply a 0.5 Newton of force to the strain gauge, what is the strain or what is the bending or what is the displacement or the force transferred to the strain gauge such that the resistance would change or the reformation would occur? To understand the stress or the strain in that particular device, we can perform simulation. To give an second example, if I have a heater a micro heater, if how the power versus temperature correlation can be obtained?

For example, if I use 100 milliwatt of power what is the temperature that heater will reach to, how we would know right? So, simulation helps us to understand for the given design what will be the performance and then you have to go for fabrication. If you stick to all the parameters correctly, then the simulation results and the fabrication and a characterization results will be close to each other that will follow each other. If the recipe is not properly followed, if the fabrication during the fabrication, if the process is not properly followed the simulation results will vary compared to the fabrication and the performance of the device.

So, for today let us see what kind of simulation tool we can use and I will take an example of a heater ok. So, the tool that we are going to use is call COMSOL multiphysics; is a company well known company, Swedish company and the usage of COMSOL is really high. Now, that does not mean that this is only simulation tool. There are other simulation tools as well alright.

Now do not get confused with Cadence and COMSOL. See cadence is for circuit design, COMSOL is for simulating a micro electromechanical sensors or a micro sensors or a transducer alright. So, today let us see how we can perform simulation for a micro heater alright.

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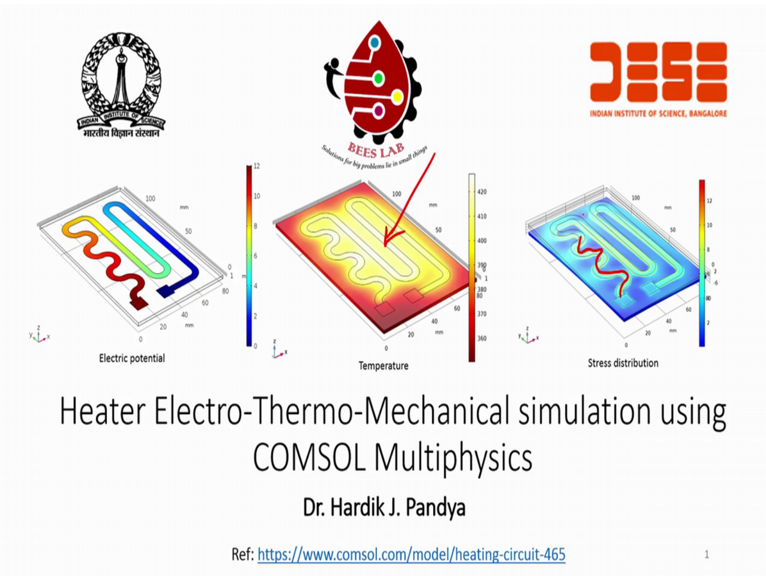

So, if you see the screen it is the heater electro thermo mechanical simulation using COMSOL multiphysics.

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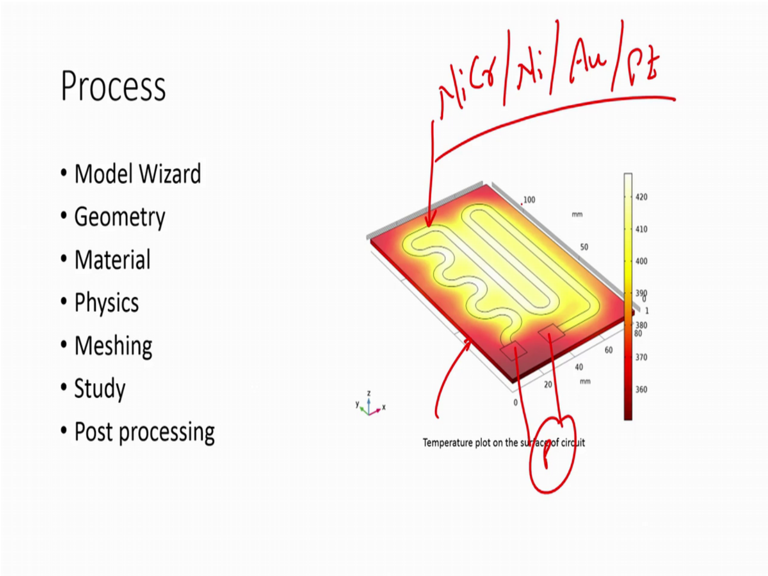

And the process generally is, so, you can see what you can do? You can use electrical potential, you can have temperature plot you can also have stress distribution on the chip. So, if you see this structure, this structure is a heater and based on the how much voltage you apply the change in the current and base in change in current or flow of current the heater will heat that you can simulate. You can simulate what is the stress over the over the pattern when we follow it right what is the stress and so on and so forth. So, let us see the first example and I will show it to you how to perform that simulation.

This is again this topic we have taken because of the questions raised in a forum that the most of the students they want to learn how we can perform simulations because, they do not have all the facilities available for fabricating the device. So, the process will consist of a model wizard, how to create geometry, what are the material that we can select, what is the physics behind it, how to measures the design and then study and post processing.

So, this is an example of temperature plot on surface of a circuit. You can just select this is as a silicon oxidize silicon chip and this is a material on which you can see like this material as a nichrome. Nichrome is NiCr, you can also use nickel, you can also use gold, you can also use platinum and there are least of materials that you can use to fabricate the heater alright.

So, once you fabricate the heater and you apply power to the this end, let say we apply some power then depending on the resistance of the heater there will be flow of current and that will generate the temperature. And, the temperature distribution plot is shown on the slide.

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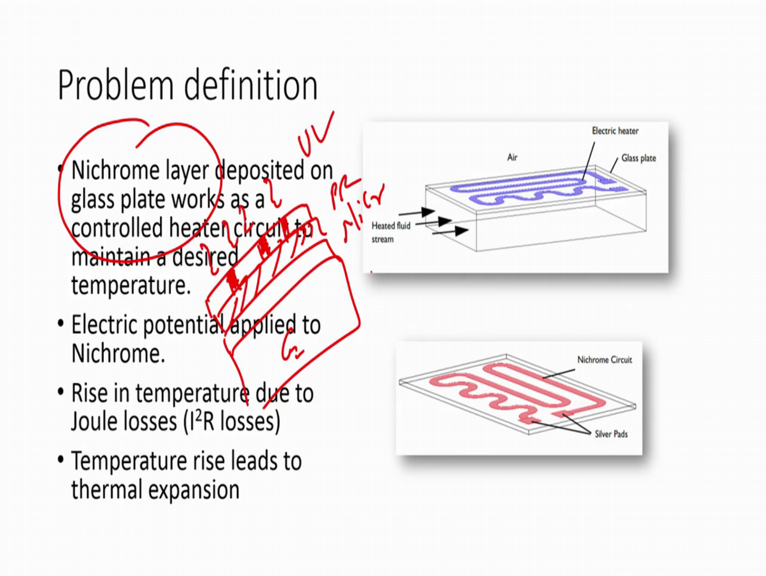

So, what is the problem definition? The problem definition for this class is that we want a heater made up of nichrome right which is deposited on a glass plate and we want to control this heater circuit to a temperature which we are which we have desired. So, we need to maintain this temperature. The electrical potential we have to apply it to nichrome and the rise in temperature is due to the joules losses, I square R losses. I told you that when you apply a voltage there is a flow of current and because the resistance there will loss which is joules heating and that losses are I square R losses. The temperature rise is leads to thermal expansion right.

