**UNIT-IV**

**MICROWAVE SEMICONDUCTOR DEVICES**

**Session - I**

**Introduction and brainstorming on semiconductor devices:**

* What is semiconductor device?

Has property in b/w insulator & metal by doping with Silicon or Germanium

* Difference b/w low and high frequency semiconductor device

Three main requirements which are reverse

Dimensions

Heat sinking

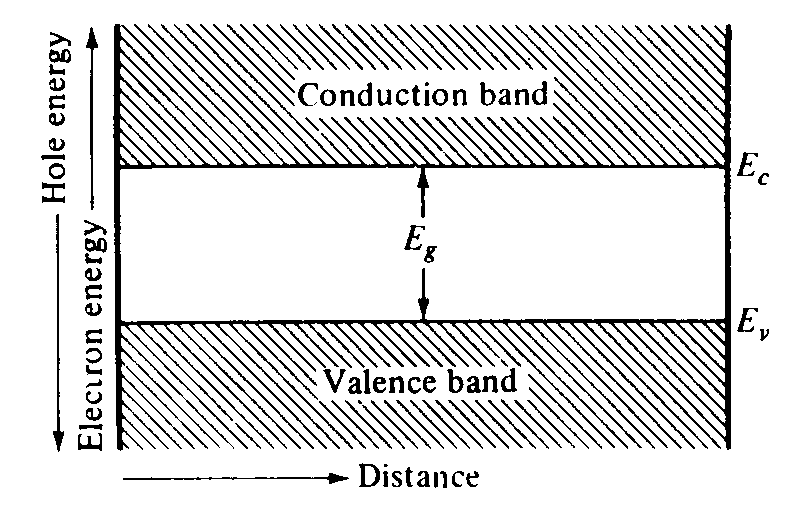
Packaging

* Frequency consideration : bands

**Presentation & discussion:**

* **Semiconductor devices**

Solid state devices becoming increasingly important at microwave frequencies

* Microwave solid state devices are preferred as its electrical proprties lie intermediate b/w metals and insulators
* Conductivity varied by change in temperature, optical excitation, impurity content
* 
* Types
* Classified into four groups

(i) microwave transistor - BJT, HBT, Tunnel diode

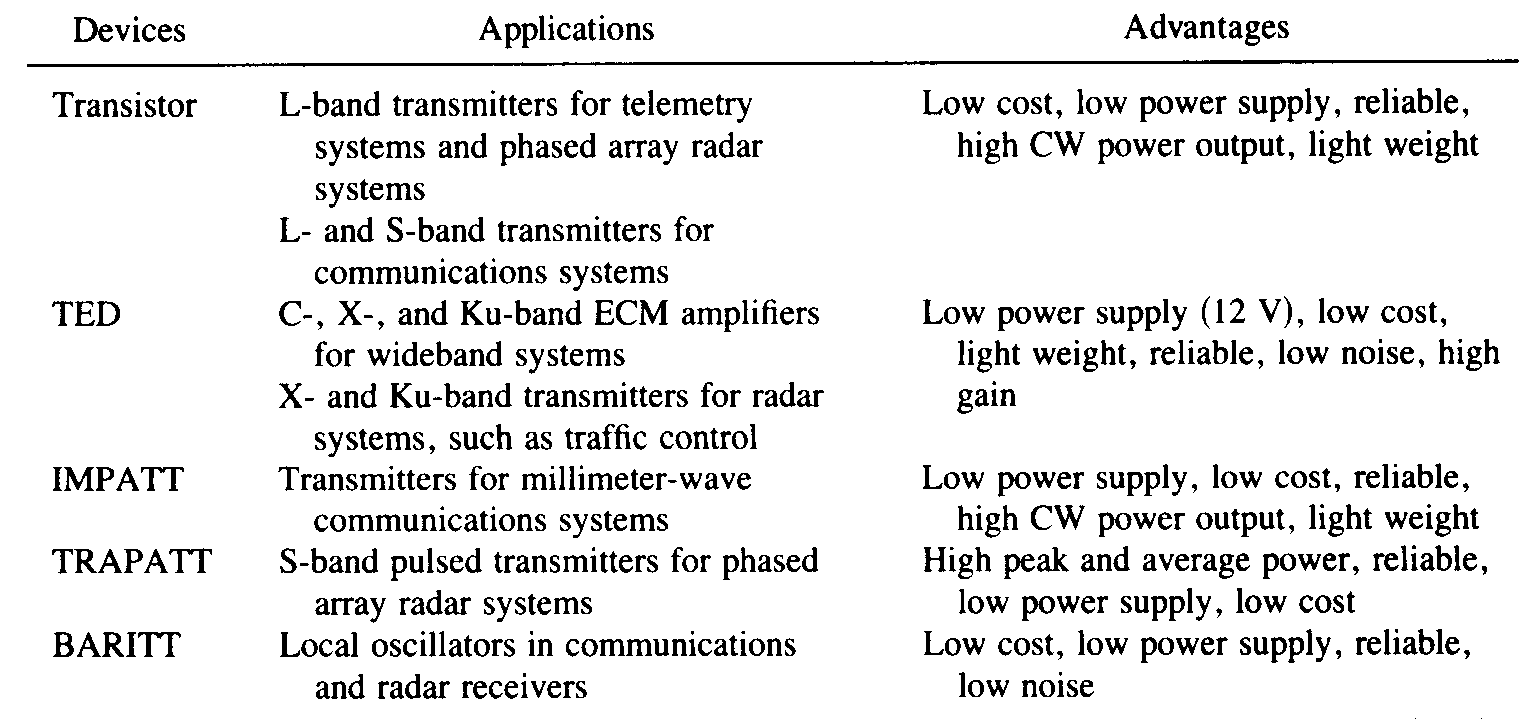
(ii) field effect transistor - FET, MESFET,HEMT, NMOS, PMOS, CCD

(iii) transferred electron devices – GUNN DIODE

(iv) avalanche transit time devices – IMPATT, TRAPPAT, BARRIT

* **Presentation & discussion**: Principle & operation of microwave semiconductor device
* Microwave transistor generate power upto 5GHz
* Gunn diode generate 1W at X-band
* LSA –highest peak power- 250 W in C-band, 100W in X-band 50W in Ku-band
* TRAPATT diode also produce power but- opearting freq. is determined by thickness of active layer in diode

