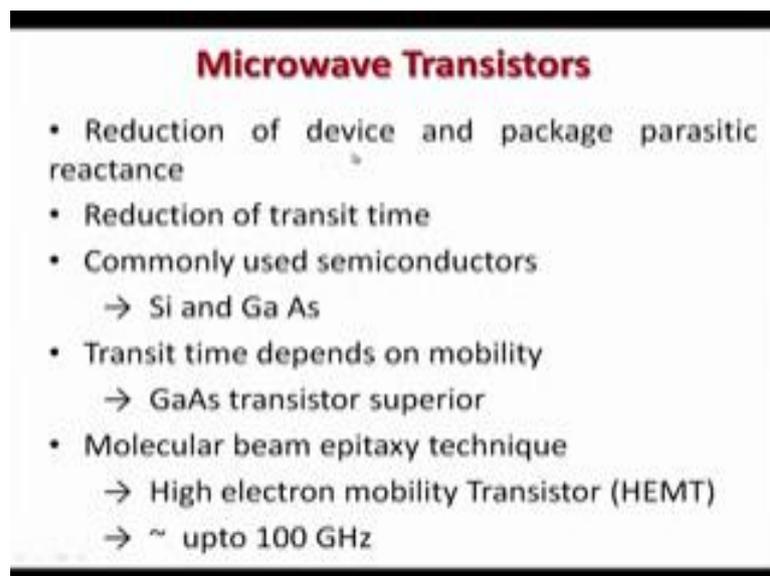


Basic Building Blocks of Microwave Engineering
Prof. Amitabha Bhattacharya
Department of Electronics and Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture- 20
Microwave Transistors

Welcome to the final 20th lecture of this course Basic Building Blocks of Microwave Engineering. So, we have seen various signal sources and we have seen diodes, we have seen tubes that can produce microwave signal obviously, people will expect that what about transistors. So, that we will cover that microwave transistors in this final lecture.

(Refer Slide Time: 00:48)



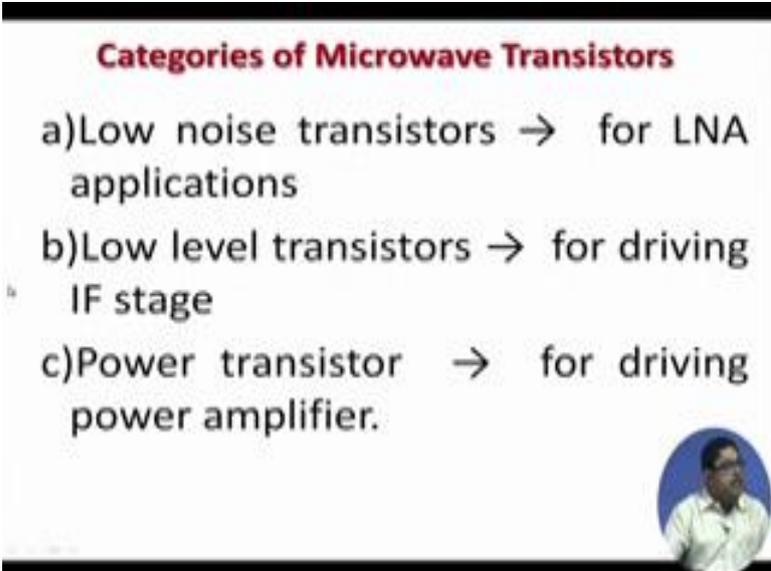
Microwave Transistors

- Reduction of device and package parasitic reactance
- Reduction of transit time
- Commonly used semiconductors
 - Si and Ga As
- Transit time depends on mobility
 - GaAs transistor superior
- Molecular beam epitaxy technique
 - High electron mobility Transistor (HEMT)
 - ~ upto 100 GHz

Now, obviously compared to small low frequency, microwave transistors will need to reduce the device and package parasitic reactants because we have explained that otherwise it will create problem for anything also transit time of the device should be reduced because since frequency of oscillation microwave region is quite high. The transit time of the carriers they should be reduced much, their transit time should be reduced and commonly used semiconductors are silicon at this microwave transistor also gallium arsenide is heavily used. So, silicon and gallium arsenide these are the two technologies from which people make microwave transistors.

Now, transit time depends on mobility. So, compared to silicon, in gallium arsenide the mobility is higher that is why for high frequency things, gallium arsenide is a superior transistor, gallium arsenide based on this term. Fabrication is very molecular beam epitaxy technique and the transistor where we have high electron mobility that is called HEMT high electron mobility transistor up to 100 gigahertz. Nowadays, you can get signals from microwave transistors, amplifiers or you can also use you know transistor can be easily used as oscillators.

