Microwave Engineering
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Lecture No. 34
Inductors

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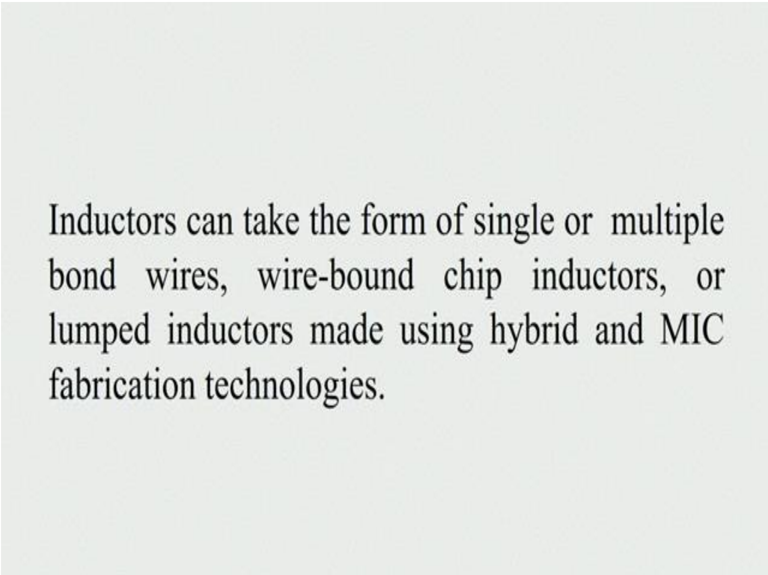

So, we have seen how the resistors and capacitors, these are made in MIC made for MIC application. Let us now consider another very important element, which is an inductor. Inductors can take form of single or multiple bond wires, wire bond chip inductors, or lumped inductors made using hybrid and MIC fabrication technologies.

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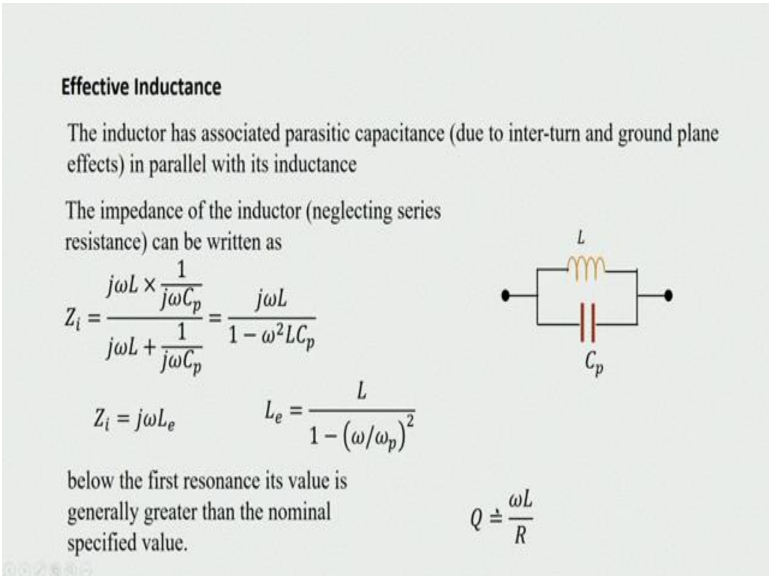
$$Z_i = \frac{j\omega L \times \frac{1}{j\omega C_p}}{j\omega L + \frac{1}{j\omega C_p}} = \frac{j\omega L}{1 - \omega^2 L C_p}$$

$$Z_i = j\omega L_e$$

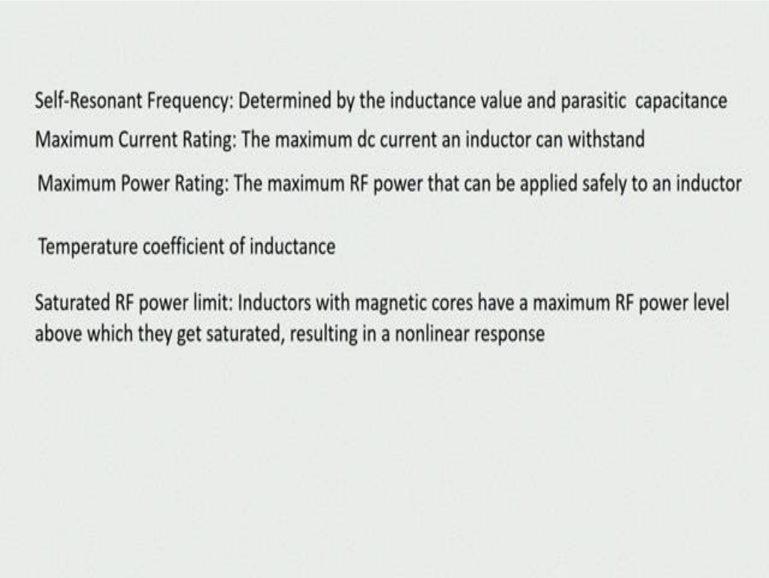
$$L_e = \frac{L}{1 - \left(\omega/\omega_p\right)^2}$$