Ex: 10GHz requires 10μm

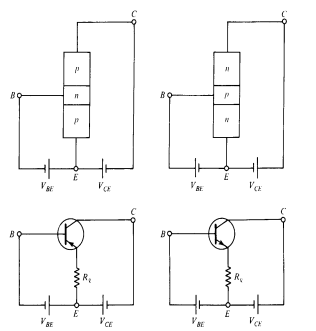
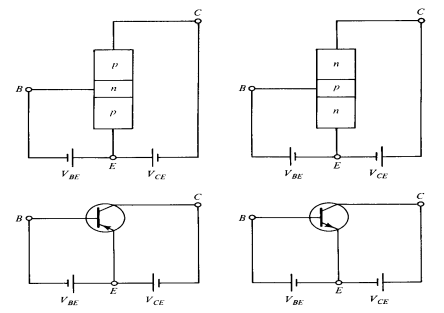
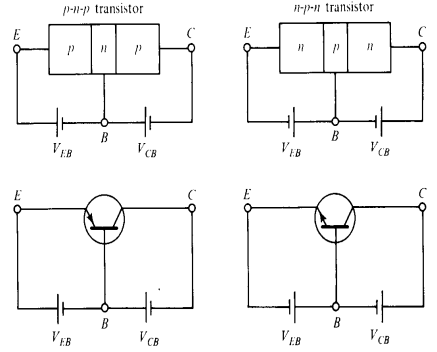
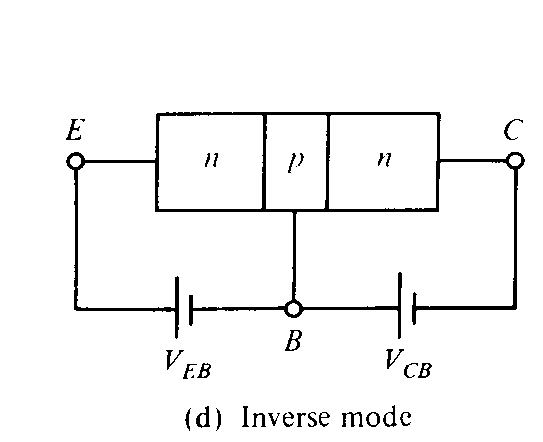
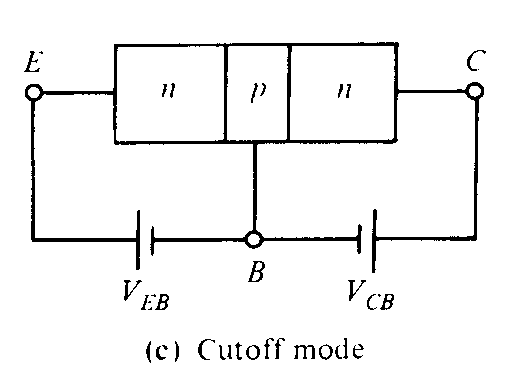
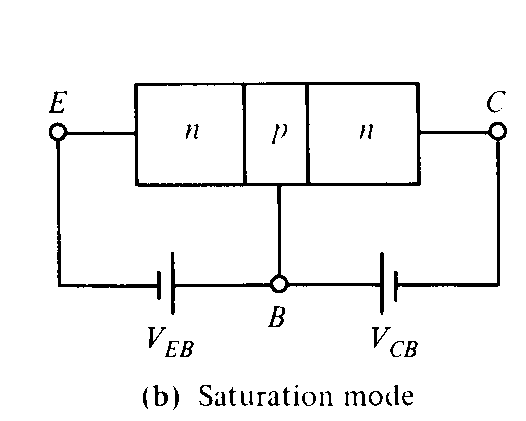
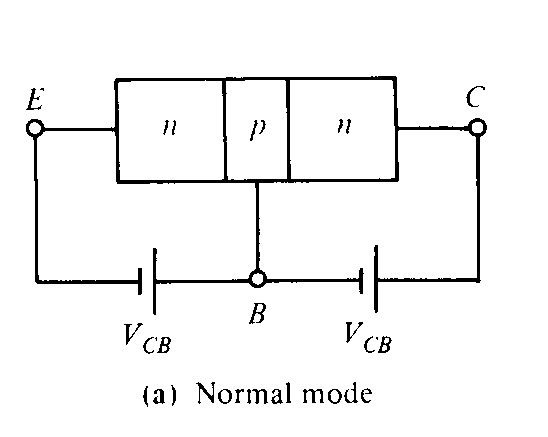


**Conclusion & Summary: recall by key words**

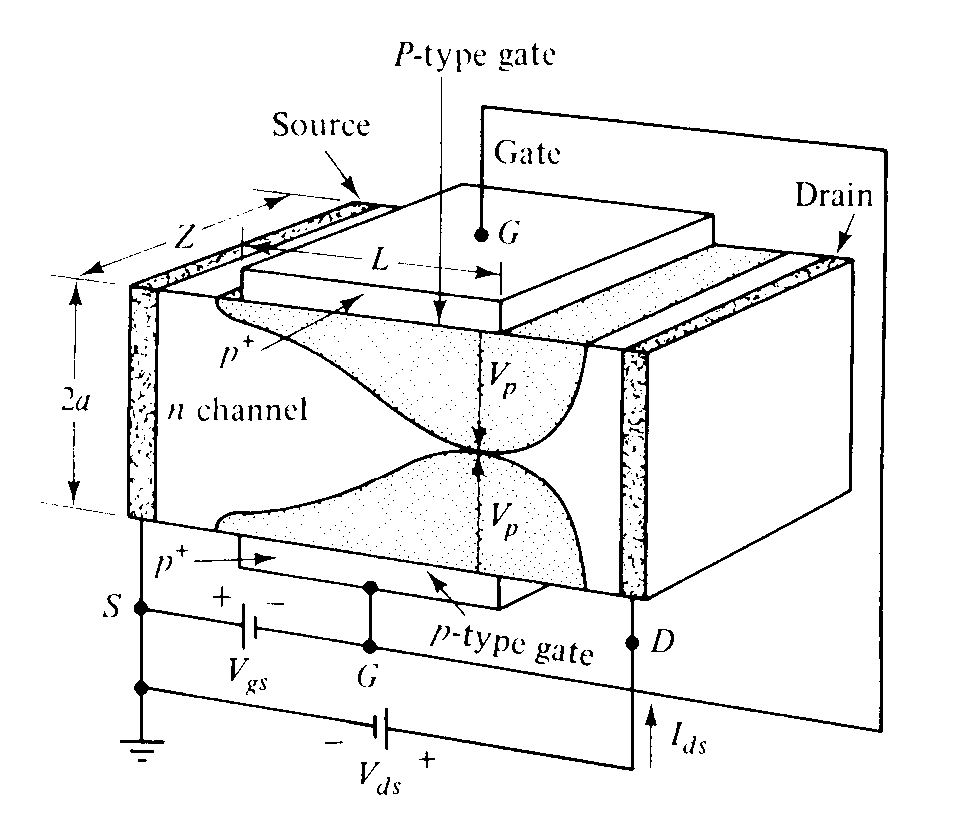
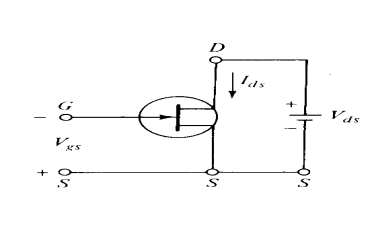
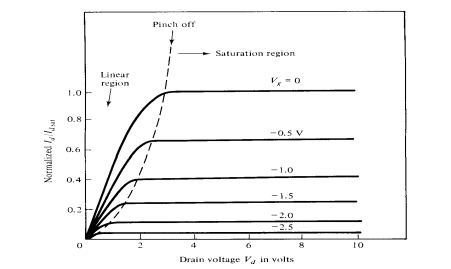
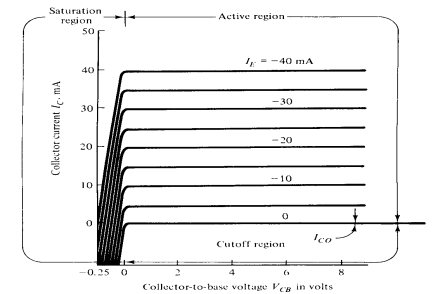
* HEMT - High electron mobility transistor
* TED – Transferred Electron diode
* IMPATT - Impact ionization avalanche transit time diode
* TRAPATT - trapped plasma avalanche triggered transit time diode
* GUNN – TED semiconductor diode

**Session – II**

**Introduction & discussion:**

* **Bipolar junction transistor – BJT:**
* Si n-p-n type – 5 GHZ oper. Freq.
* At high temp. & high radiation field GaAs used
* Three types of configuration:
* (i) common – base, (ii) common – emitter, (iii) common - collector
* 
* Mode of operation:
* (i) normal mode, (ii) saturation mode, (iii) cut-off mode, (iv) inverse mode
* 
* Field effect transistor – FET

**Presentation & discussion:**

* Operation of BJT & FET
* Three regions of I-V charcteristics:
* (i) active region- Ic depends on Vc, Ie
* (ii) saturation- Ic increases sharply
* (iii) cut-off – non active
* **High frequency Limitation:**
* At high frequencies, reactance due to junction capacitance limits the gain.
* Capacitance depletion layer width
* depends on & bias voltage
* provides
* feedback path
* Transit time reduced by narrow p & n region
* Also reduced by reducing depletion layer width but
* 🡪it need higher collector voltage without avalanche breakdown
* 🡪but increases power dissipation, damage the device
* power frequency limitation of BJT: Four equations
* 
* Vg is 0, no drain current Id
* For small Vd b/w is applied, n-type act as simple resistor, hence current Id increases linearly with Vd
* If Reverse gate voltage Vg is applied, majority of electrons depleted from the channel & charge region extends
* Characteristic & application of BJT & FET
* 