So, like I said we are interested in understanding the effect of applying a power to a heater and understanding the heating and the power losses as well as the stress in the film. Now what we have used? We have use nichrome right and we all know how to fabricate a micro heater right. Just to help you out; you take a glass substrate right, on this is a glass on which you can deposit nichrome and you perform lithography. How to perform lithography? You can deposit so, this is our nichrome, you can deposit photo resist right, you pre brake it or soft brake it and then you use mask, it can be bright film mask or dark film mask depending on what pattern you want.

After mask what you can do? You can expose with UV right. After exposure, you have to perform the photo resist development. When you will perform photo resist development, what you get?

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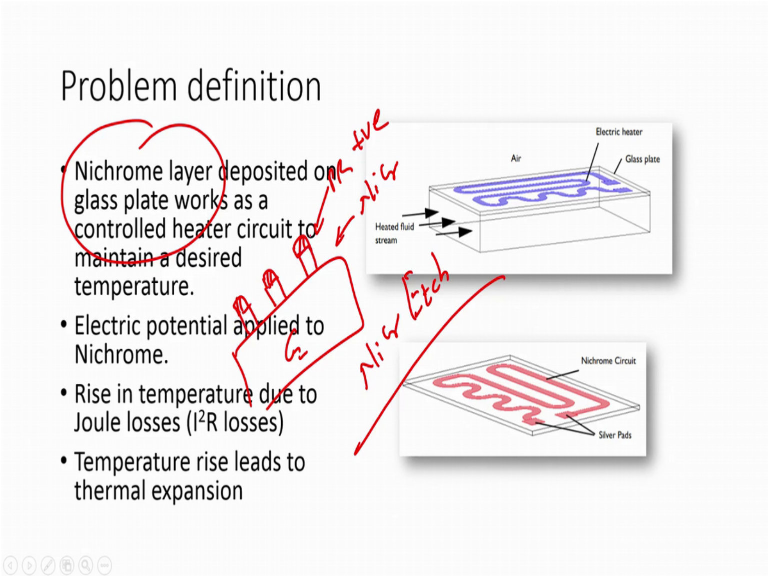

You get photo resist on this particular area. This is your photo resist, this is the nichrome. Why you have only photo resist in this area? Because your mask was a bright film mask and the photo resist that we consider is the positive photo resist. So, the area which is not exposed will get stronger right. Once you have this you can dip this wafer in nichrome etchant.

When you dip this wafer in nichrome etchant what will happen that you will only have nichrome below the photo resist right and this is because, photo resist will act as a mask; photo resist will act as a mask and save the layer below it. After this you deposit the photo, this glass with nichrome and photo resist in acetone.

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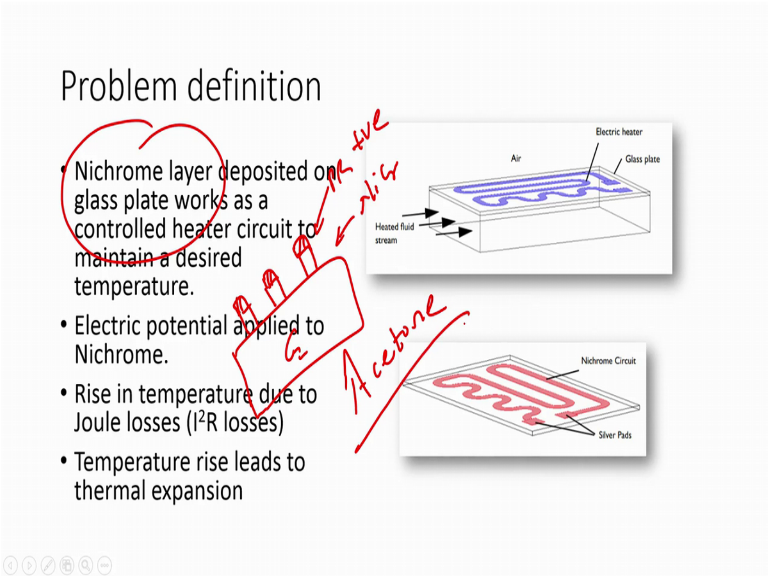

When you this wafer in acetone not deposit sorry you dip the wafer ok, you dip the wafer in acetone what will happen? It will strip off the photo resist. So, it will strip off the photo resist. When you strip off the photo resist, what will happen? You will you will be having a nichrome heater on the glass that is what is shown here that what is shown here.

And this is just an example where there is a glass plate there is a electric heater and if you heated fluid stream if it is a hollow plate or there is a there is a space for liquid to flow and if I flow a hot liquid right then what will happen? What will happen to the heater alright? This is just an example this we are using silver pads you can use a chrome gold as a contact pad instead of nichrome like I said you can use multiple materials ok.

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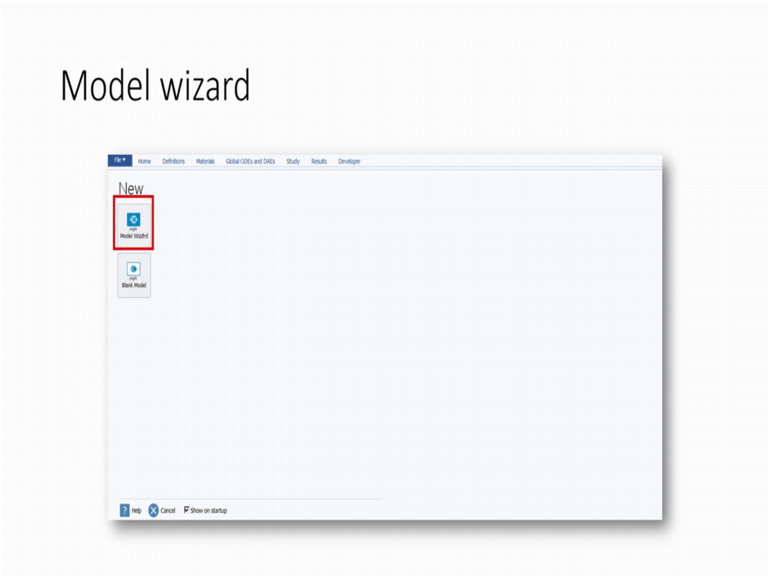

So, when you open COMSOL multiphysics, you can start with new model wizard.

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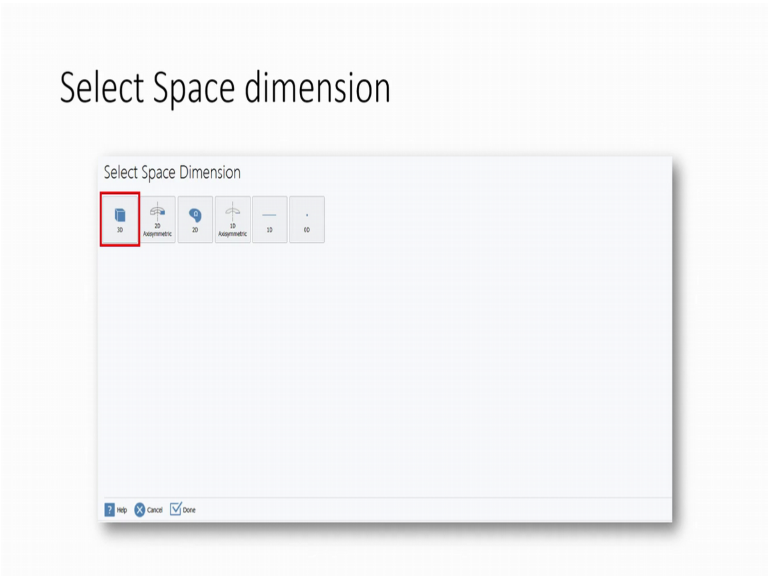

And then you can select a space dimension, you have to select a 3D as a space dimension.