$$Q = \frac{\omega L}{R}$$



So, effective inductance is a parameter that is of importance. This is because the inductor has associated parasitic capacitance and if we represent an inductor along with its parasitic capacitance, which is represented by CP. The impedance ZI is actually the parallel combination of the reactance of L and that of CP, and it can be written as J omega L divided by 1 minus omega square LCP.

And this is of the form ZI is equal to J omega LE, where LE is the effective inductance, and LE is equal to L divided by 1 minus omega by omega P square, where omega P is 1 by LCP. And below the first resonance its value is generally greater than the nominal specified value. Also in this calculation of effective inductance, we have not considered the series resistance that are normally associated with an inductor, and the Q of the inductor can be calculated as omega L by R, where R is the series resistance of this inductor. Now, there are certain issues that need to be considered while selecting a particular inductor for a given application. (Refer Slide Time: 03:25)



Self-resonant frequency. It is determined by the inductance value and parasitic capacitance value we have already seen. Then maximum current rating. The maximum DC current that an inductor can withstand, so this is another important rating. Then maximum power rating. Maximum RF power that can be applied safely to an inductor without the inductor being damaged.

Then the temperature coefficient of inductance is also another important parameter. And finally saturated RF power limit. If the inductors are fabricated with magnetic cores, then these cores have a maximum RF power level above which they get saturated, and once it goes into saturation this will result in non-linear response of the device.

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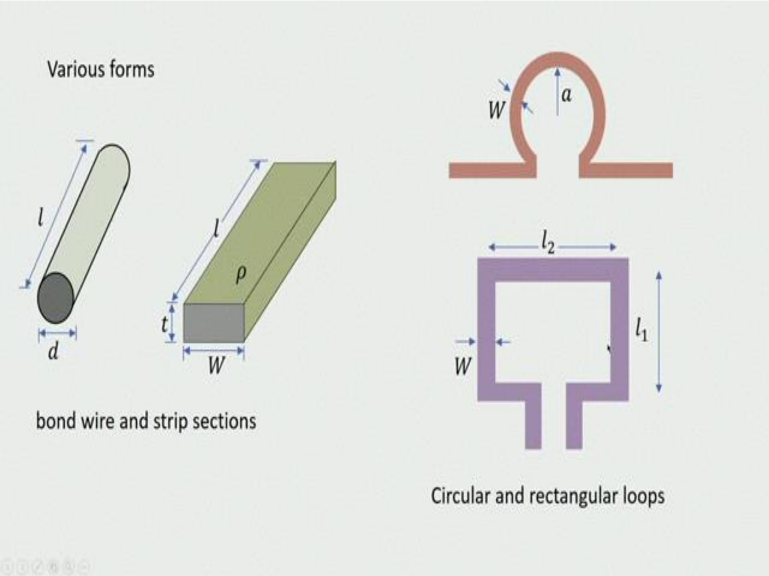

Inductors appear in various forms. So, bond wire and strip sections are shown here, and the inductance provided depends on the diameter and the length. Similarly, here the width thickness and L length. So, inductors are also realized using loops either circular loops or rectangular loops.

