17BEEC6E12 OPTO ELECTRONIC DEVICES **L T P C**
3 0 0 3

OBJECTIVES

- To know the basics of solid state physics and understand the nature and characteristics of light.
- To understand different methods of luminescence, display devices and laser types and their
  applications.
- To learn the principle of optical detection mechanism in different detection devices.
- To understand different light modulation techniques and the concepts and applications of optical switching.
- To study the integration process and application of optoelectronic integrated circuits in Transmitters and receivers.

INTENDED OUTCOMES:

- Thorough knowledge in the basics of solid state physics and characteristics of light.
- Knowledge in different methods of luminescence, display devices and laser types and their applications.
- Adequate knowledge about the principle of optical detection mechanism in different detection devices.
- Adequate knowledge about different light modulation techniques and the concepts and applications of optical switching.
- Adequate knowledge about the integration process and application of opto electronic integrated circuits in transmitters and receivers.

UNIT-I ELEMENTS OF LIGHTAND SOLID STATE PHYSICS

Wave nature of light, Polarization, Interference, Diffraction, Light Source, review of Quantum Mechanical concept, Review of Solid State Physics, Review of Semiconductor Physics and Semiconductor Junction Device.

UNIT-II DISPLAY DEVICES AND LASERS

Introduction, Photo Luminescence, Cathode Luminescence, Electro Luminescence, Injection Luminescence, Injection Luminescence, LED, Plasma Display, Liquid Crystal Displays, Numeric Displays, Laser Emission, Absorption, Radiation, Population Inversion, Optical Feedback, Threshold condition, Laser Modes, Classes of Lasers, Mode Locking, laser applications.

UNIT-III OPTICAL DETECTION DEVICES

Photo detector, Thermal detector, Photo Devices, Photo Conductors, Photo diodes, Detector Performance.

UNIT-IV OPTO ELECTRONIC MODULATOR

Introduction, Analog and Digital Modulation, Electro-optic modulators, Magneto Optic Devices, Acoustic optic devices, Optical, Switching and Logic Devices.

UNIT-V OPTO ELECTRONIC INTEGRATED CIRCUITS

Introduction, hybrid and Mono Lithic Integration, Application of Opto Electronic Integrated Circuits, Integrated transmitters and Receivers, Guided wave devices.

TEXTBOOK:

S.NO.	Author(s) Name	Title of the book	Publisher	Year of Publication
1.	Wilson.J, and Haukes.J	Opto Electronics–An Introduction	Prentice Hall of India Pvt. Ltd., New Delhi	1998

REFERENCES:

	Author(s) Name	Title of the book	Publisher	Year of Publication
1.	Bhattacharya	Semiconductor Opto Electronic Devices	Prentice Hall of India Pvt., Ltd, New Delhi	1996
2.	Jasprit Singh	Opto Electronics–As Introduction to materials and devices	McGraw-Hill International Edition, New York	1998

KARPAGAM ACADEMY OF HIGHER EDUCATION

(Deemed to be University Established Under Section 3 of UGC Act 1956)

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FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

LECTURE PLAN

NAME OF THE STAFF : Dr.A.MOHANARATHINAM

DESIGNATION : ASSISTANT PROFESSOR

CLASS : B.E-III YEAR ECE

SUBJECT : OPTO ELECTRONIC DEVICES

SUBJECT CODE : 17BEEC6E12

S.No	TOPICS TO BE COVERED	TIME DURATION	SUPPORTING MATERIALS	TEACHING AIDS
	UNIT-I ELEMENTS OF LIGHTAND SOLID STATE PHYSICS			
1	Wave nature of light	01	T1- Page.no : 3-10	BB
2	Polarization	01	T1- Page.no :9,10	BB
3	Interference	01	T1 Page.no : 14-22	BB
4	Diffraction	01	T1- Page.no : 14-22	BB
5	Light Source	01	T1 Page.no. 28-32	BB
6	review of Quantum Mechanical concept	01	T1 page.no. 37-42	BB
7	Review of Solid State Physics	01	T1 page.no.42-48	BB
8	Review of Semiconductor Physics	01	T1 page.no.51-52	BB
9	Review of and Semiconductor Junction Device.	01	T1 page.no.60-83	BB
Total Lecture Hours		**09**		
Total Hours		**09**		

	UNIT-II DISPLAY DEVICES AND LASERS			
10	Introduction, Photo Luminescence, ,	01	T1 Page.no 129-132	PPT , BB
11	Cathode Luminescence, Electro Luminescence	01	T1 Page.no 132-138	PPT , BB
12	Injection Luminescence, LED	01	T1 Page.no 138-155	PPT , BB
13	Plasma Display, Liquid Crystal Displays	01	T1 Page.no 155-162	PPT , BB
14	Numeric Displays	01	T1 Page.no 162-166	PPT , BB
15	Laser Emission, Absorption, Radiation, Population Inversion,	01	T1 Page.no 169-179	PPT , BB
16	Optical Feedback, Threshold condition	01	T1 Page.no 179-182	PPT , BB
17	Laser Modes, Classes of Lasers,	01	T1 Page.no 190-239	PPT , BB

18	Mode Locking, laser applications.	01	T1 Page.no 250-254, 258-268	PPT , BB
Total Lecture Hours		**09**		
Total Hours		**09**		

UNIT-III OPTICAL DETECTION DEVICES				
19	Photo detector	01	T1 Page.no.296-299	BB, PPT
20	Thermal detector	01	T1 Page.no.299-302	BB, PPT
21	Photo Devices	02	T1 Page.no.303-305	BB, PPT
22	Photo Conductors	02	T1 Page.no.314-324	BB
23	Photo diodes	02	T1 Page.no.305-306	BB
24	Detector Performance	01	T1 Page.no.293-296	BB
Total Lecture Hours		**09**		
Total Hours		**09**		

UNIT-IV OPTO ELECTRONIC MODULATOR				
25	Introduction	01	T1 Page.no.428	BB
26	Analog and Digital Modulation	01	T1 Page.no 429-436	BB
27	Electro-optic modulators	01	T1 Page.no 107-108	BB,PPT
28	Magneto Optic Devices	02	T1 Page.no 110-114	BB,PPT
29	Acoustic optic devices	02	T1 Page.no 114-116	BB
30	Optical, Switching and Logic Devices	02	T1 Page.no 108-110	BB
Total Lecture Hours		**09**		
Total Hours		**09**		

UNIT-V OPTO ELECTRONIC INTEGRATED CIRCUITS				
31	Introduction	01	R1 Page.no 484	BB
32	hybrid and Mono Lithic Integration	02	R1 Page.no 484-487	BB,PPT
33	Application of Opto Electronic Integrated Circuits	02	R1 Page.no 487-489	BB
34	Integrated transmitters	01	R1 Page.no 491-501	BB
35	Integrated Receivers	01	R1 Page.no 502-510	BB
36	Guided wave devices	02	R1 Page.no 510-516	BB
Total Lecture Hours		**09**		
Total Hours		**09**		

Total No of Lecture Hours Planned: 45 Hrs

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STAFF IN-CHARGE **HOD/ECE**

unit

Silicon photodiodes are used in the range of

At the receiver , a photodiode will detect the weakened optical signal and it is converted into

Relation between the energy E and frequency V of a photon is

Multimode fibers are suffered by

As the angle of incidence Φ_1 in an optically denser material becomes larger, the refracted angle Φ_2 approaches

The propagation of light along a waveguide can be described in terms of a set of guided EM waves called

calculate total no. of guided modes propagating in the MM Step Index fiber having diameter of 50μm and NA of 0.2 and λ is 1 μm

The angle Φ_1 between the incident ray and normal to surface is called

When light traveling in a certain medium is reflected off an optically denser material, this process is referred to

The boundary between truly guided modes and leaky modes is given by

A SM optical fiber has a beat length of 8cm at 1300nm determine its modal birefringence

The relative RI difference for an optical fiber is 0.05. If the entrance end of fiber is facing the air medium and RI of core is 1.46, estimate its NA calculate the V_{number} for the fiber having $n_1 = 1.53$, $n_2 = 1.50$ and $\lambda_0 = 1$ μm, radius of core is 50 μm

In practical step-Index fibers the core of radius a, has a Refractive Index n_1 which is typically equal to

The numerical aperture of a step-Index fiber for meridional ray is given by

In communication channel information is superimposing onto a sinusoidally varying EM wave is known as

What is the operating rate of N independent information streams, each running at a data rate of R bits per second

The majority of fibers are made of glass material which consists of

Standard silica fibers have a much larger signal dispersion at

Why optical amplifiers are used in fiber transmission to

A silica optical fiber has a core RI of 1.50 and a cladding RI of 1.47 , what is its critical angle at core cladding interface

What is the operating range of long wavelength region

Suppose a fiber has a diameter of 5μm and its core RI is 1.450 , cladding RI is 1.447. If the wavelength of propagation is 1μm, how many modes can be propagated inside the fiber

An optical fiber in air has an NA of 0.3 what is the acceptance angle for meridional rays

Find the core radius necessary for SM operation at 850nm of step index fiber with n1 = 1.480, n2 = 1.465

A step index fiber has a core diameter of 200 μm and NA is 0.3, compute the no. of propagating modes at an wavelength of 850 μm

calculate the maximum no. of modes propagating through the fiber having n_1 = 1.53, n_2 = 1.50 and λ_0 = 1 μm, radius of core is 50 μm

What is the operating range of EDFA

Light can be launched into a multimode fiber using a

calculate the no. of guided modes through the graded index fiber having NA 0.21, index profile 1.85 and radius of core is 25 μm at wavelength of 1.3 μm

opt1	opt2	opt3
800-900nm	1100-1600nm	1310-1550nm
Electric current	Photocurrent	Bias current
E = hV	h = EV	E = h / V
Intermodal dispersion	Intramodal dispersion	Signal dispersion
Π / 4	3Π / 4	Π / 2
Modes	Bound	Core
490	940	944
Incident ray	Angle of incidence	Normal angle
Internal reflection	External reflection	Reflected ray
$\beta = n_1 k$	$\beta = \Delta k$	$\beta = \lambda k$
$1.62 X 10^{-5}$	$1.63 X 10^{-5}$	$1.64 X 10^{-5}$
0.16	0.26	0.36

61.72	72.72	83.72
1.18	1.84	1.44
$n_2 (2\Delta)^{1/2}$	$n_1 (2\Delta)^{1/2}$	$\Delta (2 n_1)^{1/2}$
Message signal	Carrier signal	Modulated signal
N/R bits per second	N bits per second	R/N bits per second
Sio_2 Better accuracy	GaAs	InGaAs
800 than at 900nm	850 than at 1310nm	1550 than at 1300nm
Boost capacity	Reduce signal dispersion	Equipment redundancy
71.2^0	78.5^0	77.4
800-900nm	1100-1600nm	1310-1550nm
1	2	3
18.46^0 Event driven simulat	19.46^0 Circuit driven simulat	17.46^0 Hardware emula
1.554 µm	1.654 µm	1.754 µm

14589 modes	24589 modes	34589 modes
4286	4486	4686
850nm	1310nm	1550nm
LCD	LED	Laser
455	355	255

opt4 opt5 opt6

800-1600nm

Negative current

V = E / h

Wave dispersion

Π

Cladding

499

Incident angle

Refracted ray

$\beta = n_2 k$

1.65×10^{-5}

0.46

94.72

1.48

$\Delta\ (2\ n_2)^{1/2}$

Demodulated signal

NXR bits per second

InGaAsP

1700 than at 1500nm

Detect link failure

74.5

800-1600nm

4

16.46^0 Cyclic driven simulations

1.854 μm

44589 modes

4886

1300nm

Photodiode

155

Answer

800-900nm

Photocurrent

E = hV

Intermodal dispersion

Π / 2

Modes

490

Angle of incidence

External reflection

$\beta = n_2 k$

1.63×10^{-5}

0.46

94.72

1.48

$n_1 (2\Delta)^{1/2}$

Carrier signal

NXR bits per second

Sio_2 Better accuracy

1550 than at 1300nm

Boost capacity

78.5^0

1100-1600nm

1

17.46^0 Hardware emulation

1.554 μm

a 24589 modes

4486

1550nm

LED

155

Questions	opt1
The peaks and valleys in attenuation curve resulted in designation of various	Transmission losses
The latter effect is often referred to as	Fiber loss
Attenuation plays a major role in determining	maximum pulse broadening
The young's modulus of fused silica glass is about	45 Gpa
Rayleigh scattering loss is inversely proportional to	Square of wavelength
In case of SM fiber, the core cladding loss is	Maximum
A useful means of characterizing PMD for long fiber lengths is in terms of mean value of	Differential group delay
In the case of MM fiber, the relative RI difference is	Large
The dispersion effect can be explained on the behavior of	Guided modes
Intramodal dispersion arises due to the dependence on	rms pulse width
Attenuation coefficient is expressed in units of	dB/Km3
The amount of waveguide dispersion depends on	Fiber material
A measure of information capacity of an optical waveguide is usually specified by	Information distance product
Intermodal dispersion is otherwise called as	Chromatic dispersion
Material dispersion is otherwise called	Chromatic dispersion
As light travels along a fiber, its power	increase exponentially with distance
Polarization mode dispersion is measured in terms of	Group velocity
The larger value of PMD for the aerial cable is caused by sudden changes in	Frequency
Which one is correct order	Multimode dispersion > Waveguide dispersion > Material dispersion
Raman scattering occurs at	Low power input signal(<10mw)
Signal transmitting through the fiber is degraded by	attenuation and dispersion
α is generally referred as	Fiber absorption
The impurity levels in vapor phase deposition process are usually	One to eight orders of magnitude lower
The young's modulus of common jacket materials ranges from	10 to 400 Mpa
Intermodal dispersion arises due to	Variation of RI for each mode at a single frequency

Material dispersion arises due to variation of	RI of core material with wavelength
The distortion mechanisms in a fiber cause	optical signal flattening
Optical powers are commonly expressed in units of	dB m
The transition metal impurities which are present in starting materials used for	Direct melt fibers b/w 1 & 10(ppb)
The total dose a material receives is expressed in units of	rad/si

opt2	opt3	opt4
Transmission distance	Transmission power	Transmission windows
Coupling	Cabling	Bending
maximum transmission distance	maximum radiative losses	maximum structural imperfection
55 Gpa	65 Gpa	75 Gpa
Cube of wavelength	Fourth power of wavelength	Eighth power of wavelength
Minimum	Slightly higher	Negligible
Differential group velocity	Differential spectral width	Differential time delay
Small	Equal to one	Negligible
rms pulse width	Group delay	Group velocity
Fiber material	Group velocity on wavelength	Bandwidth of transmitted pulse
dB/Km2	dB/Km	dB.Km
Operating wavelength	Waveguide	Fiber design
Bandwidth distance product	Bit rate	Data rate
Material dispersion	Single mode dispersion	Multimode dispersion
Material dispersion	Single mode dispersion	Multimode dispersion
Decreases exponentially with distance	increase exponentially with time	decrease exponentially with time
Pulse broadening	Group delay	Rms pulse width
Temperature	Power	Velocity
Waveguide dispersion > Material dispersion > Multimode dispersion	Multimode dispersion > Material dispersion > Waveguide dispersion	Material dispersion > Waveguide dispersion > Multimode dispersion
High power input signal(>100mw)	Slightly high power input signal(>10mw)	Very Low power input signal(<1mw)
reflection	refraction	emission
Fiber scattering	Fiber scattering	Fiber loss
One to three orders of magnitude lower	One to two orders of magnitude lower	One to four orders of magnitude lower
20 to 400 Mpa	10 to 500 Mpa	20 to 500 Mpa
Variation of group velocity for each mode at a single frequency	Variation of index difference for each mode at a single frequency	Variation of index profile for each mode at a single frequency

Group velocity on wavelength	Bandwidth of transmitted pulse	none of these
optical signal degradation	optical signal distortion	optical signal pulses to broaden
dB/m	db km	db/km
Bulk silicon b/w 1 & 10(ppb)	(ppb Indirect melt fibers b/w 1 & 10)	Vapor phase deposition b/w 1 & 10(ppb)
rad(si)	rad(si)/Km	rad(si).Km

opt5	opt6	Answer
		Transmission windows
		Cabling
		maximum transmission distance
		65 Gpa
		Fourth power of wavelength
		Minimum
		Differential group delay
		Large
		Group velocity
		Group velocity on wavelength
		dB/Km
		Fiber design
		Bandwidth distance produc
		Multimode dispersion
		Chromatic dispersion
		decrease exponentially with distance
		Group delay
		Temperature
		Multimode dispersion > Material dispersion > Waveguide dispersion
		High power input signal(>100mw)
		attenuation and dispersion
		Fiber loss
		One to two orders of magnitude lower
		20 to 500 Mpa
		Variation of group velocity for each mode at a single frequency

Bandwidth of transmitted pulse

optical signal pulses to broaden

dB m

Direct melt fibers b/w 1 & 10(ppb)

rad(si)

Questions	opt1
In photodiode, the carrier drift time determines	Output power
One of the simplest techniques for sending binary data is	Phase shift keying
The photo detector senses the	Electric current
The photo detector should be insensitive to variations in	Speed
The photodiode is used almost exclusively for fiber optic systems because of its	Fast response time
The photo detector is normally designed so that carriers are generated mainly in	Active region
The high electric field present in the depletion region causes the carrier to separate and be collected across the	Forward biased junction
The factor Q is widely used to specify	Receiver performance

The number of electron hole carrier pairs generated per incident photon of energy is given by	Incident energy
To achieve a high Quantum efficiency, the depletion layer must be	Thick
The excess noise factor is a measure of the	Decrease in detector noise
Pin photodiode responsivities as a function of	Optical power
The carrier multiplication mechanism is known as	Avalanche effect
Pin photodiodes and Avalanche photodiodes are important photo detectors in the wavelength range	0.8 µm – 1.6 µm
The primary photocurrent generated by photodiode is	Frequency varying Poisson process
The sensitivity of a photo detector in an optical fiber communication system is describable in terms of	Minimum detectable optical power

…………….arises from electrons and or holes which are thermally generated in pn junction of the photodiode	Surface dark current
Bulk dark current is directly proportional to	Electric field
Which one is usually dominate in avalanche photodiodes	Thermal noise
The diffusion time of the photo carriers generated outside the	Depletion region
In digital signal transmission, the time slot is referred to as a	Time period
The average number of electron hole pairs created by a carrier per unit distance traveled is called	Avalanche effect
Current flow in an external circuit, with one electron flowing for every carrier pair generated. This current flow is known as	Photocurrent

At the output end of an optical transmission line, there must be a receiving device. The first element of this receiver is a	Amplifier
In digital signal transmission, the optical signal emerging from the transmitter , a 1 is represented by	Current pulse
Thermal noise arises from ……... in a conductor	Random motion of electrons
To achieve a high SNR, photo detector must have a	High Quantum efficiency
The random nature of the avalanche multiplication process gives rise to another type of	Noise figure
The diffusion current is determined by hole diffusion from	Bulk P region

………..is the minimum optical power necessary to achieve a given signal to noise ratio at the receiver | Bit error rate

opt2	opt3	opt4
Response time	Response speed	Carrier lifetime
Frequency shift keying	Angle shift keying	Amplitude shift keying
Barrier potential	Luminescent power	Emission wavelength
Bandwidth	Time	Temperature
Low sensitivity	Large size	Low response time
Depletion region	Absorption region	Recombination region
Active region	Pn junction	Reverse biased junction
System performance	transmitter performance	Source performance

Quantum efficiency	Responsivity	Detector efficiency
Thin Decrease in thermal noise	Narrow Increase in detector noise	Wider Increase in thermal noise
Wavelength	Response time	Frequency
Tunnel effect	Impact ionization	Ionization rate
0.9 µm – 2.6 µm	0.7 µm – 3.6 µm	0.6 µm – 4.6 µm
Current varying poisson process	Time varying poisson process	Signal varying poisson process
Maximum detectable optical power	Minimum detectable noise current	Maximum detectable noise current

Bulk dark current	Surface leakage current	Bulk leakage current
Time	Area	Bias current
Photo detector noise	Noise figure	Noise current
Active region	Absorption region	Recombination region
Time slot	Bit period	Bit rate
Tunnel effect	Impact ionization	Ionization rate
Bias current	Negative current	Positive current

Photo detector	Signal restorer	Drive circuit
Pulse of optical power	Time slot	Voltage pulse
Random motion of holes	Random motion of electron hole pair	Random motion of carrier
Small Quantum efficiency	Fast response time	Slow response time
Shot noise	Quantum noise	Noise factor
Bulk n region	Active region	Depletion region

Quantum limit	SNR	rms noise

opt5 opt6

Answer

Response speed

Amplitude shift keying

Luminescent power

Temperature

Fast response time

Depletion region

Reverse biased junction

Receiver performance

Quantum efficiency

Thick

Increase in detector noise

Wavelength

Impact ionization

0.8 µm – 1.6 µm

Time varying poisson process

Minimum detectable optical power

Bulk dark current

Area

Photo detector noise

Depletion region

Bit period

Ionization rate

Photocurrent

Photo detector

Pulse of optical power

Random motion of electrons

High Quantum efficiency

Shot noise

Bulk n region

SNR

Questions	opt1	opt2
High radiances are necessary to couple sufficiently level into a fiber	High optical power	Less optical power
Transverse modes determine	Frequency spectrum	Threshold current
According to ____________ law, a transition between two states involves absorption of a photon of energy	Snell's	Planck's
Power launching between source to fiber or fiber to fiber depends on	Numerical aperture	Index Profile
The isotropic pattern from a surface emitter is called as	Emission pattern	Absorption pattern
The value of threshold current increases with	Decrease of temperature	Increase of temperature
Longitudinal modes determine	Width	Size
Splice is a ____________ joint between fibers	Permanent	Temporary
In surface emitter , the emission pattern is essentially isotropic with a	1200 half power beam width	600 half power beam width
Stimulated emission will exceed absorption only if the population of the excited states is greater than that of ground state is known as	Photon absorption	Spontaneous emission
Majority carriers referred to	Holes in n type	Electrons in p type
The operation of semiconductor devices is essentially based on	Injection & extraction of minority carriers	Injection of semiconductor
The recombination of excess minority carriers is the mechanism by which is generated	Optical power	Optical radiation
The electrons & holes are located into a covalent band structure is called	Active region	Recombination region
Epitaxial layers can be formed by growth technique of	Vapor phase	Solid phase
When an external battery is connected to pn junction with its positive terminal to n type & negative terminal to p type. This junction is said to be	Forward biased	Barrier potential
The circular active area in practical surface emitter has diameter of	20 µm	30 µm
In surface emitter, a well is etched through the substrate of the device, into which a fiber is then cemented in order to accept	Reflected light	Emitted light

In recombination process the electron & hole have the same momentum value is referred as	Indirect band gap	Direct band gap
The periodic arrangement of single or group of atoms in space is defined as	Depletion region	Epitaxial growth
Radiance is a measure of	Hue	Brightness
The lattice spacing of adjacent material should be closely matched to	Fiber losses	Fiber imperfection
For optical communication systems requiring bit rates less than	100 – 200 Mb/s	100 – 300 Mb/s
As a result of reverse bias, width of depletion region will	Increase on both n side & p side	Decrease on both n side & p side
LEDs require less complex	Emitter circuit	Optical stabilization circuits
Free electron hole pairs are produced by	Recombination process	Thermal generation process
Quantum well lasers have very thin cavity so that their threshold current is	Very high	Very low
The band gap differences of adjacent layers confine the	njectedcarriers	Charge carrier
The electrical conductivity is proportional to	Electron concentration	Charge concentration
The guiding layers both have a refractive index which is lower than	Depletion region	Active region
Progress in ________ and other related semiconductors material processing led to the feasibility of monolithic microwave integrated circuits.	GaAs .	Silicon
The substrate of an MMIC must be a ______________ to accommodate the fabrication of all the type of devices.	Semiconductor .	Insulator
Transmission lines and other conductors in microwave devices are usually made with ___________	Gold metallization .	Silver metallization
For the capacitors used in MMICs, the insulating dielectric films used are	Air	SiO .
Resistors used at normal operating frequencies can be directly used at microwave frequencies in MMIc.	Ion implantation .	Net list generation
Microwave tubes are grouped into two categories depending on the type of	Electron beam field interaction	Amplification method

________ is a single cavity klystron tube that operates as on oscillator by using a reflector electrode after the cavity.	Backward wave oscillator	Reflex klystron
In a _________ oscillator, the RF wave travels along the helix from the collector towards the electron gun.	Interaction oscillator	Backward wave oscillator
Extended interaction oscillator is a ________ beam oscillator that is similar to klystron	Linear beam	Crossed beam
. ____________ is a microwave device in which the frequency of operation is determined by the biasing field strength.	VTM	Gyratron
Which among the following is provided by an optical receiver for the regeneration of data signal with minimum error?	Photo-diode	Signal Processing Circuits
Which property/ies of PCM stream determine/s the fidelity to original analog signal?	Sampling rate	Bit depth
If a light travels in a certain medium and it gets reflected off an optically denser medium with high refractive index, then it is regarded as _______	External Reflection	Internal Reflection
In an optical fiber, the concept of Numerical aperture is applicable in describing the ability of __________	Light Collection	Light Scattering
During the design of FOC system, which among the following reasons is/are responsible for an extrinsic absorption?	Atomic defects in the composition of glass	Impurity atoms in glass material
____________ limits receiver sensitivity.	Noise	Depletion layer
A ____________ performs the linear conversion of the received optical signal into an electric current	Receiver	Converter
__________ are provided to reduce distortion and to provide a suitable signal shape for the filter.	Detector	Equalizer
A _________ maximizes the received signal-to-noise ratio in the receiver circuitry.	Filter	Equalizer
How many structures of pre-amplifiers exist?	Two	Three

opt3	opt4	opt5
Zero optical power	Emitted optical power	
Drive current	Output Power	
Mass action	Fresnel transmission	
Spectral width	Index difference	
Lambertian pattern	Surface pattern	
Decrease of wavelength	Increase of wavelength	
Frequency spectrum	Output radiation pattern	
Periodic	Semi temporary	
400 half power beam width	2400 half power beam width	
Population inversion	Stimulated emission	
Electrons in p type	Free electron hole pairs in pn junction	
Injection of carriers	Injection & extraction of majority carriers	
Optical emission	Optical source	
Barrier potential	Depletion region	
Gas phase	Isotropic atom	
Space charge	Reverse biased	
40 µm	50 µm	
Radiated light	Scattered light	

Band gap energy	Barrier potential
Lattice Luminance	Heterostructure Intensity
Fiber bending	Temperature induced stresses
100 – 400 Mb/s Decrease on n side & Increase on p side	100 – 500 Mb/s Increase on n side & Decrease on p side
Thermal circuits	Drive circuit
Auger process	Mass action
Zero	Decreases with time
Electron hole pairs	Carrier recombination
Carrier concentration	Holes concentration
Surrounding material	Circular metal contact
Germanium	GaAlAs
Partial conductors	Metals operable at high frequencies
Copper metallization	Zinc metallization
Titanium	GaAs
Floor planning	None of the mentioned
Power gain achieved	Construction methods

Travelling wave tube	Magnetrons
Magnetrons	None o the mentioned
Parallel beam	M beam
Helix BWO	None of the mentioned
Linear Circuitry	None of the above
Both a and b	None of the above
Both a and b	None of the abov
Light Dispersion	Light Polarization
Basic constituent atoms of fiber material	All of the above
Avalanche	Current
Detector	Reflector
Filters	Amplifier
Detector	Reflector
Four	One

opt6 Answer

High optical power
Threshold current

Planck's

Numerical aperture

Lambertian pattern

Increase of temperature
Frequency spectrum

Permanent

1200 half power beam width

Population inversion

Electrons in p type

Injection & extraction of minority carriers

Optical radiation

Depletion region

Vapor phase

Reverse biased

50 µm

Emitted light

Direct band gap

Lattice
Brightness

Temperature induced stresses

100 – 200 Mb/s

Increase on both n side & p side

Drive circuit

Thermal generation process

Very low

Charge carrier

Carrier concentration

Active region

GaAs

Semiconductor

Gold metallization

SiO

Ion implantation

Electron beam field interaction

Reflex klystron

Backward wave oscillator

Linear beam

Gyratron

Linear Circuitry

Both a and b

External Reflection

Light Collection

Impurity atoms in glass material

Noise

Detector

Equalizer

Filter

Three

Questions
A single mode fiber can provide ultimate bit rate distance pı
The optical power that can be coupled into a fiber from an L
As Δ increases, ___________ increases correspondingly
The spectral width of an LED and dispersion characteristics c
In choosing a particular photodetector, mainly need to dete
A pin photodiode receiver is simpler, more stable with chan
Pin photodiode bias voltages are normally less than
Avalanche photodiode bias voltage are ranges from
The information carrying capacity of a fiber is increased by
when choosing the attenuation characteristics of a cabled fi
Modal partition noise becomes more pronounced for

In mode partition noise, signal to thermal noise ratio is redu
In chirping, α represents
A rise time budget analysis is a convenient method for detel
In rise time budget, the total transition time degradation of
The transmitter rise time is attributable primarily to the
The receiver rise time results from the
Modal noise occurs when
The 3dB electrical bandwidth of the receiver is represented
Determining the fiber rise times resulting from
The 3dB optical bandwidth B3Db is defined as the
In the 800-t0-900nm region, D is about
___________ arises when the light from the coherent las
In chirping, factor α ranges from ___________ for InGaAsp
The modal distortion resulting from interference between a
A device which is used at the interconnection point to transl
In chirping, factor α ranges from ___________ for AlGaAS lá
Use a SM fiber, since it supports
___________ is associated with intensity fluctuations in loı
Intensity fluctuation can occur among the various modes on

Each of the longitudinal modes that is coupled into the fiber
The signal to noise ratio is due to mode partition noise is inc
In mode partition noise, x represents

The response of receiver front end can be modeled by a __
WDM technique is very useful in the optical domain, bit rate
The chirping induced power penalty increases with
The power penalty for an APD system can be estimated fror
The best approach to minimizing chirp effects is to choose tl
A popular protocol used in optical LANs is
A key characteristics of SONET & SDH is that they are usuall
Solitons are pulses which travel down the fiber without any
By using PC connectors and optical isolators ___________
Solitons are defined as
Principle of optical amplifier is based on
Use a laser which has a large no. of
___________ is the logical manner in which nodes are link
Solitons having pulse width of
SONET is the
SONET operating at a base rate of
SONET/SDH rings are commonly called as
In system consideration, advantage of lower attenuation an
Use a fiber with a large NA, since it supports a
Recently a transport network in WAN called a
In SDH, the basic building block is called as
SONET is used in
The basic building block of SONET has a bit rate of
standard SONET level of OC-192 has link rate of
First generation optical wavelength are in the range of
In the link power budget analysis one first determines the
Once the link power budget has been established, the desig
Progress in ________ and other related semiconductors ma
The substrate of an MMIC must be a _____________ to acc

Transmission lines and other conductors in microwave devic
For the capacitors used in MMICs, the insulating dielectric fi
Resistors used at normal operating frequencies can be direc
Microwave tubes are grouped into two categories dependi
________ is a single cavity klystron tube that operates as o
In a _________ oscillator, the RF wave travels along the hel
Extended interaction oscillator is a ________ beam oscillat
. ____________ is a microwave device in which the frequen
Which among the following is provided by an optical receive
Which property/ies of PCM stream determine/s the fidelity
If a light travels in a certain medium and it gets reflected of
In an optical fiber, the concept of Numerical aperture is app
During the design of FOC system, which among the followin
____________ limits receiver sensitivity.
A ____________ performs the linear conversion of the recei
__________ are provided to reduce distortion and to provi
A _________ maximizes the received signal-to-noise ratio in
How many structures of pre-amplifiers exist?

opt1
200(Gb/s)
Bandwidth
Fiber coupled power
50(Mb/s).km
Maximum optical power
Humidity
5V
5V to several hundred volts
Splicing technique
Fiber to fiber joint
High data rates

Raising bias power level, reduces the signal pulse power
Absorption coefficient factor
Bit error rate
Group velocity dispersion
Light source & its drive circuitry
Amplifier response
Fluctuation in frequency
BWrx
GVD & modal dispersion
Optical frequency
0.05 ns/ (nm.km)
Wavelength chirp
-1 to -8
Modulation ripple of frequency
Node
1.5 to -5.5
Only one mode & no modal interference
Modal noise
High

Same attenuation & time delay
Signal current
Excess noise factor of an APD

First order high pass filter
10 Kb/s
Higher bias levels
SNR degradation
Intramodal dispersion
AODV
Bus architecture
Amplitude
Modal noise
Very wider laser pulses
Mass action
Lateral mode
Node
10-11 sec
LAN
115.52 Mbit/s
Self healing routing
1300 to 1550 nm
Small no. of modes & gives a smaller no. of speckles
Multiplier optical network
Synchronous transport module
North Africa
21.84 Mb/s
6653.28 Mb/s
0.7µm to 0.8µm
Rise time analysis
System link analysis
GaAs .
Semiconductor .