**Conclusion & summary: recall by key words**

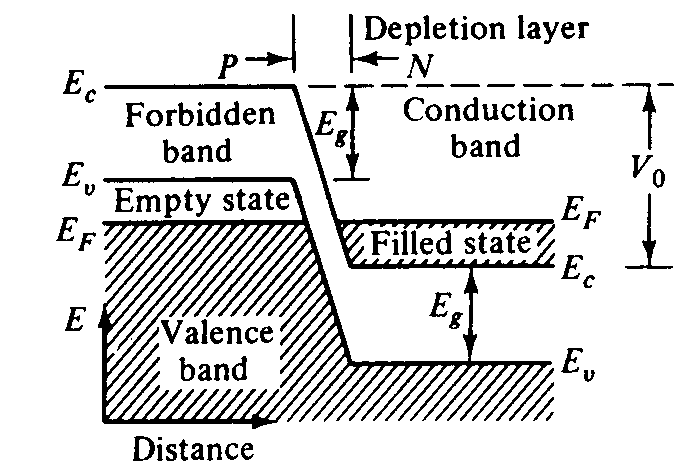
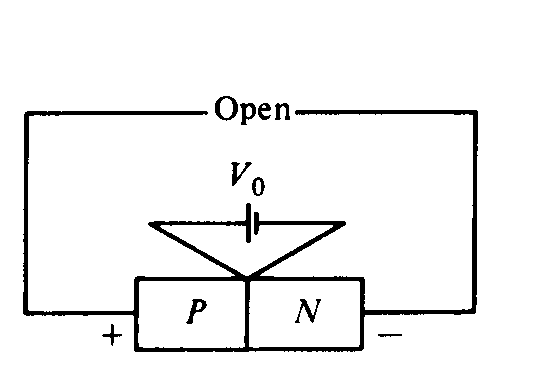
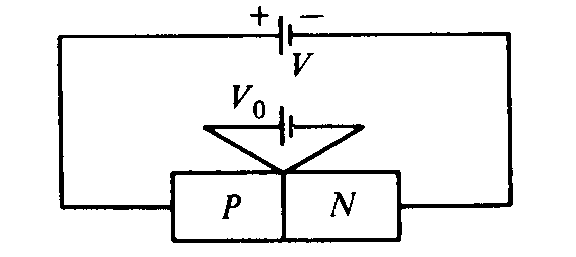
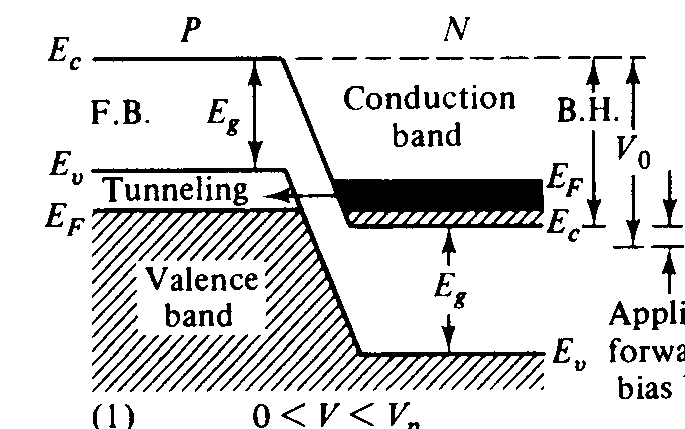
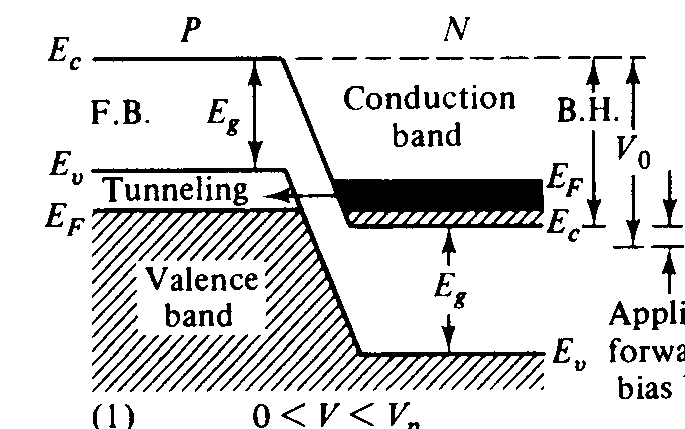
* Negative resistance
* Energy band
* Forbidden band
* Valence and conduction band
* Tunneling
* Comparison b/w PN diode & tunnel diode

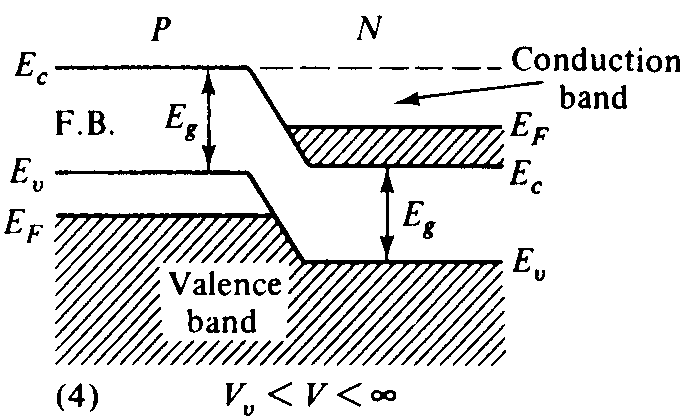
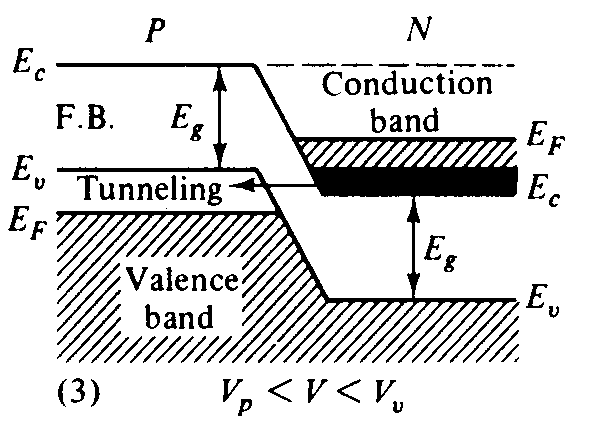
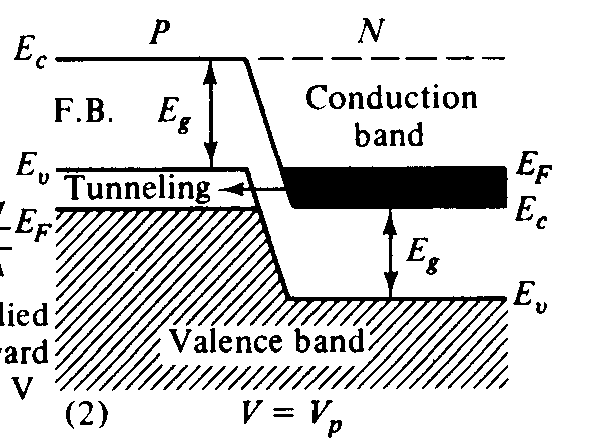
**Session – III**

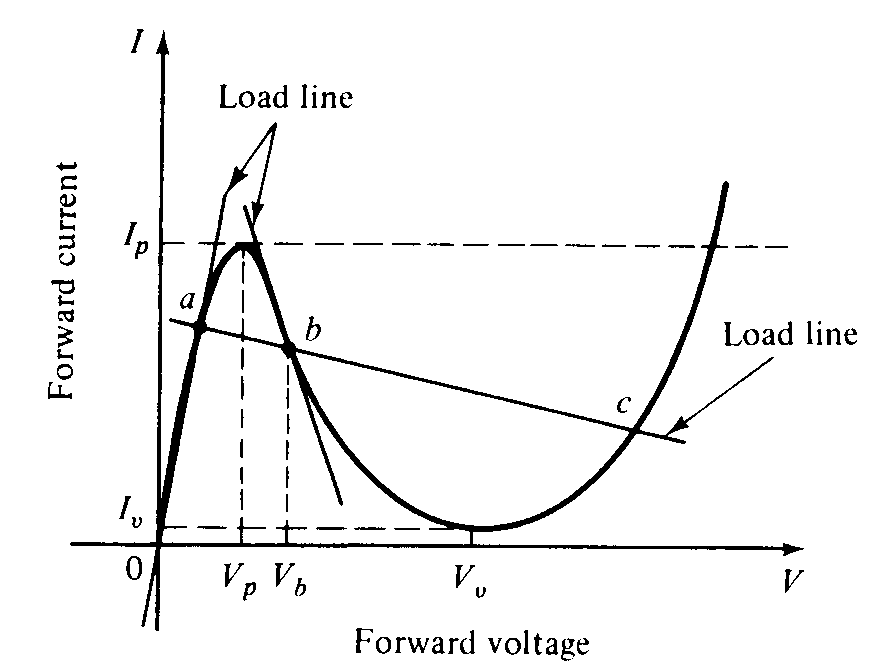
**Presentation & Video:**

* Operation of Tunnel diode
* Negative resistance semiconductor p-n junction diode
* Negative resistance is created by tunnel effect of electrons in p-n junc.
* Both have high impurity concentration of 1019 to 1020
* Useful in amplification, oscillation and binary memory