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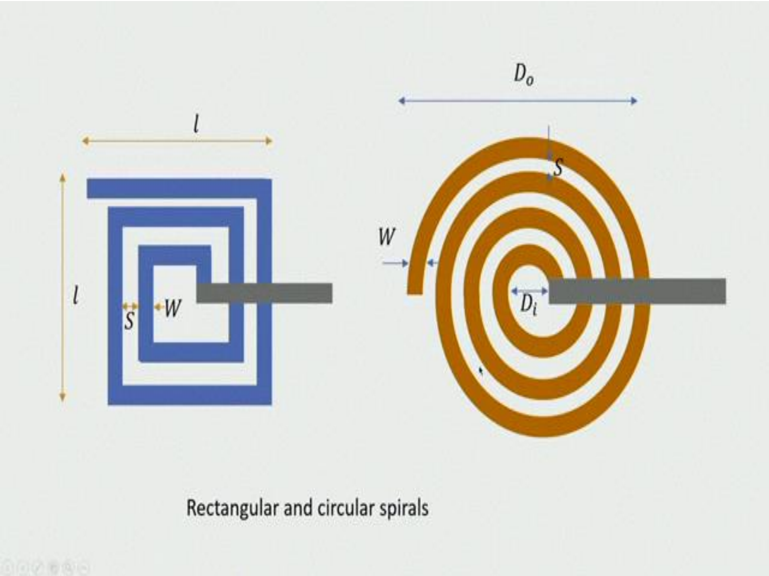

Another very popular realization of inductance is using spirals. We can have a rectangular or circular spiral as shown in the figures. And design of this type of inductors depends on determinant width, then the length, then the spacing between the individual spiral arms or determining the diameter. Again, the spacing and both analytical and numerical computations are done for finding out the dimensions of this spiral inductors for realizing specific values of inductances. Of course, many parasitic elements are also needed to be considered while making the calculation. For example, we can have an intra-ton capacitance.

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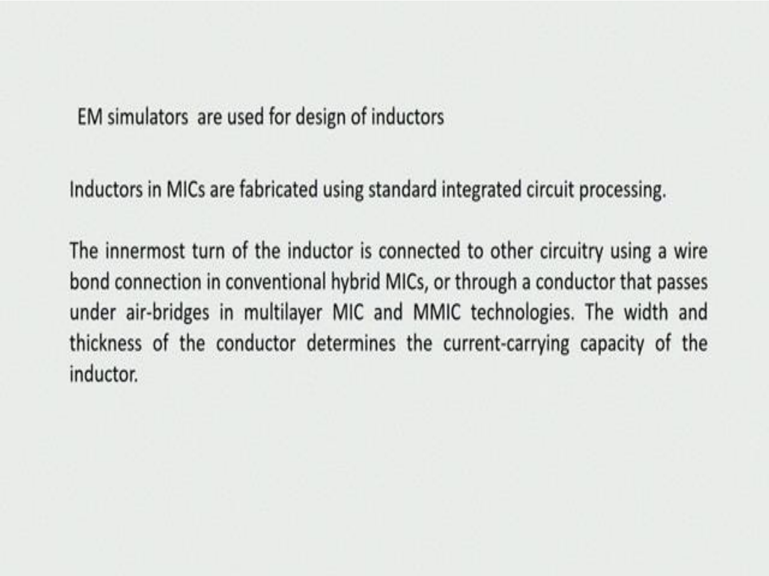

Usually, EM simulators are used for design of inductors. And inductors in MICs are fabricated using standard integrated circuit processing. The innermost turn of the inductor is connected to other circuitry using a wire bond connection in conventional hybrid MICs or through a conductor that passes under air-bridges in multilayer MIC and MMIC technologies. The width and thickness of the conductor determine the current-carrying capacity of the inductor.

So, we have discussed the basics of inductors and different forms of the inductor that are available, which are suitable for MIC and MMIC technologies.

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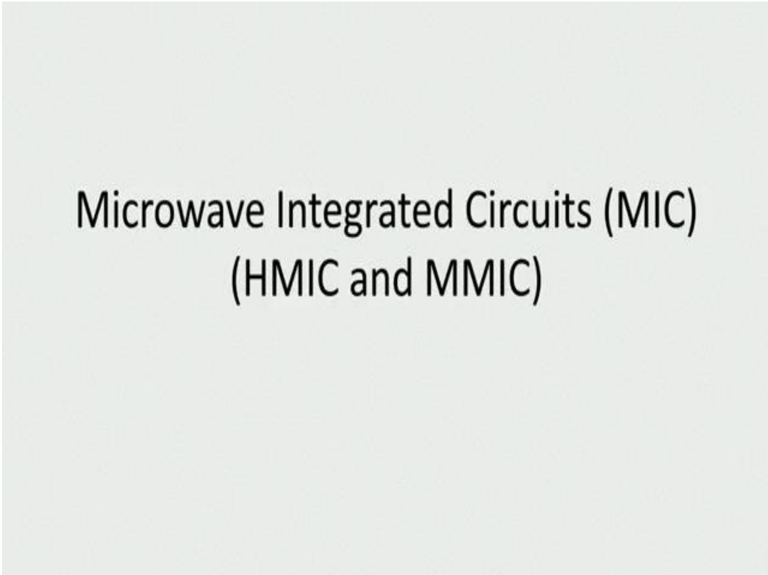

We briefly discuss some features of microwave integrated circuits or MIC, and we will consider both hybrid microwave integrated circuit HMIC and monolithic microwave integrated circuit. In this discussion we will very briefly highlight some of the salient features of these two technologies, and we will provide an overview of these two technologies.