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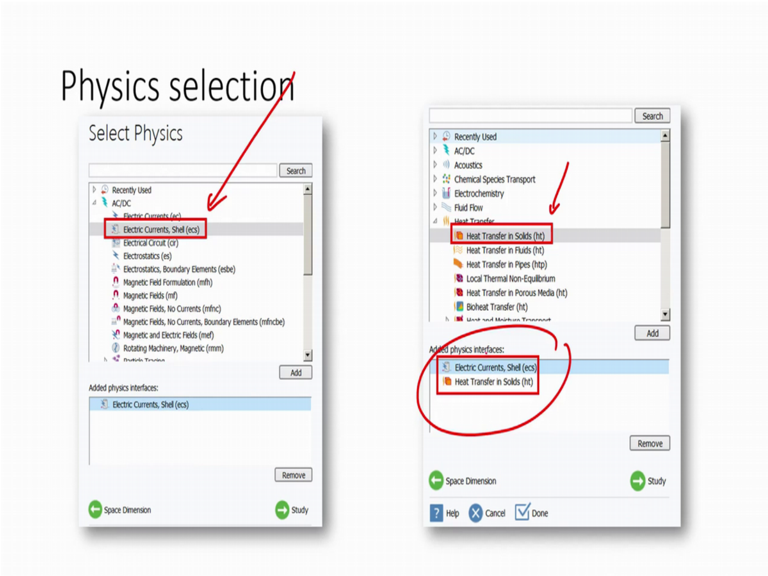

After that what is the next step? Next step is that you have to understand your physics and what you want to understand you want to understand electric currents right. So, you are selecting electric currents. And then in the heat transfer what you understand? You want to understand heat transfer in solid. So, you have to select heat transfer in solid. Now, you have selected two things; one is electric current and second is heat transfer in solids that you can see exactly on the this on the GUI, where you can see at the physics interfaces that you have added would be electric current shells and heat transfer in solids.

After this what is the next step? Now, you see you have a you have the choice of adding multiple physics interfaces. For example, if you want to understand magnetic field you have to understand a rotating machinery if there is a magnetic field and electrical fields if you want to understand the magnetic fields without any current and so and so forth. Same way you can also understand heat transfer in porous material, heat transfer in pipes in fluids. So, you have a multiple options of selecting. Once you select, you can see the selected items in a window which is shown right over here. So, that is a process that you need to follow.

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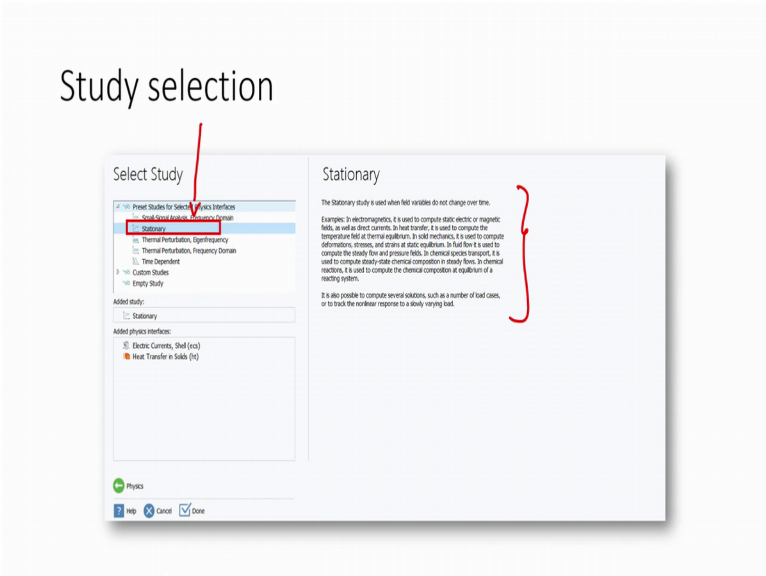

After that what is the study selection? Study selection is that we are selecting a stationary as an option. What do you mean by stationary? So, stationary study is used when field variables do not change over time and it; that means, that if I apply a constant power or a constant voltage to a heater and we not changing any it is not a variable movement. For example, if there is a cantilever and cantilever is not steady it is vibrating continuously, I can select the another study instead of the static study alright or stationary study.

Now, the reason of or what exactly stationary means, it is already given in this particular paragraph that the stationary study is used when the field variables do not change over time and the example is in an electromagnetic it is used to compute static electric or magnetic fields as well as direct currents. In heat transfer that is our example to compute temperature field at thermal equilibrium we can use the stationary. Also in solid mechanics, it is used to complete deformations, stresses, strains static equilibrium not in dynamic in not in dynamic condition.

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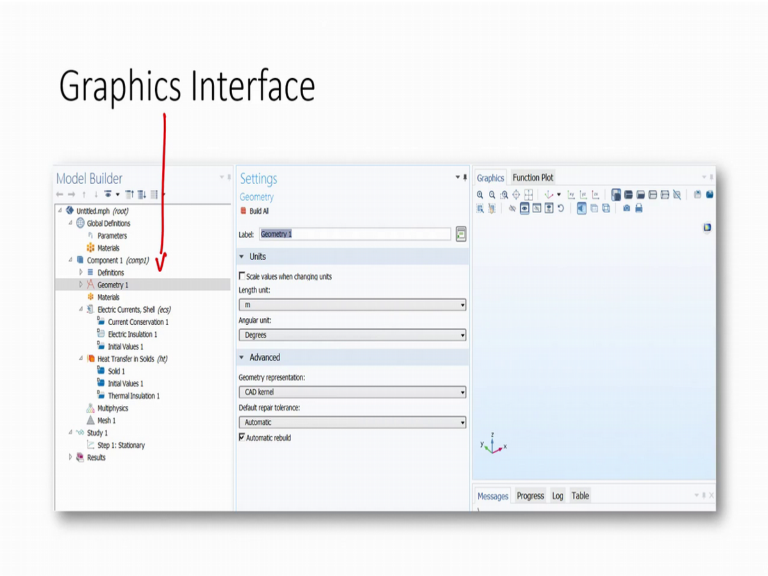

So, let us see once you do that the next step is to select the geometry. So, you are selecting a geometry from the component window and then you can select the length is it in meters, micrometer, the unit in degrees or what if you want to go for advanced geometric representation is using cad and your repair tolerance can be automatic. When you select this item then the next step would be that you have to select the model parameters.

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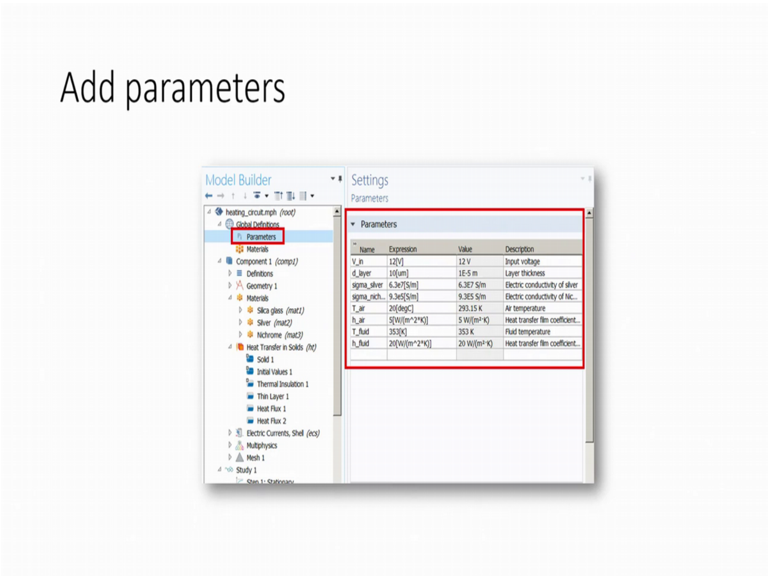

So, what is the parameter that you are using for your for your selected design? In the in our case what is the selected design? The selected design is a heater. So, what we have to understand? What is the voltage that you want to apply? So, here is a voltage. Then what is the layer thickness? Then you are selecting here, what is the layer thickness? About 10 micrometer, 12 volts is the maximum voltage.