(Refer Slide Time: 02:44)



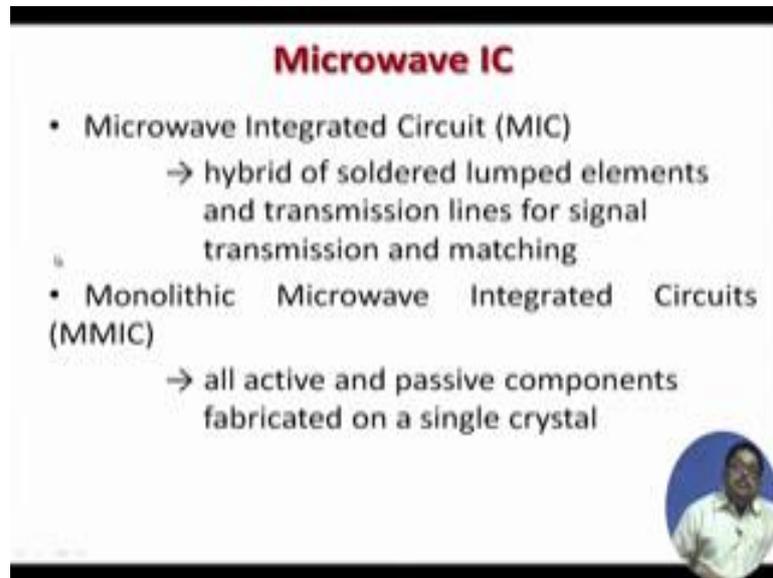
Categories of Microwave Transistors

- a) Low noise transistors → for LNA applications
- b) Low level transistors → for driving IF stage
- c) Power transistor → for driving power amplifier.



In Categories of Microwave Transistors if you want low noise transistors say LNA, you can use them then if you have low level transistors for driving IF stage, you can use microwave transistors and for power amplifying signals you can have power transistor for driving power amplifier.

(Refer Slide Time: 03:07)



Microwave IC

- Microwave Integrated Circuit (MIC)
 - hybrid of soldered lumped elements and transmission lines for signal transmission and matching
- Monolithic Microwave Integrated Circuits (MMIC)
 - all active and passive components fabricated on a single crystal

Now, you know that Microwave ICs are of two varieties, one is called Microwave Integrated Circuit or MIC or another is called MMIC. In MIC, its a hybrid of obviously, the active devices are there, but there are also some lumped elements soldered to that thing and transmission lines are there for signal taking and matching etc, not the simple wires, but transmission line concerted you, but still there are some lumped elements, particularly the inductors are lumped and also some of the other lumped devices are there resistance etc, but in monolithic microwave integrated circuits, all active and passive components are fabricated on a single crystal. So, the transmission lines, active devices, and passive devices everything is on a monolithic crystal that is why the name monolithic microwave integrated circuit.

(Refer Slide Time: 04:24)

Construction of Microwave Transistors

- a) Bipolar → three semiconductor doping region (pnp or npn)
 - both electron and hole are carrier
 - Si BJT in UHF – S band
 - higher gain.
- b) Unipolar → One or two semiconductor doping region
 - either electron or hole carrier
 - Si BJT / GaAs FET → S – C band
 - better noise performance
 - higher frequency of operation



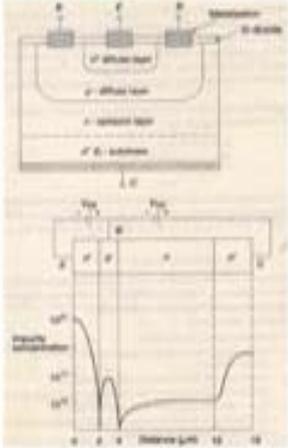
Now, these microwave transistors are used in both of these varieties of ICs either MIC or MMIC and construction of you can have Bipolar transistors. So, in bipolar transistors we know three semiconductor doping region either pnp or npn type of variety and we know that in bipolar, both electron and hole are carrier and silicon BJT in UHF-S band is used, these are higher gain.

But you can also have Unipolar transistors. So, you know in unipolar one or two semiconductor doping region, in unipolar there is only one carrier all like low frequency things either electron will be carrier or hole, will be carrier depending on the channel etc silicon BJT or GaAs FET are of these type. So, S band and C band operations are available, S bands 2 to 4, C band is 4 to 6 gigahertz. Unipolar has better noise performance we know that GaAs FETS are better and their frequency of operation is higher and only thing their gain is not much like bipolar.

(Refer Slide Time: 05:49)

Microwave Bipolar Transistors

- Planar in form
- Mostly Si
- Upto 5 GHz
- Geometry
 - inter digitated
 - overlay
 - matrix forms



The diagram shows a cross-section of a microwave bipolar transistor with layers labeled: p+ emitter, p base, n collector, and p+ substrate. It also shows a planar layout with interdigitated fingers and a graph of the current gain magnitude versus frequency, showing a roll-off at high frequencies.