Gold metallization .
Air
Ion implantation .
Electron beam field interaction
Backward wave oscillator
Interaction oscillator
Linear beam
VTM
Photo-diode
Sampling rate
External Reflection
Light Collection
Atomic defects in the composition of glass
Noise
Receiver
Detector
Filter
Two

opt2
300(Gb/s)
Bit error rate
Numerical aperture
100(Mb/s).km
Minimum optical power
Area
12V
12V to several hundred volts
Multiplexing technique
Cabling process
High bit rates

Raising bias power level, raising the signal pulse power
Line width enhancement factor
`Dispersion
Group delay
Regeneration
Photodetector response
Fluctuation in coherent time
Brx
Attenuation & modal dispersion
Modulation frequency
0.06 ns/ (nm.km)
Modal noise
-2 to -8
Sinusoidal ripple of frequency
Topology
2.5 to -5.5
Number of modes & no modal interference
Mode partition noise
Small

Different attenuation & time delay
Signal voltage
Excess noise factor of a PIN photo detector

Second order high pass filter
10 Mb/s
Lower bias levels
BER degradation
Intermodal dispersion
DSR
Star architecture
Frequency
Mode partition noise
Very narrow laser pulses
Laser action
Axial mode
Topology
10-12 sec
WAN
155.52 Mbit/s
Self healing rings
1310 to 1550 nm
Large no. of modes & gives a smaller no. of speckles
Multi wavelength optical network
Asynchronous transport module
South Africa
31.84 Mb/s
9953.28 Mb/s
0.8µm to 0.9µm
Bit error rate
System rise time analysis
Silicon
Insulator

Silver metallization
SiO .
Net list generation
Amplification method
Reflex klystron
Backward wave oscillator
Crossed beam
Gyratron
Signal Processing Circuits
Bit depth
Internal Reflection
Light Scattering
Impurity atoms in glass material
Depletion layer
Converter
Equalizer
Equalizer
Three

opt3
400(Gb/s)
Core size
Core size
150(Mb/s).km
Maximum optical power
Time
40V
40V to several hundred volts
Point to point link
Point to point links
Low data rates

Reduces bias power level, reduces the signal pulse power
Spectral width enhancement factor
Signal to noise ratio
Non return to zero
Transmitter
Receiver response
Spectral pattern fluctuation
EBrx
Rise time budget & modal dispersion
Message frequency
0.07 ns/ (nm.km)
Spectral broadening
-4 to -8
Cosine ripple of frequency
Switching
-3.5 to -5.5
Number of modes & increased modal interference
Wavelength chirp
Zero

High attenuation & small time delay
Signal power
Excess loss factor of an APD

Photodetector response
10 Gb/s
Higher frequency levels
Signal degradation
Zero dispersion wavelength
DSDV
Ring architecture
Time
Chirping noise
Highly dispersion laser pulses
LED action
Longitudinal mode
Switching
10-13 sec
MAN
215.52 Mbit/s
Self healing switch
1300 to 1500 nm
Small no. of modes & gives a greater no. of speckles
Synchronous optical network
Multiplier transport module
North America
41.84 Mb/s
3353.28 Mb/s
0.9µm to 1.0µm
Power margin
System power analysis
Germanium
Partial conductors

Copper metallization
Titanium
Floor planning
Power gain achieved
Travelling wave tube
Magnetrons
Parallel beam
Helix BWO
Linear Circuitry
Both a and b
Both a and b
Light Dispersion
Basic constituent atoms of fiber material
Avalanche
Detector
Filters
Detector
Four

opt4
500(Gb/s)
Core cladding index difference
Bandwidth
200(Mb/s).km
Minimum optical power
Temperature
100V
100V to several hundred volts
Fiber to fiber joint
Source to fiber joint
Low bit rates

Reduces bias power level, raising the signal pulse power
Bandwidth enhancement factor
Power margin
Return to zero
Amplifier
Transmitter response
Spectral width broadening
Erx
Power margin & modal dispersion
Carrier frequency
0.08 ns/ (nm.km)
Mode partition noise
-6 to -8
Spectral pattern of frequency
Routing
-4.5 to -5.5
Only one mode & increased modal interference
Reflection noise
Constant

Same attenuation & high time delay
Signal time
Excess loss factor of a PIN photo detector

Second order low pass filter
10 Tb/s
Lower frequency levels
Power degradation
Wavelength dispersion
FDDI
Mesh architecture
Bit rate
Reflection noise
Very broadening laser pulses
Source action
Latitudinal mode
Routing
10-14 sec
Intranet
255.52 Mbit/s
Self healing node
1310 to 1500 nm
Large no. of modes & gives a greater no. of speckles
Asynchronous optical network
Multi wavelength transport module
South America
51.84 Mb/s
7753.28 Mb/s
1.0µm to 1.1µm
Link analysis
System wavelength analysis
GaAlAs
Metals operable at high frequencies

Zinc metallization
GaAs
None of the mentioned
Construction methods
Magnetrons
None o the mentioned
M beam
None of the mentioned
None of the above
None of the above
None of the abov
Light Polarization
All of the above
Current
Reflector
Amplifier
Reflector
One

opt5

opt6

Answer
500(Gb/s)
Core cladding index difference
Fiber coupled power
150(Mb/s).km
Minimum optical power
Temperature
5V
40V to several hundred volts
Multiplexing technique
Cabling process
High bit rates

Raising bias power level, reduces the signal pulse power
Line width enhancement factor
`Dispersion
Non return to zero
Light source & its drive circuitry
Photodetector response
Spectral pattern fluctuation
Brx
GVD & modal dispersion
Modulation frequency
0.07 ns/ (nm.km)
Modal noise
-6 to -8
Sinusoidal ripple of frequency
Routing
-3.5 to -5.5
Only one mode & no modal interference
Mode partition noise
Constant

Different attenuation & time delay
Signal power
Excess noise factor of an APD

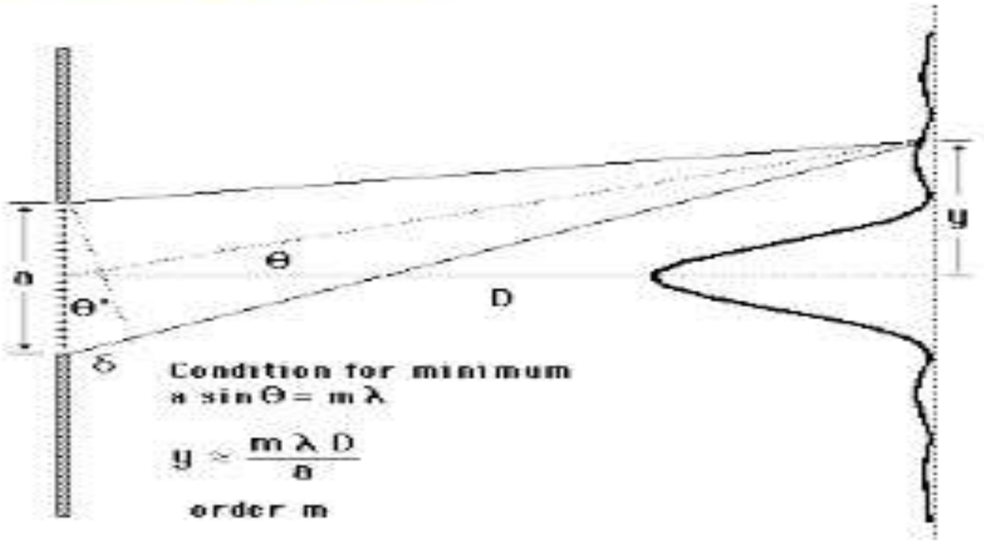
Photodetector response
10 Tb/s
Lower bias levels
SNR degradation
Zero dispersion wavelength
FDDI
Ring architecture
Amplitude
Reflection noise
Very narrow laser pulses
Laser action
Longitudinal mode
Topology
10-14 sec
WAN
155.52 Mbit/s
Self healing rings
1300 to 1550 nm
Large no. of modes & gives a greater no. of speckles
Multi wavelength optical network
Synchronous transport module
North America
51.84 Mb/s
9953.28 Mb/s
0.8µm to 0.9µm
Power margin
System rise time analysis
GaAs
Semiconductor

Gold metallization
SiO
Ion implantation
Electron beam field interaction
Reflex klystron
Backward wave oscillator
Linear beam
Gyratron
Linear Circuitry
Both a and b
External Reflection
Light Collection
Impurity atoms in glass material
Noise
Detector
Equalizer
Filter
Three

Diffraction through a single slit

http://physicsstudio.indstate.edu/java/physlets/java/slitdiffr/index.html

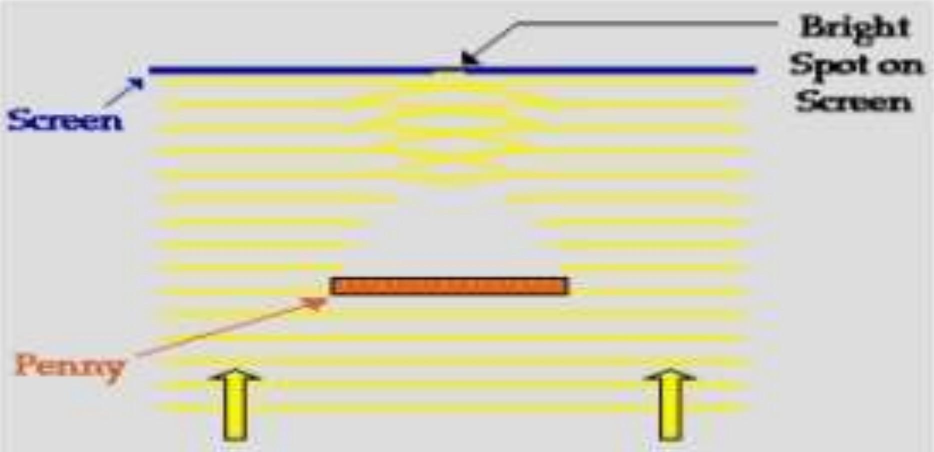
- Diffraction refers to the spreading or bending of waves around edges.



The fringe pattern formed by a single slit consists of Alternate bright and dark fringes and the fringes fade away from the centre.

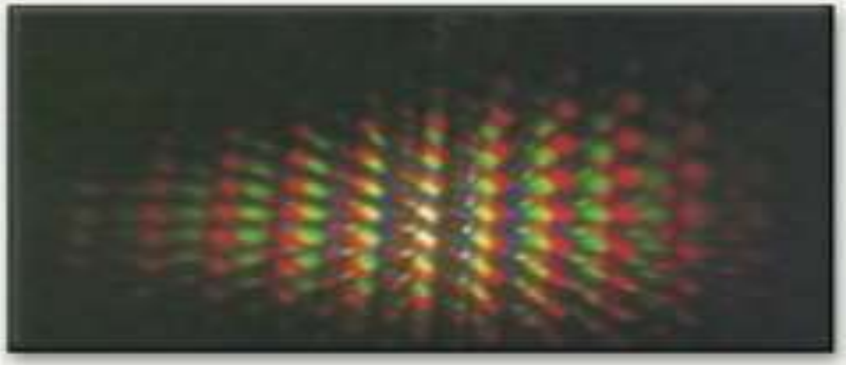
Diffraction pattern through an obstacle

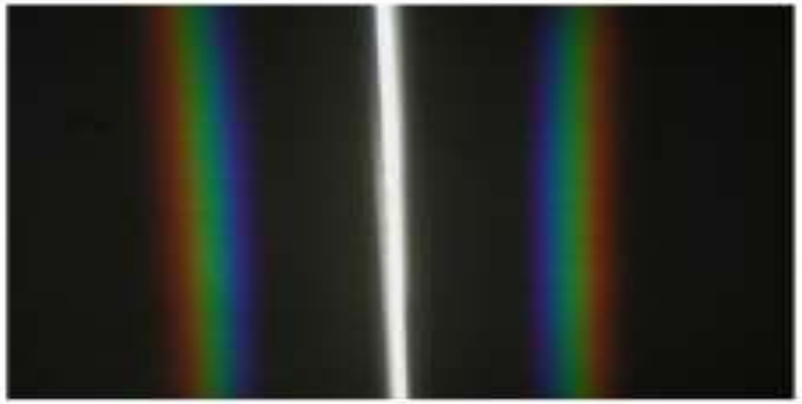
Light diffracts around a penny - observe the light spot in the center of pattern.



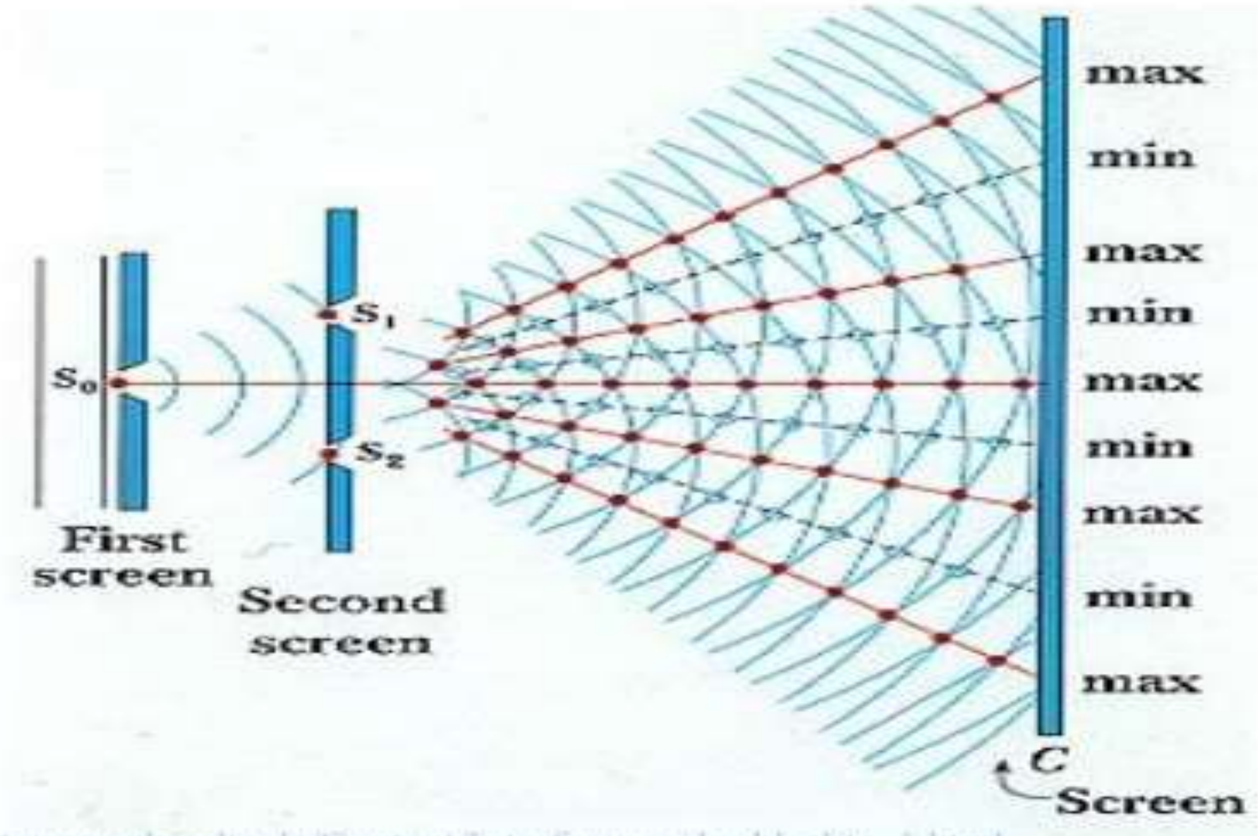
The diffraction of light around a penny and its ultimate interference upon a screen produces a pattern which could only be observed if light is a wave.

Diffraction Patterns



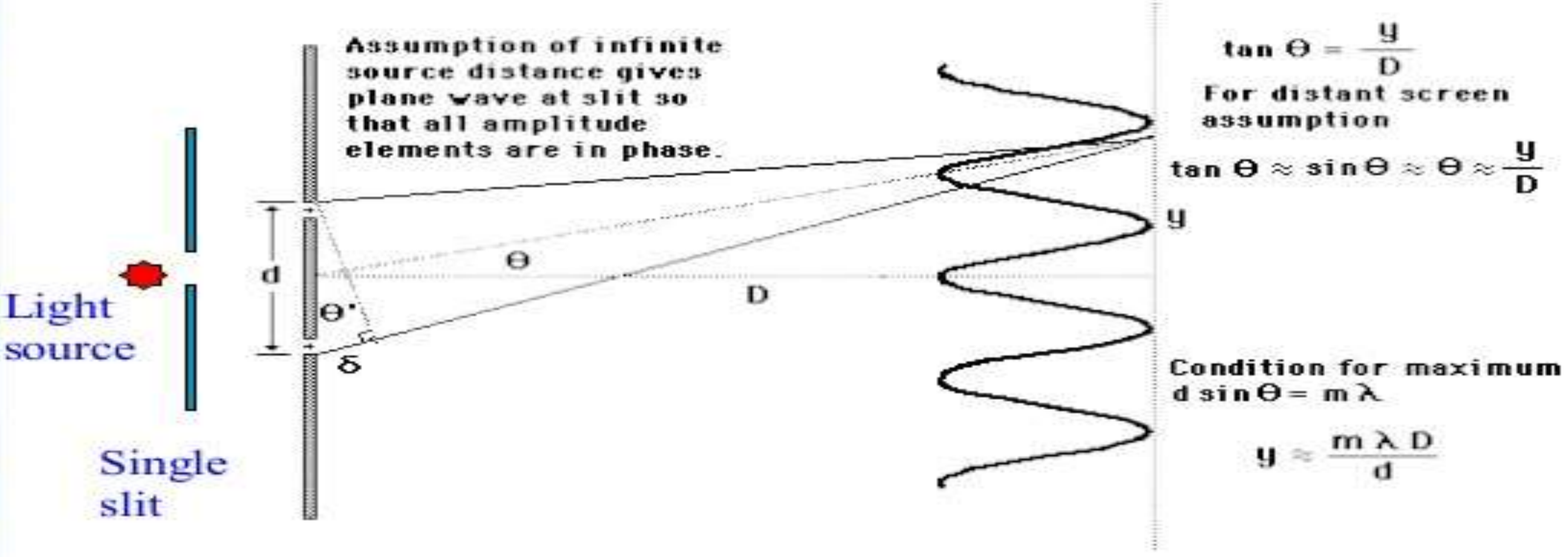


Young's experiment



http://www.matter.org.uk/schools/Content/Interference/doubleslits_1.html

Schematic diagram of Young's double-slit experiment



http://www.walter-fendt.de/ph11e/interference.htm

Conditions for Observable Interference

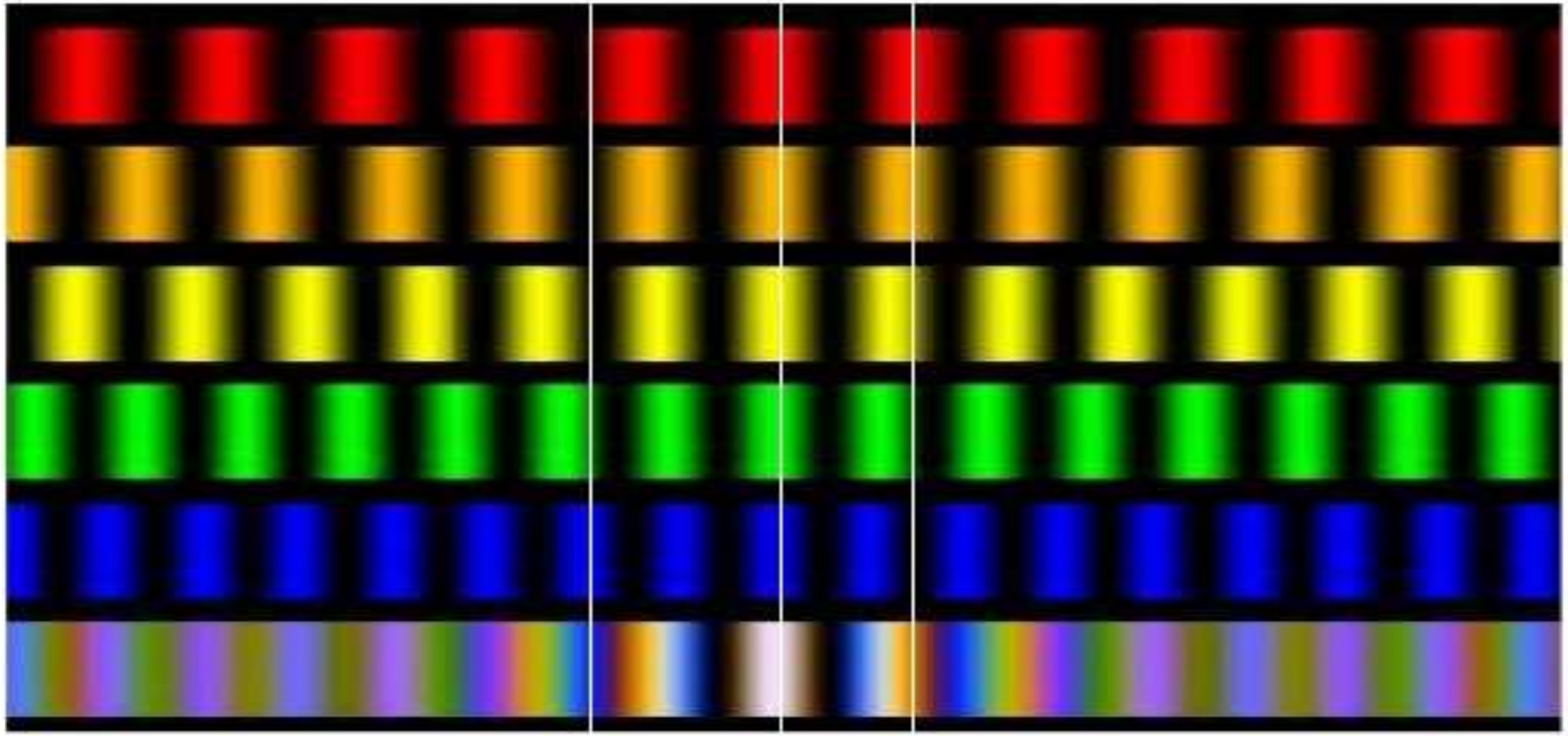
- Coherent Sources
  - Coherent sources are those which emit light waves of the same wavelength or frequency and are always in phase with each other or have a constant phase difference.
- Polarization
  - The wave disturbance have the same polarization.
- Amplitudes
  - The two sets of wave must have roughly equal amplitude.
- Path Difference
  - The path difference between the light waves must not be too great.

Appearance of Young's interference Fringes

http://micro.magnet.fsu.edu/primer/java/doubleslit/index.html

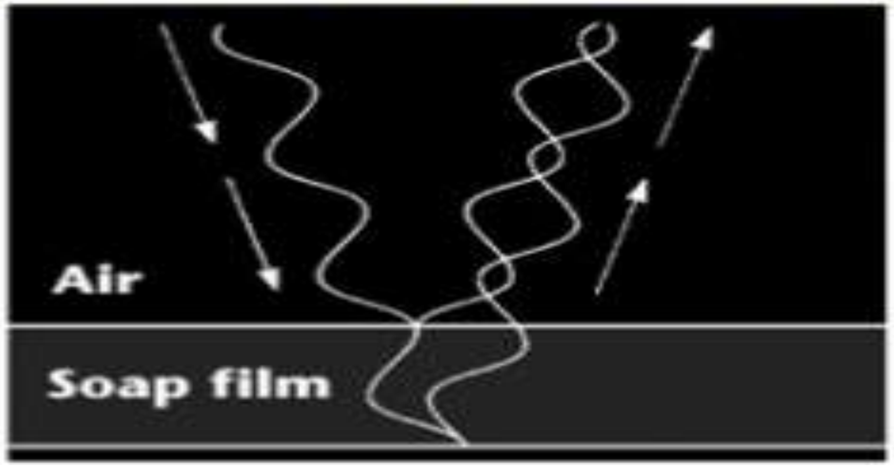
- If the source slit is moved nearer to the double slits the separation of the fringes is unaffected but their brightness increases.
- If the separation of the double slits decreases, the separation of the fringes increases.
- If the width of slits is widened, the number of fringes decreases.
- If white light is used the central fringe is white and the fr [illegible] coloured.

Interference Fringe Pattern



Parallel-sided Thin Film(2)

- If light travelling in a less dense medium is reflected by a dense medium, the reflected wave is phase-shifted by π.
- If light travelling in a dense medium is reflected by a less dense medium, the reflected wave does not experience any phase shift.