**Principle of operation:**

* Depletion layer barrier at junction is very thin such that particle will tunnel through the barrier even though no kinetic energy
* Filled energy state in one side and allowed empty state on other for tunneling
* 
* 
* **0 < V <Vp:**
* 
* **V=Vp: Vp< V <Vv: Vv< V <α :**



* Characteristic & application of Tunnel diode
* 
* [www.youtube-tunneldiode.flv](http://www.youtube-tunneldiode.flv)

Presentation:

* Principle of Varactor diode
* Operation of Varactor diode

Video Presentation:

[www.youtube.com/watch?v=dTEOVD0eBsM](http://www.youtube.com/watch?v=dTEOVD0eBsM)

[http://www.learnerstv.com/video/Free-video-Lecture-5089-engineering.htm#](http://www.learnerstv.com/video/Free-video-Lecture-5089-engineering.htm)

Presentation:

* Principle of Step recovery diode
* Operation of Step recovery diode

Conclusion & summary: List by key words

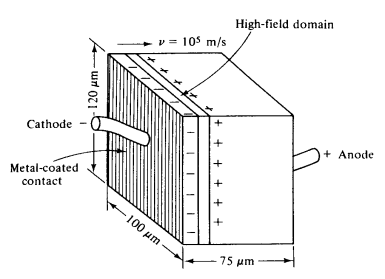
* Voltage variable junction capacitance
* Varactor frequency multiplier
* Comparison b/w varactor& step recovery diode

**Session – IV**

Introduction:

* TED – Transferred Electron Devices
* **Microwave transistor**
* Operate with either junction or gates
* Elemental semiconductor are Silicon and germanium
* Transistor operate with “warm” electrons of thermal energy of 0.026 eV at room temperature

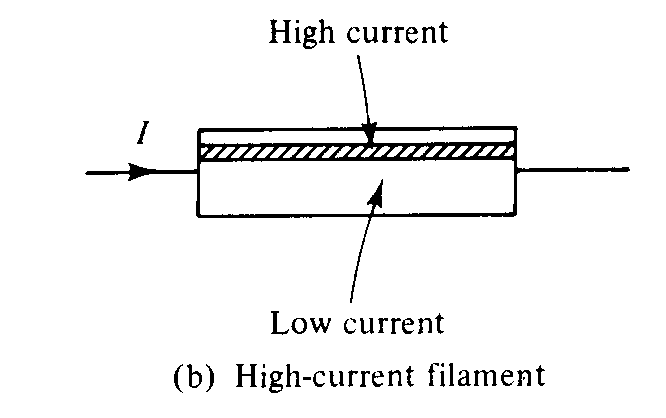
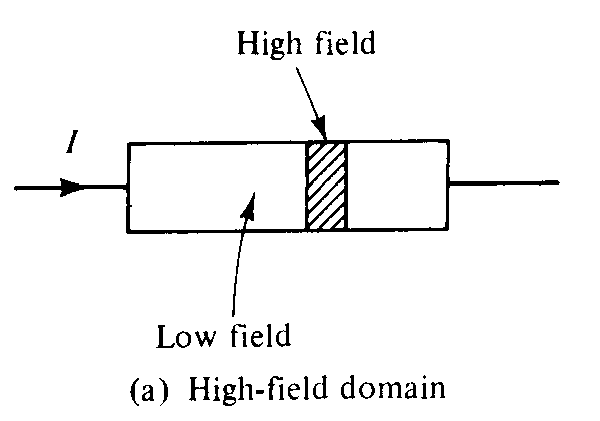
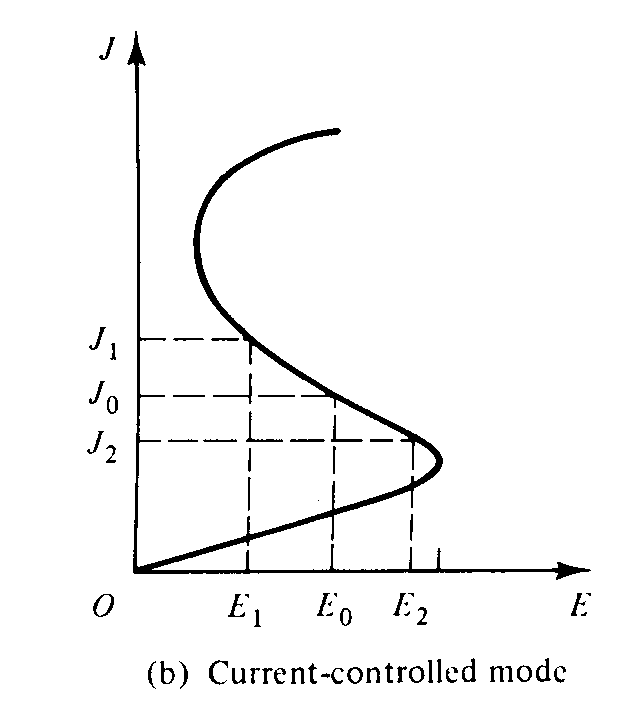
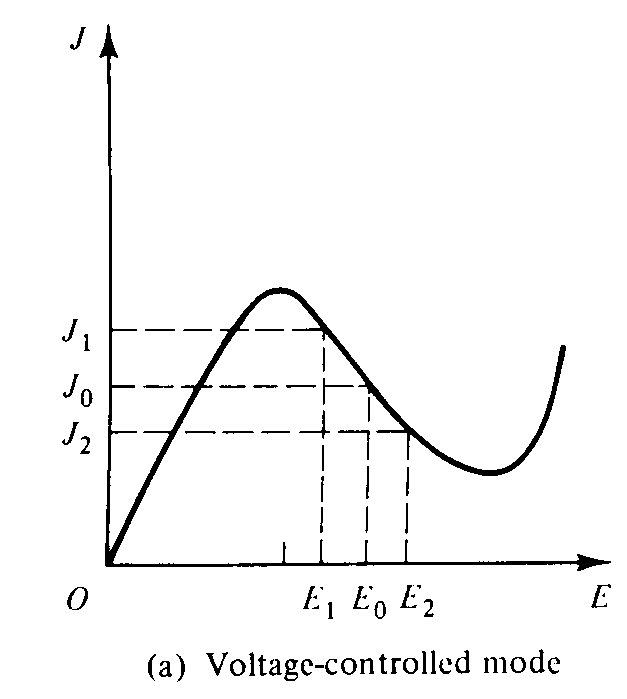
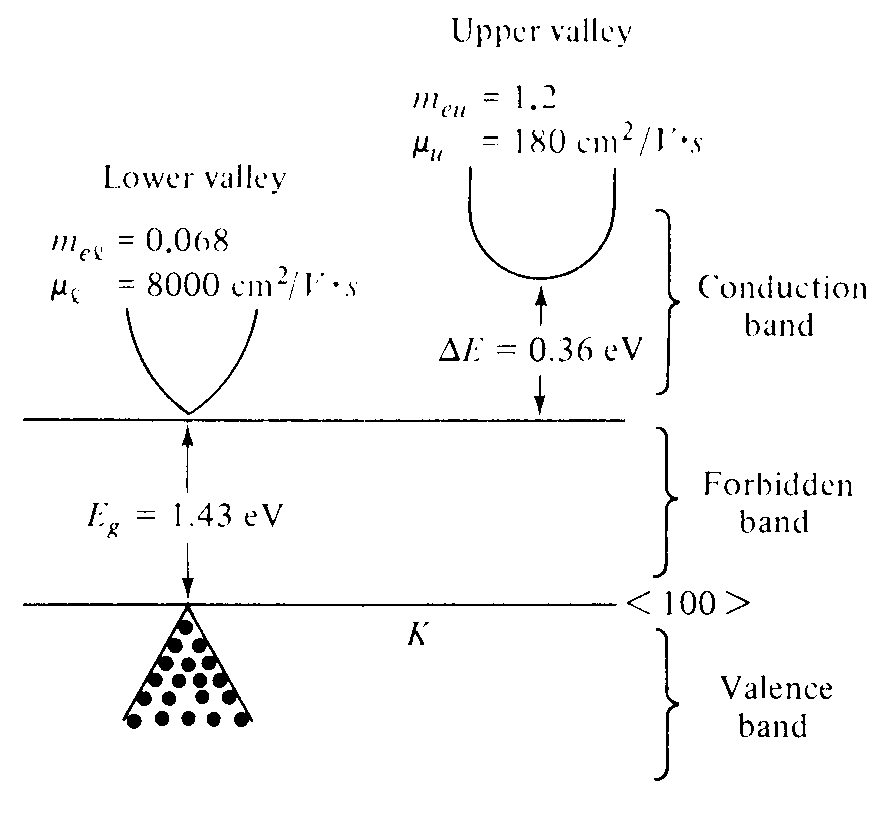
**Transferred electron devices**