So, microwave bipolar transistors let us see they are planar in form, this is the structure and this is the ray mostly silicon up to 5 gigahertz they work geometry for monolithic thing they can be inter digitated, overlay or in matrix forms. So, microwave bipolar transistors from silicon technology.

(Refer Slide Time: 06:15)

β cutoff frequency $f_T \sim 22\text{GHz}$

$$f_T = \frac{1}{2\pi T}$$

Transit Time $T = T_{jcb} + T_b + T_{bc} + T_{jbc}$

where T_{jcb} → Emitter base junction capacitor charging time

T_b → base region transit time

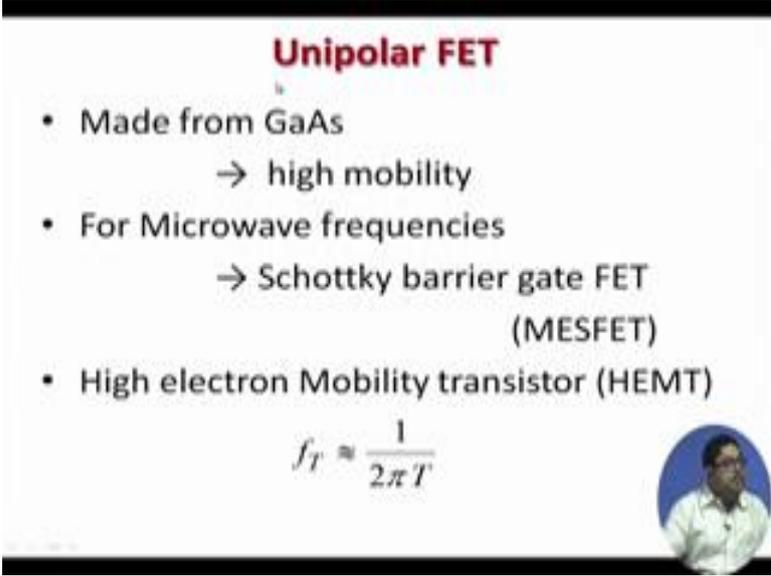
T_{bc} → base collector region depletion layer transit time

T_{jbc} → base collector junction capacitor charging time

$$\approx T_b + T_{bc}$$

Then beta cutoff frequency is typically 22 gigahertz. So, up to 5 gigahertz they are used and transit time depends on these you see the transit time will depend on emitter base junction capacitor charging time, base region transit time, base collector region depletion layer transit time then base collector junction capacitor charging time out of these this capacitor charging times they can be neglected, but these base region transit time and base collector region depletion layer transit time that means, basically you will have to cross the base and then also there is a this large depletion layer here. So, that depletion layer, these two you will have to consider.

(Refer Slide Time: 07:09)



Unipolar FET

- Made from GaAs
→ high mobility
- For Microwave frequencies
→ Schottky barrier gate FET
(MESFET)
- High electron Mobility transistor (HEMT)

$$f_T \approx \frac{1}{2\pi T}$$


So, that was about bipolar, but unipolar FET, mostly they are made from GaAs, they are high mobility devices for microwave frequencies and they use Schottky barrier gate and that is called MESFET, also there is a variety called high electron mobility transistor HEMT.

Now, again here the transit time if you can minimize you can get much higher beta cutoff frequency f_T , but f_T you know that they are at f_T , the gain is 1. So, people do not use that beta cutoff frequency who wanted much lower than that, but up to that theoretically you can have the amplifiers.

(Refer Slide Time: 07:52)

MESEFT

- Gain $\sim 10 - 15$ dB at 2 GHz
- Noise Figure < 1 dB

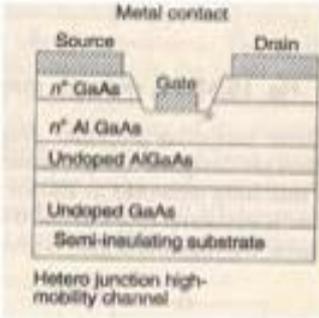


The diagram illustrates the structure and operation of a MESEFT. The top part is a cross-sectional view showing a depletion region in the n-type GaAs layer, with a semi-insulating GaAs substrate below. The bottom part is a circuit diagram showing a common-source configuration with a gate voltage V_g and a drain current I_d .

So MESFET, its gain is typically 10 to 15 dB at 2 gigahertz, noise figure you see that impact doubts etc they were giving 30 dB etc but here noise figure is less than 1 dB that is required because in practical LNA etc type of application you require 3.4 dB. This is a MESFET structure you have sourced, you have gate, and you have drain and Semi-insulating GaAs substrate in epitaxial gap and so, basically same structure.