Parallel sided Thin Film (3)

- Constructive interference occurs if the path difference between the two reflected light beams is

$$(n+\frac{1}{2})\lambda \qquad \text{Where } n = 0, 1, 2, \ldots$$

- Destructive interference occurs if the path difference between the two reflected light beams is

$$n\lambda \qquad \text{Where } n = 0, 1, 2, \ldots$$

- If the film has a refractive index μ then we get

$$\lambda = \frac{\lambda_o}{\mu}$$

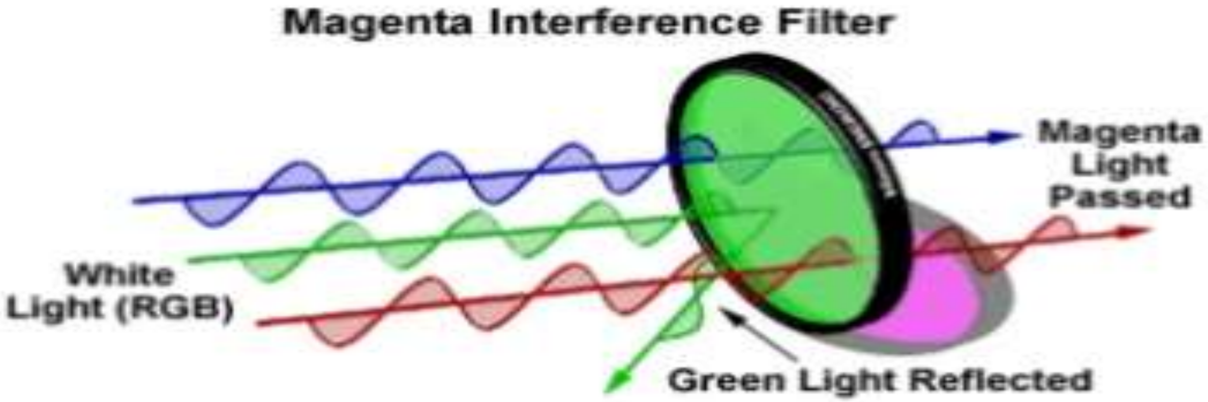
Parallel sided Thin Film (4)

- On the other hand, the part reflected at the lower surface must travel the extra distance of 2 t, where t is the thickness of the film.
- That is, $2t$ is the path difference between the two reflected beams.
- If $2t = (n+½)\ \lambda$ then constructive interference occurs.
- If $2t = n\lambda$ then destructive interference occurs.
- When t is large, several values of λ satisfy the equation. The film will appear to be generally illuminated.

Blooming of Lenses (3)

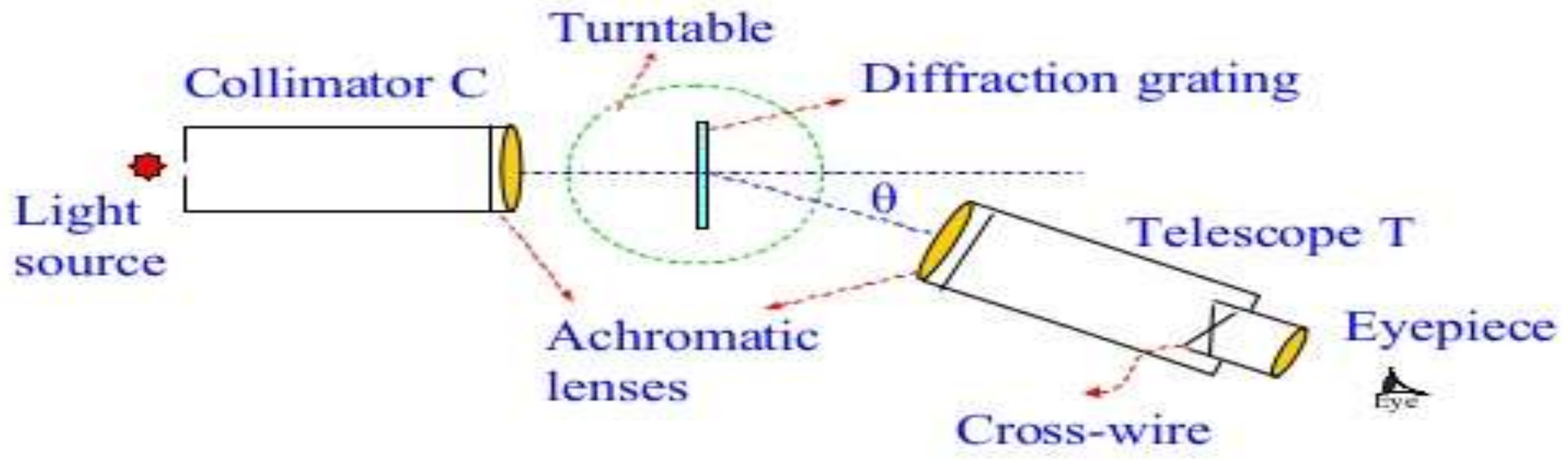
- The thickness of the film is chosen so that light reflecting from the front and rear surfaces of the film destructively interferes.
- For cancellation of reflected light,

$$2t = \frac{1}{2}\left(\frac{\lambda_o}{\mu}\right)$$



Using a diffraction grating to measure the wavelength of light

- A spectrometer is a device to measure wavelengths of light accurately using diffraction grating to separate.



Review of Quantum Mechanical concept

An equation for matter waves?

De Broglie postulated that every particles has an associated wave of wavelength:

$$\lambda = h / p$$

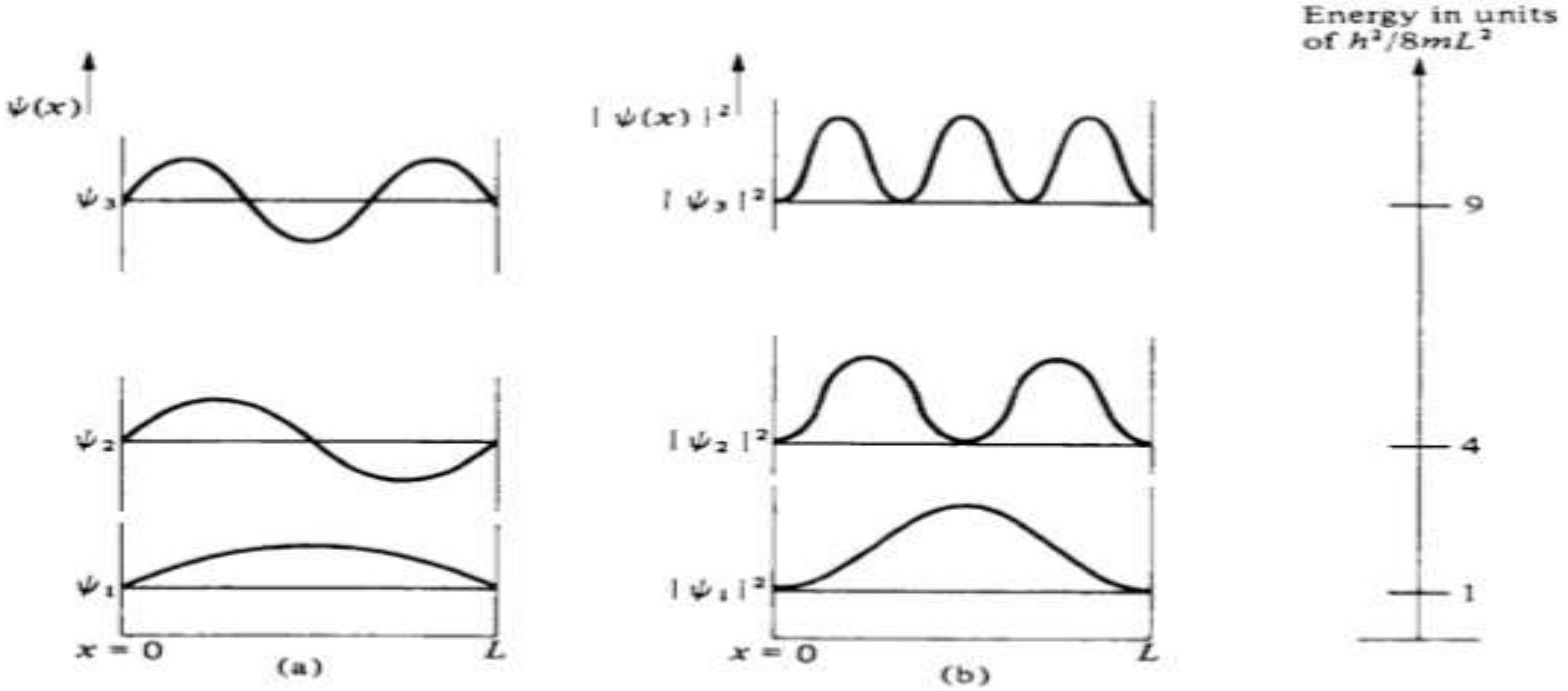
Wave nature of matter confirmed by electron diffraction studies *etc* (see earlier).

If matter has wave-like properties then there must be a mathematical function that is the solution to a differential equation that describes electrons, atoms and molecules.

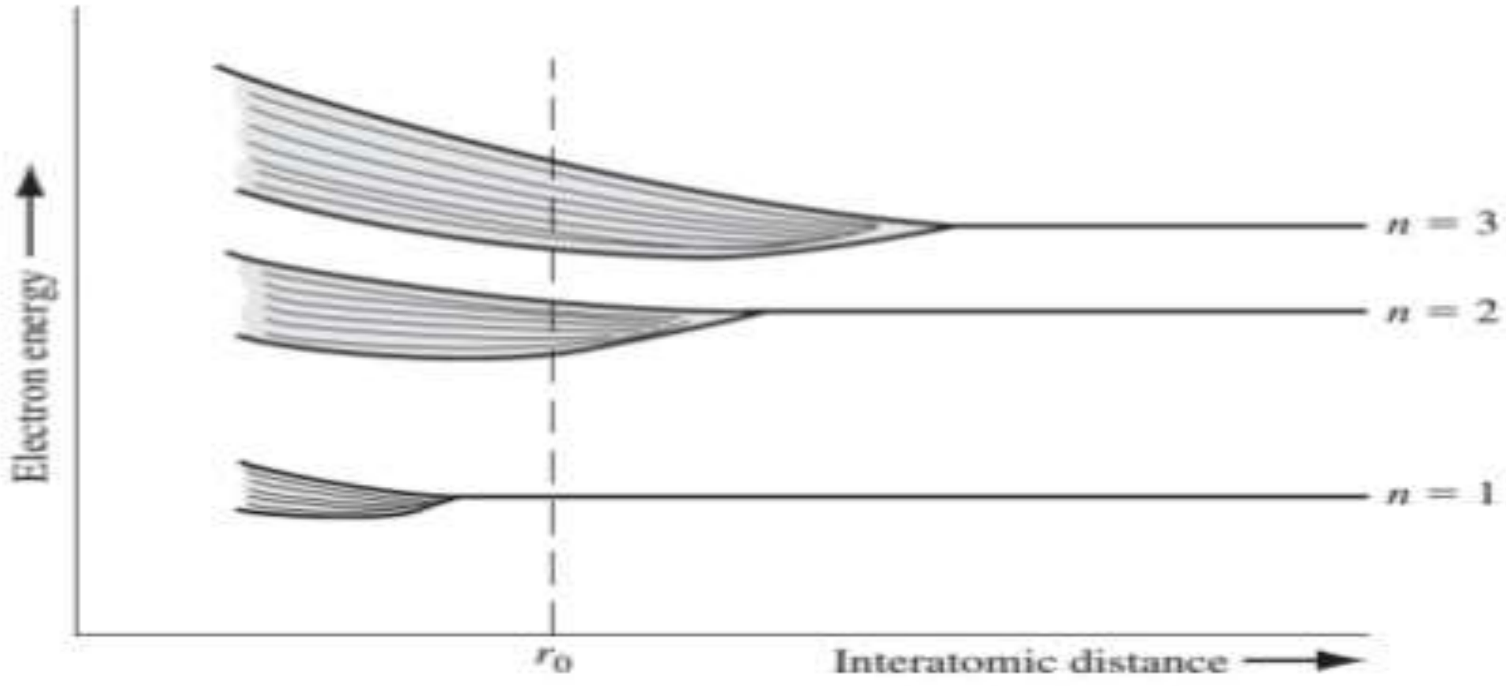
The differential equation is called the *Schrödinger equation* and its solution is called the *wavefunction*, Ψ.

What is the form of the *Schrödinger equation* ?

Electron wave function of first 3 states

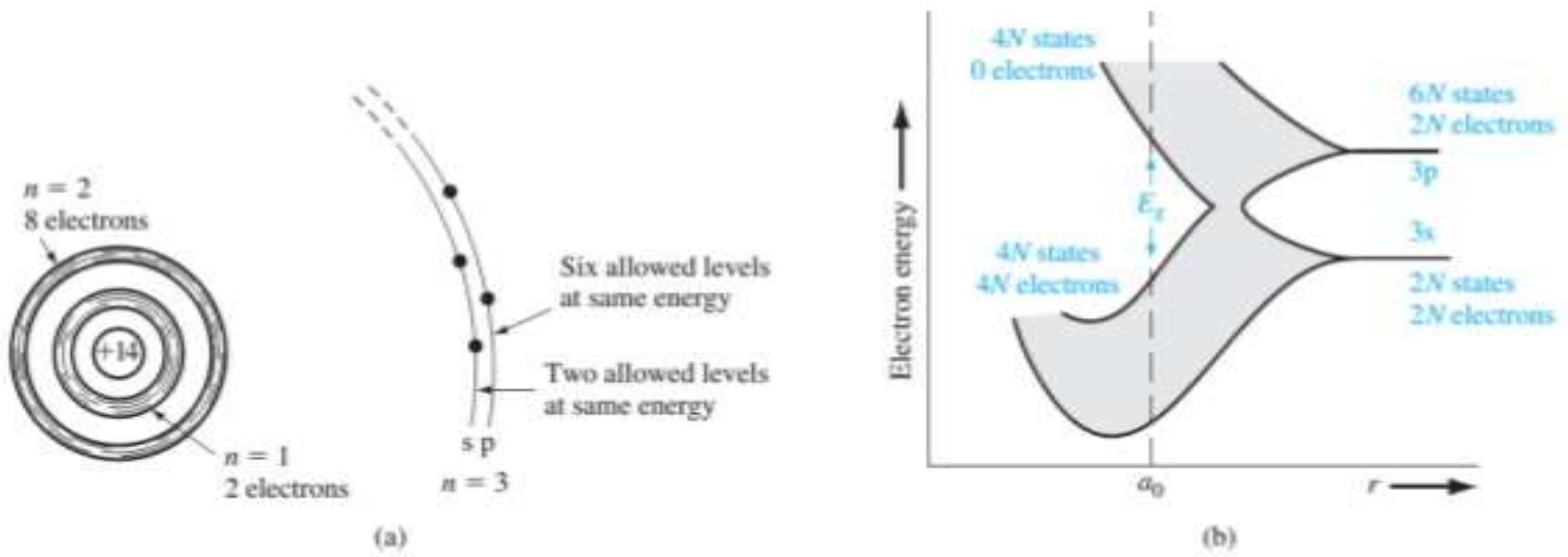


Energy band diagram of more than one electron of an atom



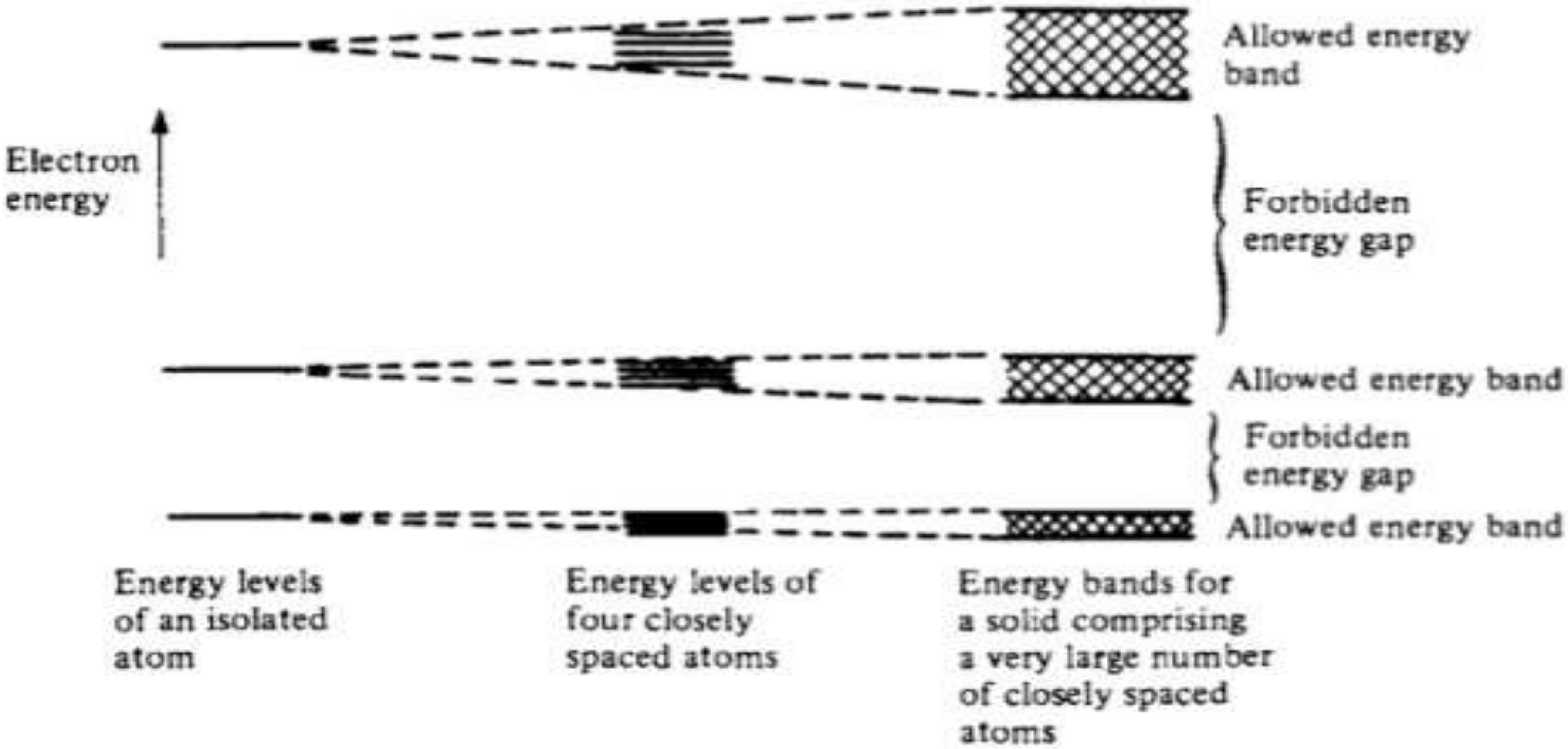
Splitting of 3 energy states into allowed band of energy

Isolated silicon and silicon crytal



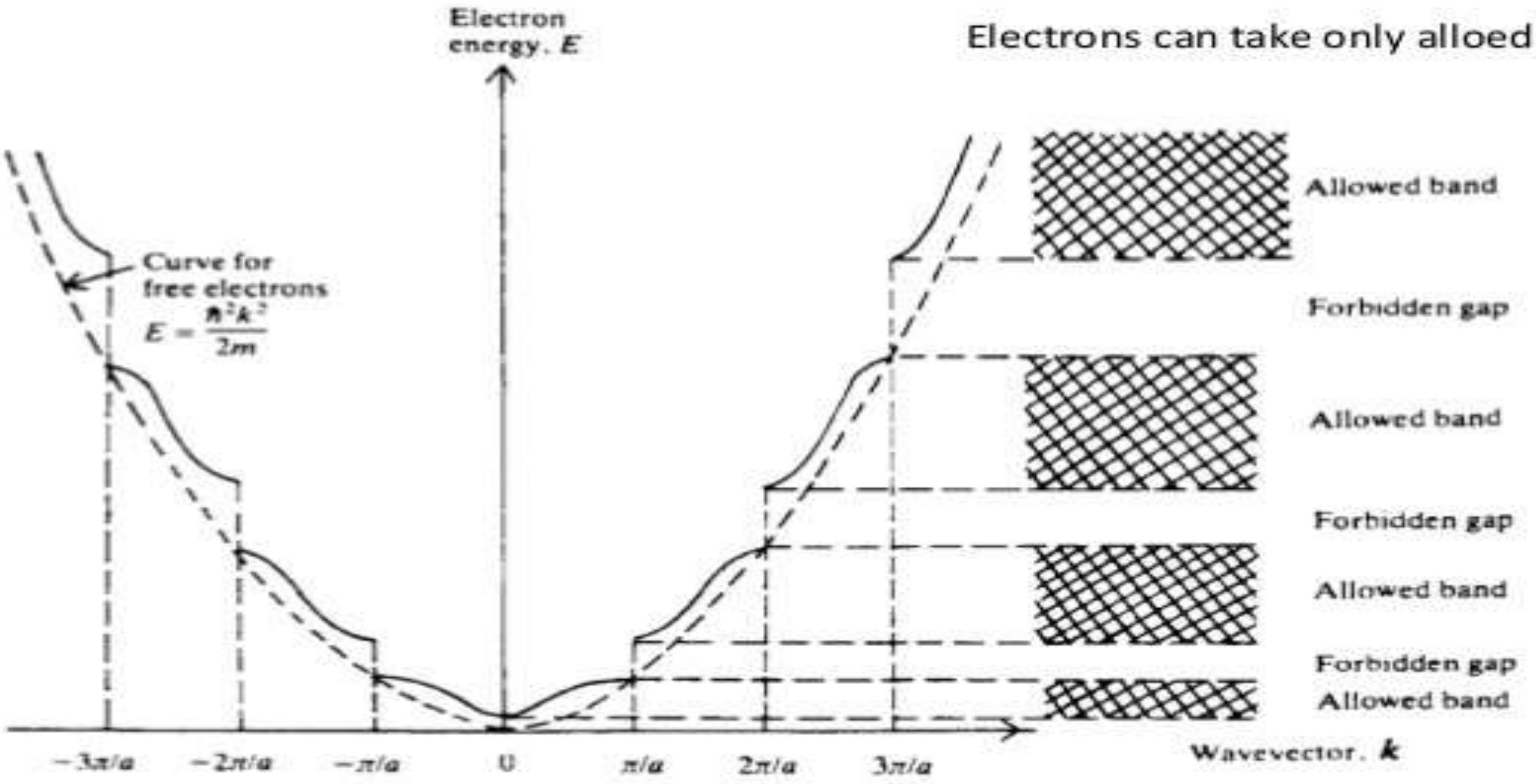
Valence band electrons are losely bound
N=1,2 are full occupied gets less interaction

Energy levels of interfacing atoms forms energy bands in solids

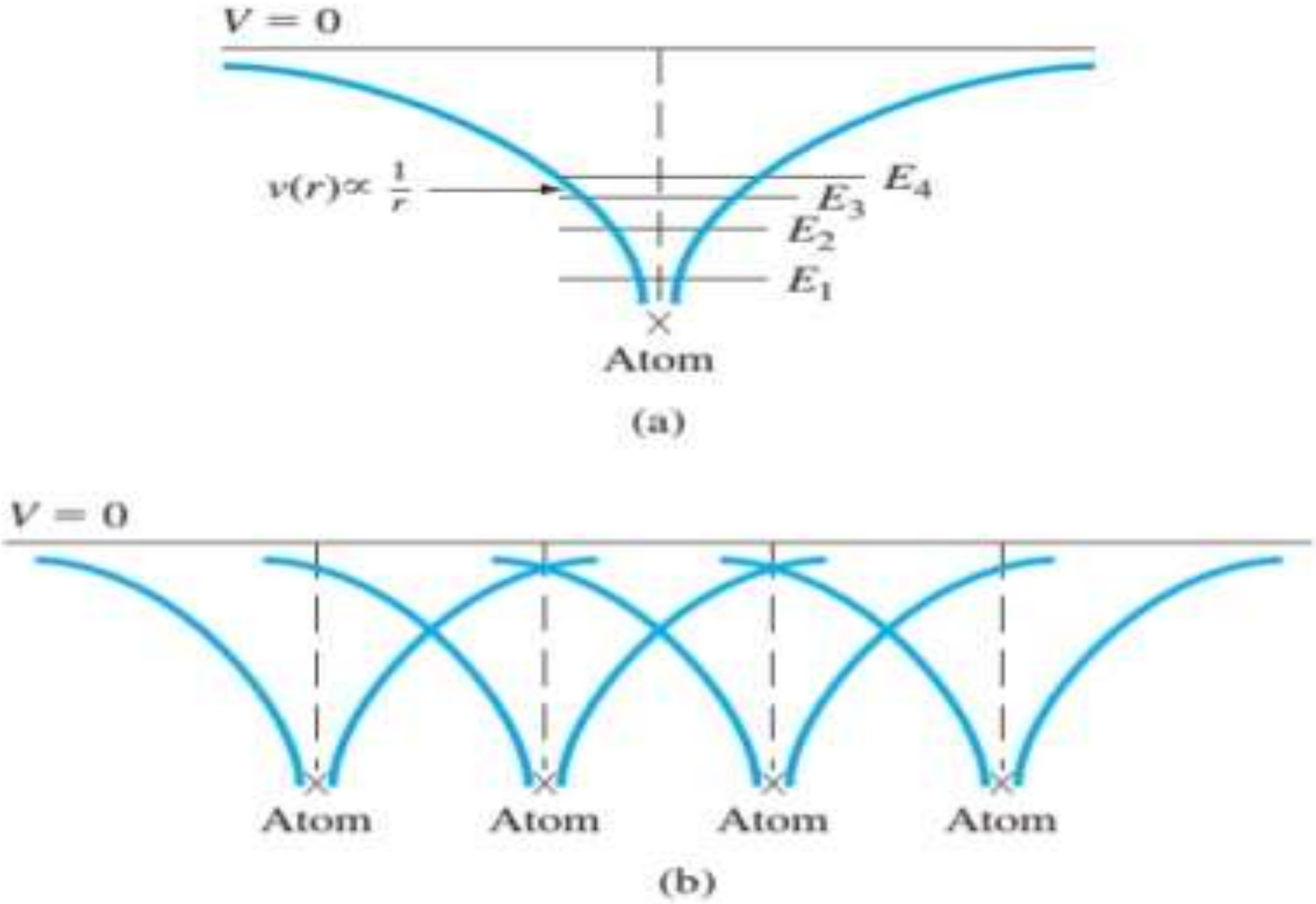


E-K relationship of the Kronig-Penny model and the energy band strcuture

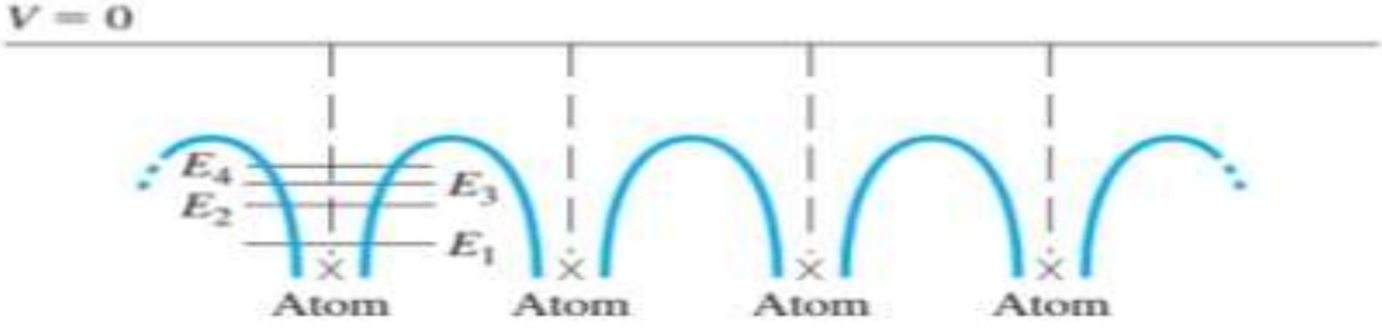
Electrons can take only alloed energy va

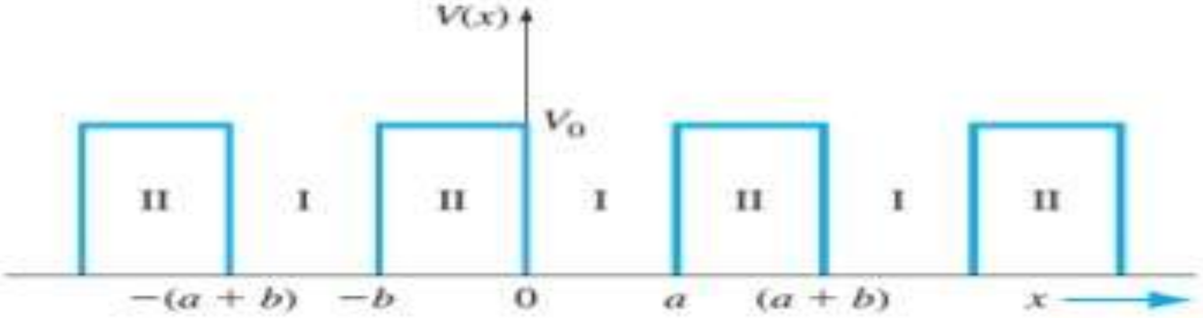


Potential function of single isolated atom and overlapping of adjacent atom



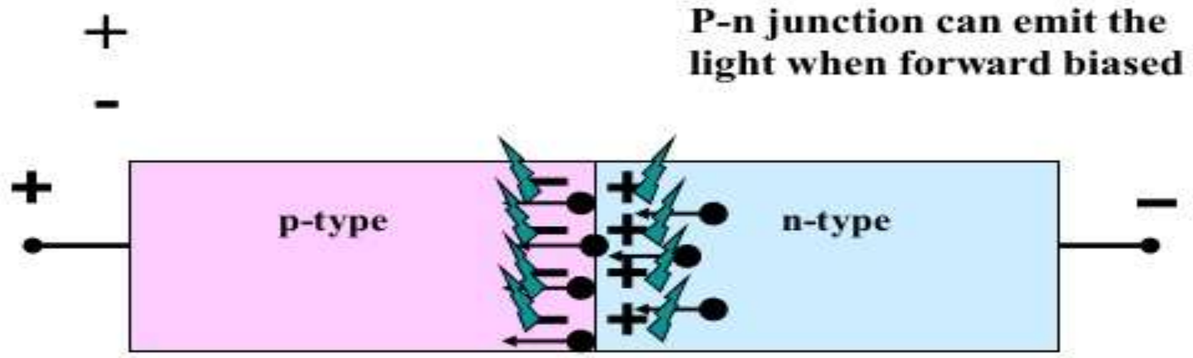
Net potential function of one dimensional single crytal





One dimensional periodic function of kroneg penny mod

p- n diode applications:
Light emitters



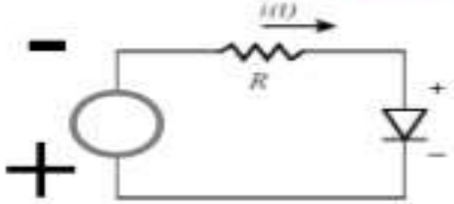
Electrons drift into p-material and find plenty of holes there. They "RECOMBINE" by filling up the "empty" positions.