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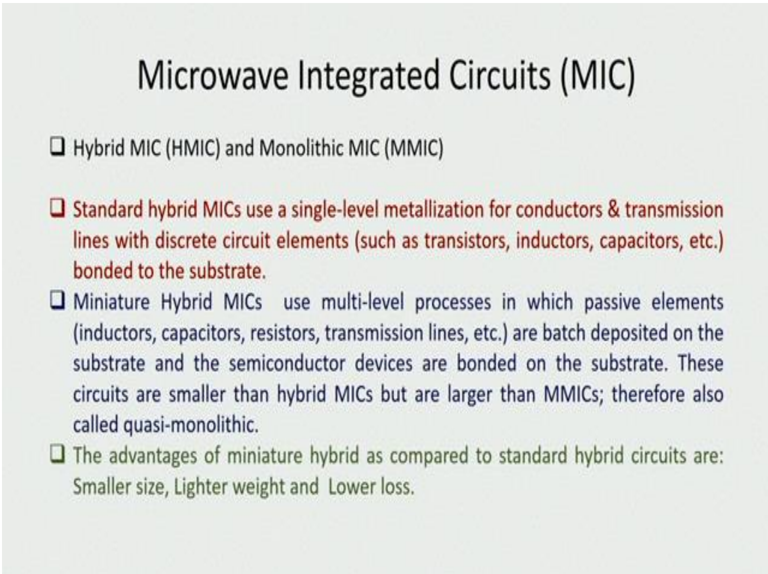

So, microwave integrated circuits may come in the form of hybrid MIC or HMIC and monolithic MIC or MMIC. Standard hybrid MICs use a single-level metallization for conductors, and transmission lines with discrete circuit elements such as transistors, inductors, capacitors, etc bonded to the substrate.

Miniature hybrid MICs use multi-level processes in which passive elements inductors, capacitors, resistors, transmission lines, etc. are batch deposited on the substrate, and the semiconductor devices are bonded on the substrate. These circuits are smaller than hybrid MICs, but are larger than MMICs; therefore they are also called quasi-monolithic. The advantages of miniature hybrid as compared to standard hybrid circuits are; smaller size, lighter weight, and lower loss.

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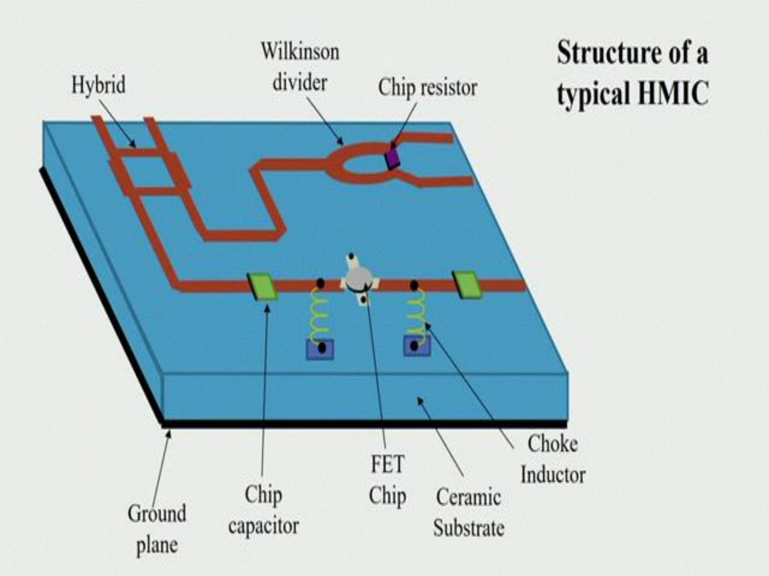

So, here, the structure of a typical hybrid MIC is shown. So, we have a substrate, ground plane, and then on this the transmission line and transmission line based components. For example, here we show a branch line coupler, the schematic of a power divider these are fabricated. And then we have the chip resistor, chip capacitors these are connected. Then we have these choke inductors, and finally we have the active devices connected. So, in this type of MICs we can see that some of the components are bonded or shouldered, and transmission line based circuitry they are fabricated on the substrate.