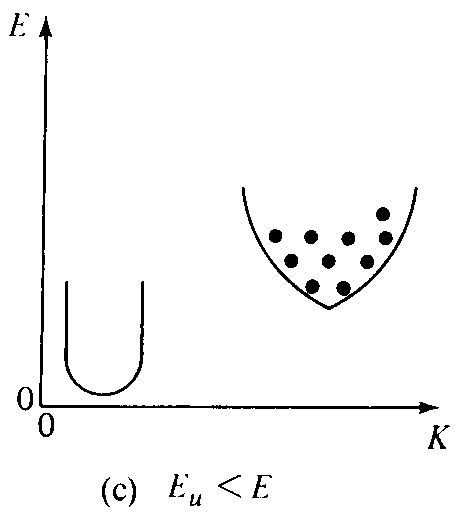
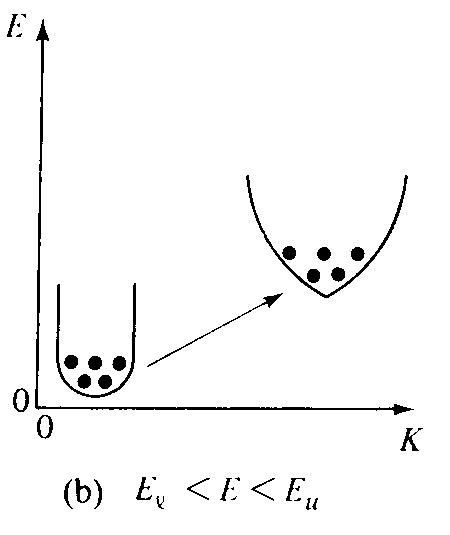
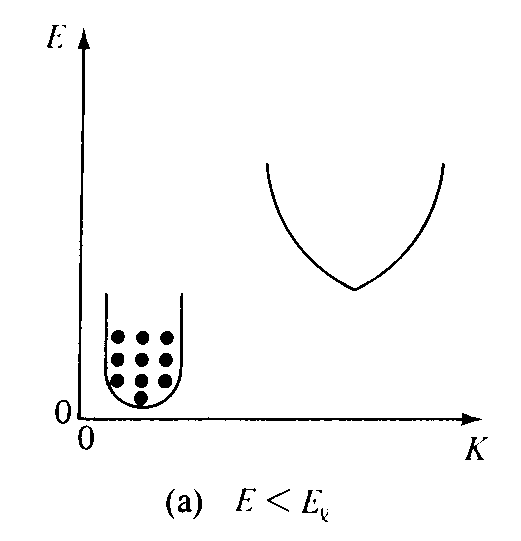
* Bulk devices with no junction or gates
* GaAs, InP, Cd Te
* Transistor operate with “hot” electrons very much greater then thermal energy
* Gunn diode
* 

Presentation:

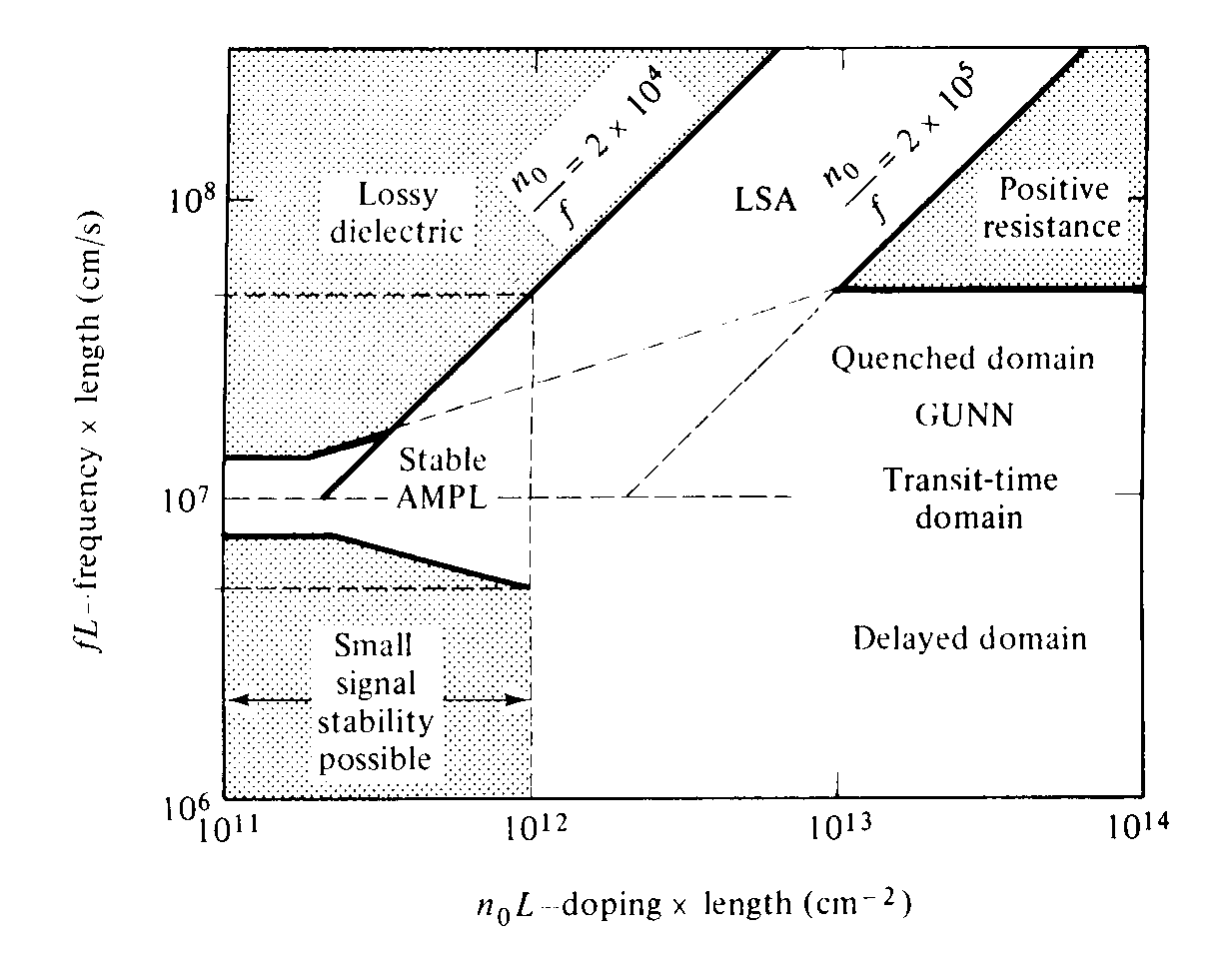
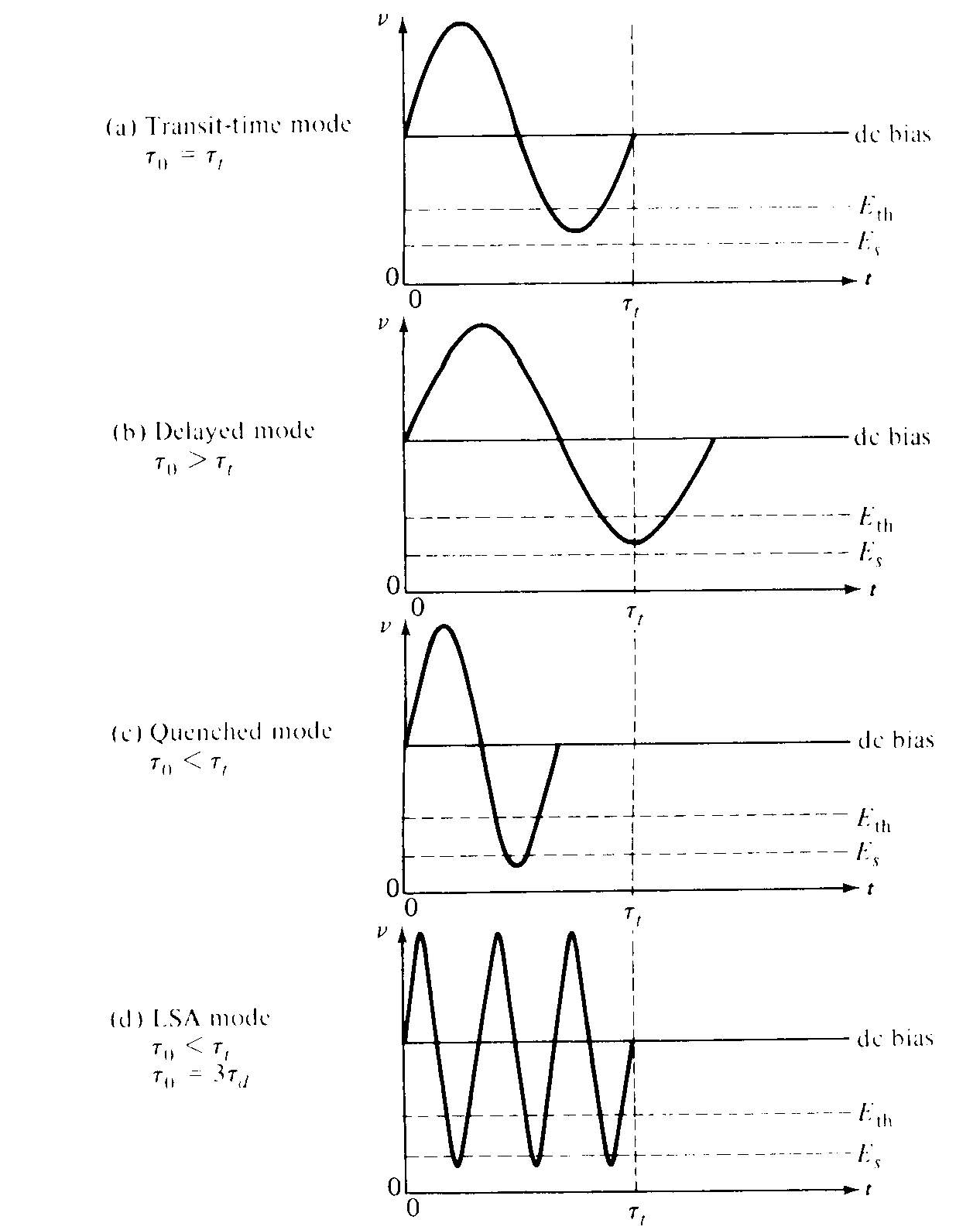
* Gunn effect
* Above some critical voltage of electric field of 2000 to 4000 volts/cm, current in every specimen become a fluctuating function of time
* In GaAs, it is in the form of periodic oscillation
* Frequency of oscillation is determined mainly by specimen and not by external circuit
* Period of oscillation was inversely proportional to specimen length and closely equal to transit time of electron b/w electrodes
* Carrier drift velocity is linearly increased from 0 to maximum, When electric field is varied from 0 to threshold value
* When electric field is beyond threshold value of 3000 V/cm, for n-type GaAs, the drift velocity is **decreased and diode exhibit negative resistance**
* RWH theory:
* **Voltage controlled:**
* Current density can be multi-valued
* High field domain separated by two low domain

**Current controlled:**

* Voltage density can be multi-valued
* Splits the samples with high current filament running along the field directly
* 
* 
* Two valley model
* 



Slide Presentation:

* Domain formation
* Applied voltage across n+ n n+GaAs, crystal exceeds a threshold level
* Electrons are transferred from lower energy to upper high energy
* Heavier electrons bunch together to form a electric field dipole domain near cathode
* Electric field remains below the threshold level across the rest of the crystal as applied voltage remains constant, thus formation of further domains prevented
* High field domain travels and reaches the end contact, again a high domain formed
* Each domain results in a pulse of current at the output
* These current fluctuations occurs at microwave frequencies to produce output signal at the low impedance RF circuit with a period equal to the transit-time
* Modes of operation
* (i) Gunn oscillation mode
* (ii) Stable amplification mode
* (iii) Limited space charge accumulation mode
* (iv) Bias circuit oscillation mode
* 
* 

Video Presentation:

<http://www.youtube.com/watch?v=MmRaRh-oUHY>

<http://www.youtube.com/watch?v=P9Tr4Q6oFig>

<http://www.youtube.com/watch?v=svuJ42v6RPI>

Conclusion & summary: List by key words: Quiz

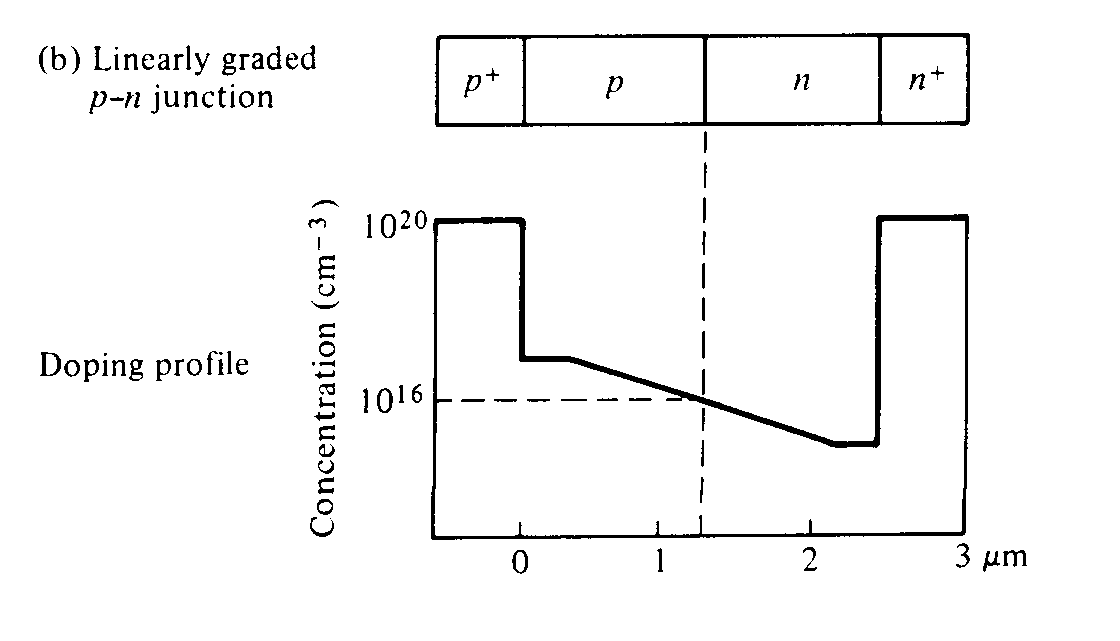
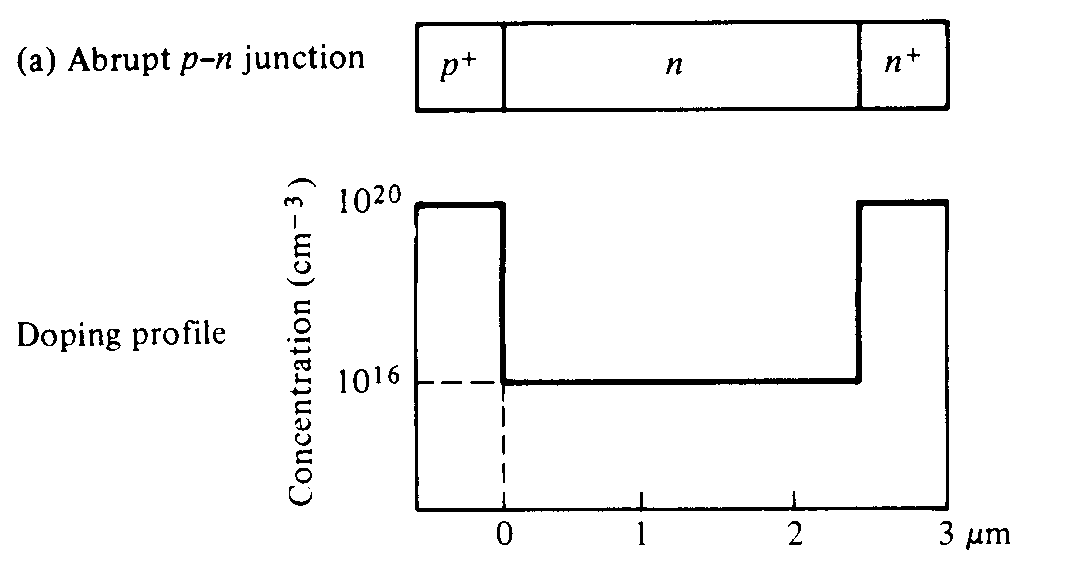
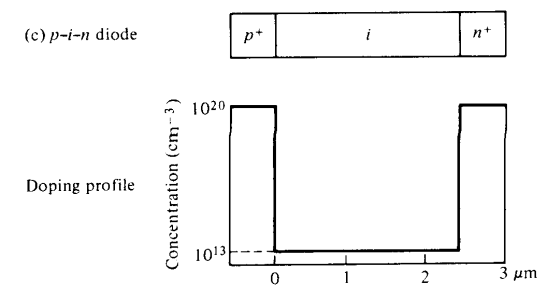
* Difference b/w TED & BJT
* Transferred electron effect
* Materials used
* Transit time
* LSA
* High domain
* Quenched domain