Holes drift into n-material and find plenty of electrons there. They also "RECOMBINE" by filling up the "empty" positions.

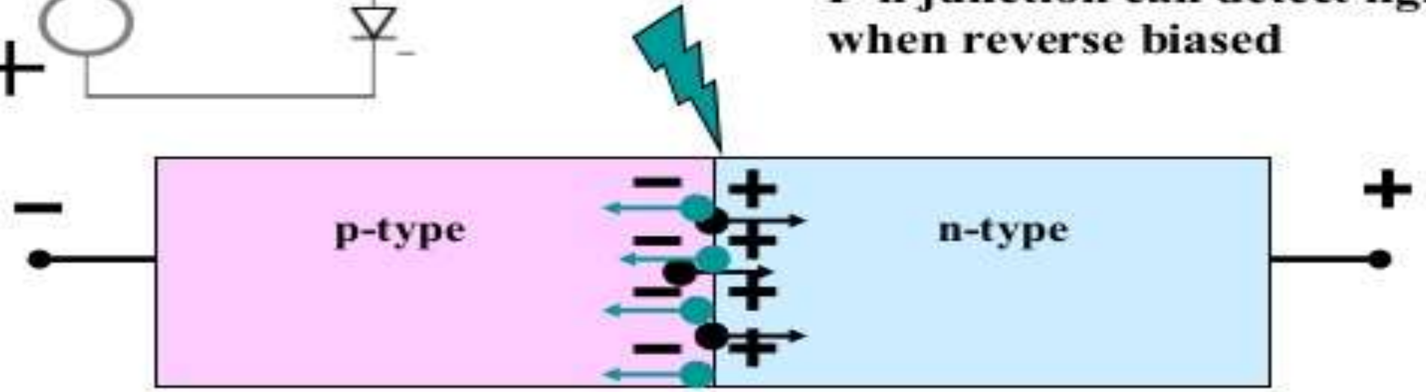
The energy released in the process of "annihilation" produces

PHOTONS – the particles of light

p- n diode applications: Photodetectors



P-n junction can detect light when reverse biased



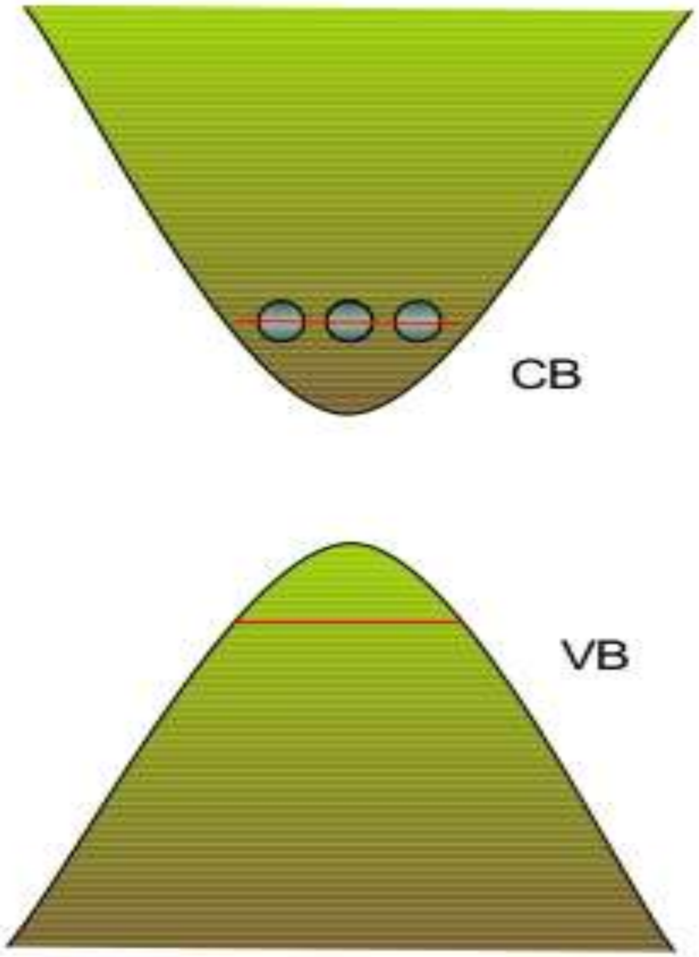
When the light illuminates the p-n junction, the photons energy RELEASES free electrons and holes.

They are referred to as PHOTO-ELECTRONS and PHOTO-HOLES

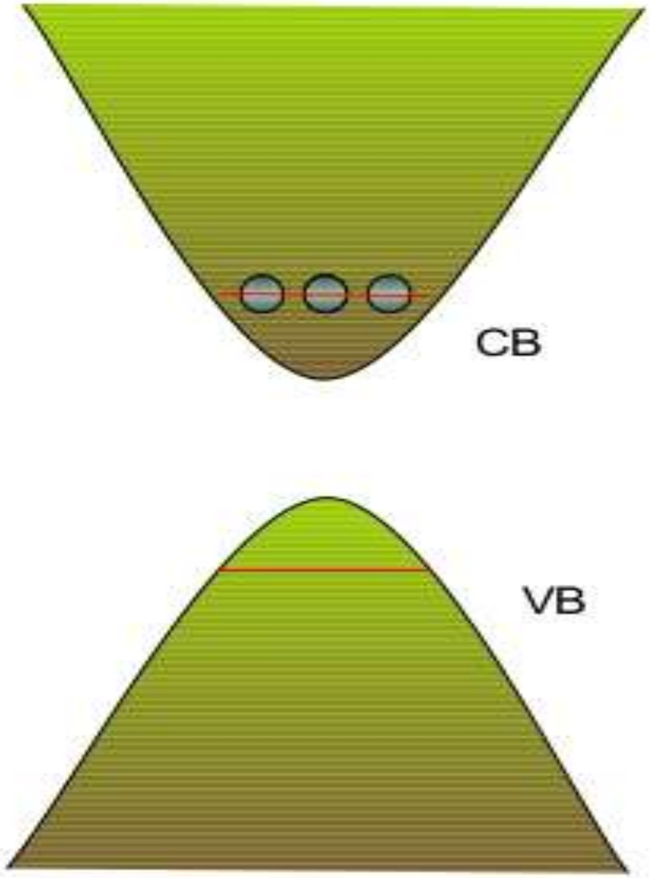
The applied voltage separates the photo-carriers attracting electrons toward "plus" and holes toward "minus"

As long as the light is ON, there is a current flowing through the p-n junction

When the electron falls down from conduction band and fills in a hole in valence band, there is an obvious loss of energy.



In order to achieve a reasonable efficiency for photon emission, the semiconductor must have a direct band gap.



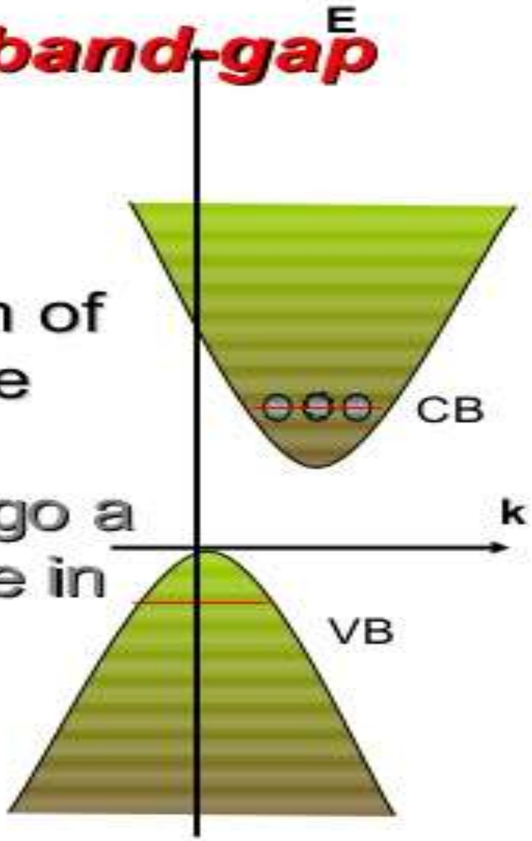
For example;

Silicon is known as an ***indirect band-gap material.***

What this means is that

as an electron goes from the bottom of the conduction band to the top of the valence band;

it must also undergo a significant change in momentum.



- As we all know, whenever something changes state, one must conserve not only energy, but also momentum.
- In the case of an electron going from conduction band to the valence band in silicon, both of these things can only be conserved:

The transition also creates a quantized set of lattice vibrations, called phonons, or "heat“ .

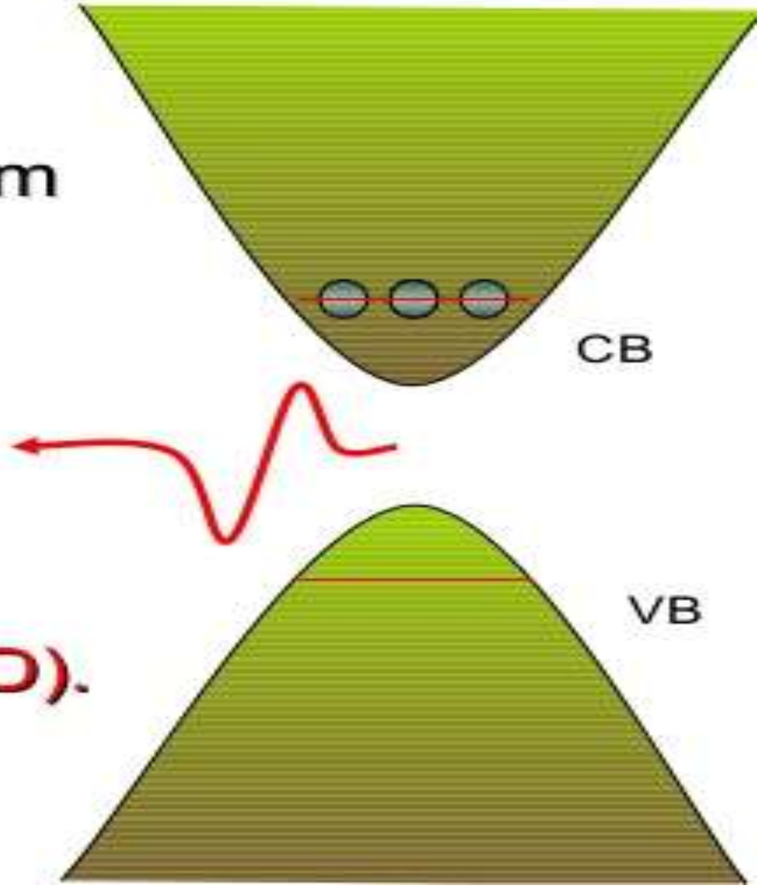
- Phonons possess both energy and momentum.
- Their creation upon the recombination of an electron and hole allows for complete conservation of both energy and momentum.
- All of the energy which the electron gives up in going from the conduction band to the valence band (1.1 eV) ends up in phonons, which is another way of saying that the electron heats up the crystal.

In a class of materials called ***direct band-gap semiconductors***;

» the transition from conduction band to valence band involves essentially **no change in momentum**.

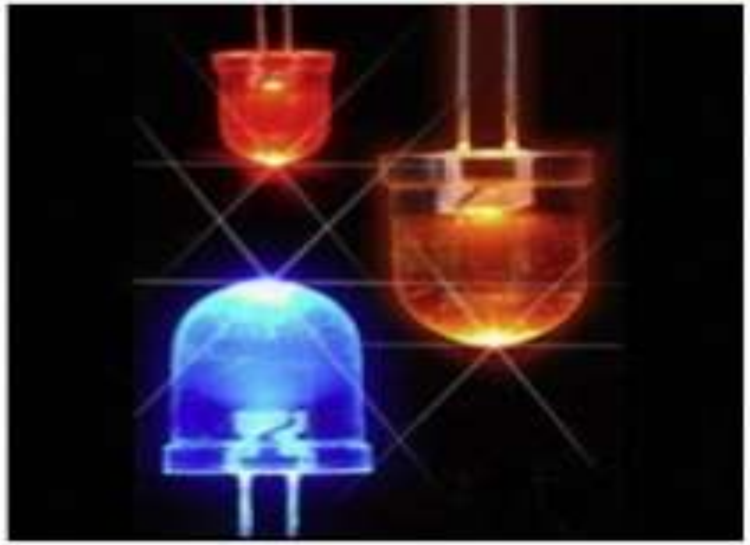
» Photons, it turns out, possess a fair amount of energy (several eV/photon in some cases) but they have very little momentum associated with them.

- Thus, for a direct band gap material, the excess energy of the electron-hole recombination can either be taken away as heat, or more likely, as a photon of light.
- This radiative transition then conserves energy and momentum by giving off light whenever an electron and hole recombine.



This gives rise to (for us) a new type of device;
the light emitting diode (LED).

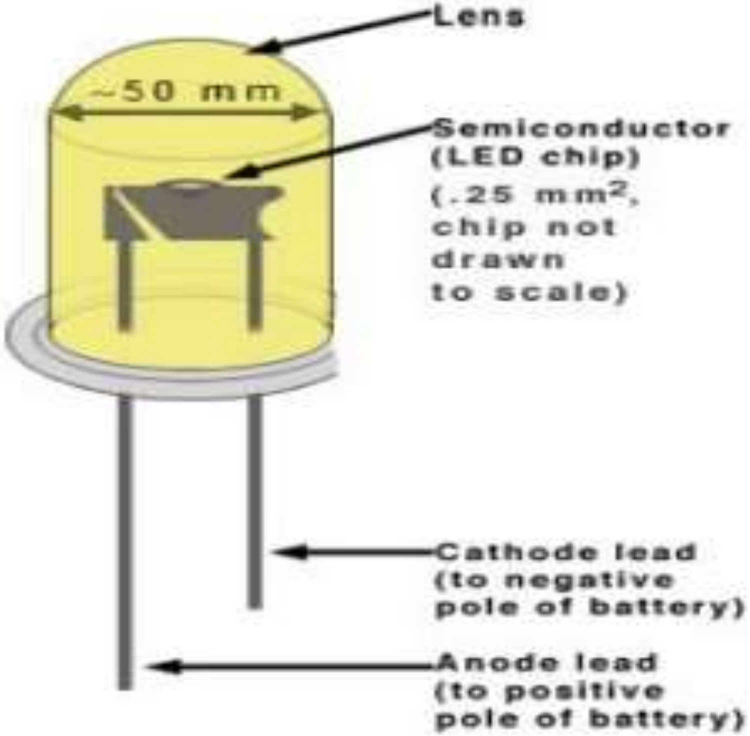
What is LED?



Semiconductors
bring quality
to light!

LED are semiconductor p-n junctions that under forward bias conditions can emit radiation by electroluminescence in the UV, visible or infrared regions of the electromagnetic spectrum. The qaunta of light energy released is approximately proportional to the band gap of the semiconductor.

Getting to know LED



Advantages of Light Emitting Diodes (LEDs)

Longevity:

The light emitting element in a diode is a small conductor chip rather than a filament which greatly extends the diode's life in comparison to an incandescent bulb (10 000 hours life time compared to ~1000 hours for incandescence light bulb)

Efficiency:

Diodes emit almost no heat and run at very low amperes.

Greater Light Intensity:

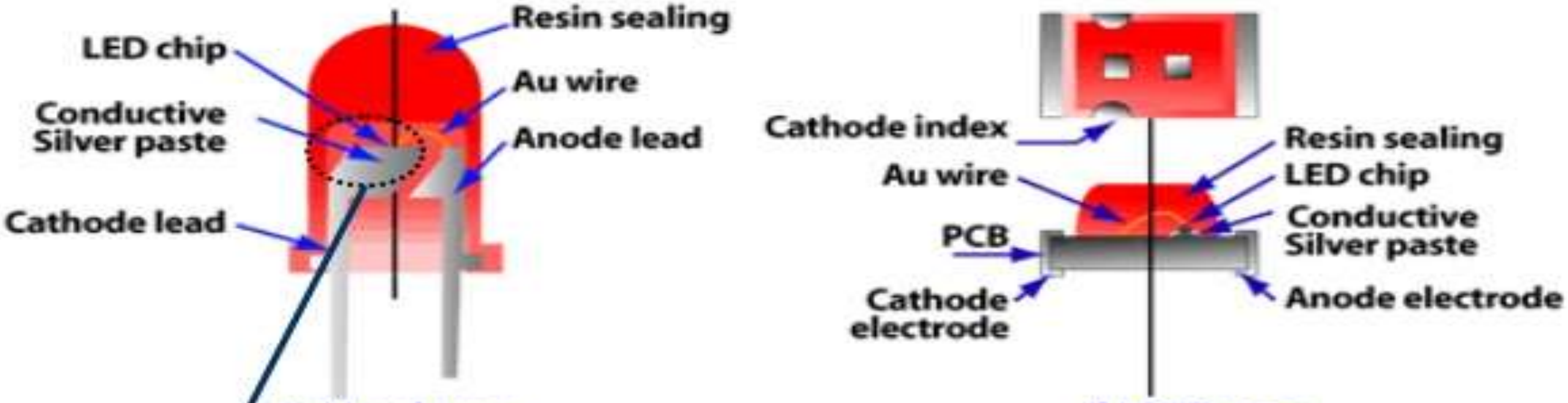
Since each diode emits its own light

Cost:

Not too bad

Robustness:

Solid state component, not as fragile as incandescence light bulb



(a) Lead-type

(b) SMD-type

LED chip is the part
that we shall deal
with in this course

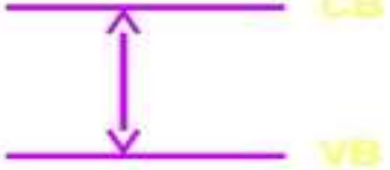
Luminescence is the process behind light emission

- Luminescence is a term used to describe the emission of radiation from a solid when the solid is supplied with some form of energy.
- Electroluminescence → excitation results from the application of an electric field
- In a p-n junction diode injection electroluminescence occurs resulting in light emission when the junction is forward biased

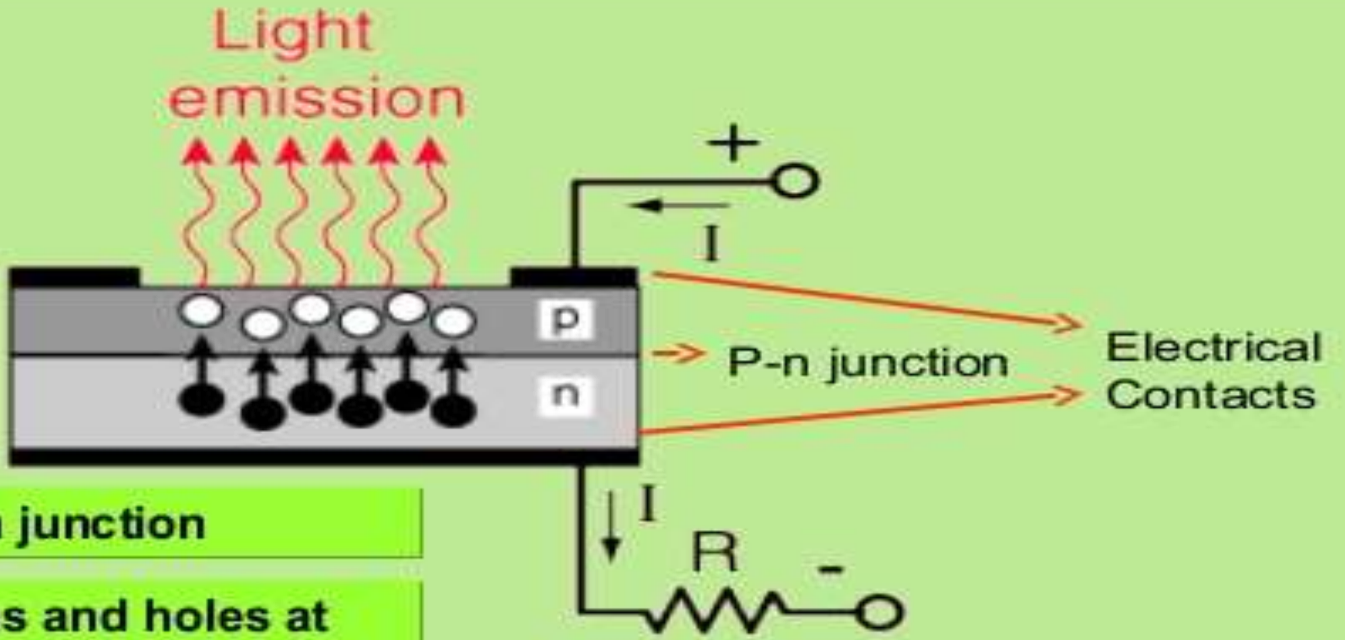
Producing photon

Electrons recombine with holes.

Energy of photon is the energy of band gap.



How does it work?



A typical LED needs a p-n junction

There are a lot of electrons and holes at the junction due to excitations

Electrons from n need to be injected to p to promote recombination

Junction is biased to produce even more e-h and to inject electrons from n to p for recombination to happen

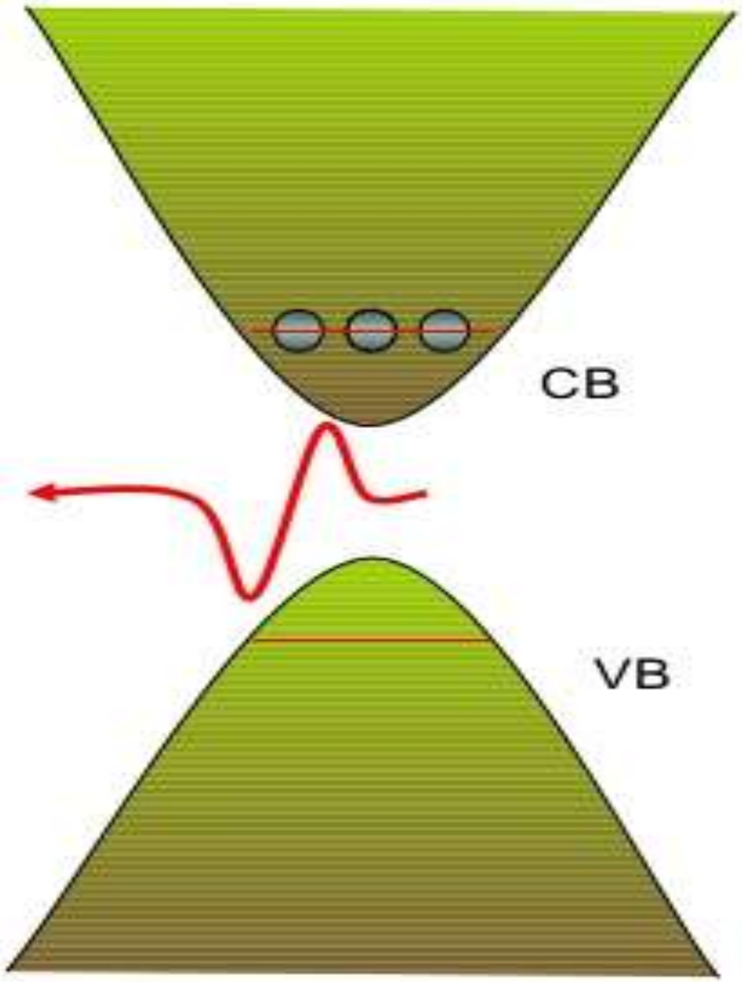
Recombination produces light!!

Injection Luminescence in LED

- Under forward bias – majority carriers from both sides of the junction can cross the depletion region and entering the material at the other side.
- Upon entering, the majority carriers become minority carriers
- For example, electrons in n-type (majority carriers) enter the p-type to become minority carriers
- The minority carriers will be larger → minority carrier injection
- Minority carriers will diffuse and recombine with the majority carrier.
- For example, the electrons as minority carriers in the p-region will recombine with the holes. Holes are the majority carrier in the p-region.
- The recombination causes light to be emitted
- Such process is termed radiative recombination.

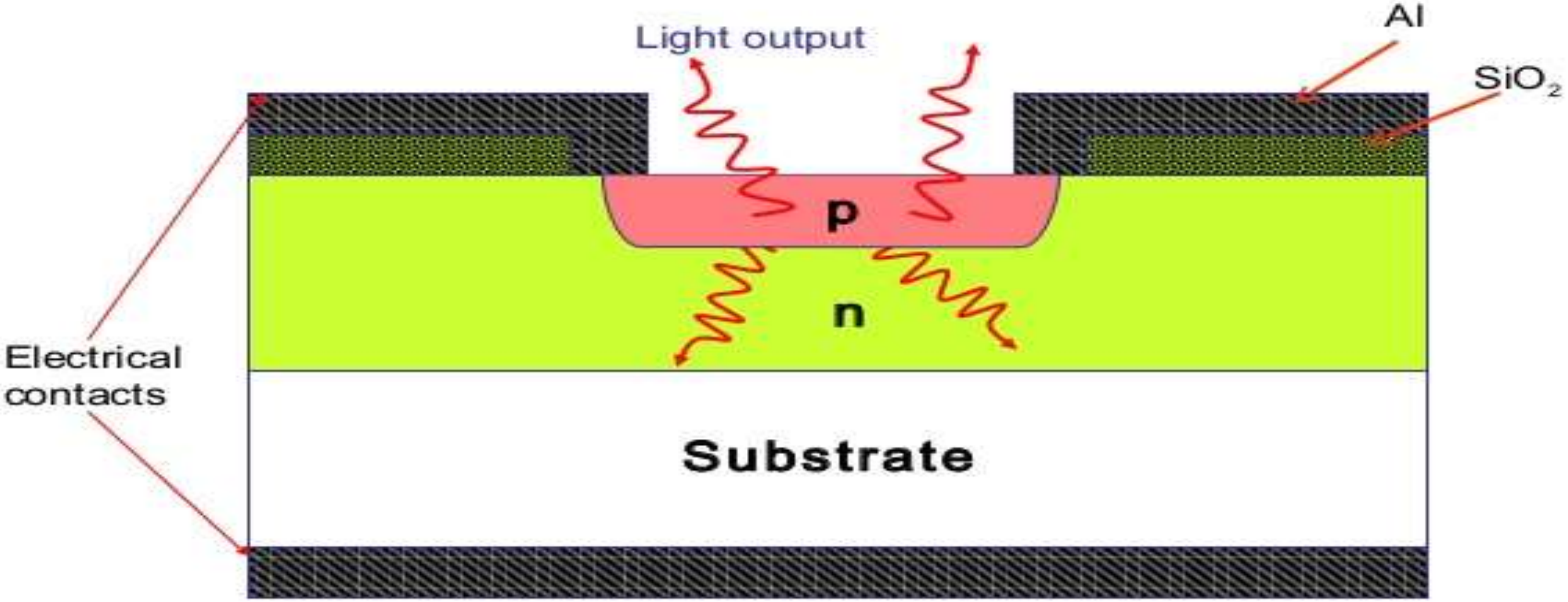
MATERIALS FOR LEDS

- The semiconductor bandgap energy defines the energy of the emitted photons in a LED.
- To fabricate LEDs that can emit photons from the infrared to the ultraviolet parts of the e.m. spectrum, then we must consider several different material systems.
- No single system can span this energy band at present, although the 3-5 nitrides come close.



- Unfortunately, many of potentiallly useful 2-6 group of direct band-gap semiconductors (ZnSe,ZnTe,etc.) come naturally doped either p-type, or n-type, but they don't like to be type-converted by overdoping.
- The material reasons behind this are complicated and not entirely well-known.
- The same problem is encountered in the 3-5 nitrides and their alloys InN, GaN, AlN, InGaN, AlGaN, and InAlGaN. The amazing thing about 3-5 nitride alloy systems is that appear to be direct gap throughout.

