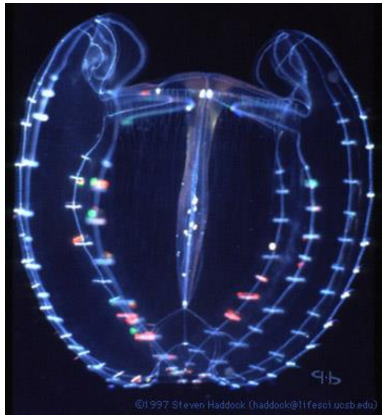
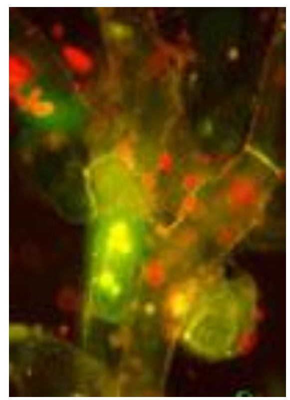
Part 2. Light source

Prof. Xu would like to thank his Ph.D supervisor Prof. Lian K. Chen at The Chinese University of Hong Kong, for providing the slides.

Light source in Nature - *Bioluminescence*



http://e-info.org.tw



http://www.lifesci.ucsb.edu/~biolum/organism/photo.html

Outline

- Semiconductor Principles, PN junction, Photon Generation
- Light Emitting Diode (LED): Structure and Characteristics
- Laser Diode: Structures and Characteristics
- Longitudinal Mode Control
- Laser Types
- Direct Modulation of Optical Sources

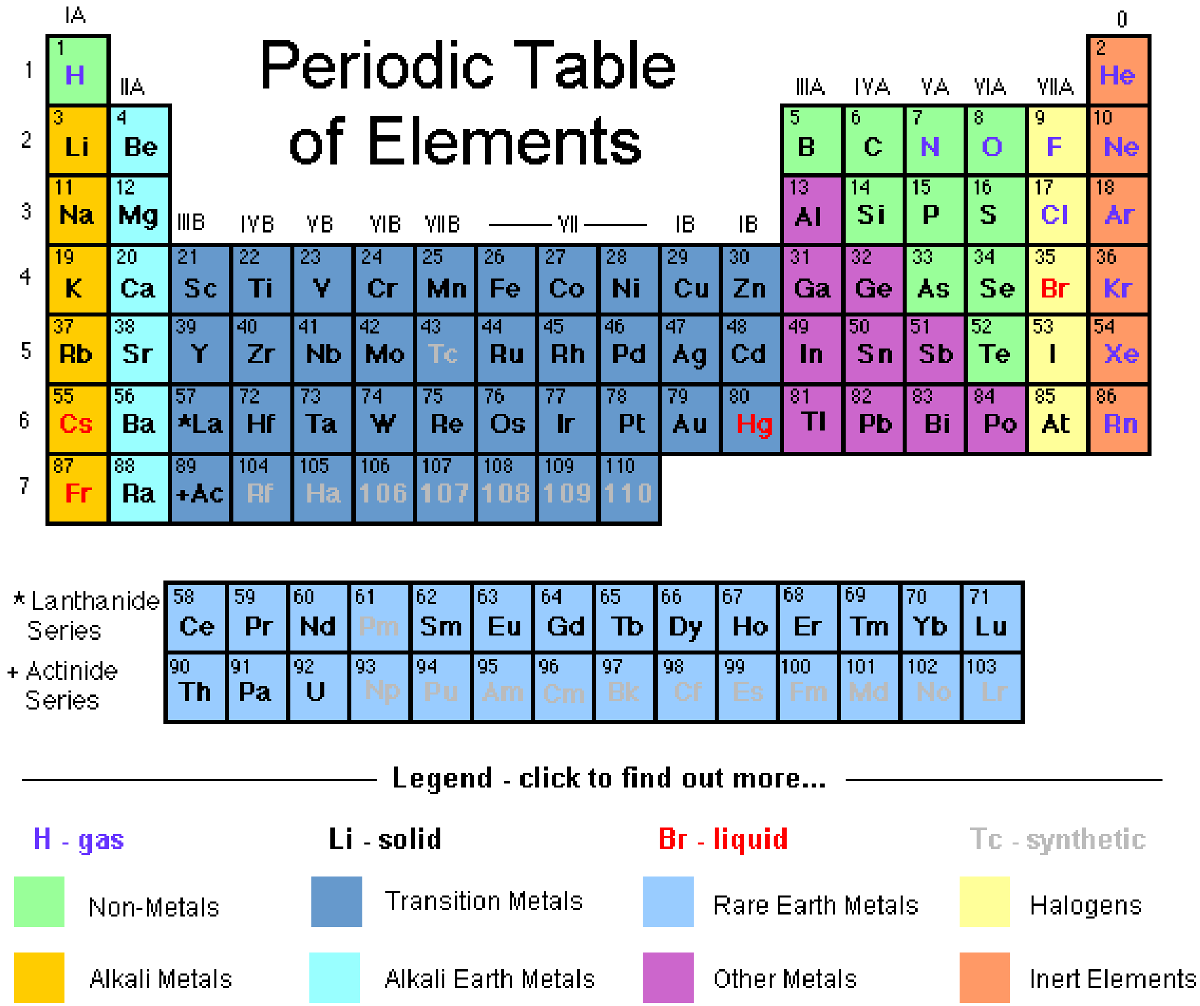
Ref: [Keiser Ch 4 and Ch 5.1, 5.2][Agrawal Ch 3]