So, the electrical conductivity of silver we have to select because the contact if you remember are made up of silver. Then we have to understand the electrical conductivity of nichrome. So, we are selecting electric conductivity of nichrome, then the temperature; air temperature is the temperature acts into the heat transfer film coefficient then fluid temperature because we took an example of a fluid flowing below the heater. So, there is temperature of that fluid and then heat transfer film coefficient.

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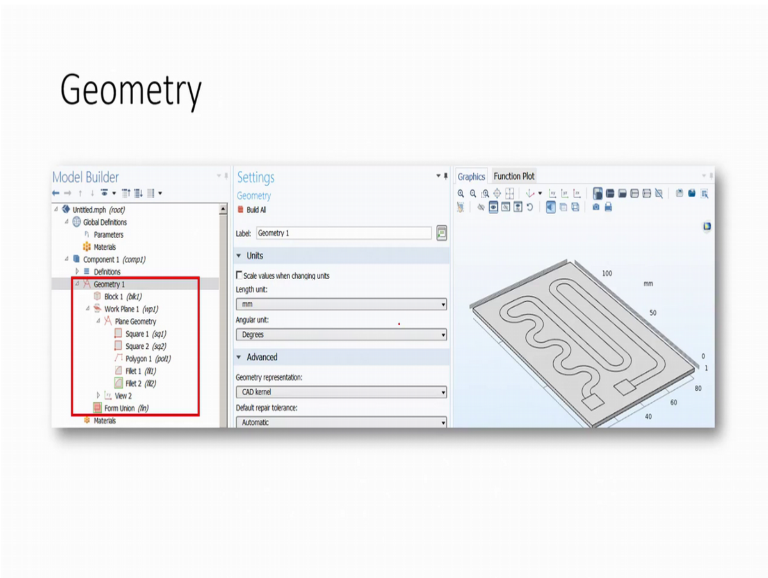

So, when you select this parameter and then you use the; so, this parameter will be applied to this particular section, where you have a glass plate and you have a heating film alright. So, here we have selected a little bit bigger heater just to explain you up and when you select the geometry you have a multiple options here also. So, what is square 1, square 2, filet 1, filet 2 is that plane geometry or not?

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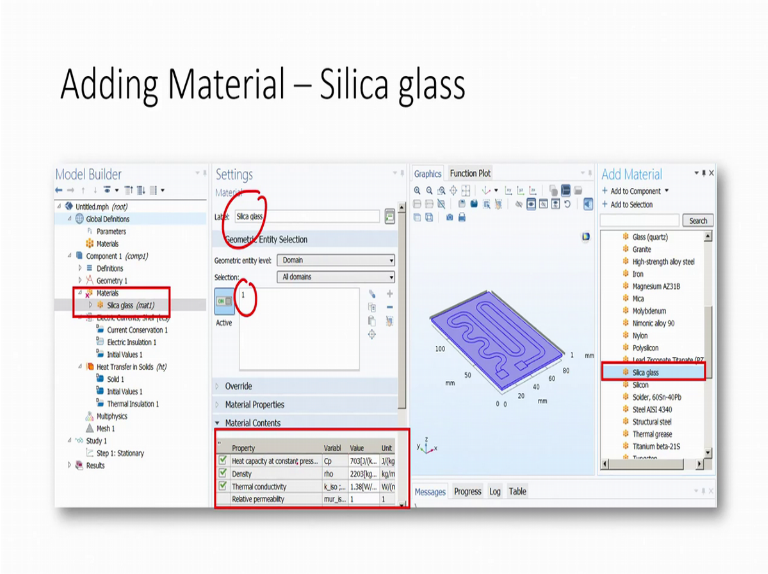

And then what is the material? So, what is the material that is on which you are fabricating the heater, is it silicon or is it a glass or is it some polymer? So, we have a option of selecting the material where you have selected here silica glass. You can see here lot of material options are there.

You can select glass, granite, iron, magnesium, mica, molybdenum, polysilicon and lot of other materials to be used or that can be we can select as a substrate; substrate you know that on which we are creating a or fabricating a device right. So, the material selection is possible by adding the material on the material selection window.

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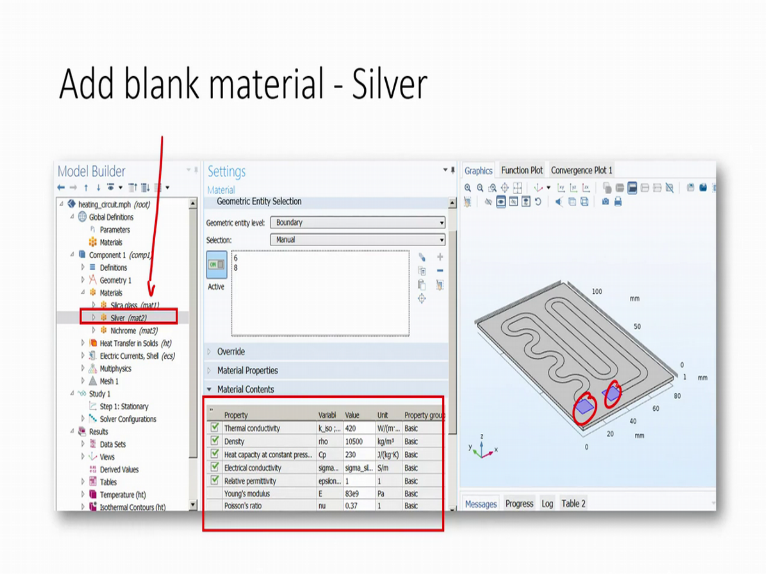

Followed by; now, we want to just see select here silver. You see here what we are selected; silver and so, this is a material 2 or material 1 is a glass that is our material 1 right. So, here it is you see is material 1 which is our silica glass, material 2; it is the silver right which is right over here then we see material 3.

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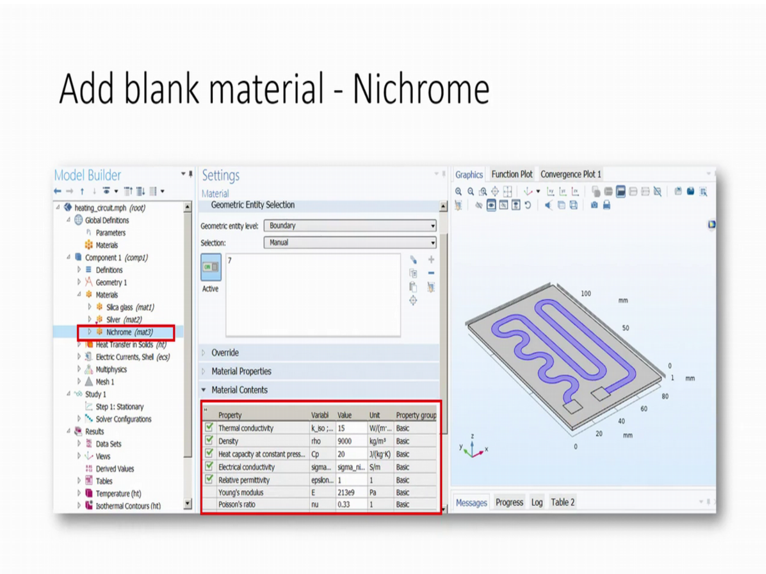

So, material 3 would be the nichrome, it is right over here right. So, we have 3 selections; one is the glass, one is a nichrome and one is silver pad.