Construction of Typical LED



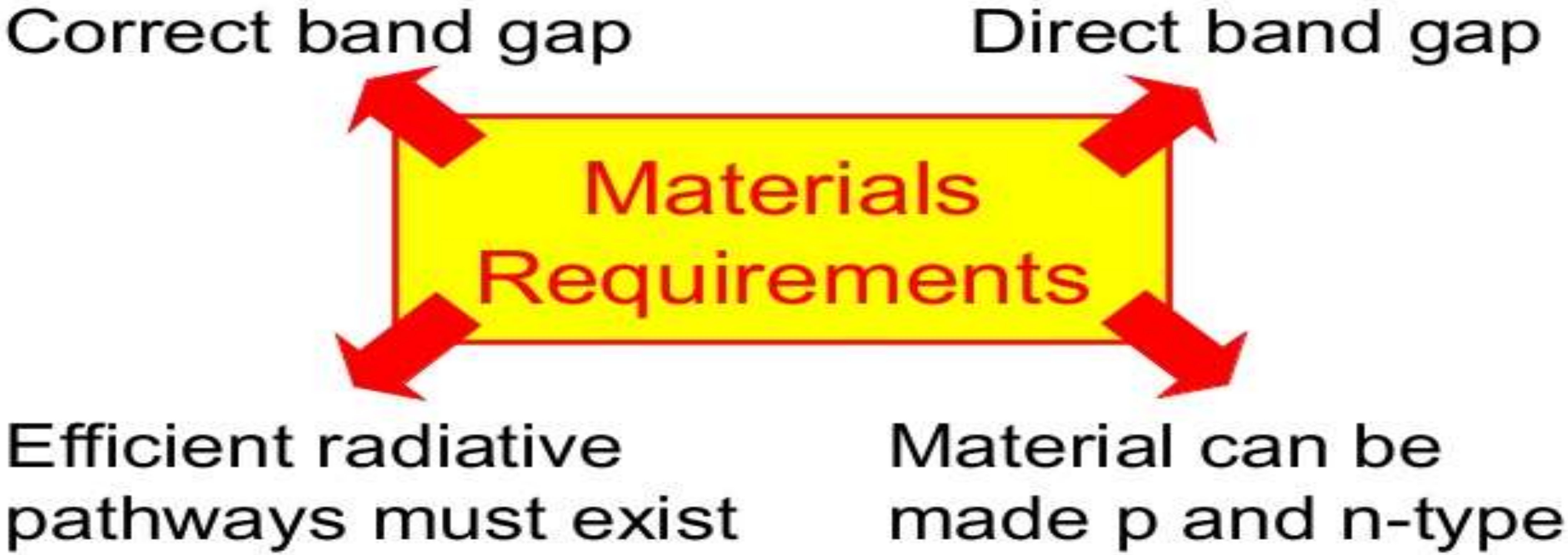
LED Construction

- Efficient light emitter is also an efficient absorbers of radiation therefore, a shallow p-n junction required.
- Active materials (n and p) will be grown on a lattice matched substrate.
- The p-n junction will be forward biased with contacts made by metallisation to the upper and lower surfaces.
- Ought to leave the upper part 'clear' so photon can escape.
- The silica provides passivation/device isolation and carrier confinement

Efficient LED

- Need a **p-n junction** (preferably the same semiconductor material only different dopants)
- **Recombination must occur** → Radiative transmission to give out the ‘right coloured LED’
- ‘Right coloured LED’ → $\mathbf{hc/\lambda = E_c - E_v = E_g}$

  → **so choose material with the right $\mathbf{E_g}$**
- **Direct band gap** semiconductors to allow efficient recombination
- All photons created must be able to leave the semiconductor
- Little or **no reabsorption** of photons


Correct band gap
Direct band gap
Materials Requirements
Efficient radiative pathways must exist
Material can be made p and n-type

Direct band gap materials

e.g. GaAs not Si

UV-ED λ ~0.5-400nm

E_g > 3.25eV

→ LED - λ ~450-650nm

E_g = 3.1eV to 1.6eV

→ IR-ED- λ ~750nm- 1nm

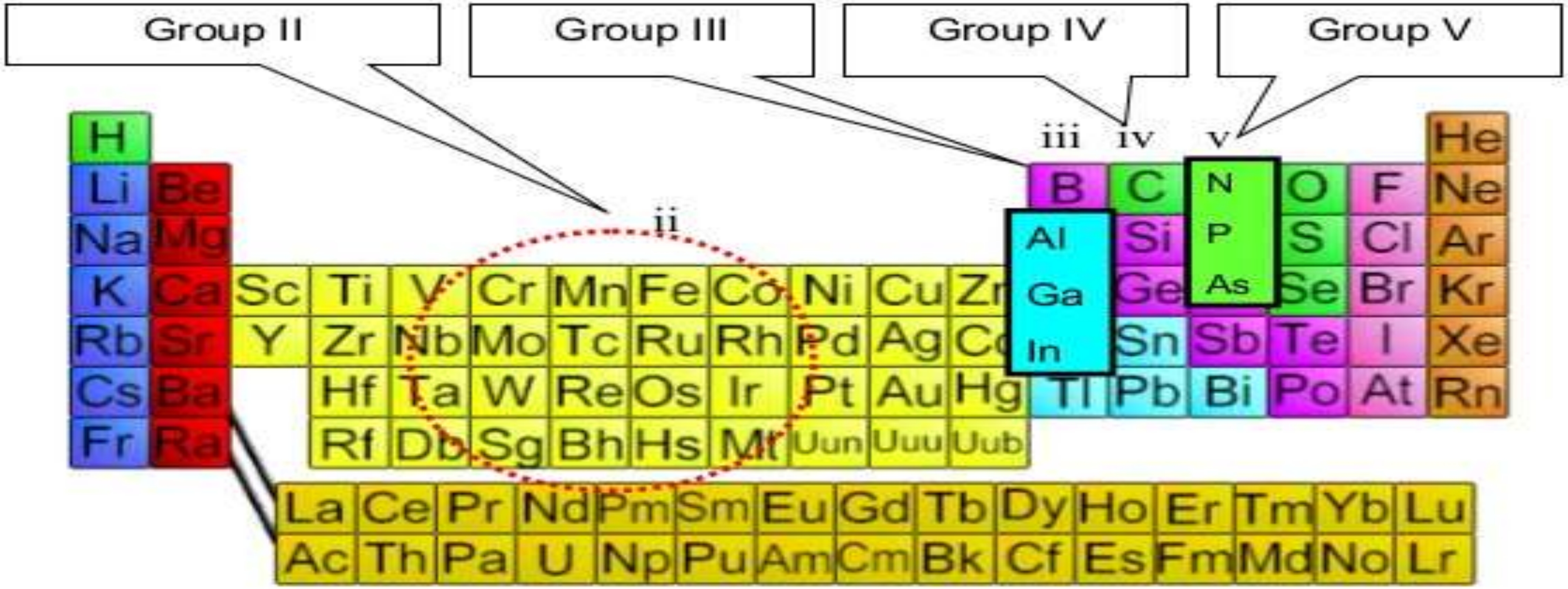
Eg = 1.65eV

Candidate Materials

Materials with refractive index that could allow light to 'get out'

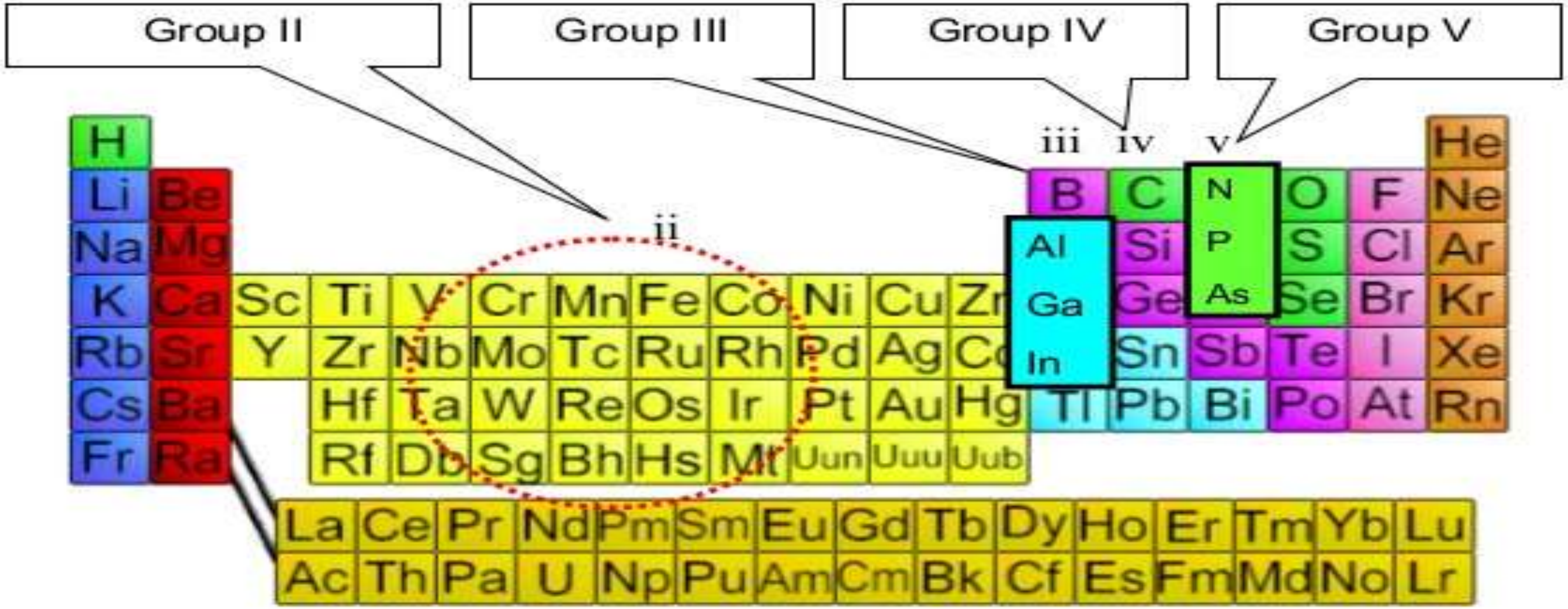
Readily doped n or p-types

Candidate Materials
Group III-V & Group II-VI



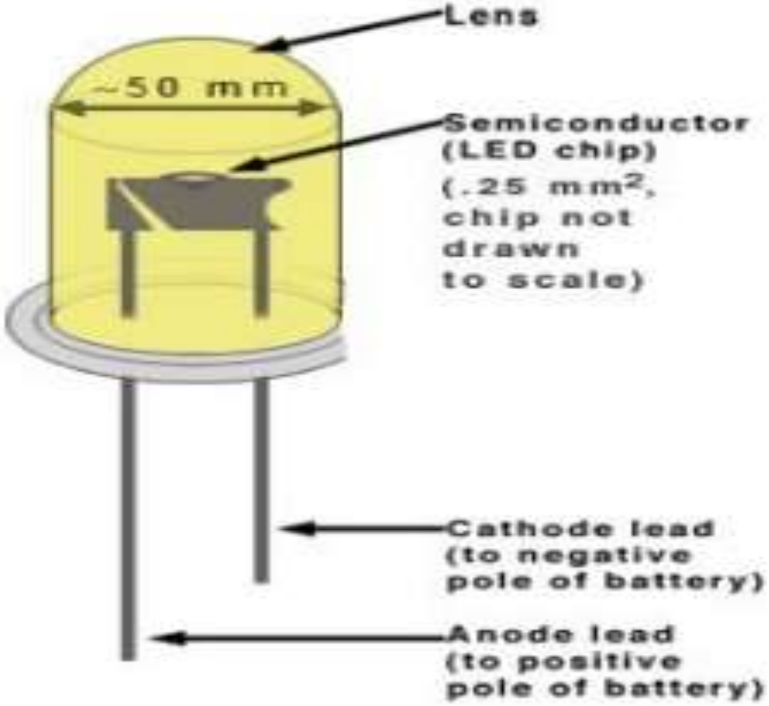
Periodic Table to show group III-V and II-V binaries

Candidate Materials
Group III-V & Group II-VI



Color Name	Wavelength (Nanometers)	Semiconductor Composition
Infrared	880	GaAlAs/GaAs
Ultra Red	660	GaAlAs/GaAlAs
Super Red	633	AlGaInP
Super Orange	612	AlGaInP
Orange	605	GaAsP/GaP
Yellow	585	GaAsP/GaP
Incandescent White	4500K (CT)	InGaN/SiC
Pale White	6500K (CT)	InGaN/SiC
Cool White	8000K (CT)	InGaN/SiC
Pure Green	555	GaP/GaP
Super Blue	470	GaN/SiC
Blue Violet	430	GaN/SiC
Ultraviolet	395	InGaN/SiC

Getting to know LED



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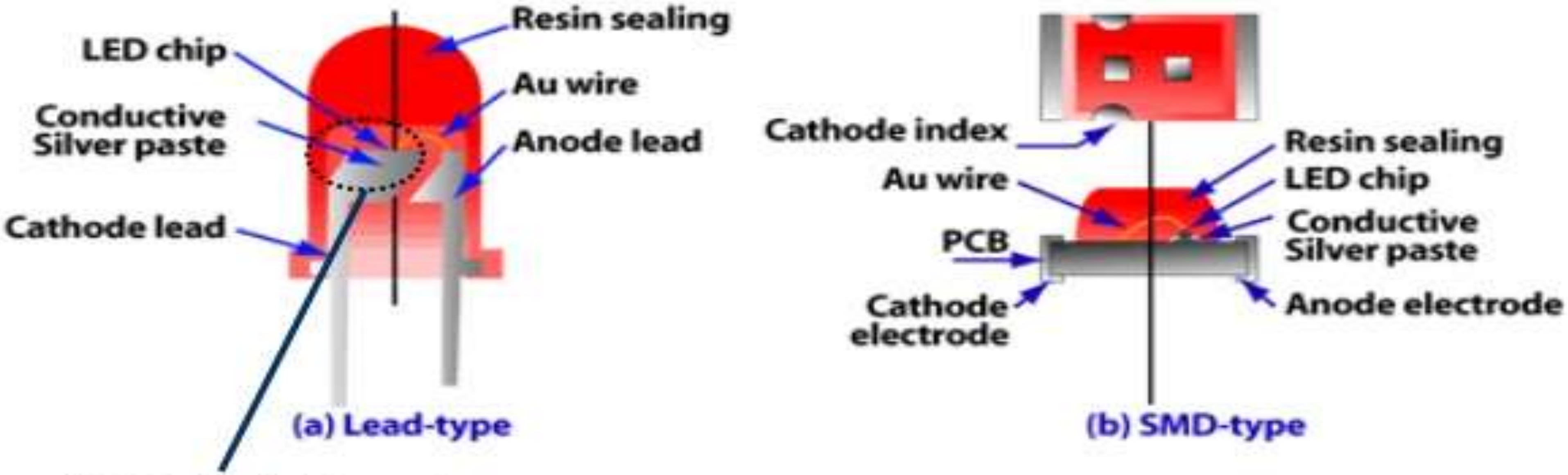


LED chip is the part
that we shall deal
with in this course

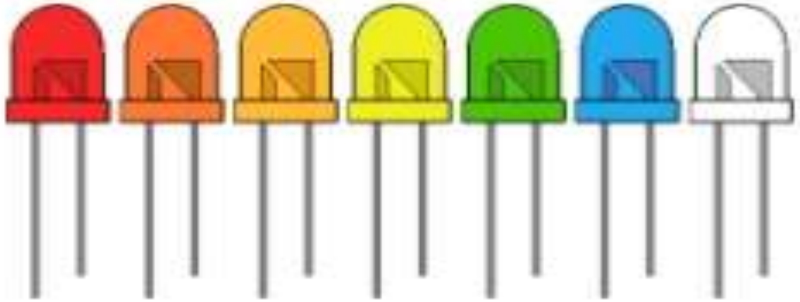
Some Types of LEDs

Bargraph

7-segment

Starburst

Dot matrix



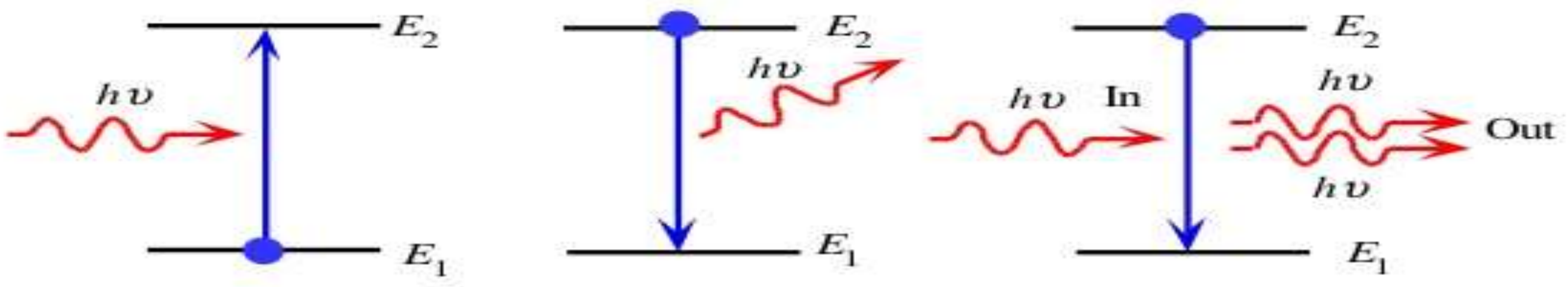
Applications of LEDs

LASER

- What is the word LASER stands for?

- Light amplification by Stimulated Emission of Radiation

Stimulated Emission

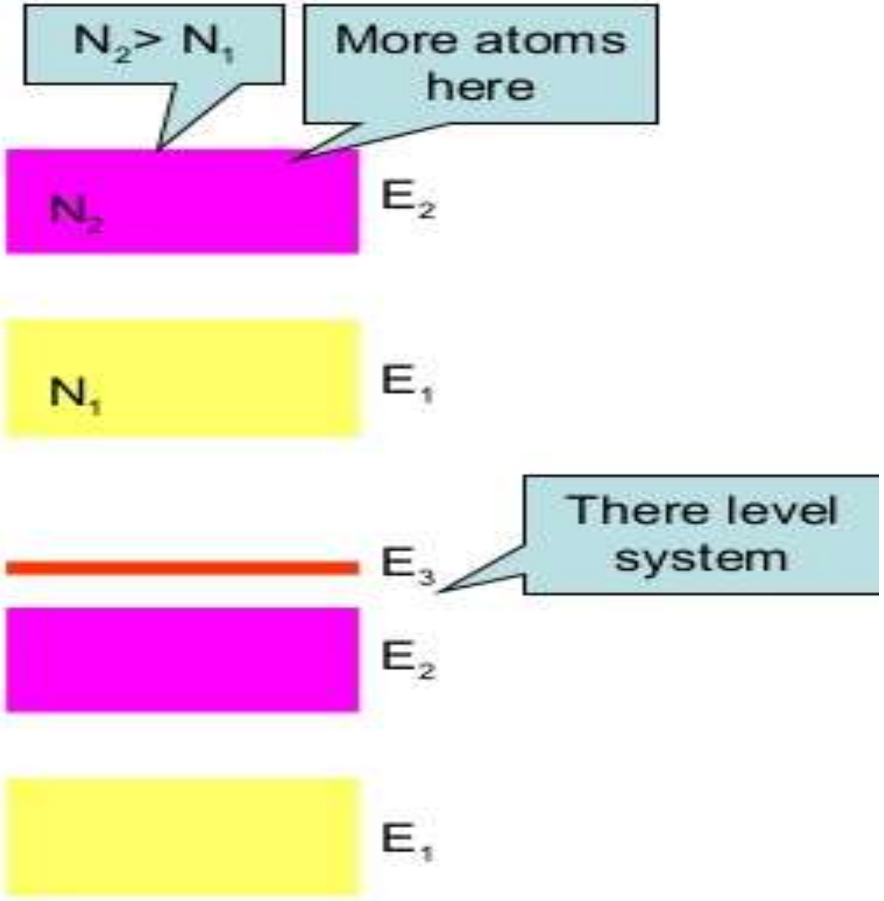


(a) Absorption (b) Spontaneous emission (c) Stimulated emission

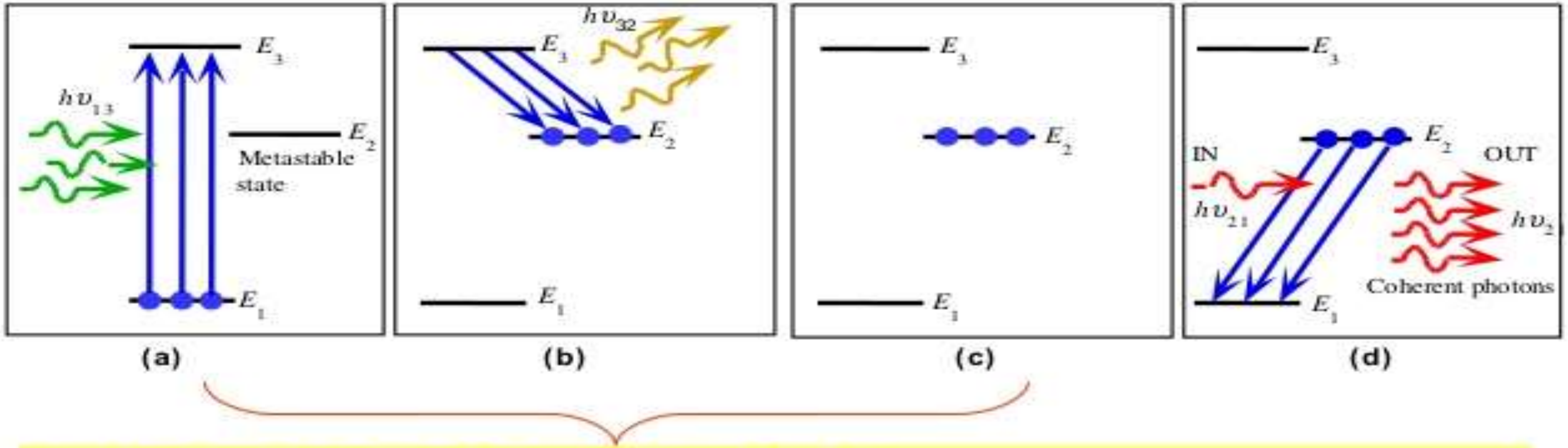
- In stimulated emission, an incoming photon with energy $h\upsilon$ stimulates the emission process by inducing electrons in E_2 to transit down to E_1.
- While moving down to E_1, photon of the same energy $h\upsilon$ will be emitted
- Resulting in 2 photons coming out of the system
- Photons are amplified – one incoming photon resulting in two photons coming out

Population Inversion

- Non equilibrium distribution of atoms among the various energy level atomic system
- To induce more atoms in E_2, i.e. to **create population inversion**, a large amount of energy is required to excite atoms to E_2
- The excitation process of atoms so $N_2 > N_2$ is called **pumping**
- It is difficult to attain pumping when using two-level-system.
- Require 3-level system instead



Principles of Laser



- In actual case, excite atoms from E_1 to E_3.
- Exciting atoms from E_1 to E_3 → optical pumping
- Atoms from E_3 decays rapidly to E_2 emitting $h\upsilon_3$
- If E_2 is a **long lived state**, atoms from E_2 will not decay to E_1 rapidly
- Condition where there are a lot of atoms in E_2 → population inversion achieved! i.e. between E_2 and E_1.

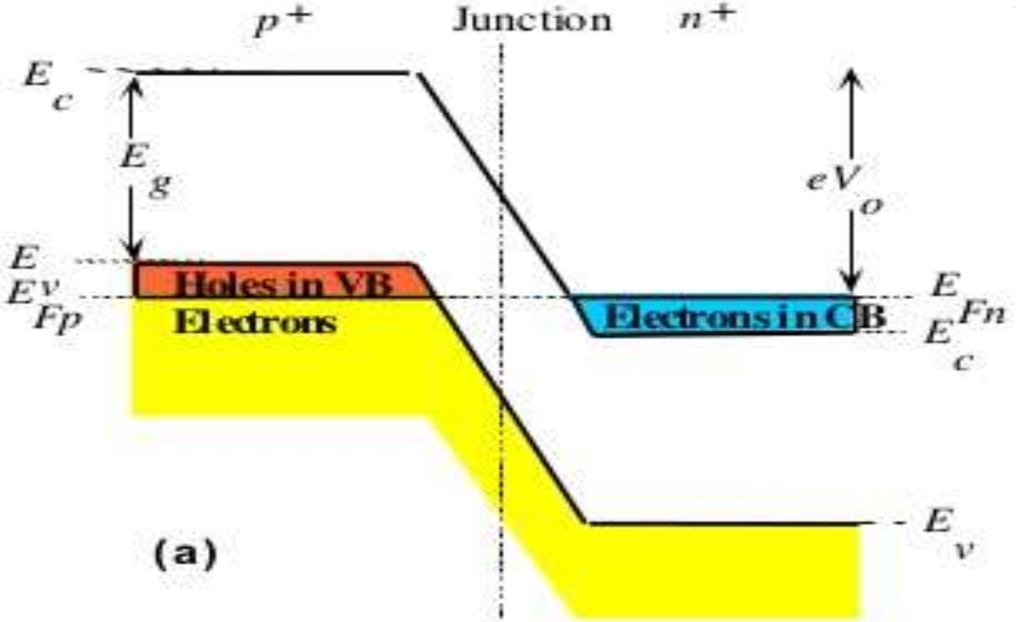
Coherent Photons Production (explanation of (d))

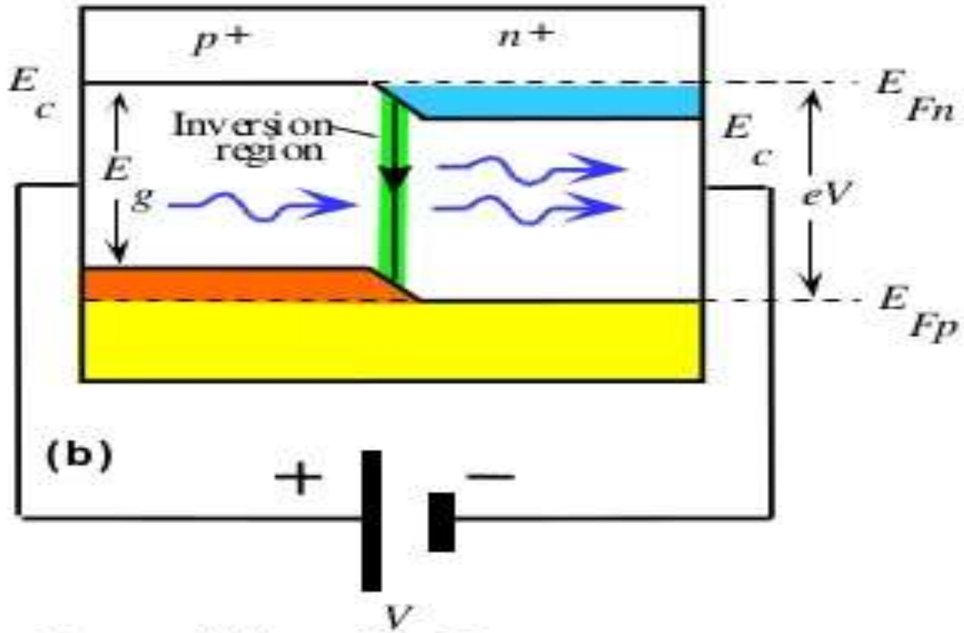
- When one atom in E_2 decays spontaneously, a random photon resulted which will induce stimulated photon from the neighbouring atoms
- The photons from the neighbouring atoms will stimulate their neighbours and form avalanche of photons.
- Large collection of coherent photons resulted.

Laser Diode Principle

- Consider a p-n junction
- In order to design a laser diode, the p-n junction must be **heavily doped**.
- In other word, the p and n materials must be **degenerately doped**
- By degenerated doping, the Fermi level of the n-side will lies in the conduction band whereas the Fermi level in the p-region will lie in the valance band.