Semiconductor

- Solid-state materials include *insulator*, *semiconductor*, *conductor*.
- ***Semiconductor*** : a solid substance that is a non-conductor when pure or at low temperature but has a conductivity between that of a insulators and that of most metals when containing a suitable impurity or at a high temperature.
- Typical semiconductors : group IV elements (Si, Ge, ..) or III-V compounds (GaAs, InP..)

Group:	III	IV	V
	B	C	N
	Al	Si	P
	Ga	Ge	As
	In	Sn	Sb

Periodic Table of Element



http://www.webelements.com/

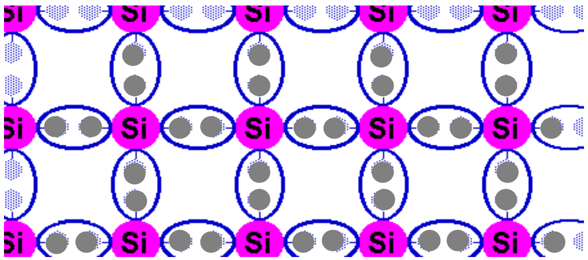
Classification of Materials

- **INSULATOR**
  (Eg >> 1 eV)
- **SEMICONDUCTOR**
  (Eg ~ 1-10 eV)
  group
  IV or III-V
  - **INTRINSIC**
    (undoped)
  - **EXTRINSIC**
    (doped)
    - *n*-types
      (doped with V; *donor*)
    - *p*-types
      (doped with III; *acceptor*)
- **CONDUCTOR**
  (Eg < 0)

Eg: energy gap
eV: electron volt

Energy Bands

- The conduction properties of semiconductor can be interpreted by the *energy bands* – the *conduction band*, the *valence band*, and the band in between the two that no electron is allowed to stay.
- The gap between conduction and valence bands is called *energy gap* or *band gap*, in which no energy level exists.
- For pure (intrinsic) crystal at low temperature, the *valence band* is full and the *conduction band* is empty.
- Considering Si atom, it has four electrons in its outer shell and forms *covalent bond* with its neighboring atoms in a crystal.