(Refer Slide Time: 08:30)

HEMT

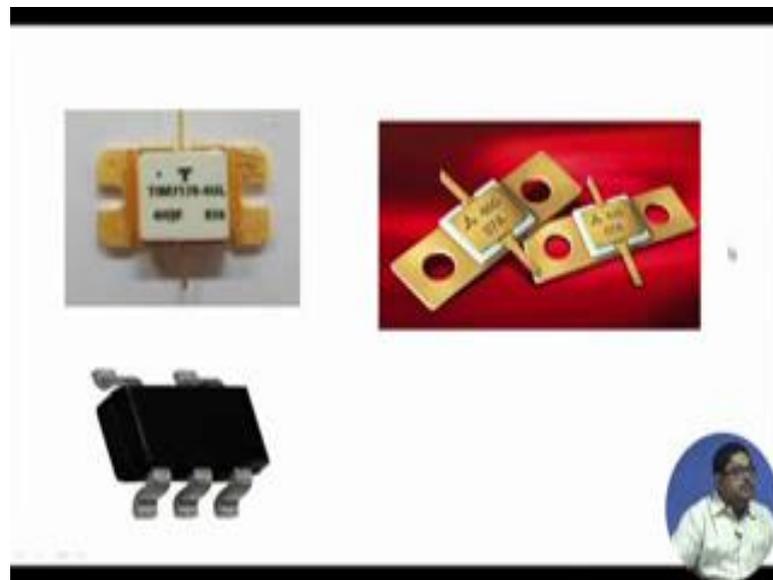


The diagram illustrates the structure of a HEMT. It shows a hetero junction high-mobility channel with layers of n^+ GaAs, n^+ Al GaAs, undoped AlGaAs, undoped GaAs, and a semi-insulating substrate. Metal contacts for Source, Gate, and Drain are shown.

- Gain ~ 15 dB at 8 GHz
6 dB at 50 GHz
- Noise Figure ~ 0.4 dB at 8 GHz
1.8 dB at 50 GHz

Then HEMT you have this special device. So, again source get drained but the GaAs and gain is 15 dB quite good at 8 gigahertz, but if you go to 50 gigahertz 6 dB, but you see the noise figure 0.4 dB at 8 gigahertz. At 50 gigahertz obviously, problem 1.8 dB, but the HEMT it has a very good noise figure. So, from noise applications etc are very low noise application HEMT is preferred and it is giving quite good amount of gain if you see fifteen dB of gain at 8 10 gigahertz from a transistor it was unthinkable 10 15 years ago but now, we are having this type of microwave transistors.

(Refer Slide Time: 09:32)



So, these are some figures we have in our laboratory these type of packaging these are MESFET and HEMTS. So, looks like normal transistors, this looks like normal IC but quite good packaging and cost wise also what was the cost of the transistor few years ago these are having same thing. So, nowadays, the low frequency things we cannot now say that microwave people do not have transistors in your professional life you will see that this microwave transistors will be heavily used instead of other various devices, but for sometime this high frequent and high power applications will be still dominated by tubes etc.

But for low power applications all will be solid state things they are this other devices own with here and we have seen only diode based oscillators etc with this microwave

transistors you can get much better oscillators. So, in microwave region you will see much better stable oscillators with the use of this I think with that we end this course where we have meant the scene the various microwave technologies some building blocks particularly the transmission side that how to model the whole transmission system and what are the various key concept in waves particularly the mode concept.

So, what are the basic modes then we have seen that how with the knowledge of that modes you can analyze that how microwave signal propagates to various transmission structures and then we have seen some passive microwave devices those are necessary for manipulating the signal transmission and then we have seen that obviously, a transmission system you need some active devices.

So, we have seen what are the sources of power which can give you power which can with their negative resistance or with their some mechanism of gan, etcetera or mechanism of some carrier flow of hole or ray we can produce microwave level microwave frequency signals. With that, we think you have got a good glimpse of this, but obviously I again remind you that prerequisite to these were another course we had on this NPTEL those basic tools of microwave engineering where we have introduced three basic tools the SMI chart, the scattering parameter and signal flow graph you need to have that knowledge so that, you can utilize that tools to have understanding of this basic blocks and with this we hope to proceed it further that other microwave technologies and other facades we will try to introduce in later NPTEL courses.

So, I think you put the concept you try to make simpler, but if you still feel that you require more understanding etc, you can contact us will be happy to share our knowledge with that and also I say that some of the reading materials will be uploading and from that you can gain more incise particular the mathematics part which I took it minimum so that, you can focus on the understanding concept of physical things, but that mathematics is also required for understanding the technology and that you can refer to our notes which we will be uploading them soon.

Thank you, enjoy and take this microwave technology as one of your carrier thing and it is a pleasure I tell you that this microwave technology gives lot of pleasure to us hope

that with this sharing of knowledge you will be also able to enjoy this technology and change the world.

Thank you.