Diode Laser Operation





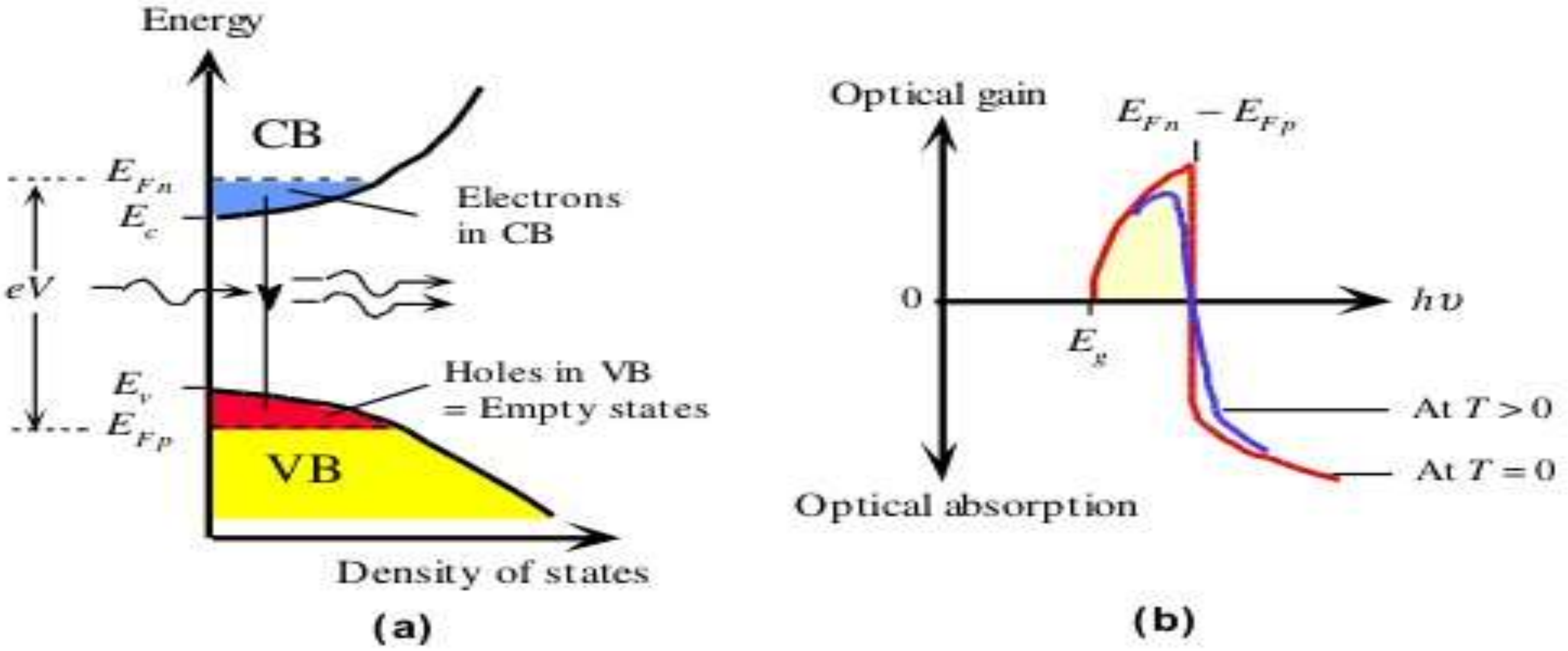
- P-n junction must be degenerately doped.
- Fermi level in valance band (p) and conduction band (n).
- No bias, built n potential; eV_o barrier to stop electron and holes movement

- Forward bias, $eV > E_g$
- Built in potential diminished to zero
- Electrons and holes can diffuse to the space charge layer

Application of Forward Bias

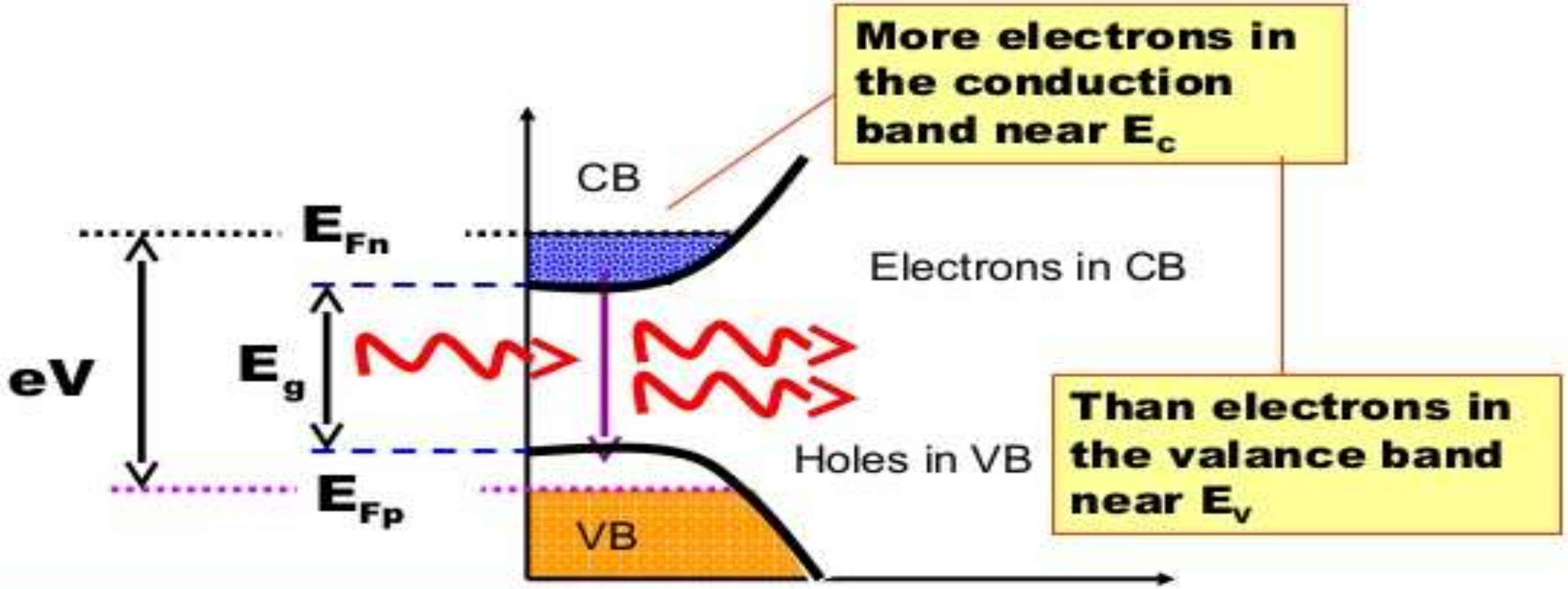
- Suppose that the degenerately doped p-n junction is forward biased by a voltage greater than the band gap; $eV > E_g$
- The separation between E_{Fn} and E_{Fp} is now the applied potential energy
- The applied voltage diminished the built-in potential barrier, eV_o to almost zero.
- Electrons can now flow to the p-side
- Holes can now flow to the n-side

Population Inversion in Diode Laser



(a) The density of states and energy distribution of electrons and holes in the conduction and valence bands respectively at $T \approx 0$ in the SCL under forward bias such that $E_{Fn} - E_{Fp} > E_g$. Holes in the VB are empty states. (b) Gain vs. photon energy.

Population Inversion in Diode Laser



E_{Fn}-E_{fp} = eV

eV > E_g

eV = forward bias voltage

Fwd Diode current pumping → injection pumping

❑There is therefore a **population inversion** between energies near E_c and near E_v around the junction.

❑This only achieved when degenerately doped p-n junction is forward bias with energy > E_{gap}

The Lasing Action

- The population inversion region is a layer along the junction → also call inversion layer or active region
- Now consider a photon with $E = E_g$
- Obviously this photon can not excite electrons from E_v since there is NO electrons there
- However the photon CAN STIMULATE electron to fall down from CB to VB.
- Therefore, the incoming photon stimulates emission than absorption
- The active region is then said to have ‘optical gain’ since the incoming photon has the ability to cause emission rather than being absorbed.

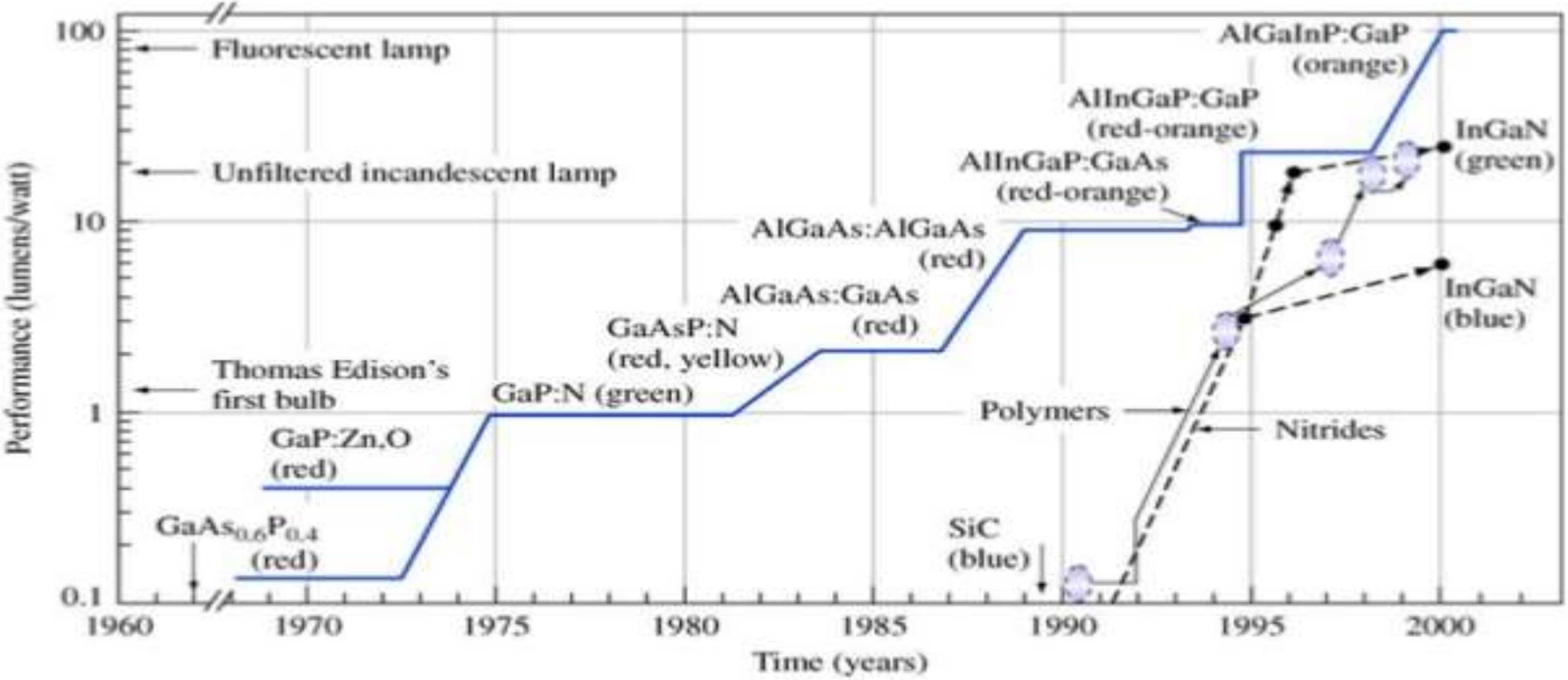
Pumping Mechanism in Laser Diode

- It is obvious that the population inversion between energies near E_c and those near E_v occurs by injection of large charge carrier across the junction by forward biasing the junction.
- Therefore the pumping mechanism is FORWARD DIODE CURRENT → Injection pumping

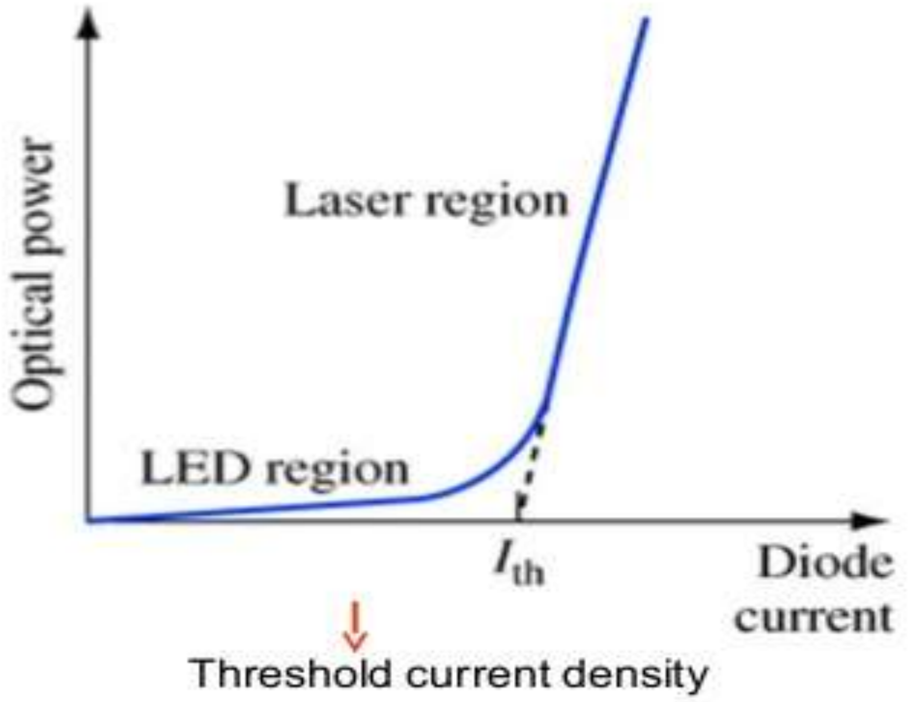
For Successful Lasing Action:

1. Optical Gain (not absorb)
   - Achieved by population inversion
2. Optical Feedback
   - Achieved by device configuration
   - Needed to increase the total optical amplification by making photons pass through the gain region multiple times
   - Insert 2 mirrors at each end of laser
   - This is term an oscillator cavity or Fabry Perot cavity
   - Mirrors are partly transmitted and party reflected

Materials for Laser Diodes



Optical Power in Laser is Very High due to Optical Feedback and Higher Forward Bias Current.

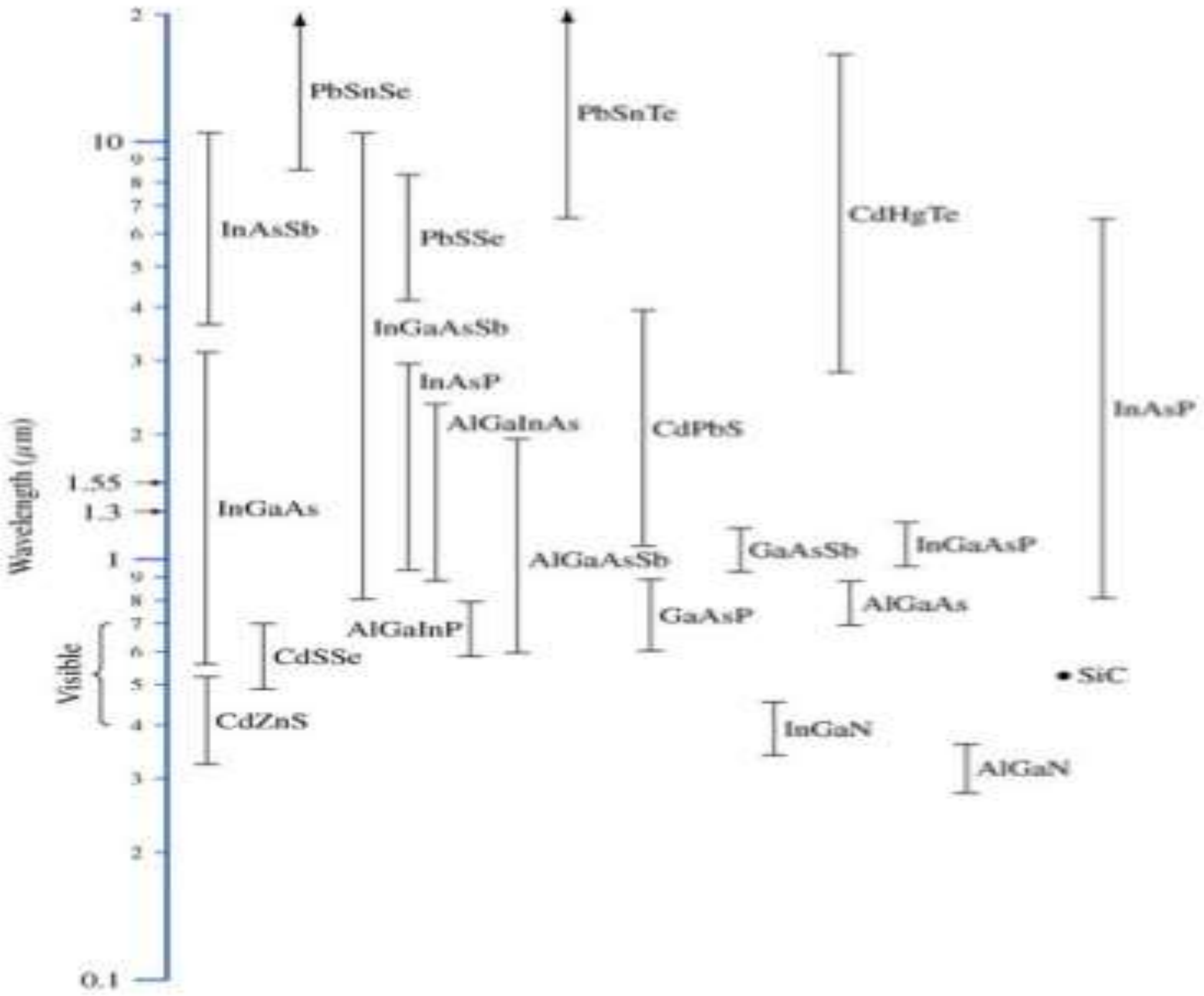


Direct Gap Diode Laser

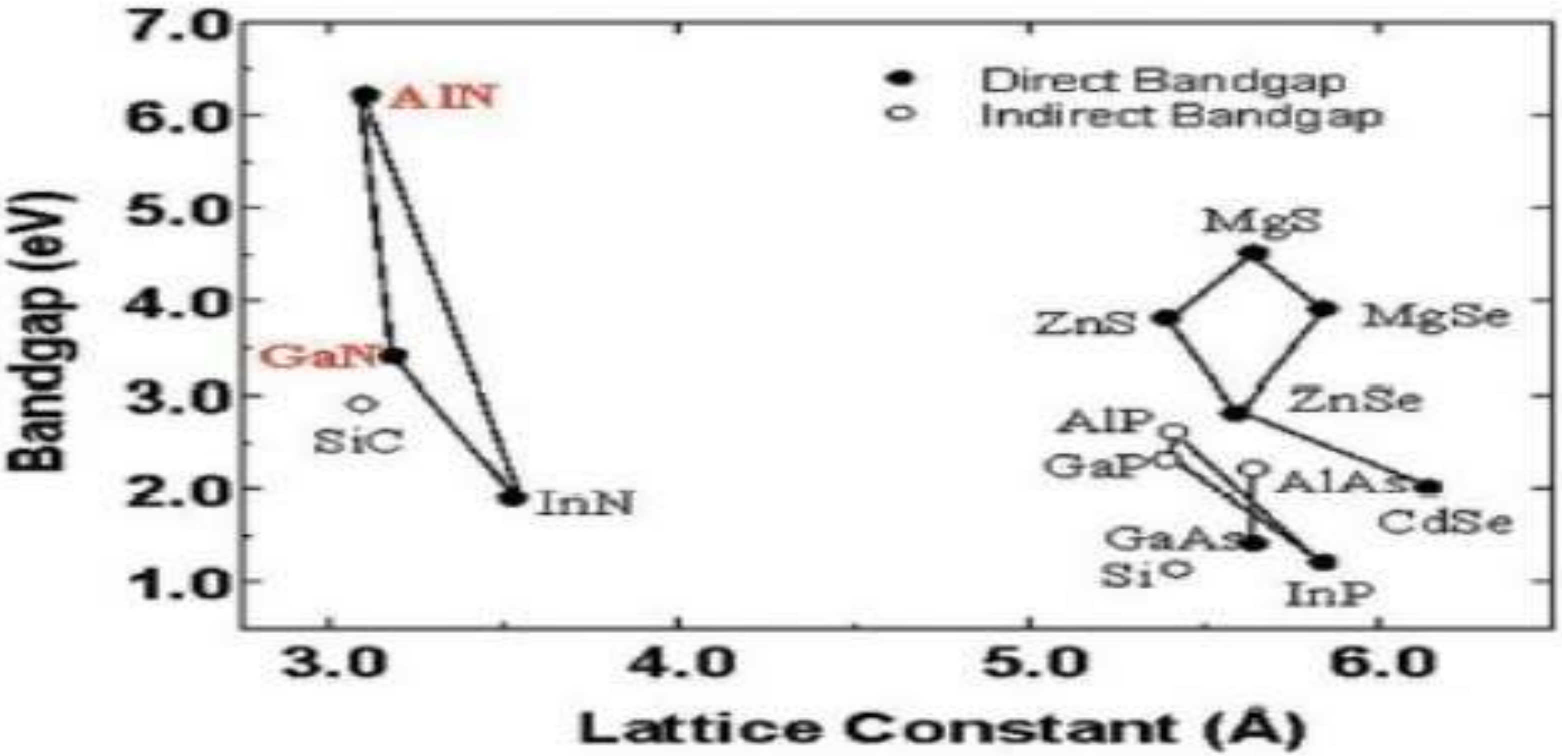
- Direct band gap → high probability of electrons-holes recombination → radioactively

- The recombination radiation may interact with the holes in the valance band and being absorbed or interact with the electrons in the conduction band thereby stimulating the production of further photons of the same frequency → stimulated emission

Materials Available



Technologically Important Material for Blue Laser



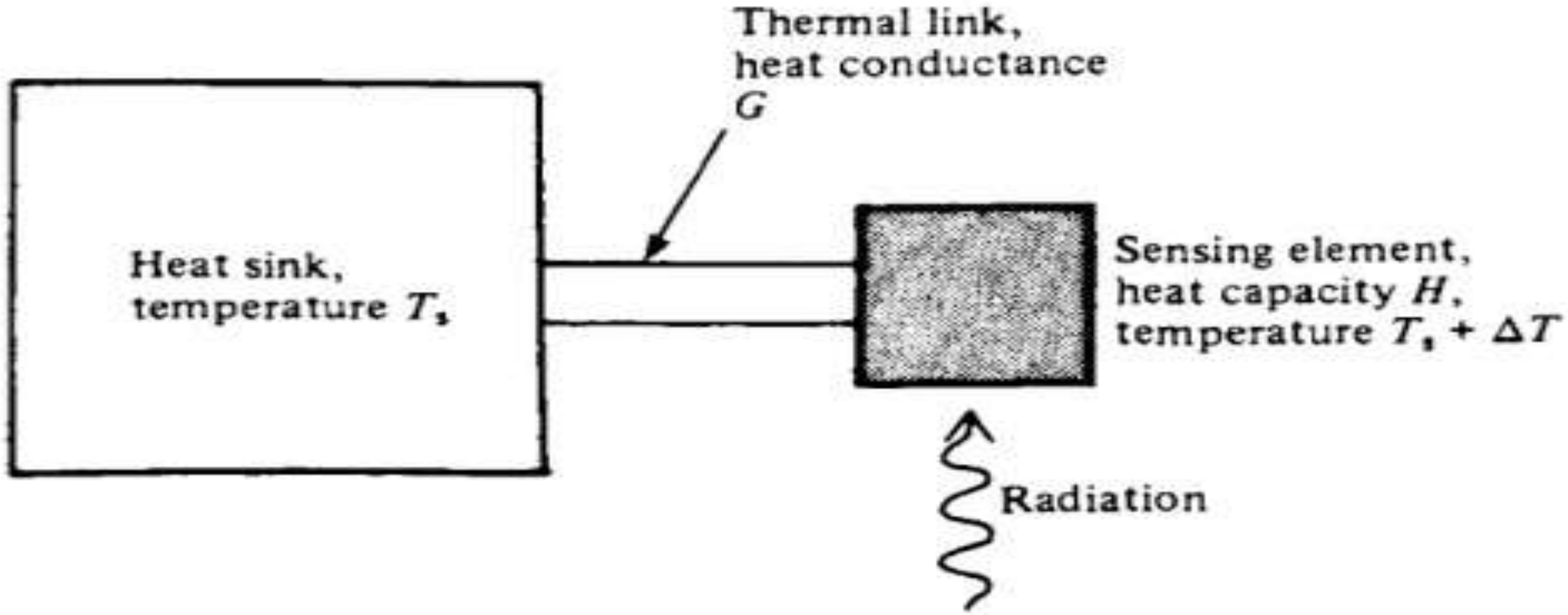
InGaN and AlGaN

- InGaN and AlGaN have been produced over the entire composition range between their component binaries; InN, GaN, AlN
- InAlN is less explored.
- GaN and AlN are fairly well lattice-matched to SiC substrates,
- SiC has substrate is better as it can be doped (dopability) and high thermal conductivity relative to more commonly used Al_2O_3 substrates.
- AlN and GaN can be used for high temperature application due to wide bandgaps and low intrinsic carrier concentrations.

OPTICAL DETECTION DEVICES

- In thermal detectors, **the absorption of light raises the temperature of the device** and this in turn results in **changes in some temperature dependent parameter (eg. Electrical conductivity).**
- the **output of thermal detectors** is usually **proportional to the amount of energy absorbed per unit time by the detector**

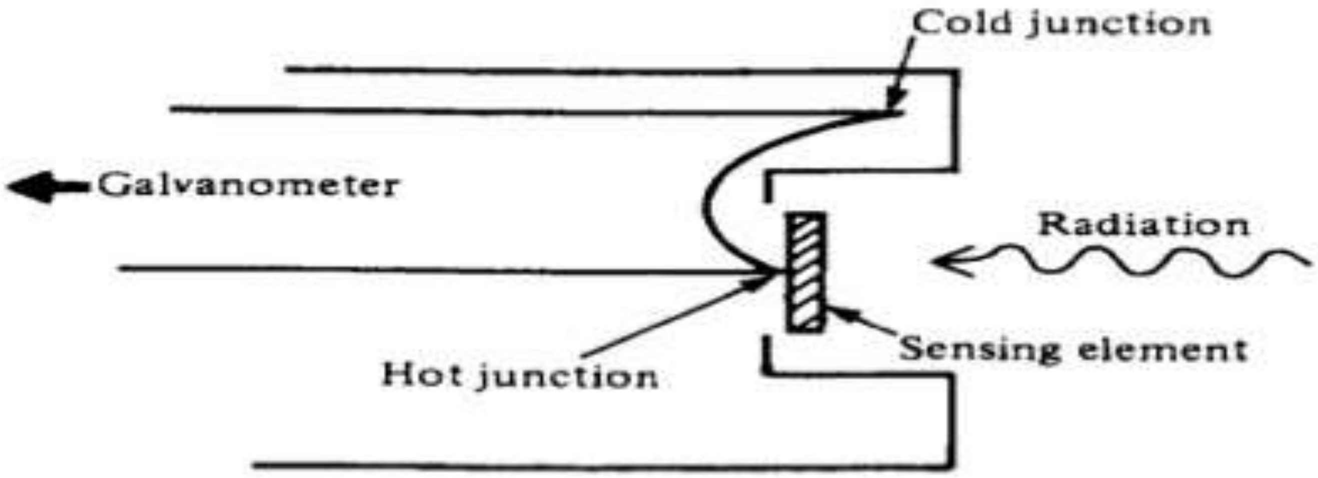
Thermal detectors



Thermoelectric detectors

- Thermoelectric detectors use the **principle of the thermocouple (i.e. the Seebeck effect)** whereby the **heating of one junction between two dissimilar metals relative to the other causes a current to flow round the circuit which is proportional to the temperature difference between the junctions.**

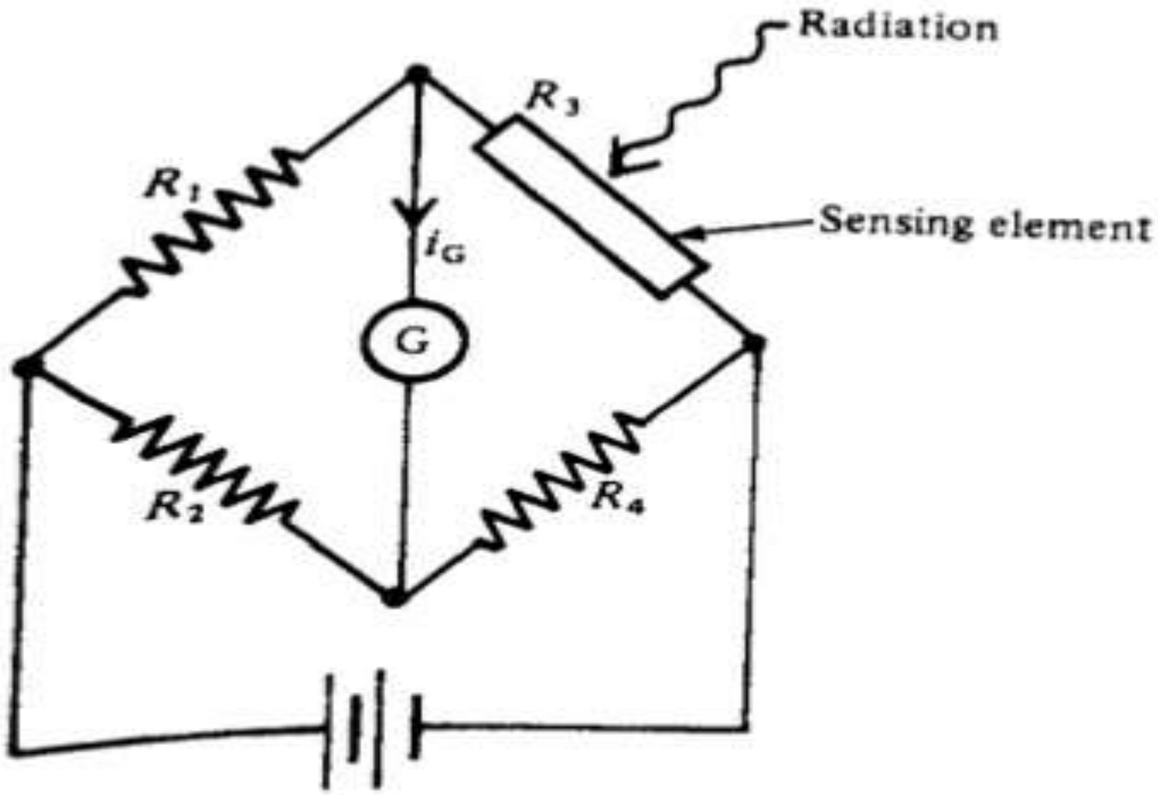
- thermoelectric detectors **one junction is used to sense the temperature rise of the receiving element** whilst the **other is maintained at ambient temperature,** as shown in Figure below



- more **sensitive detector may be made by connecting several thermocouples together in series**; the device is then known as a **thermopile.**
- **Efficient operation** calls for materials with **large electrical conductivities (to minimize Joule heating effects) and also small thermal conductivities (to minimize heat conduction losses).**
- These **two requirements** are usually **incompatible, and a compromise has to be reached.**

- <u>**The bolometer**</u>
- In the bolometer **the incident radiation heats a fine wire or metallic strip causing a change in its electrical resistance**
- for example, the element be inserted into one arm of a Wheatstone bridge

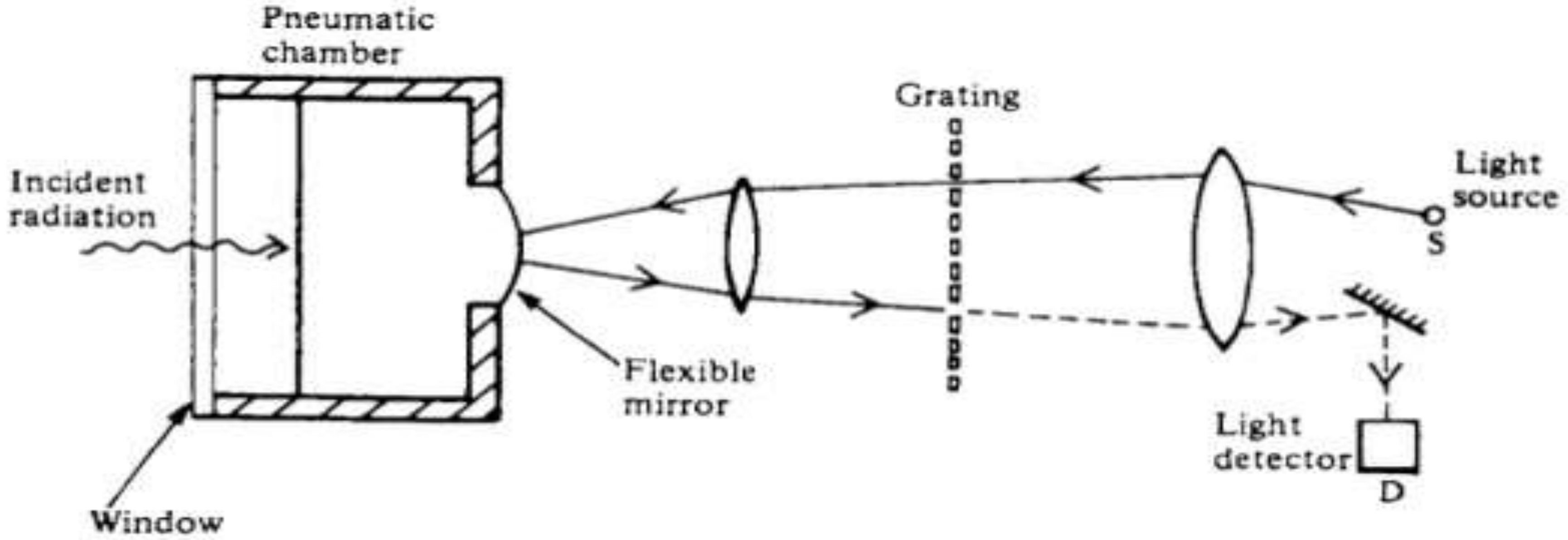
- Wheatstone bridge Circuit incorporating a bolometer radiation sensing element. When the resistance values are such that $R_1/R_2 = R_3/R_4$, then the current i_G through the galvanometer is zero. If the Sensing element resistance changes slightly then a current will flow which is proportional to resistance change.