- The conductivity of a material depends on its energy gap value. At room temperature, the energy gap is

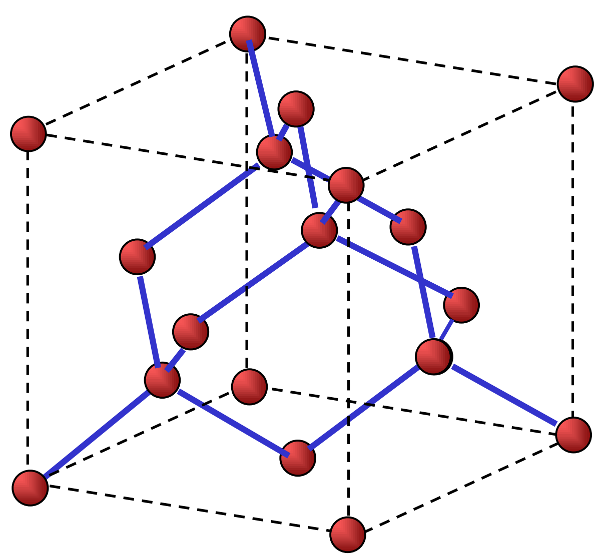
  ~ 1.12 eV for Si; 1.42 eV for GaAs. eV: electron volt

  > 9 eV for insulator.

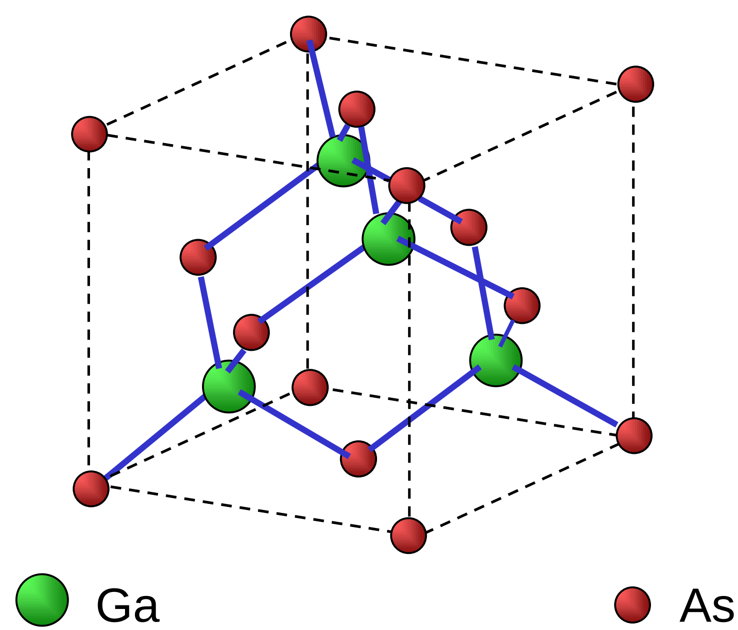
  < 0 eV for metals (conduction and valence band are overlapped).

Crystal Structure

- Group IV element (C, Si, Ge)



- Group III-V compound (GaAs)

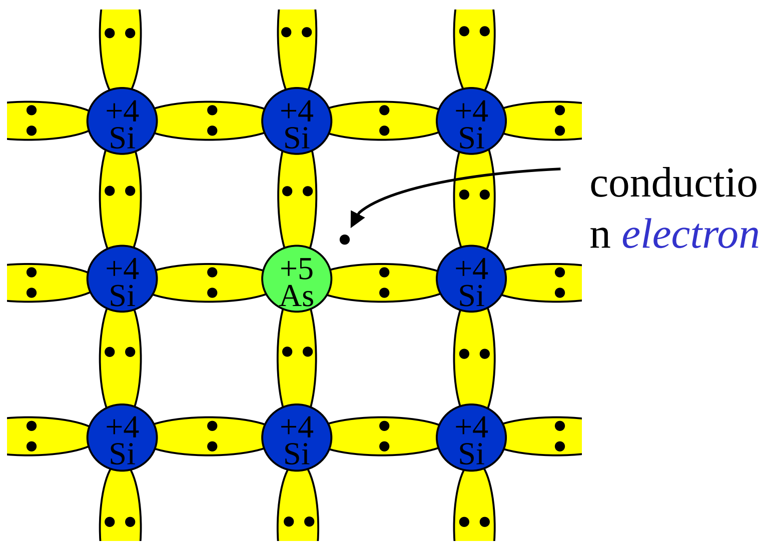


Intrinsic and *Extrinsic* materials

- The conductivity of semiconductor can be greatly increased by adding impurity to intrinsic semiconductor. This process is called *doping* and the doped semiconductor is *extrinsic* material.