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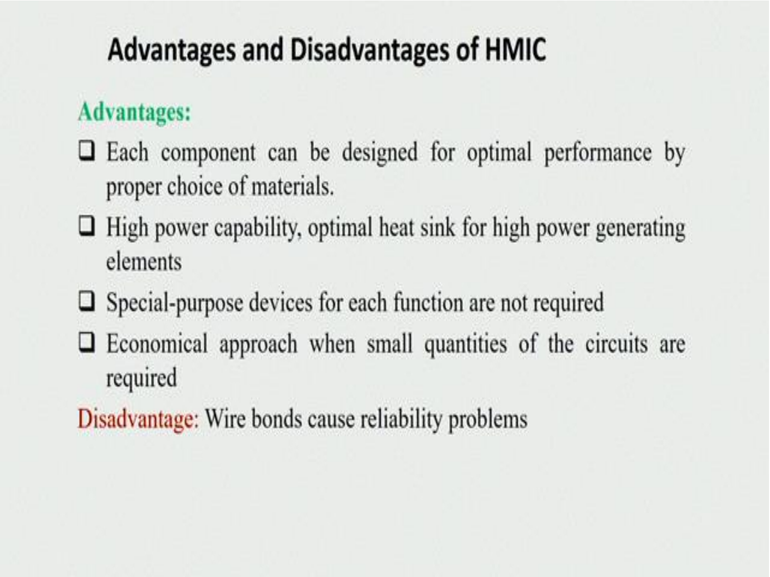

HMICs offer some advantages in the form that each component can be designed for optimal performance by proper choice of materials. High power capability, an optimal heat sink for high power generating elements. Then special-purpose devices for each function are not required. Economical approach when small quantities of circuits are required. But they have the disadvantage that when you have the components bonded through wire bonds, reliability problems are there. The wire bonds may break.

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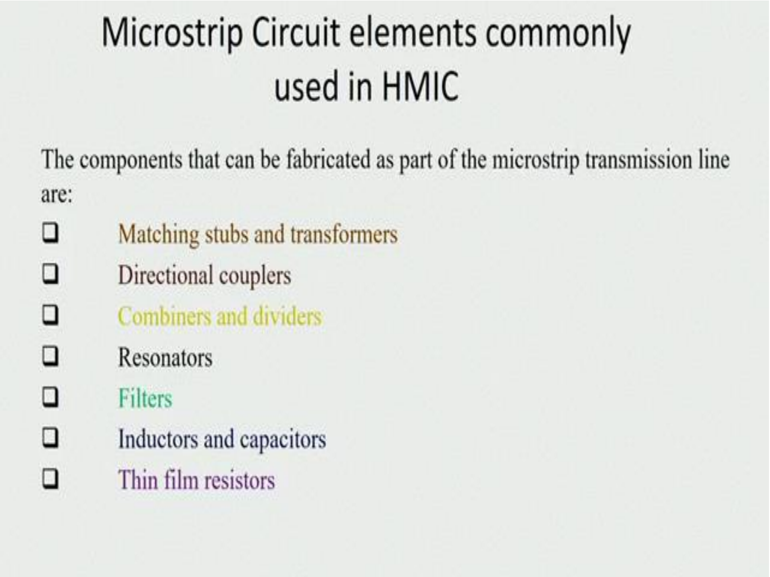

Microstrip circuit elements that are commonly used in HMIC as a part of the microstrip line. These are matching stubs and transformers. Directional couplers. Combiners and dividers. Resonators. Filters. Inductors and capacitors. So, these are some of the components which can be fabricated as a part of the microstrip transmission line, while fabricating the transmission lines. Thin-film resistors also can be fabricated.