Now, for each of those if you see the values would change. For silica, you have heat capacity, density, thermal conductivity; for the silver, you have thermal conductivity, density, heat capacity, electrical conductivity, relative permittivity; while for the nichrome, also it will be same because it is a conductor right

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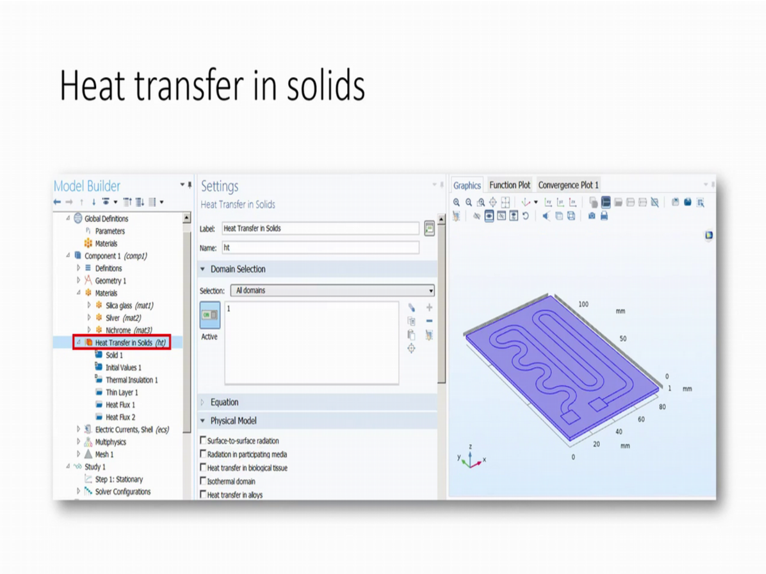

Now, after this heat transfers in solid; here you can select this heat transfer in solid and then first you select thin layer 1 right.

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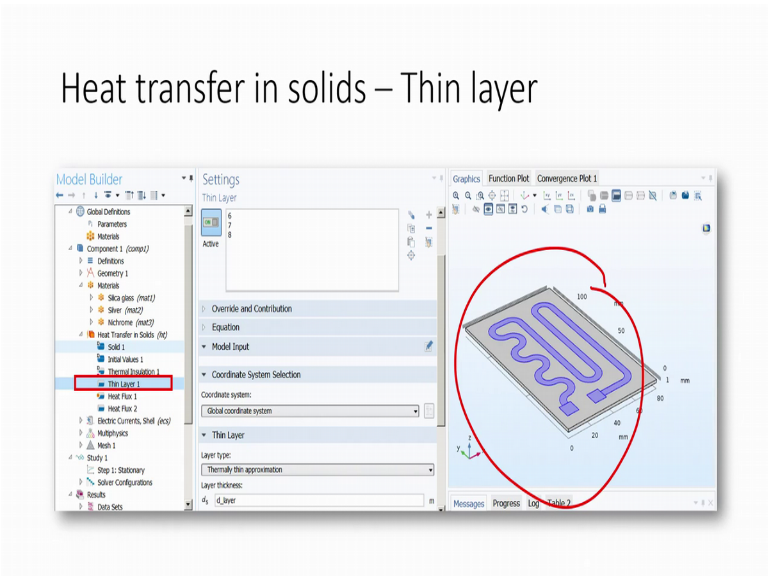

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So, thin layer 1 we have selected, we have selected coordinate system as global, layer type we want to know is thermal thin approximation right.

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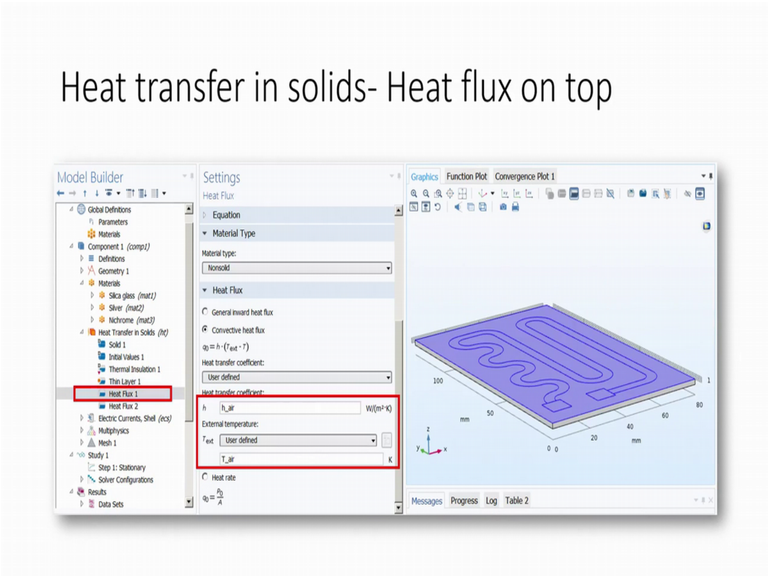

And then when you select heat flux you want to see what is the heat transfer coefficient, which is h air and if you want to see the temperature it will be T air.

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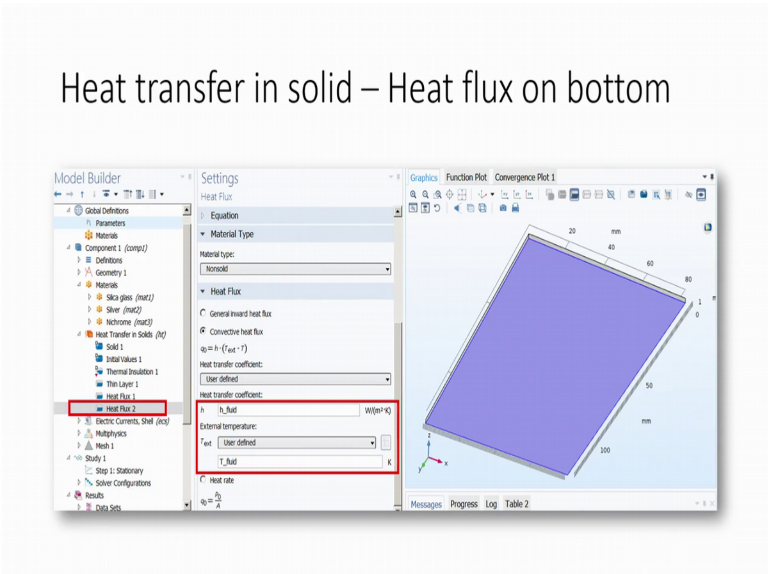

So, when you want to further, you have to understand what is the convective heat flux and earlier what we have seen is we are selecting heat flux 1 and then we are selecting heat flux 2 that is the first one is in the front and second one if you see it is on the another side.

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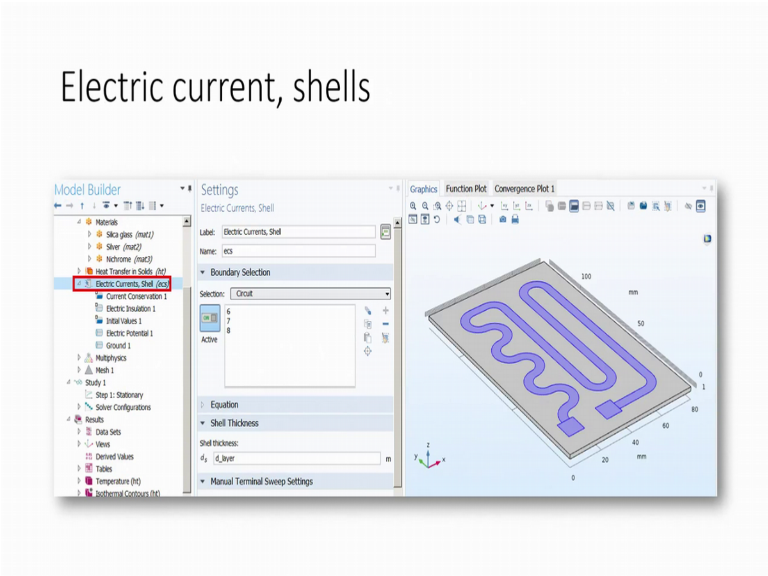

Then after that you are using electrical currents right that is flowing through this one.