(1) If group V impurity (e.g. P, As) is added to group IV, 4 electrons are bonded by *covalent bond* and one loosely bonded *electron* is available for conducting.

→ The impurity is called *donor* ; ***n*** is increased; and this material is *n-type*.

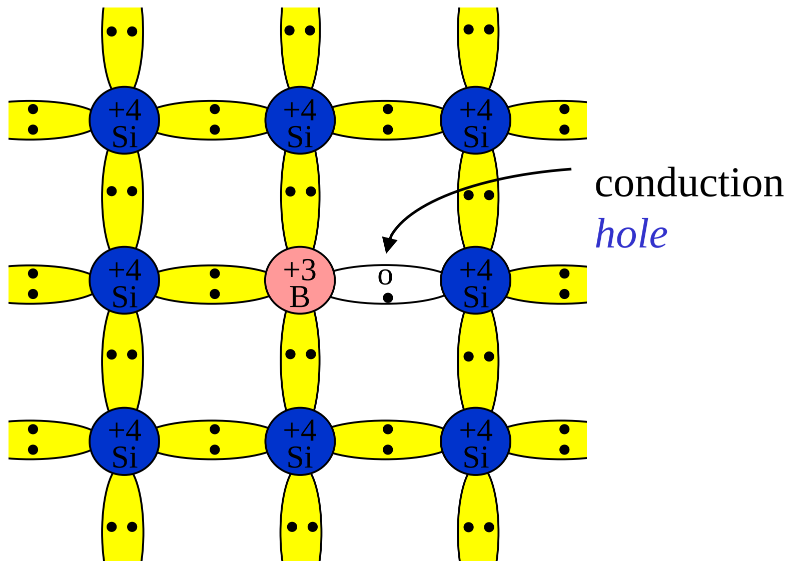


n-type Si (with donor – As)

Schematic Bond Structure of extrinsic semiconductor

(2) If group III impurity (e.g. Al, Ga) is added to group IV, 3 electrons are bonded by covalent bond and one <u>*hole*</u> is created and can accept free electrons.

→ The impurity is called *acceptor* ; ***p*** is increased; and this material is *p-type*.



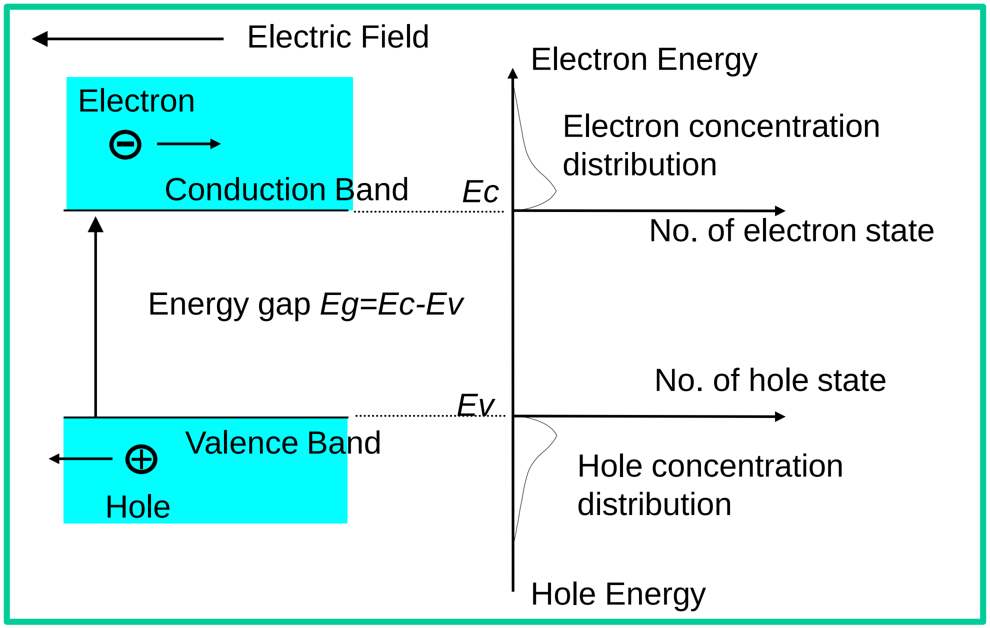
p-type Si (with acceptor – B)