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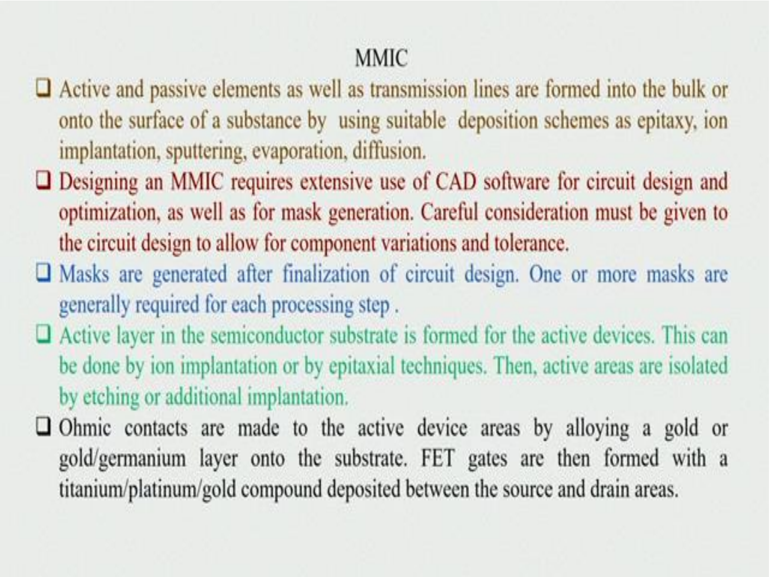

Let us now very briefly consider MMIC. Active and passive elements, as well as transmission lines, are formed into the bulk or onto the surface of a substrate by using suitable deposition schemes such as epitaxy, ion implantation, sputtering, evaporation, diffusion, etc. So, these are all standard integrated circuit fabrication technology processes.

Designing an MMIC structure requires extensive use of CAD software for circuit design and optimization, as well as for mask generation. Now, MMIC involves several SAP processes, and several levels of maskings are required. Careful consideration must be given to circuit design to allow component variations and tolerance. Masks are generated after finalization of circuit design. One or more masks are generally required for each processing step.

The active layer in the semiconductor substrate is formed for the active devices. This can be done by ion implantation or by epitaxial technique. Then, active areas are isolated by etching or additional implantation. So, first we need to create space for the active elements. Ohmic contacts are made to the active device areas by alloying a gold or gold aluminum layer into the substrate. Field-effect transistor gates are then formed with titanium, platinum, gold compound deposited between the source and the drain areas.

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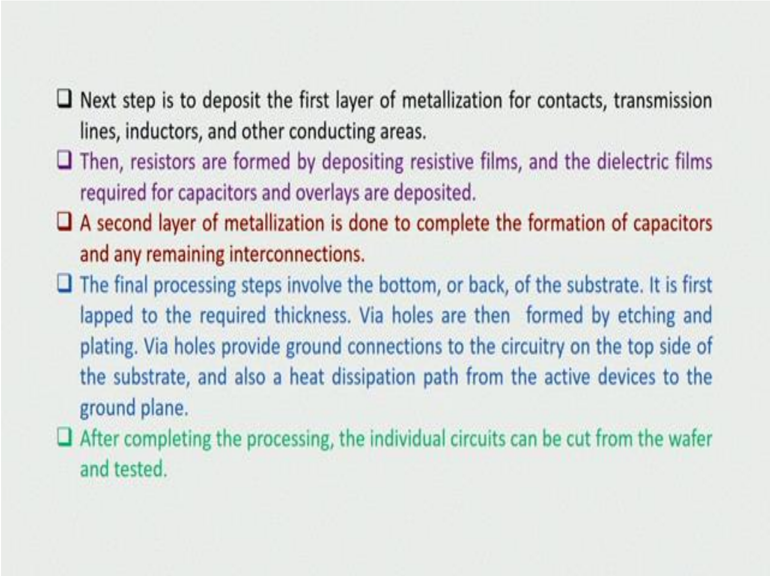

So, after depositing the layers for the active elements, the next step is to deposit the first layer of metallization for contacts, transmission lines, inductors, and other conducting areas. So, contacts to the active elements, transmission line components connecting different parts or different components. These are done in the first layer of metallization. Then, resistors are formed by depositing resistive films, and the dielectric films are required for capacitors and overlays are deposited.

The second layer of metallization is done, so after doing the first layer of metallization we deposit resistors and then dielectric films, etc for the capacitor. Then in the second layer of metallization is done to complete the formation of capacitors and any remaining interconnections.

The final processing steps involve the bottom or back of the substrate. It is first lapped to the required thickness. Via holes are then formed by etching and plating. Via holes provide ground connections to the circuitry on the top side of the substrate and also a heat dissipation path from active devices to the ground plane. After completing the processing, the individual circuits can be cut from the wafer and tested. So, we have a lot of process steps to be followed for realizing MMIC.