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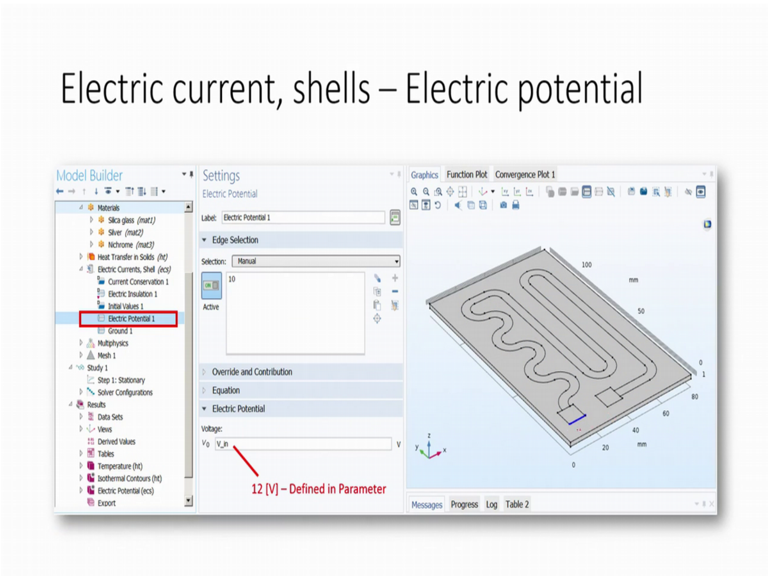

Then electrical potential where you will apply you have to select this boundary this is what we selected and then we have say that here we will apply 12 volts right. So, this is with respect to this. So, this will be grounded and this will be; so, voltage applied between these 2 pads.

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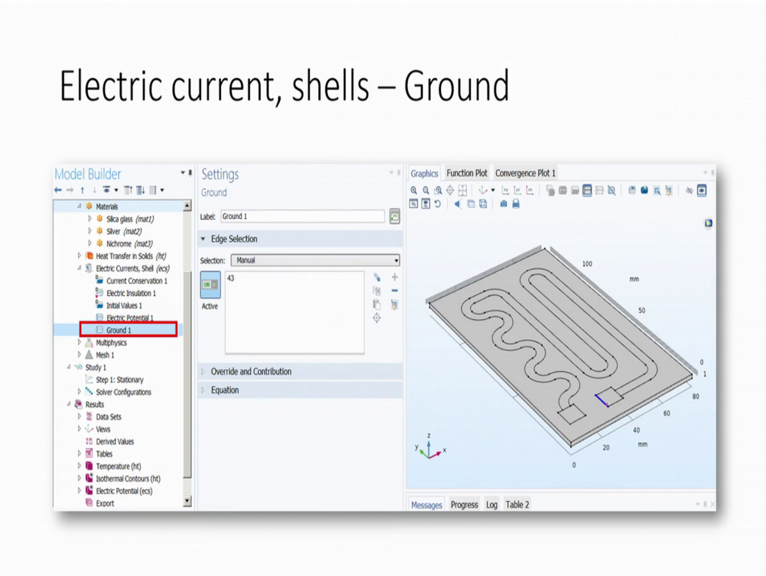

See this ground. So, here earlier if you see on the pad 1 that is the silver pad right here which is a blue color line you are applying 12 volts this one ok. And then you apply where is a ground, so, ground is right over here right. So, we applied electric potential between two pads followed by temperature coupling right and then electromagnetic heating.

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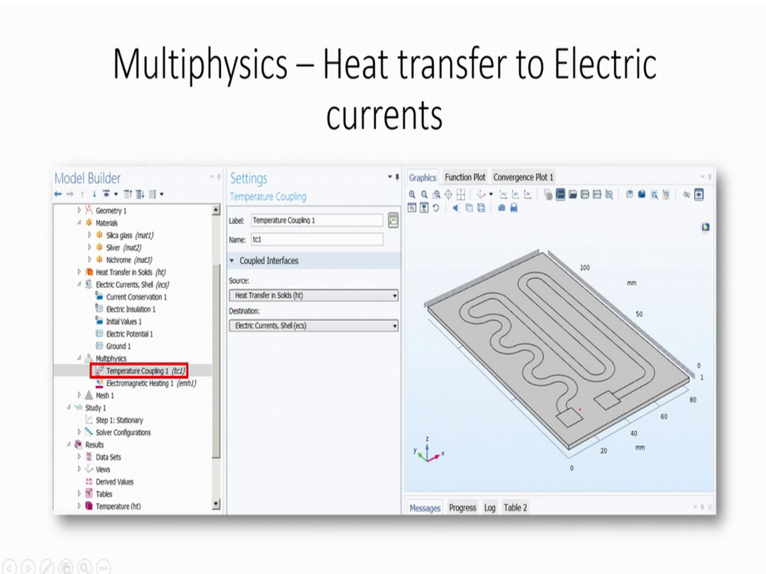

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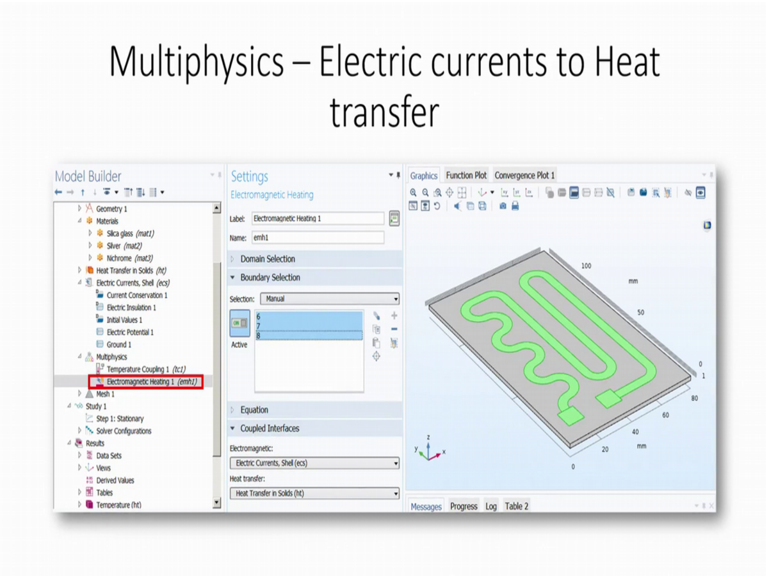

So, temperature coupling can be; so, electromagnetic heating we want to interested, we are interested in the pattern right, what is the pattern and how it will be heated up.