Radiation
R_3
R_1
i_G
Sensing element
G
R_2
R_4

- **Pneumatic detectors**
- The **receiving element** in a pneumatic detector is placed inside an **airtight chamber.**
- **Radiation falling on the element** causes the **air temperature inside the chamber to rise** and hence the **air pressure to increase.**

- This **pressure increase may be detected** in several ways.
- the **Golay cell,** a **wall of the chamber has a hole in it covered by a flexible membrane** silvered on its outside surface.
- This **acts as a mirror whose focal length depends on the pressure within the chamber** is shown in figure.



Pneumatic chamber
Incident radiation
Window
Flexible mirror
Grating
Light source
S
Light detector
D

- A beam oflight originating from a source S passes through a grating, is then reflected from the flexible mirror to repass through the grating, and finally is directed onto a detector D.
- When no radiation isbeing absorbed within the chamber, the optics are arranged so that an image of the transmitting region ofthe grating is superimposed on a non-transmitting region and there is no output from D.

- However, if the mirror changes its curvature slightly, light will be transmitted through the grating and recorded by D.
- **The output from D is then proportional to the amount of radiation absorbed within the chamber.**
- **Golay cells** are available which **can detect radiation powers down to 10^{-11} W;** they are, however, **rather fragile and difficult to set up.**

- **Pyro-electric detectors:**
- The **incident radiation is absorbed in a ferroelectric material** which has molecules with a **permanent electrical dipole moment.**
- **Below a critical temperature**, the **curie temperature,** the **dipoles are partially aligned along a particular crystallographic axis giving rise to a net electrical polarization of the crystal as a whole.**

- When the **material is heated** the increased **thermal agitation of the dipoles decreases the net polarization, which eventually becomes zero above T_C**, as shown in figure below.

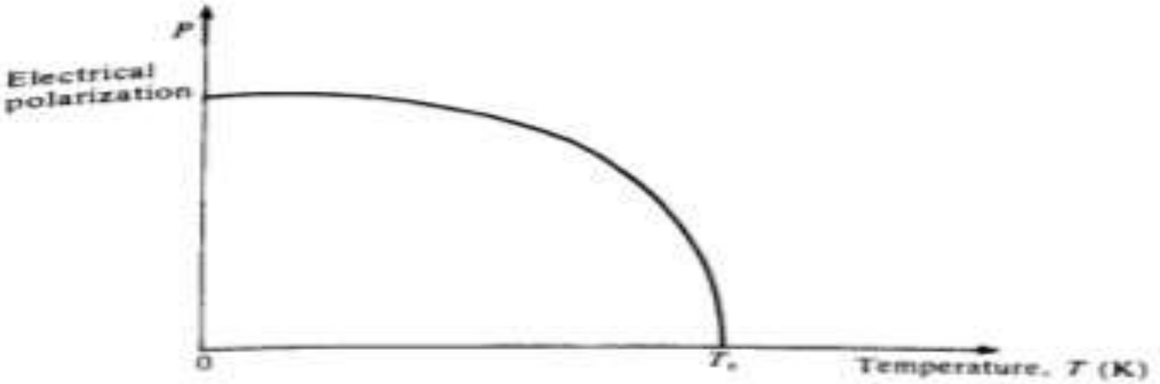


FIG. 7.6 Spontaneous electrical polarization versus temperature for a ferroelectric material (schematic diagram). The polarization falls to zero at the Curie temperature T_c.

INTRODUCTION TO PHOTODETECTOR:

- A photo detector is an optoelectronic device that absorbs optical energy and converts it to electrical energy, which usually manifests as a photocurrent.

- There are generally three steps involved in the process of photo detection process.
- (1) Absorption of optical energy and generation of carriers,
- (2) Transportation of the photo generated carriers across the absorption and/or transit region, with or without gain, and
- (3) Carrier collection and generation of a photocurrent which flows through external circuitry.

- Photo detectors are used to detect optical signals ranging over a very wide range of the optical spectrum.
- Photo detectors are widely used in optical communication systems. In this application, detectors receive the transmitted optical pulses and convert them, with as little loss as possible, into electronic pulses that can be used by telephone, a computer or other terminal at the receiving end.

- The performance requirements from the detector are high sensitivity, low noise, wide bandwidth, high reliability, and low cost.
- For communication applications, there is usually a need for high-speed detectors. For several other applications high gain is necessary. Therefore, bandwidth and gain are fundamental physical trade-offs And the final application decides which photo detector is the most suitable

- The three main types of detectors are photoconductors, PIN diodes, and avalanche photodiodes.
- The first and the third types have internal gain.
- PIN photodiode does not have internal gain but can have very large bandwidths

- Photo detectors are also classified into intrinsic and extrinsic types.
- An intrinsic photo detector usually detects light of wavelength close to the bandgap of the semiconductor. Photo excitation creates electron-hole pairs, which contribute to the photocurrent.
- An extrinsic photo detector detects light of energy smaller than the bandgap energy. In these devices the transition corresponding to the absorption of photons involves deep impurity and defect levels within the bandgap.

- The quantum efficiency η of a photo detector is given by
- $\eta = \frac{I_{ph}/_{q}}{P_{inc}/_{h\nu}} = \frac{I_{ph}}{q} . \frac{h\nu}{P_{inc}}$
- η is also called as external quantum efficiency η_{ext}
- Which is the no of carriers collected to produce the photocurrent I_{ph} divided by the number of incident photons. P_{inc} is the incident optical power.

- The internal quantum efficiency η_i is the number of pairs (electron and hole pairs) created divided by the number of photons absorbed and is usually very high, if not unify, in pure, defect free materials.
- The external quantum efficiency depends on the absorption coefficient of the material and the thickness of the absorbing region:
- $\eta_{ext} = \eta\infty(1 - e^{-\alpha a})$
- Where α is the absorption coefficient of the semiconductor and a is the thickness of the active region.

- The responsivity of a detector R is defined as
-

$$R = \frac{I_{ph}}{P_{inc}}$$

- $$R = \frac{\eta q}{hv}$$
- $$R = \frac{\eta\lambda(\mu m)}{1.24}\,(A/w)$$
- η is dependent on the absorption coefficient α, which in turn depends on the incident wavelength.

PHOTOCONDUCTORS

- The photoconductor is perhaps the simplest optical detector that exhibits an internal gain mechanism and clearly demonstrates the gain-bandwidth limitation.
- Its operationis based on the increase in conductivity of a specific region with photo-excitation.
- Thephotogenerated electrons and holes are collected by opposite contacts and result in a photocurrent

- **Construction:**
- The active layer is formed epitaxially, or sometimes by ion implantation, on a high-resistivity substrate, and suitable contacts are delineated ontop by evaporation of metals and subsequent alloying.

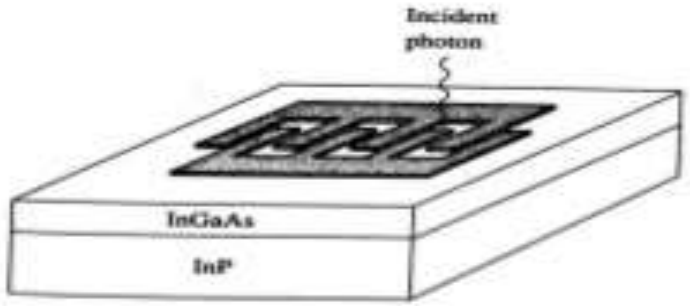


Figure 8.3 Schematic of an InGaAs/InP photoconductor with interdigitated top contacts.

- The separation between the contact pads, either in linear or interdigitated form, is also an important parameter in the operation of the device.
- A suitable bias is applied across the contacts to collect the photo-generated carriers
- To increase the quantum efficiency, anantireflective coating, or a wider bandgap window layer needs to be formed on the surface of the absorbing region.

- <u>Noise in photoconductor:</u>
- Another important consideration in the performance of the device is noise generation. The noise is principally generated by the large dark current of the device and isknown as Johnson or thermal noise that has its origins in the random motion of carriers that contribute to the current. The resulting noise current, i_j, was given by
- $\overline{{i_J}^2} = \frac{4K_B TB}{R_L}$
- Where B is the bandwidth of the device and RC is the resistance of the photoconductingchannel.

- Current always flows through the photoconductor, and therefore the,signal-to-noise ratio, S/N, can be approximately expressed as
- $\frac{S}{N} = \frac{(conductivity)_{light}}{(condutivity)_{dark}}$
- Dark conductivity has to be reduced to reduce noise.

- **<u>Response time of the device</u>:**
- The rate and density of data transmission depends on the response speed of the device.
- The photogenerated electrons and holes move in opposite directions in the active region under the applied bias.

- The resulting photocurrent will persist until both carriers are collected at the electrodes, or until they recombine in the bulk of the semiconductor before reaching the respective contacts.
- The time for detection of the photogenerated current is limited by the transit time between electrodes of the faster carrier-usually the electrons.
- Therefore, the shortest response time (maximum bandwidth) can be obtained by minimizing the distance between the contacts.

- Bandwidth$\infty \frac{1}{\tau}$
- Where τ = minority carrier recombination life time.
- where $\tau = \tau_h$.
- However, the continued persistence of the hole in the channel will drawmore electrons to maintain charge neutrality. This constitutes a photocurrent gain, Γ_G which is defined as
- $\Gamma_G = \frac{\tau}{t_{tr}}$
- t_{tr} = transit time of the electrons.
- Therefore,
- Gain x Bandwidth = K
- Where the constant K is determined by the electron transit time.

- **Operation of the Photoconductor:**

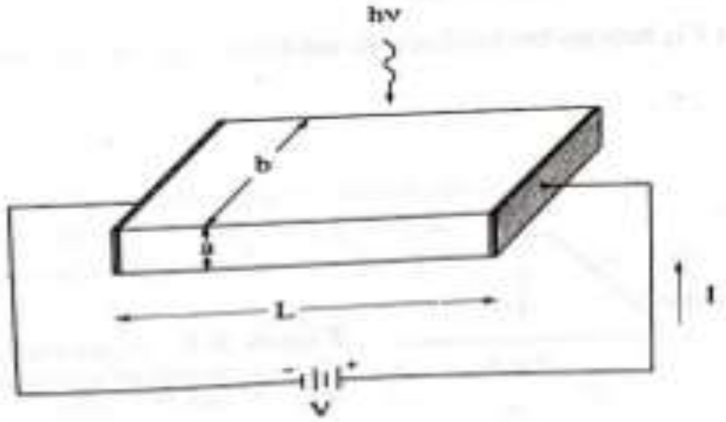


Figure 8.4 Schematic of an ideal photoconducting slab for analysis. The device has side contacts.

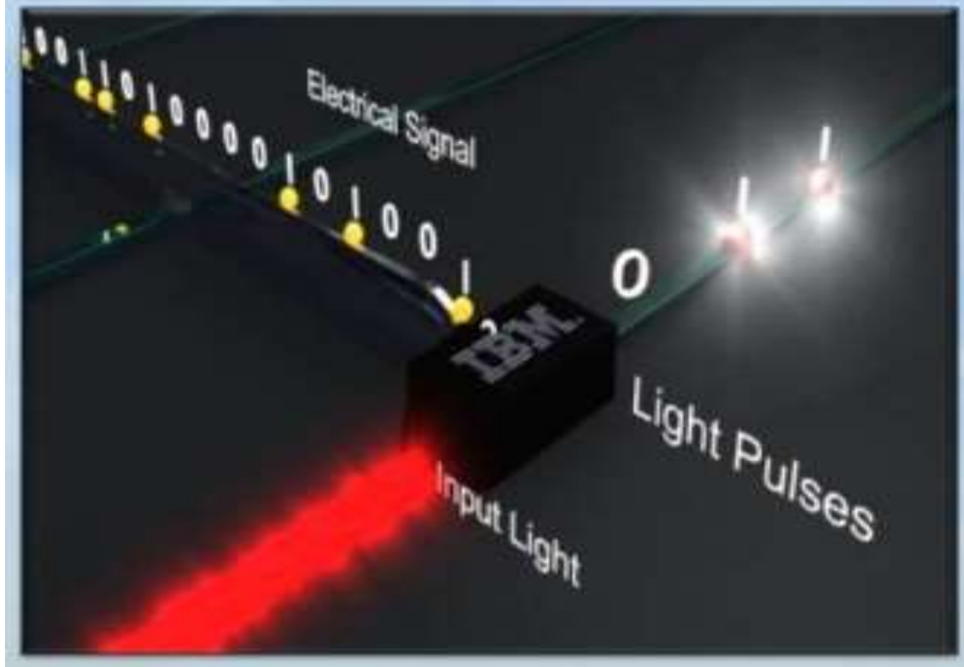
- This current can be expressed as
- $I = abq(n\mu_e + p\mu_h)\frac{V}{L}$
- $= I_D + I_{ph}$
- I_D = dark current and I_{ph} = the photocurrent produced by incident light.
- n and p are the concentrations of free carriers and μ_e and μ_h are their respective mobilities.

- The number of photons incident on the semiconductor per second = $P_{inc}/h\nu$
- P_{inc} is the incident optical power.
- If the corresponding generation rate isGand all the incident photons are absorbed, then the internal quantum efficiency, of the photoconductor is given by
- $\eta_i = \frac{G}{R_{abs}} = \frac{GV_v}{\frac{p_{inc}}{h\nu}}$
- where V_ν is the volume.

- Some light of the incident optical power P_{inc} will be transmitted after absorption in thematerial.
- The light power leaving the lower surface is given by
- $P(a) = P_{inc}e^{-a\alpha}$
- Where a is the absorption coefficient of the photoconductor material. Also
- $GV_v = \eta_i \frac{P_{inc} - P(a)}{hv}$

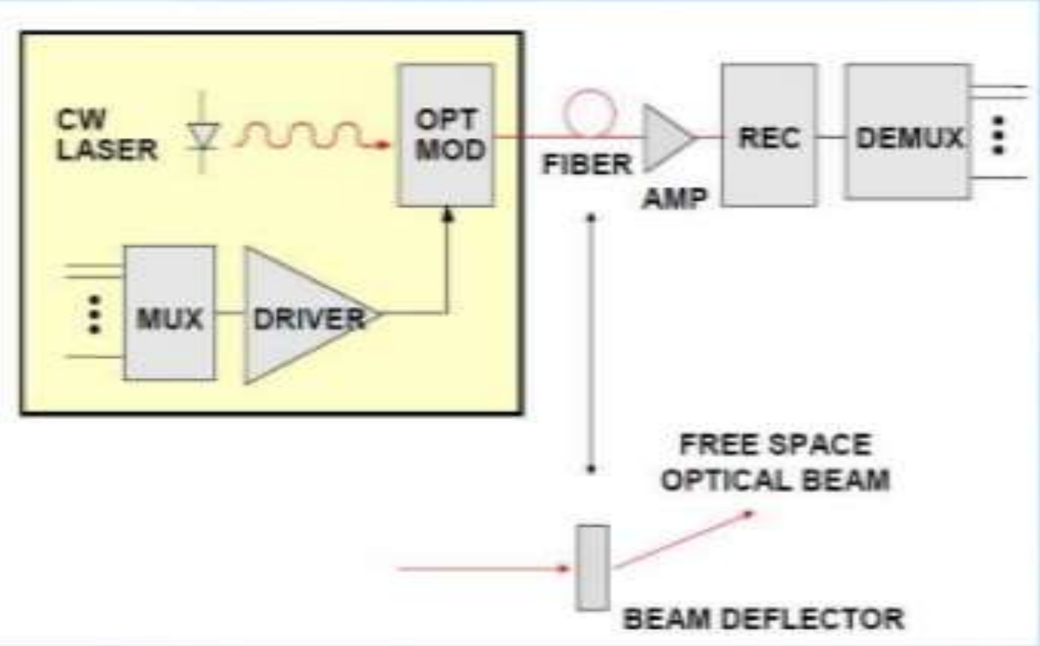
- $= \eta_i \frac{P_{inc}}{hv}(1 - e^{-\alpha a})$
- and the quantum efficiency can be expressed as
- $\eta = \eta_i(1 - e^{-\alpha a})$

What Is Optical Modulator



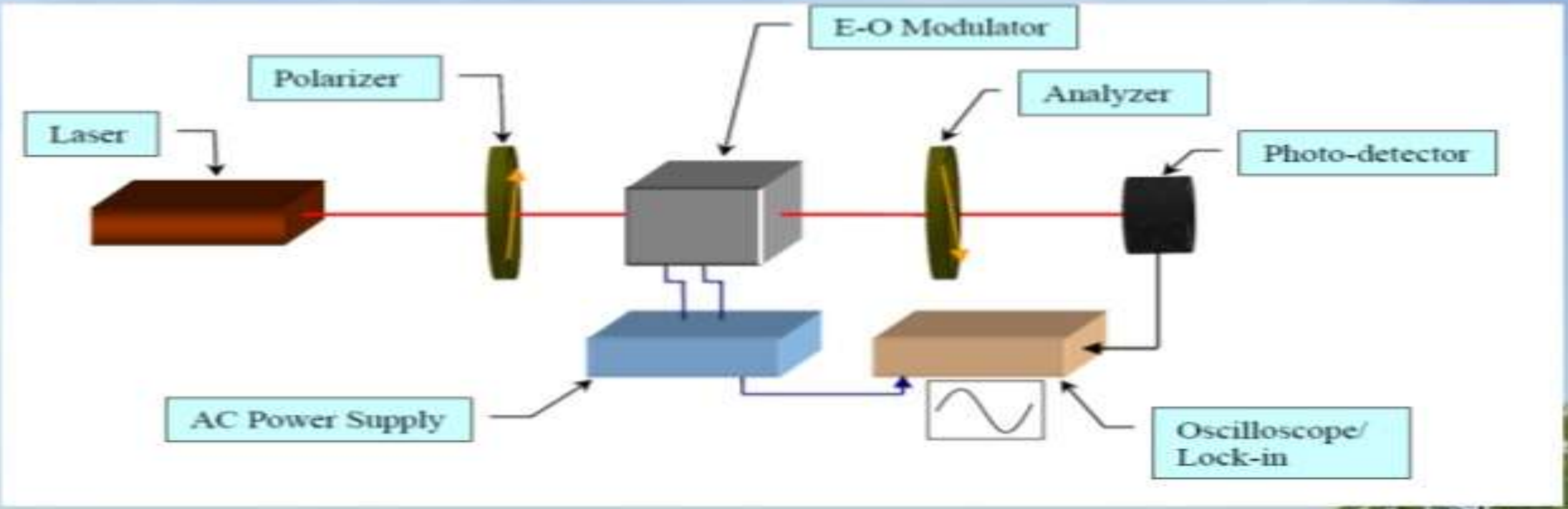
- A device that modulates or varies the amplitude of an optical signal in a controlled manner.
- Generates desired intensity, color in the passing light by changing optical parameters such as the transmission factor, refractive index, reflection factor, degree of deflection and coherency of light in the optical system according to the modulating signal .

Why Do we use an Optical Modulator



- Directly modulating the laser causes frequency chirp,pulse spreading in optical fibers, and loss of information.
- We may also use an optical modulator when we cannot easily or rapidly vary the output of a laser.

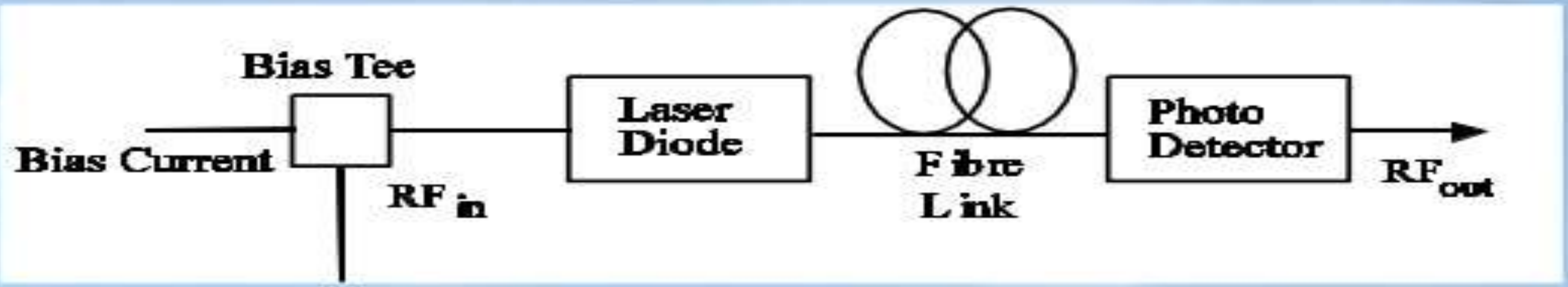
How Does It Work?



Modulation Techniques

- Direct modulation of laser diode
  - Vary the current supply to the laser diode
  - Directly modulates the output power of the laser
  - Output frequency drifts
    - carrier induced (chirp)
    - temperature variation due to carrier modulation
  - Limited modulation depth (don't want to turn off laser)

Direct Modulation

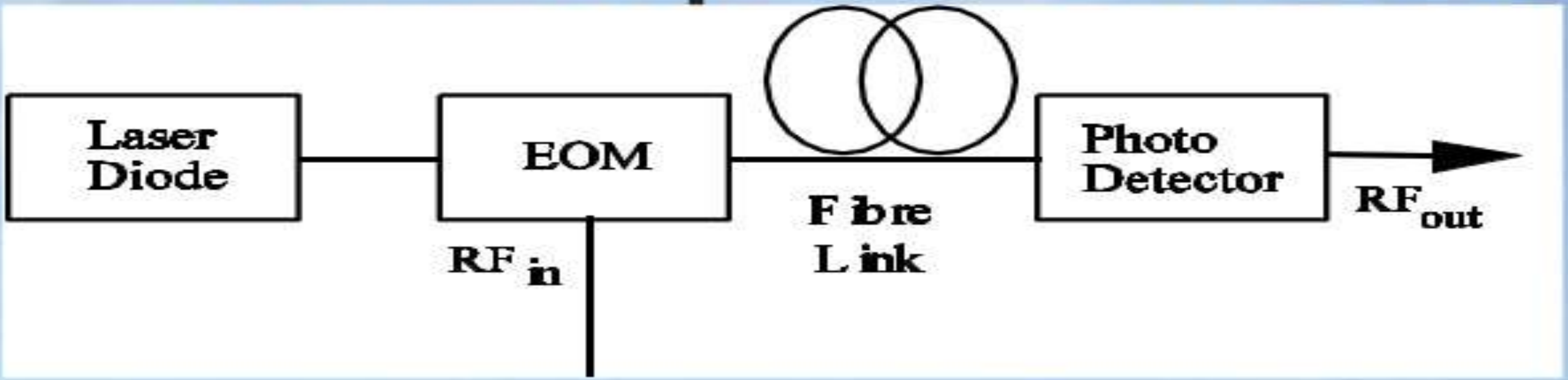


- The message signal (ac) is superimposed on the bias current (dc) which modulates the laser
- Robust and simple, hence widely used
- Issues: laser resonance frequency, chirp, turn on delay, clipping and laser nonlinearity

External modulation

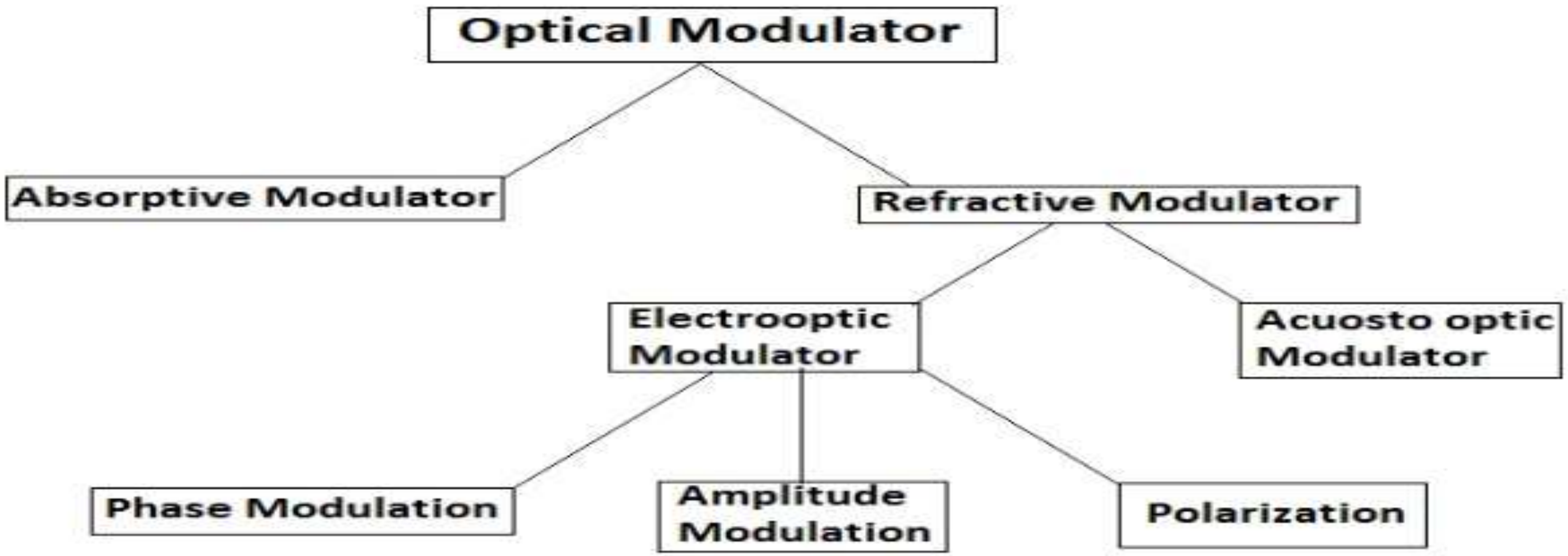
- Change the transmission characteristics
- Change the power of a continuous wave laser
- Electro-optical modulation (low efficiency)
- Electroabsorption (EA) modulation (smaller modulation bandwidth).