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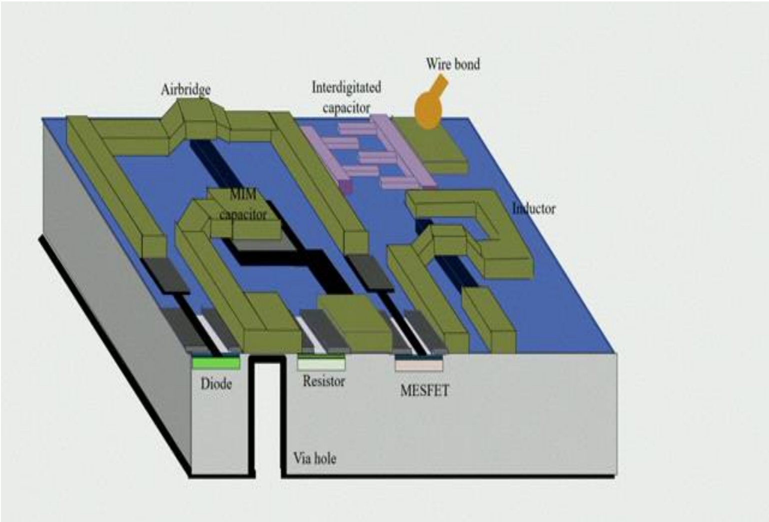

Structure of a typical MMIC

A schematic of an MMIC is shown. Here we show this is only a representative view, how the different components are organized. So, we have substrate. We have resistor, inductor, interdigital capacitor. We have air-bridge, we mentioned that the air-bridge is provided when we need to have a metallization layer pass underneath it. A MIM capacitor is shown, and then we have the resistor via the whole. So, this is how a typical MMIC will be organized, and different levels of fabrication steps will be carried out.

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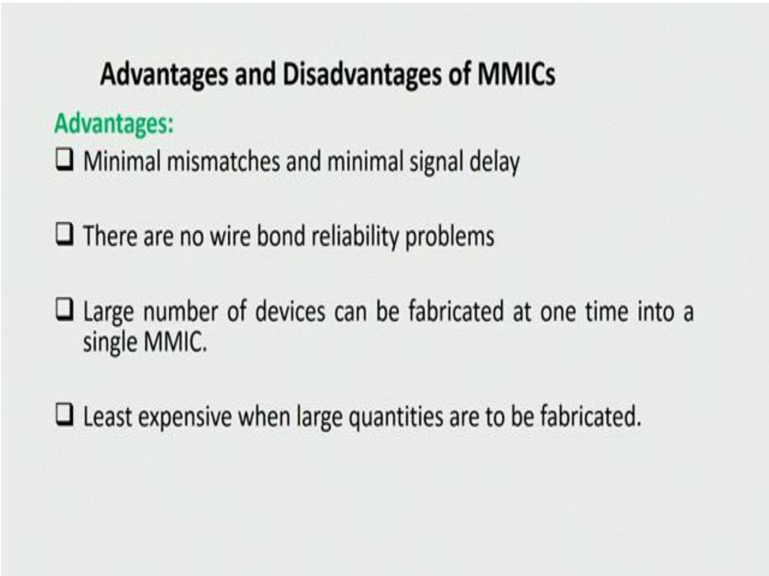

We now discuss some of the advantages and disadvantages of MMICs. The major advantages are minimal mismatches and minimal signal delay. Because everything is being fabricated on the same substrate. Wire bond reliability problems are eliminated. A large number of devices can be fabricated at one time into a single MMIC. It is the least expensive when large quantities are to be fabricated.

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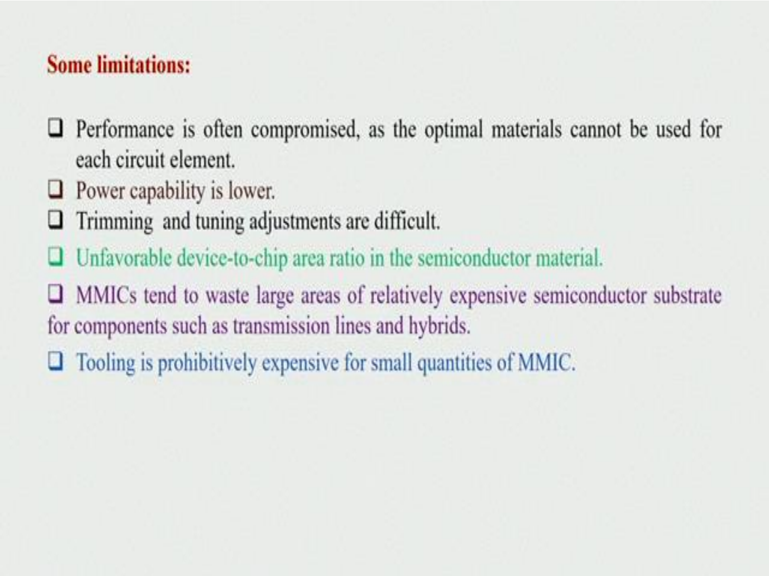