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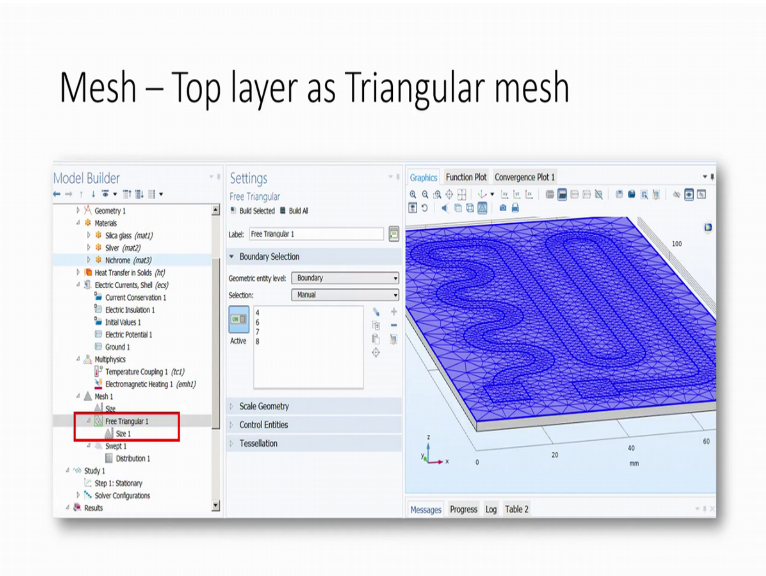

Then we have to create a mesh right. So, if the mesh size is extremely small it will take longer time and you will get a better result compared to a larger mesh you need to use a smaller dimension in the mesh.

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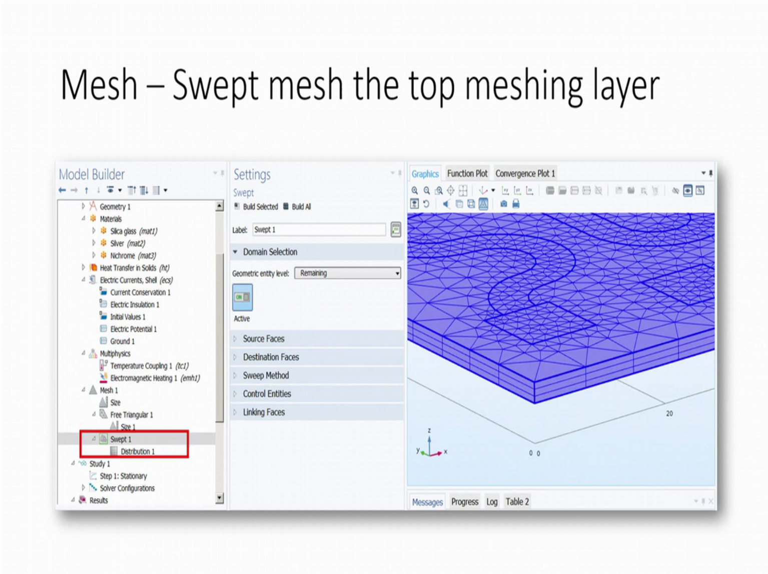

After that you are using a study phase 1 right; where your step 1 is a stationary.

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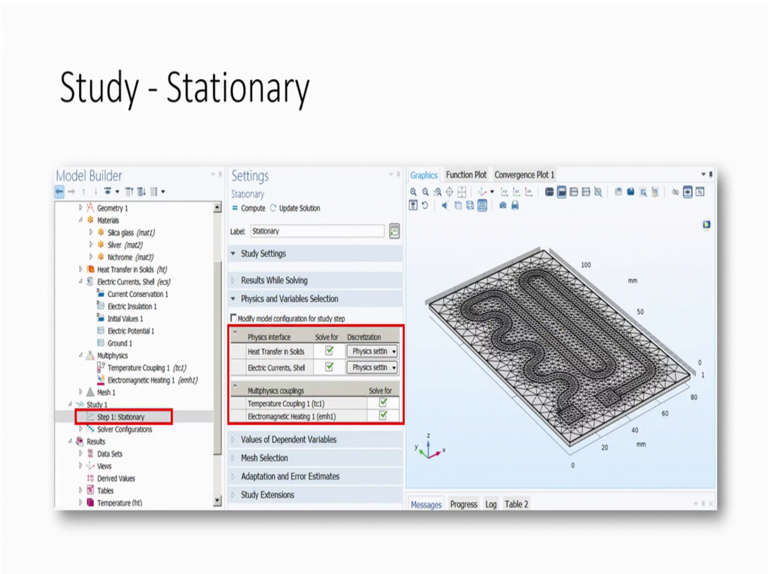

You have selected all the parameters, heat transfers, electrical current, temperature coupling, electromagnetic coupling, right and then you see what is the temperature.

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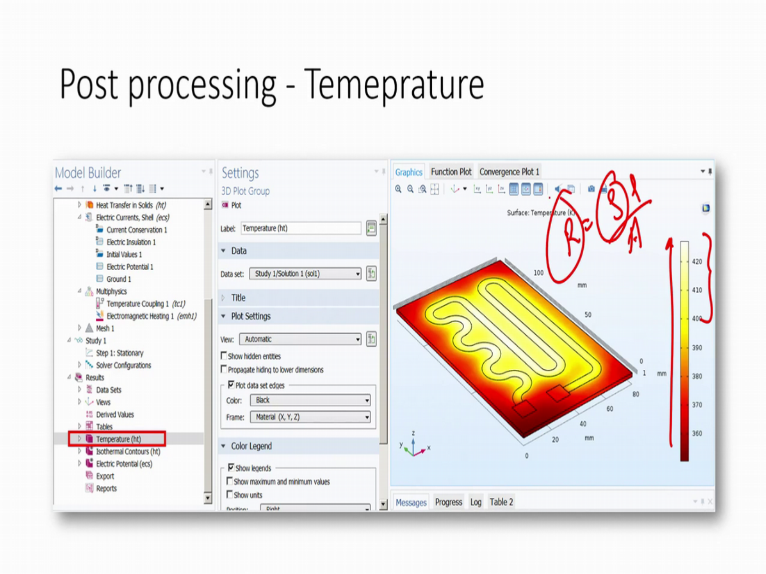

So, now, if we see the effect of the voltage, 12 volt to this particular chip on which there is a heater, you will see that the temperature distribution right over the chip and as you can see the maximum heating that is about 420 degree centigrade is in this particular region. There is another parameter you need to understand why the heating is more in a particular area compare to other area. You can also see that it is kind of uniform in the centre right.

So, this lies between 400 to 420 degree centigrade, while the corners are colder compared to the central region because there is no resistor on the chip, right. So, there is no heater. When I say resistor and heater, it is same thing because it is the metal that you have formed a structure and you know resistor is a thing rho R equals rho l by A right, where rho is resistivity, l is length and A is area. So, you are creating a longer length to increase the resistance and the resistivity depends on the material that you have selected which is your nichrome.

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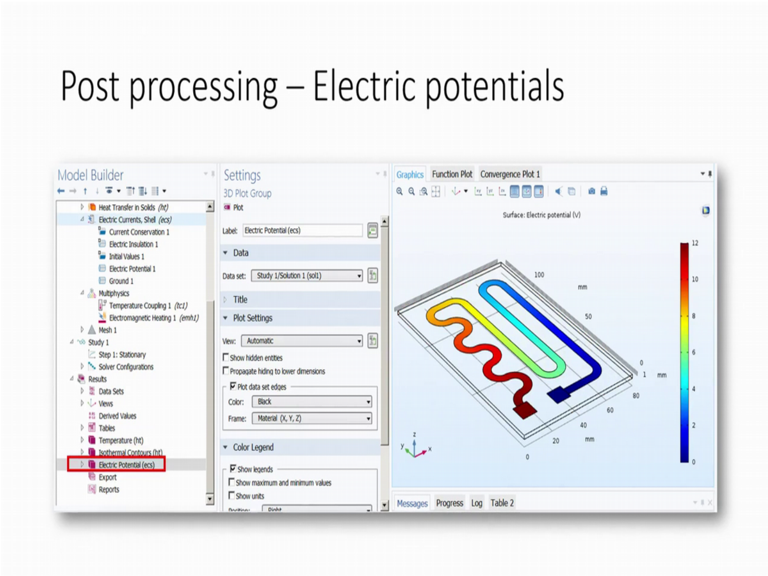

After this the next step would be to see the electrical potential. So, you can see when you apply 12 volts, right over here and this is a ground which you can see here, how the electrical potential varies across the resistor? Across this resistor how the electrical potentials are varying um? So, that is another thing that you can work on you can see ok.