**Session –V**

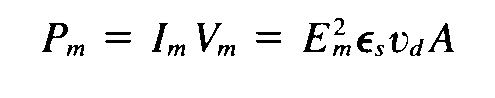
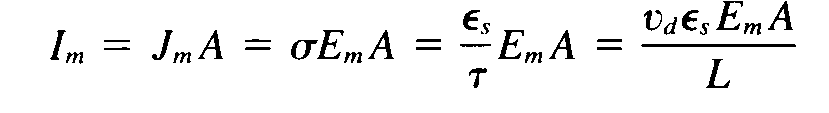
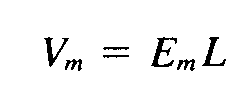
Introduction:

* Avalanche transit time diodes – IMPATT & TRAPATT
* It rely on effect of voltage breakdown across a reverse biased PN junction to produce a supply of holes (or) electrons
* It depends on 2 mechanism
* (i) generation of charge carrier
* (ii) movement of these charge carrier through a drift space within the semiconductor

Presentation:

* IMPATT – physical structure - principle - operation
* Impact ionization avalanche transit time diode
* Employs impact ionization and transit time properties to produce negative resistance at microwaves.
* Negative resistance arise due to two delays (i) avalanche delay
* (ii) transit time delay
* Avalanche delay is caused by finite build up time of avalanche current
* Transit time delay is due to the finite time taken by the carriers to cross the drift region
* These two delays add upto 180°, the diode electronic resistance becomes negative and corresponding to that frequency, ionization occurs which results in large multiplication of current (or) avalanche breakdown occurs
* By proper thickness, doping level, a desired RF frequency can be generated
* Construction:
* many forms such as
* n+ p i p+ (or) p+ n i p+
* p+ n p+ abrupt junction
* p+  i n+ diode
* 
* 

Presentation & Derivation:

* Negative resistance
* Manufactured from Ge, Si, GaAs, InP
* But GaAs provide highest efficiency, highest operating frequency and least noise figure but fabrication is difficult and expensive than Si.
* When large reverse bias voltage is applied, some electrons & holes in region of peak field gain enough energy and thus ionize the atoms in the crystal
* Thus an impact ionization mechanism creates an electron & hole pair
* The electrons and holes thus created are accelerated by the field in the opposite direction and can cause additional impact
* Power output
* 
* Performance, Advantages, Applications, Equivalent circuits

Conclusion & summary: recall by key words:

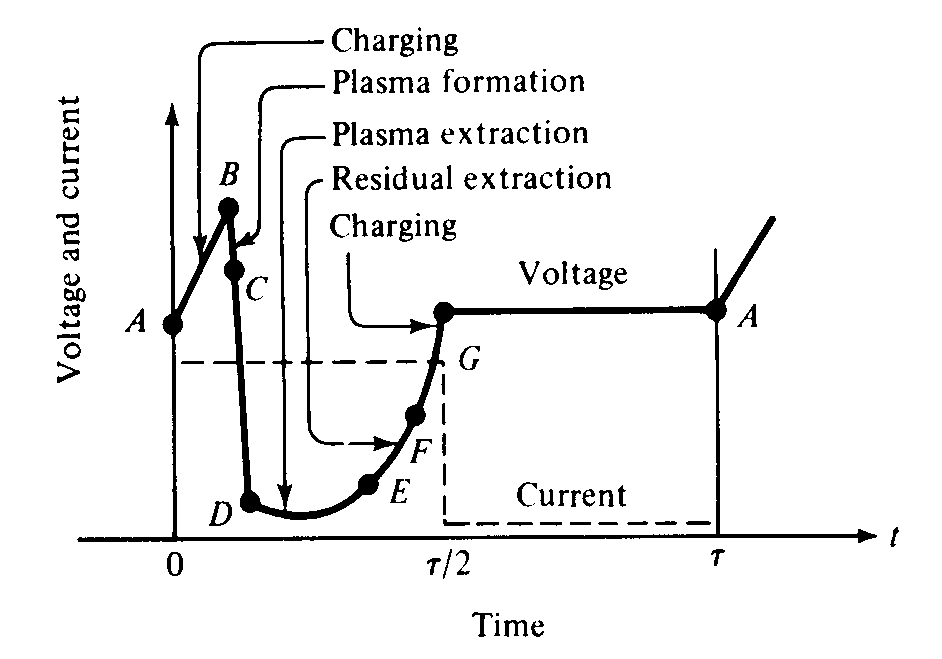
* Avalanche breakdown
* Avalanche transit time
* Delayed transit time
* Doping level
* Noise figure
* Disadvantage

**Session –VI**

Introduction:

* TRAPATT
* Trapped plasma avalanche triggered transit time diode
* 

Presentation:

* Principle –physical structure-operation of TRAPATT
* High efficiency oscillation of several hundred MHz to several GHz
* Dense plasma of electrons and holes are formed and fills in depletion layer and trapped in low field region
* 
* **Performance:**
* CW power = 1-3W
* Pulse power = 1-3W
* Operating voltage = 60-150V
* Efficiency = 15 -40%
* Noise figure = >30dB
* Frequency = 3 – 50GHz
* **Disadvantages:**
* High noise figure
* Generates strong harmonics due to short duration of current pulse
* **Application:**
* Used in low power Doppler radar
* Used as local oscillator for radar, microwave beacon landing system, radio altimeter, phased array radar

Conclusion & summary: list by key words:

* Configurations
* Carrier transit time
* Plasma formation
* Plasma extraction
* Comparison b/w IMPATT & TRAPATT

**Session –VII**

Introduction:

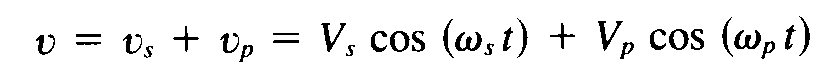
Parametric devices – its use:

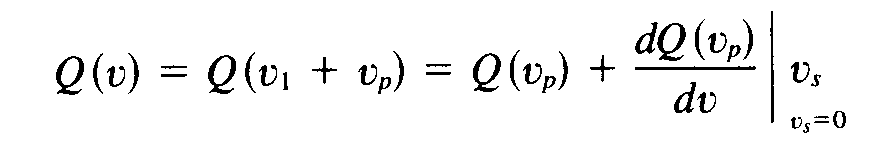
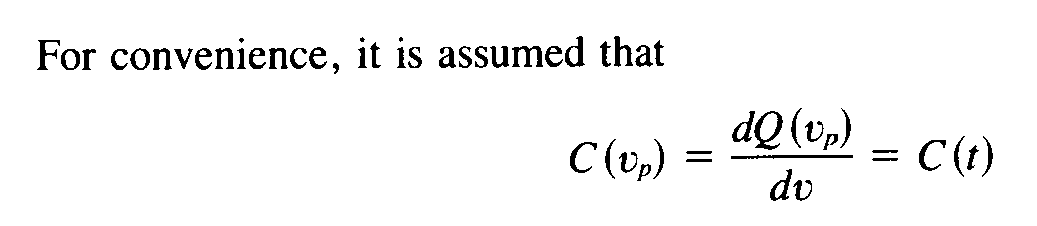
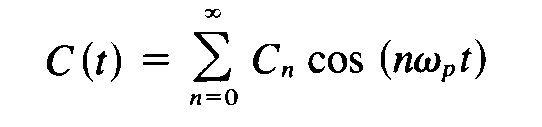
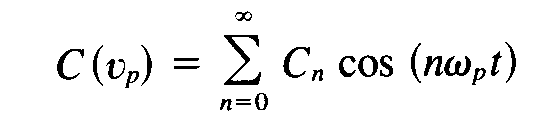
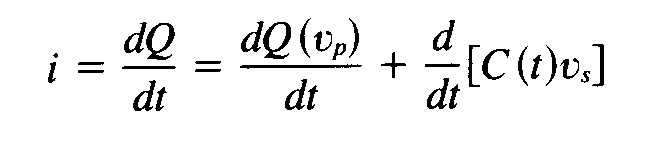
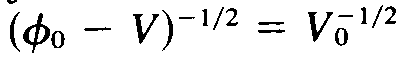
* Uses nonlinear reactance (or) time varying reactance
* Used to produce capacitance or inductive excitation
* Varactor diode is most used as parametric amplifier for its low noise amplification
* Uses ac voltage rather than dc voltage

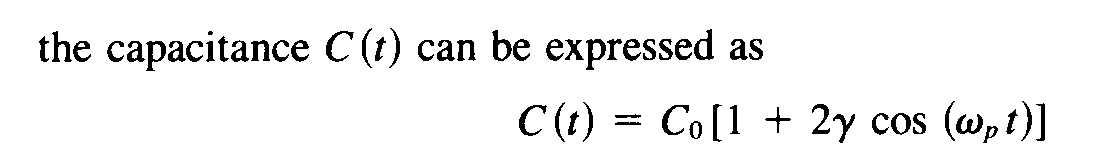
Presentation& derivation:

Principle:

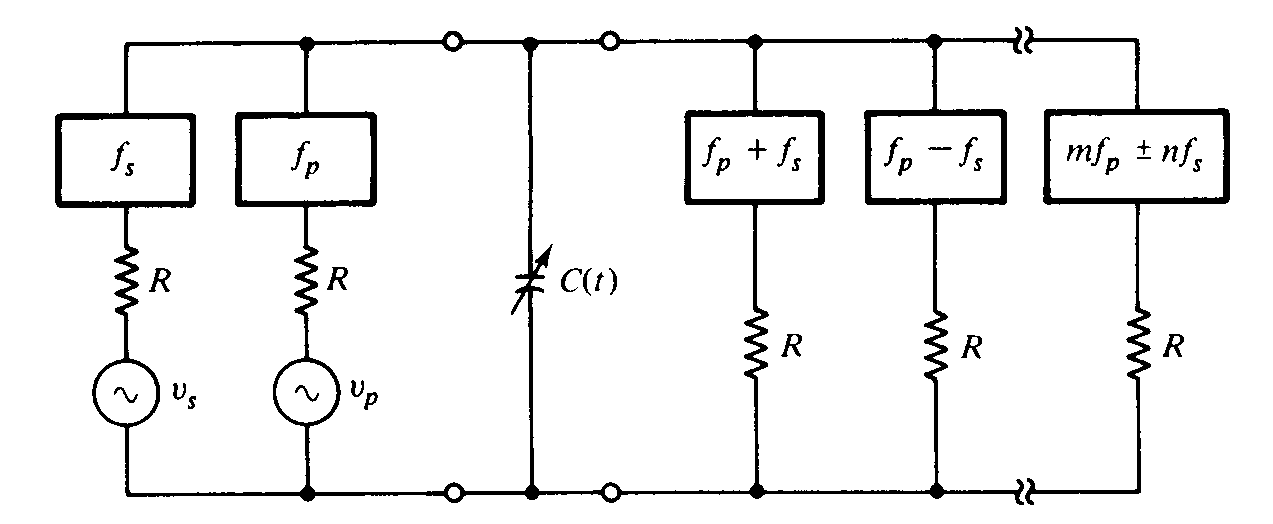
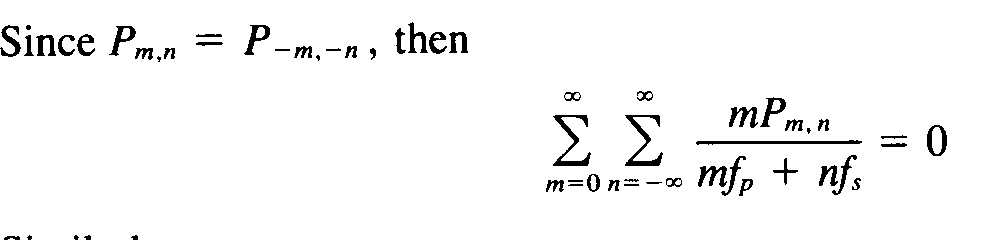
* **Negative resistance analysis:**
* Reactance – circuit element that stores and releases electromagnetic energy
* capacitance c = Q / V
* For nonlinear C(v) = ∂Q / ∂ V
* For inductance L(i) = ∂Q / ∂ i
* **Small signal method:**
* Signal voltage(Vs) smaller than pumping voltage(Vp)
* Total voltage across nonlinear capacitor C(t) is



* 
* 
* 
* 
* **ii)Large signal method:**
* Signal voltage not small compared to pumping voltage
* Capacitance C is proportional to



Manley Rowe power relation:

* Derived a set of general energy relations regarding power flowing into and out of an ideal nonlinear reactance
* 
* 

Presentation & derivation & Video:

* Operation – up & down converter – application
* Video presentation
* <http://www.youtube.com/watch?v=zVlWCz9vTL4>
* <http://www.youtube.com/watch?v=KrEGji7zzSA&feature=related>
* http://www.youtube.com/watch?feature=endscreen&NR=1&v=yiJPfuKYXWA

Conclusion & summary: recall by key words:

* Manley Rowe relation
* Idler frequency
* Signal frequency
* Pumping frequency
* Degenerate mode
* Regenerate mode
* Up converter
* Down converter

**Session –VIII**

Discussion & introduction:

* Integrated circuits
* Microwave monolithic integrated circuits(MMIC)

Presentation:

* Microwave monolithic integrated circuit
* Materials used– substrate – conductive

Presentation:

* MMIC -dielectric materials - resistive materials

Conclusion & summary: list by key words: Quiz

* Substrate material & conductive materials
* Dielectric & resistive materials
* Properties of materials
* Etchability
* Solderability

**Session – IX**

Discussion & introduction:

* Microwave monolithic integrated circuits(MMIC)

Video Presentation:

* Fabrication techniques – oxidation – deposition – etching – examples
* Video presentation
* <http://www.youtube.com/watch?v=6T8axj-hMxc&feature=fvwrel>
* <http://www.youtube.com/watch?v=gBAKXvsaEiw>
* <http://www.youtube.com/watch?v=Q5paWn7bFg4&feature=related>
* <http://www.youtube.com/watch?v=i8kxymmjdoM&feature=related>
* <http://www.youtube.com/watch?v=aoDgulny31M&feature=related>

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Conclusion & summary: recall by key words

* Ion implantation
* Diffusion
* Lithography
* Epitaxial growth
* Etching process
* Photo resist
* Dc sputtering
* Vacuum evaporation