However, MMIC technology also has some limitations. Performance is often compromised, as the optimal materials cannot be used for each circuit element. So, we had that flexibility in hybrid MIC, when the material for individual components would be chosen. But here we do not have this flexibility. Power capability is limited. This type of MMICs can handle limited amount of power.

Trimming and tuning adjustments are difficult. In hybrid MIC, to optimize the functionality, some of the component parameters can be trimmed. But in MMIC that flexibility is not there, and it is extremely difficult to do any fine-tuning or trimming. Unfavorable device to chip area ratio in semiconductor material. This is very important because MMICs tend to waste large areas of relatively expensive semiconductor substrate for components such as transmission lines, hybrids, etc.

So, when we fabricate this type of metallic structure lines on the MMIC substrate, a large amount of substrate area is used, and we do not which actually reduces the device to chip area ratio. Because active devices take relatively much smaller area as compared to this type of passive elements, transmission lines when they are fabricated on the semiconductor substrate.

Tooling is prohibitively expensive for small quantities of MMIC, because this fabrication process, it is very intensely involved, it becomes prohibitively expensive. If you want to fabricate only a limited number of MMIC. Whereas hybrid MIC this problem is not there.

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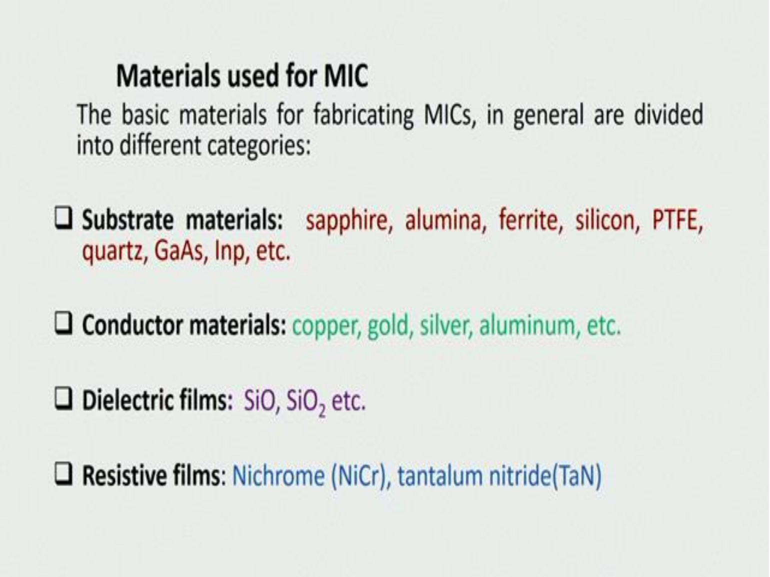

We will now consider some of the materials, which are typically used in a microwave integrated circuit. We have already mentioned many of them in our discussion about the discrete components, the active devices. Here we just summarise some of these materials. Basic material for fabricating MICs, in general are divided into different categories; one is the substrate materials. There can be of various types sapphire, alumina, ferrite, silicon, PTFE, quartz, gallium arsenide, indium phosphide.

So, depending upon the type of circuit that we want to fabricate the substrate material where we have chosen. Then conductor material, because we need to do lot of metallization and conductor materials are copper, gold, silver, aluminum, etc. Then we need to deposit dielectric films SiO and SiO2, silicon dioxide. These are typically used. And finally, the resistive films we have already mentioned nichrome, and tantalum nitride are very popular ones.

So, with this, we conclude our discussion on MIC and MMIC. The RF integrated circuit or microwave integrated circuit, this fabrication technologies, this consists of very very involved processes, and here we have just try to give an overview of some of these processes which are involved, some of the materials which are used. The different configurations for the passive components such as capacitor, inductors, resistances. How they can be realized and also we have briefly mentioned the parasitic elements, how they affect the nominal values of these components.

So, we conclude this module with these discussions. In the next module we will see some of the applications of microwave engineering. Microwave engineering has got lot of applications radar, cellular communication, satellite communication, industrial microwave. So, various applications are there, and we will discuss some of these applications.