External Optical Modulation



- Modulation and light generation are separated
- Offers much wider bandwidth → up to 60 GHz
- More expensive and complex
- Used in high end systems

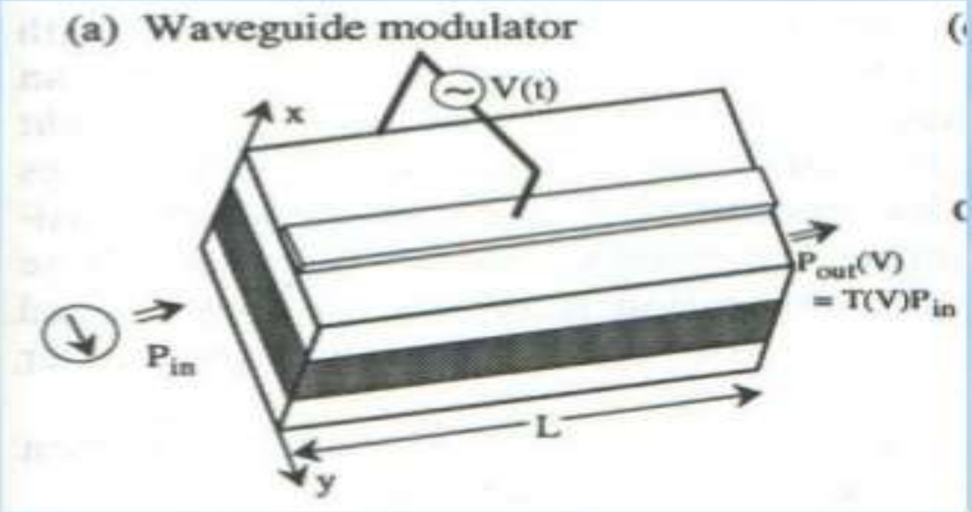
Types of Optical Modulators

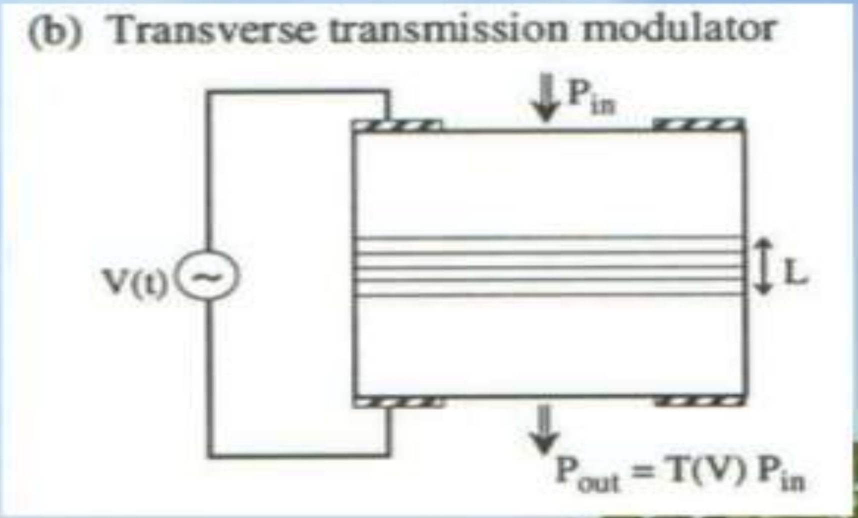


Electroabsorption (EA) Modulator

EA modulator is a semiconductor device which can be used for controlling the intensity of a laser beam via an electric voltage.Principle of operation is based on Franz-Keldysh effect i.e. a change in the absorption spectrum caused by an applied electric field,which changes the band gap energy.

Schematics of an EA modulator





Advantages of EA modulators

- Zero biasing voltage
- Low driving voltage
- Low/negative chirp
- high bandwidth

Electro Optic Modulator

- An electro-optic modulator is a device which can be used for controlling the power, phase or polarization of a laser beam with an electrical control signal. It typically contains one or two Pockels cells, and possibly additional optical elements such as polarizers. Different types of Pockels cells are shown in Figure 1. The principle of operation is based on the linear electro-optic effect (also called the *Pockels effect*), i.e., the modification of the refractive index of a nonlinear crystal by an electric field in proportion to the field strength.

- Pockels Effect:

  In many materials the s term is negligible

  $\Rightarrow \eta(E) \approx \eta + \mathrm{r}\cdot E$ $\quad\quad$ r: Pockels coefficient

  $\quad n(E) \approx n - \frac{1}{2}\mathrm{r}\cdot n^3 E$

  Typical value of $\mathbf{r}$ 10^{-12}-10^{-10} m/V (1-100 pm/V);

  For E=10^6 V/m => $\mathbf{r}n^3E/2$ ~10^{-6}-10^{-4} (very small).

  Most common crystals used as Pockels cells:

  $NH_4H_2PO_4$ (ADP), KH_2PO_4 (KDP), $LiNbO_3$, $LiTaO_3$.

- Kerr Effect:

  If the materials is centrosymmetric, as is the case

  gases, liquid, and certain crystals, $n(E)$ must be a

  even function => $\mathbf{r} = 0$

  $\Rightarrow \eta(E) = \eta + \mathrm{s}\cdot E^2$ $\quad\quad$ s: Kerr coefficient

  $\quad n(E) \approx n - \frac{1}{2}\mathrm{s}\cdot n^3 E^2$

Types of Electro-optic Modulators

- **Phase Modulators**

The simplest type of electro-optic modulator is a phase modulator containing only a Pockels cell, where an electric field (applied to the crystal via electrodes) changes the phase delay of a laser beam sent through the crystal.The polarization of the input beam often has to be aligned with one of the optical axes of the crystal, so that the polarization state is not changed.

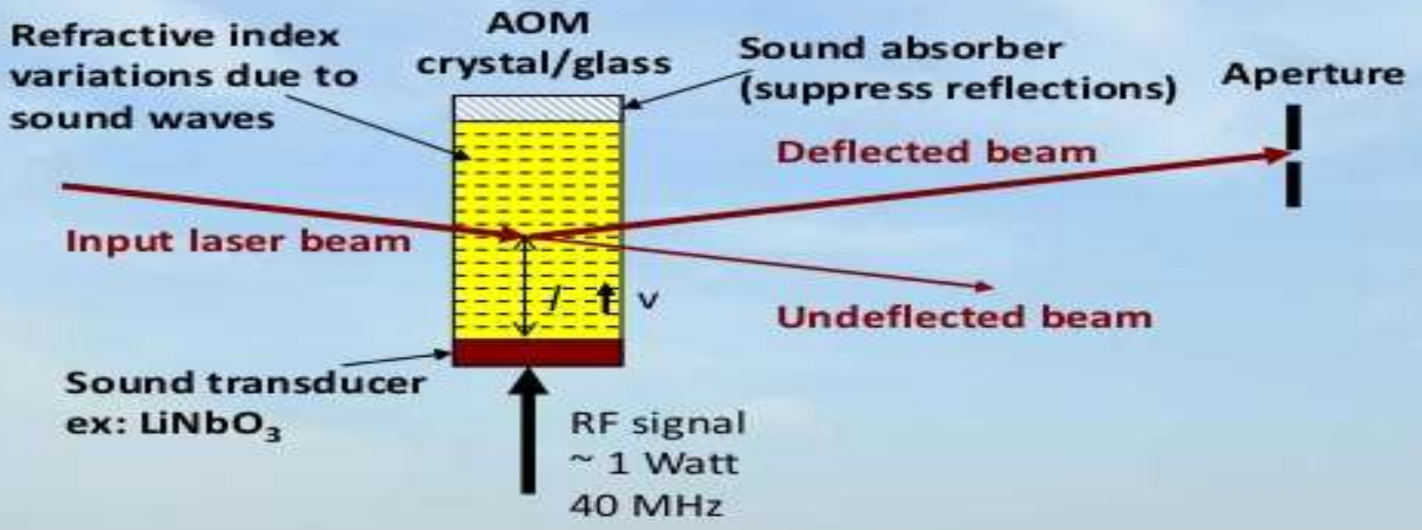
Polarization Modulators

- Depending on the type and orientation of the nonlinear crystal, and on the direction of the applied electric field, the phase delay can depend on the polarization direction. A Pockels cell can thus be seen as a voltage-controlled <u>waveplate.</u>

Amplitude Modulators

- Combined with other optical elements, in particular with polarizers, Pockels cells can be used for other kinds of modulation. In particular, an *amplitude modulator* is based on a Pockels cell for modifying the polarization state and a polarizer for subsequently converting this into a change in transmitted optical amplitude and power.

AOM = acousto optic modulator



AOM = acousto optic modulator

- AOM = acousto optic modulator (or deflector)
- RF signal converted to sound waves in crystal
  - Use fast piezo-electric transducer like Li NbO_3
- Sound waves are collimated to form grating
- Bragg scatter from grating gives deflected beam
  - can separate from original
- Problem with AOM -- weak link
- Sound takes time to travel from transducer to laser beam
  - Time delay: $t_D = l / v$ -- acts like multi-pole rolloff
  - (phase shift increases with frequency)

AOM Contd..

The acoustic wave may be absorbed at the other end of the crystal. Such a *traveling-wave geometry* makes it possible to achieve a broad modulation <u>bandwidth</u> of many megahertz. Other devices are resonant for the sound wave, exploiting the strong reflection of the acoustic wave at the other end of the crystal. The resonant enhancement can greatly increase the modulation strength (or decrease the required acoustic power), but reduces the modulation <u>bandwidth</u> .

AOM Contd..

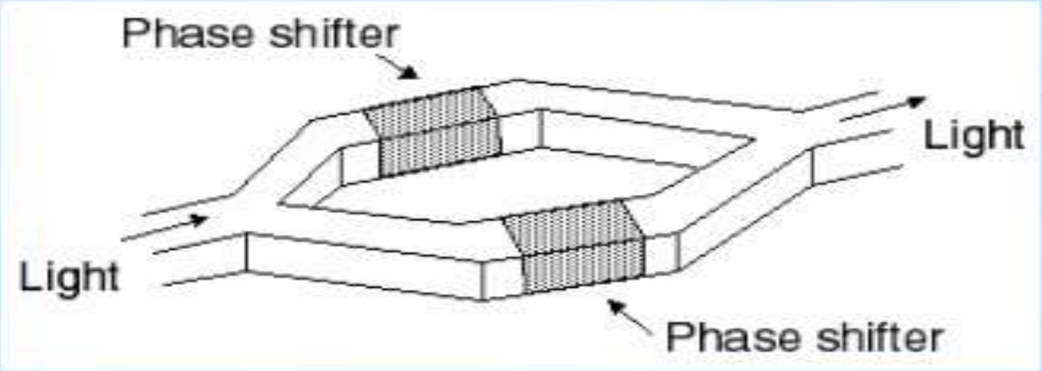
- Common materials for acousto-optic devices are tellurium dioxide (TeO_2), crystalline quartz, and fused silica. There are manifold criteria for the choice of the material, including the elasto-optic coefficients, the transparency range, the optical damage threshold, and required size. One may also use different kinds of acoustic waves. Most common is the use of longitudinal (compression) waves. These lead to the highest diffraction efficiencies, which however depend on the polarization of the optical beam. Polarization-independent operation is obtained when using acoustic shear waves (with the acoustic movement in the direction of the laser beam), which however make the diffraction less efficient.

What is Mach-Zender optical modulator?

- Optical modulators based on the external modulation principles include a Mach-Zehnder interferometric optical modulator (MZ, or MZI).
- First silicon-based modulator with frequency > 1GHz!
- Attractive from cost point of view
- Advanced electronics on silicon (widely used bipolar and CMOS technology)
- Needed to encode data on a continuous wave of light output by a laser, for use in an optical communication link

The Mach-Zender modulator – how does it work?

Novel phase-shifter Design embedded in a passive silicon waveguide Mach-



Zender interferometer. Optical modulators based on the external modulation principles include a Mach-Zehnder interferometric optical modulator .

Contd....

- A Mach-Zehnder interferometer optical modulator utilizes a mechanism such that when light propagated through a waveguide is branched in two directions and a modulation signal current is flowed through the center of each branch, there occur magnetic fields of opposite phases with respect to grounds provided on opposite sides in a sandwiching relation to the waveguides, so that the phases of light signals propagated through the respective routes become opposite to each other and the phase lead and lag are offset each other when both lights are later combined together.

Applications and Commercial products

- **Electro-optic modulator**

  Phase Modulator is a high performance, low drive voltage External Optical Modulator designed for customers developing next generation transmission systems. The increased bandwidth allows for chirp control in high-speed data communication.

Contd…..

- modulating the power of a laser beam, e.g. for laser printing, high-speed digital data recording, or high-speed optical communications
- in laser frequency stabilization schemes, e.g. with the Pound–Drever–Hall method
- Q switching of solid-state lasers (where the EOM serves to block the laser resonator before the pulse is to be emitted)

Contd……

- active mode locking (where the EOM modulates the resonator losses or the optical phase with the round-trip frequency or a multiple thereof).

- switching pulses in pulse pickers, regenerative amplifiers and cavity-dumped lasers.

Applications Of AOM

- They are used for Q switching of solid-state lasers. The AOM, called Q switch, then serves to block the laser resonator before the pulse is generated. In most cases, the zero-order (undiffracted beam) is used under lasing conditions, and the AOM is turned on when lasing should be prohibited. This requires that the caused diffraction losses (possibly for two passes per resonator round trip) are higher than the laser gain. For high-gain lasers (for example, fiber lasers), one sometimes uses the first-order diffracted beam under lasing conditions, so that very high resonator losses result when the AOM is turned off. However, the losses in the lasing state are then also fairly high.

Contd……

- AOMs can also be used for cavity dumping of solid-state lasers, generating either nanosecond or ultrashort pulses. In the latter case, the speed of an AOM is sufficient only in the case of a relatively long laser resonator; an electro-optic modulator may otherwise be required.

Contd…

- Active mode locking is often performed with an AOM for modulating the resonator losses at the round-trip frequency or a multiple thereof.

- An AOM can be used as a pulse picker for reducing the pulse repetition rate of a pulse train, e.g. in order to allow for subsequent amplification of pulses to high pulse energies.

Contd….

- In laser printers and other devices, an AOM can be used for modulating the power of a laser beam. The modulation may be continuous or digital (on/off).
- An AOM can shift the frequency of a laser beam, e.g. in various measurement schemes, or in lasers which are mode-locked via frequency-shifted optical feedback.
- In some cases one exploits the effect that the diffraction angle depends on the acoustic frequency. In particular, one can scan the output beam direction (at least in a small range) by changing the modulation frequency.

WHAT IS AN OPTICAL SWITCH?

DEFINITION: A switch that enables signals in optical fibers or integrated optical circuits (IOCs) to be selectively switched from one circuit to another.

OPERATION:

- **MECHANICAL MEANS** such as physically shifting an optical fiber to drive one or more alternative fibers.
- **ELECTRO-OPTIC EFFECTS**, **MAGNETO-OPTICS**, or other methods.

TYPES OF OPTICAL SWITCHES(SPEED):

- Slow optical switches, such as those using moving fibers, may be used for **ALTERNATE ROUTING** of an optical transmission path, *e.g.*, routing around a fault.
- Fast optical switches, such as those using electro-optic or magneto-optic effects, may be used to perform logic operations.

“SYSTEMS WHICH PERFORM THE FUNCTION OF OPTICAL SWITCHING BY PHYSICALLY SWITCHING LIGHT ARE REFERRED TO AS **PHOTONIC**.”

SWITCHING TYPE TECHNOLOGIES/OPTICAL SWITCHES

❖ **MECHANICAL SWITCH**

- ➢ Each individual fiber is manually moved.
- ➢ optical fiber is physically moved to drive alternate fibers.
- ➢ Physically shifting an optical fiber to drive one or more alternative fibers.

❖ **ELECTRO-OPTIC SWITCH**

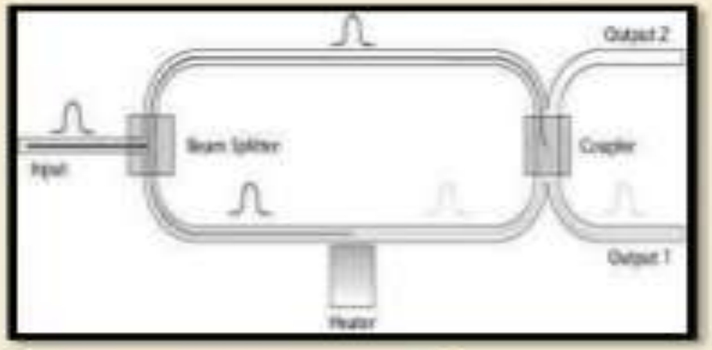
- ➢ Change in electric field that varies slowly in comparison to the speed or intensity of light.

❖ **MAGNETO-OPTIC SWITCH**

By use of electro-magnetic forces, the switch can be made to transfer the data from one fiber to the other.

❖ **THERMO-OPTIC SWITCH**

Utilizes thermo optic effect in optical waveguides.(main materials are silica and polymers)



❖ **ACOUSTIC-OPTIC SWITCHING**

- ➢ It employs the acousto-optic effect.
- ➢ In acousto-optic Q-switches, an ultrasonic wave is launched into a block of transparent optical material, usually fused silica. By switching on the acoustic field ,a fraction of the energy of the main beam is diffracted out of the resonator, that prevents laser action(due to loss).
- ➢ When acoustic field is switched off, full transmission through the Q-switch cell is restored and a laser pulse is created.

❖ **IMPORTANCE OF OPTICAL SWITCHING**

1.LESS CROWDED NETWORK

2.REDUCED PROTOCOL ISSUES

3.INCREASED BANDWIDTH

4.INCREASED DISTANCE

5.WIDE RANGE OF USE

❖ **APPLICATIONS**

- COMPUTER AND NETWORKING PURPOSES.
- PHONE SYSTEMS
- LIGHTENING AND STORMS
- OADM(OPTICAL ADD/DROP MULTIPLEXERS)
- OXC(OPTICAL CROSS-CONNECTS)
- PROTECTION SWITCHING

Optoelectronic Integrated Circuit

Optoelectronic integrated circuits (OEIC)

- Monolithic Integration of optical and electronic semiconductor devices
- Hybrid technology in which photonic component (such as laser, modulator, photodetector) co-exists as same chip as a functional electronic circuit(e.g. Laser diode)
- Compound semiconductors such as GaAs-based and InP-based alloy semiconductors are used.

*monolithic: composed of both active and passive components formed into a single chip.

Optoelectronic integrated circuits (OEIC)

- Two types of OEIC exist
  - One is integration of light emitting devices (example: LD) and driving FET circuits
  - The other is integration of optical detection device like PD and electronic circuits for amplification and signal processing

- OEICs, integrate optical devices was originally developed for communication system and electronic devices was developed for the signal processing system

Classification

- Based on integration
  - Monolithic Integration
  - Hybrid Integration
  - Modular Integration
- Based on type of substrate material
  - Indium Phosphide (InP)
  - Gallium Arsenide (GaAs)
  - Lithium Niobate
  - Silicon (Si)
  - Silica-on-Silicon
  - Silicon on Insulator

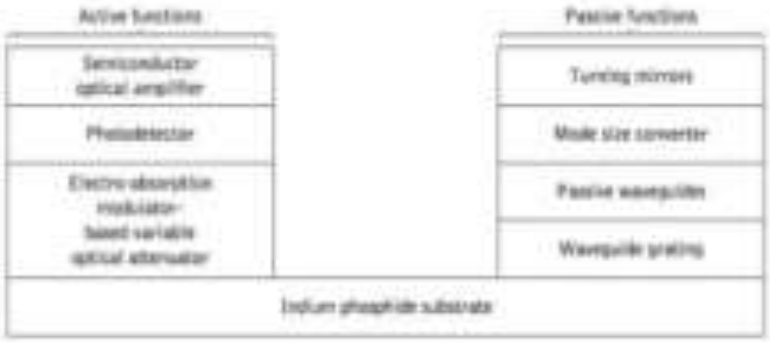
Basic Components in OEIC

- PASSIVE
  - Waveguides/Couplers
  - Switches (optical interconnect, wavelength selective switches)
  - Filters (add-drop filters, MUX/DEMUX)
  - Dispersion compensators
  - Attenuator
  - Gain equalizer
  - Isolators/Circulators

  - ACTIVE
    - Amplifiers
    - Lasers
    - LED
    - Modulators
    - Detectors
    - Wavelength Converters

Fabrication

Structural strategy for the fabrication of OEIC onto an InP substrate



Basic steps : Epitaxial growth
Waveguide etching
Passivation and planarization
Metallization and interconnect

Features of OEICs

- High Speed operation
  - OEICs consists electronics circuit such as drivers or amplifiers which assists in speeding the signal processing
- Multichannel Light signal processing
  - OEICs not only emit and receive signals but also process them. Large scale integration prove useful in multichannel light signal processing systems such as optical LANs and the optical interconnection of computer systems.
- Small size, high reliability and low cost
  - Their small size, high reliability and low cost will be a distinct advantage when OEICs are used in subscriber system

APPLICATIONS OF OEIC

- Digital Transmission
- Analog Transmission
- Switching
- Fiber Optic Gyroscopes
- WDM Systems
- Optical Storage and Display

Waveguide

- Waveguide is a structure that guides waves such as electromagnetic waves with minimal loss by restricting expansion to one or two dimension i.e. it confines electromagnetic energy and channels it from one point to another.
- It only carries or propag : a certain frequency, known as cut-off frequen

c) Slab Waveguide
d) Strip Waveguide

Optical Waveguide

- An optical waveguide is a spatially homogeneous structure for guiding light, i.e. for restricting the spatial region in which light can propagate.
- Central to integrated optics is the concept of guiding light in dielectric waveguide structure
- The dimension of dielectric waveguide is comparable to wavelength of guided light i.e. size of the waveguide determines its operating frequency.
- A dielectric waveguide confines light to the core of the waveguide structure by reflecting power back towards the core that would otherwise diffract or propagate away

Basics of Slab Waveguide

- The core of the region is called film which has the refractive index of n1
- The film is deposited on a layer called substrate and has the refractive index of n2
- The cladding on the film is called superstrate and has refractive index n3
- When n2=n3 it is symmetric slab waveguide
- When n2 is different from n3 it is asymmetric slab waveguide

Basics of Slab Waveguide

- This type of wave guide supports finite number of guided modes as well as infinite numbers of radiation mode
- In order to achieve this n1>n2≥n3

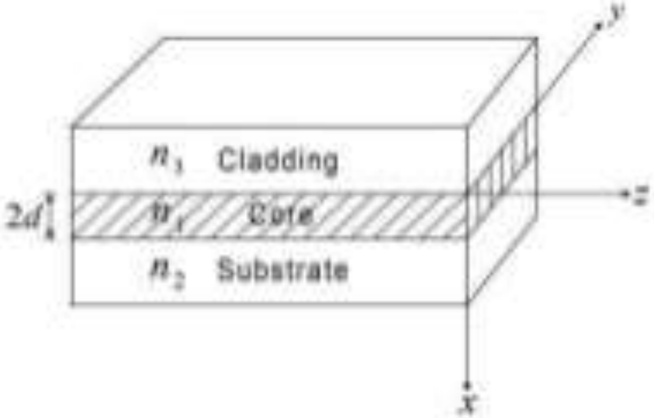


Figure 2.1: Schematic Diagram of A Dielectric Slab Waveguide

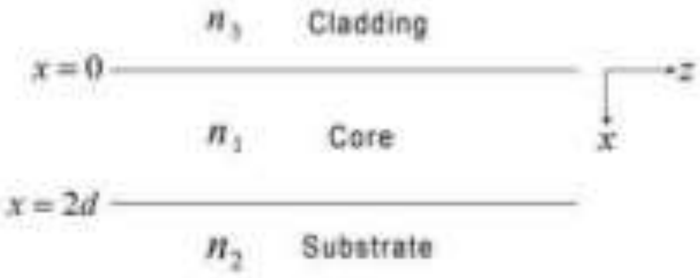
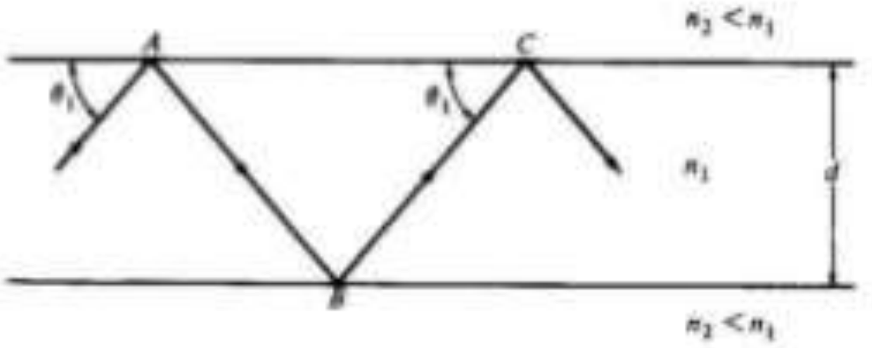


Figure 2.2: A Three-Layer Dielectric Slab Waveguide

Symmetric Slab Waveguide

- It is composed of three layers of homogeneous dielectrics
- Analysis of slab structure is done using Ray-optics approach
- In Ray optics, two types of phase changes
  - One while reflection
  - Other while travelling
- Steady 

e at each point

Symmetric Slab Waveguide

- After propagation and two reflections, phase rejoins itself with an integral multiple of 2π phase shift
- Give core thickness, limited number of propagation angles exists in the core

Symmetric Slab Waveguide

- Critical angle for total internal reflection $\theta \text{crit} = \sin^{-1}\left(\frac{n_0}{n_1}\right)$

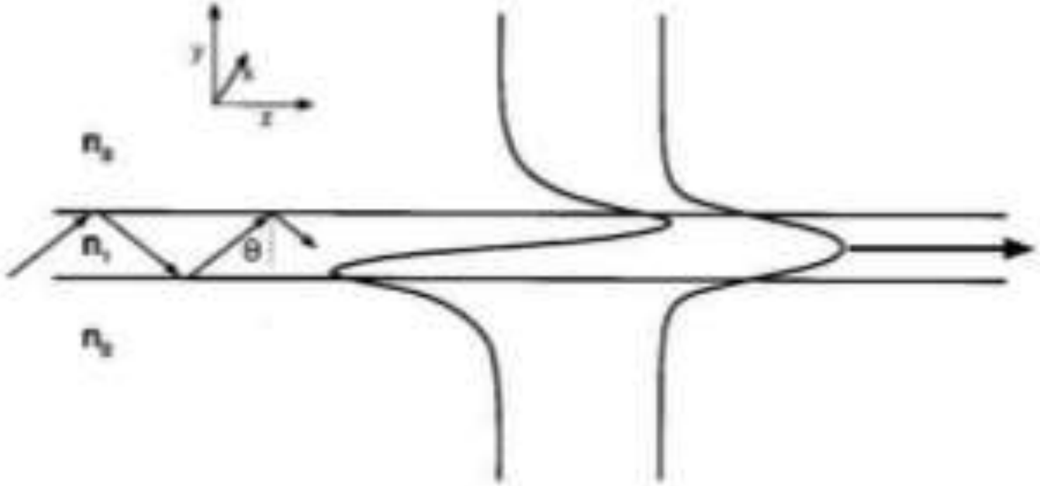


FIGURE 1 A symmetric three-layer slab waveguide. The fundamental even and first odd mode are shown.

Symmetric Slab Waveguide

- Critical angle depends on index of refraction of materials which may vary according to wavelength of light
- Thicker and higher index waveguide core admits larger no. of propagation angles
- Upon total internal reflection phase shift occurs also known as Goos-Hanchen shift
- Slab waveguide employs TIR from an abrupt index discontinuity for confinement

Symmetric Slab Waveguide

- TE and TM modes of symmetric slab is never cutoff
- For guided modes symmetric waveguides are either even or odd in field distribution
- The number of guided modes supported in slab waveguides depends on thickness, wavelength, indices of refraction n1,n2,n3

Strip Waveguide

- A strip waveguide is basically a strip of layer confined between cladding layers
- Strip waveguides are planar waveguide (guides light in one direction) only
- A central chip with high refractive index is bordered by material with smaller indices
- This results in total internal reflection at the lateral(sides) interface and thus forming guided modes(a mode whose field decays monotonically in transverse direction everywhere external to the core)

Strip Waveguide : Rectangular Waveguide

- The simplest case of strip waveguide is rectangular waveguide
- A rectangular waveguide supports TM and TE modes but not TEM mode as it