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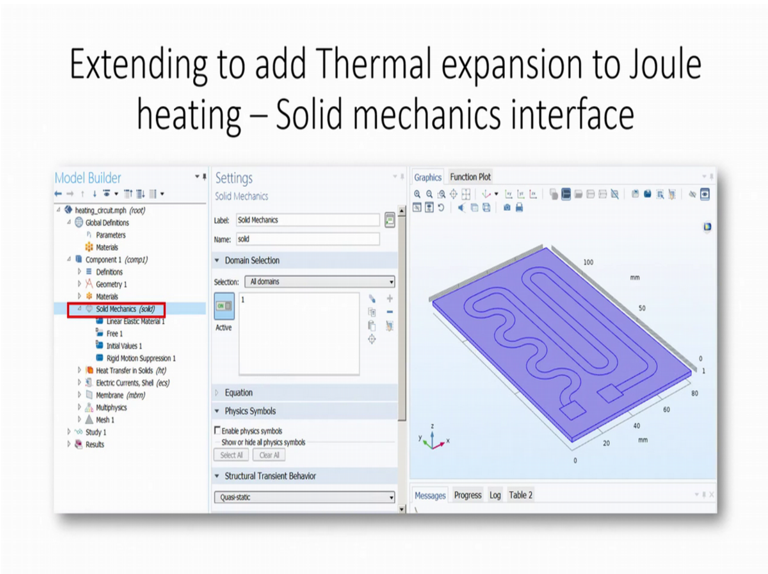

Then the next would be solid mechanics and then you have to go further.

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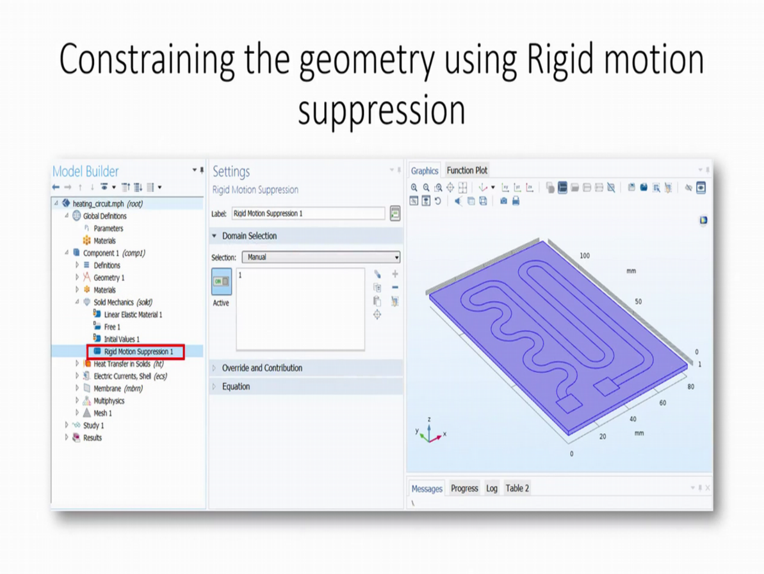

This is for rigid motion suppression, you need to understand if I if I apply a stress or the strain to the heater what will happen.

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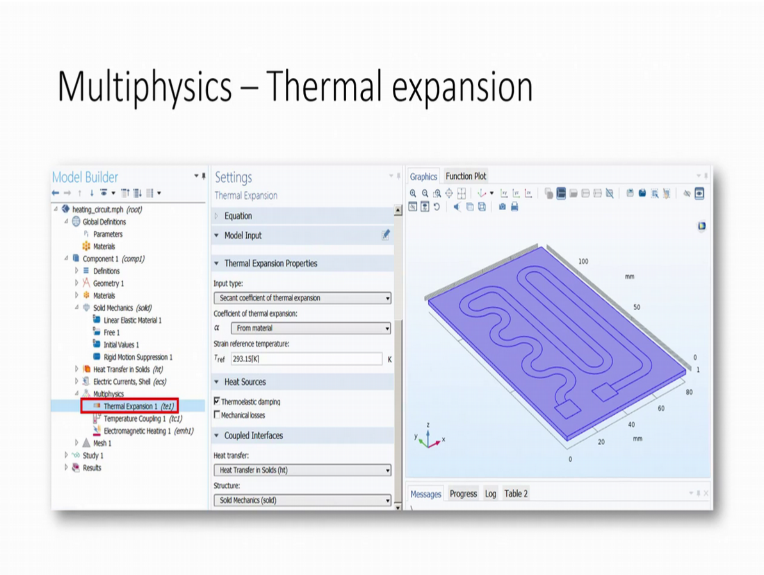

Something goes for thermal expansion right. So, this is what we have seen is you see here lets us go for here heating right and then you can see the electrical electric potentials followed by solid mechanics in which you can see the rigid motion suppression, after that there is a thermal expansion followed by a stationary and so on and so forth.

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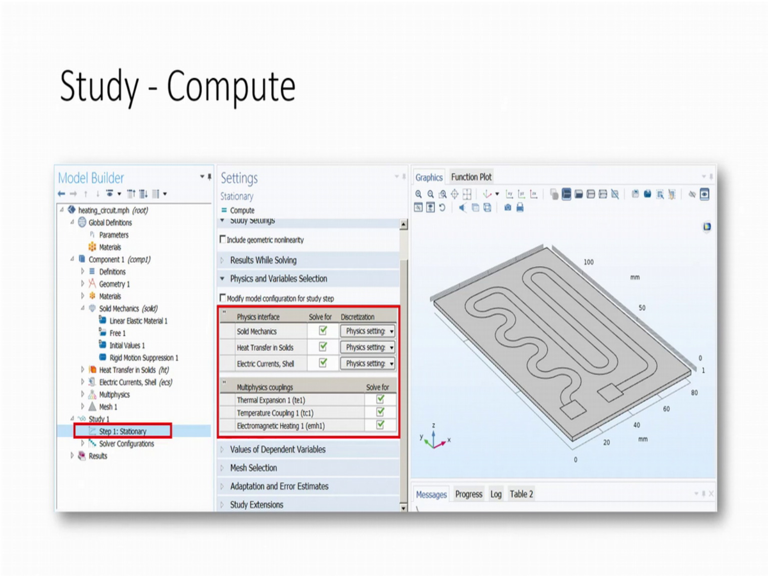

So, let us just understand until here for today's class and we will follow with another module in which I will explain you further details. So, for today's class what we understood is that there is a simulation tool called COMSOL multiphysics using which we can understand the effect of voltage on the on the heater and what is the temperature distribution over the chip when form a particular design.

At same time you we also have seen the change in the electrical potential for the given resistor. In the following class we will see lot of other things such as the solid mechanics and we will see the region motions suppression, we will see thermal expansion, we will also see the effect of the stress on the heater parameter, we will see the effect of the.

So, the point is there are multiple parameters that you can find out using simulation tools. So, let us stop our lecture now. You revisit this lecture and I will continue for one more module on which I will explain you the remaining part of this particular simulation.

Till then you take care have a nice time, bye.