Energy-Level diagram#

- The Energy-level diagram below shows that electrons can be thermally excited to *conduction band*, leaving holes in the *valence band*.
- Both conduction *electrons* and *holes* (the carriers) contribute to the material's conductivity.
- For intrinsic materials, the electron and hole concentrations equal to the intrinsic carrier concentration n_i.

$$n_i = n = p = K \exp\left(-\frac{E_g}{2k_B T}\right)$$

where $K = 2(2\pi k_B T / h^2)^{3/2}(m_e m_h)^{3/4}$

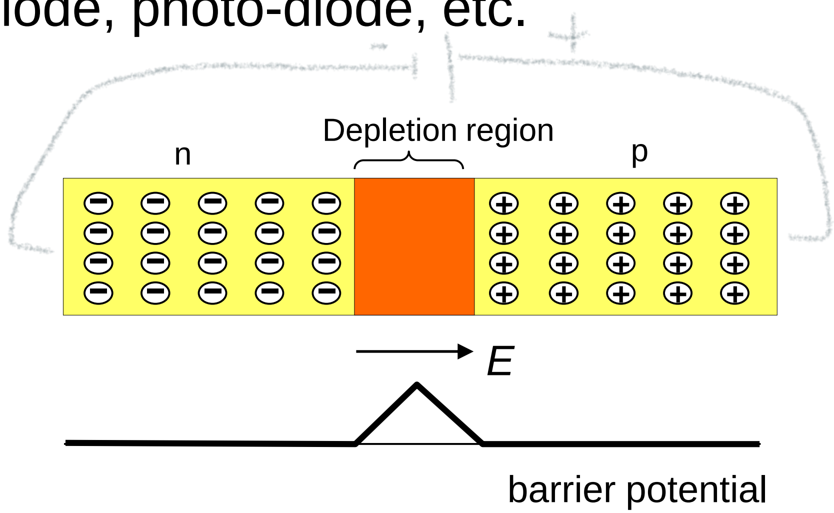


n_i, n, and p are the concentration of intrinsic carrier, electron carrier, and hole carrier, respectively. m_e and m_h are the effective mass of electron and hole. k_B is the Boltzmann's constant, T is the temperature in ºK, and h is the Planck's constant.

(From G. Keiser)

PN Junction

- When *p-type* and *n-type* semiconductors are jointed, the majority carriers (holes in p-type or electrons in n-type materials) diffuse across the junction and combine with the carriers of opposite polarity on the other side.
- A *depletion region* (space charge region) is created where no mobile carrier exists and an electric field (potential barrier) is formed.
- Many useful components are made by *pn-junction*; e.g. diode, transistor, laser diode, photo-diode, etc.



Recombination

- Recombination of electron and hole releases energy in different ways.

Recombination

- ***Non-radiative***
  - ***Trap defects***
  - ***Surface Recombination***
  - ***Auger Recombination***
    (energy release by this recombination is given to another ele/hole pair as kinetic energy)
- ***Radiative***
  - ***Spontaneous Emission***
  - ***Stimulated Emission***

The process that generates light.

Quantum efficiency

- *Internal quantum efficiency*

$$\boxed{\eta_{\text{int}} = \frac{R_{rr}}{R_{total}} = \frac{R_{rr}}{R_{rr} + R_{nr}}}$$

where R_{rr} = radiative recombination rate $= \dfrac{N}{\tau_{rr}}$

R_{nr} = nonradiative recombination rate $= \dfrac{N}{\tau_{nr}}$

N: carrier density

- *External quantum efficiency*

η_{ext} = external quantum efficiency (total emitting power degraded due to internal absorption, reflection at air-semiconductor interface)

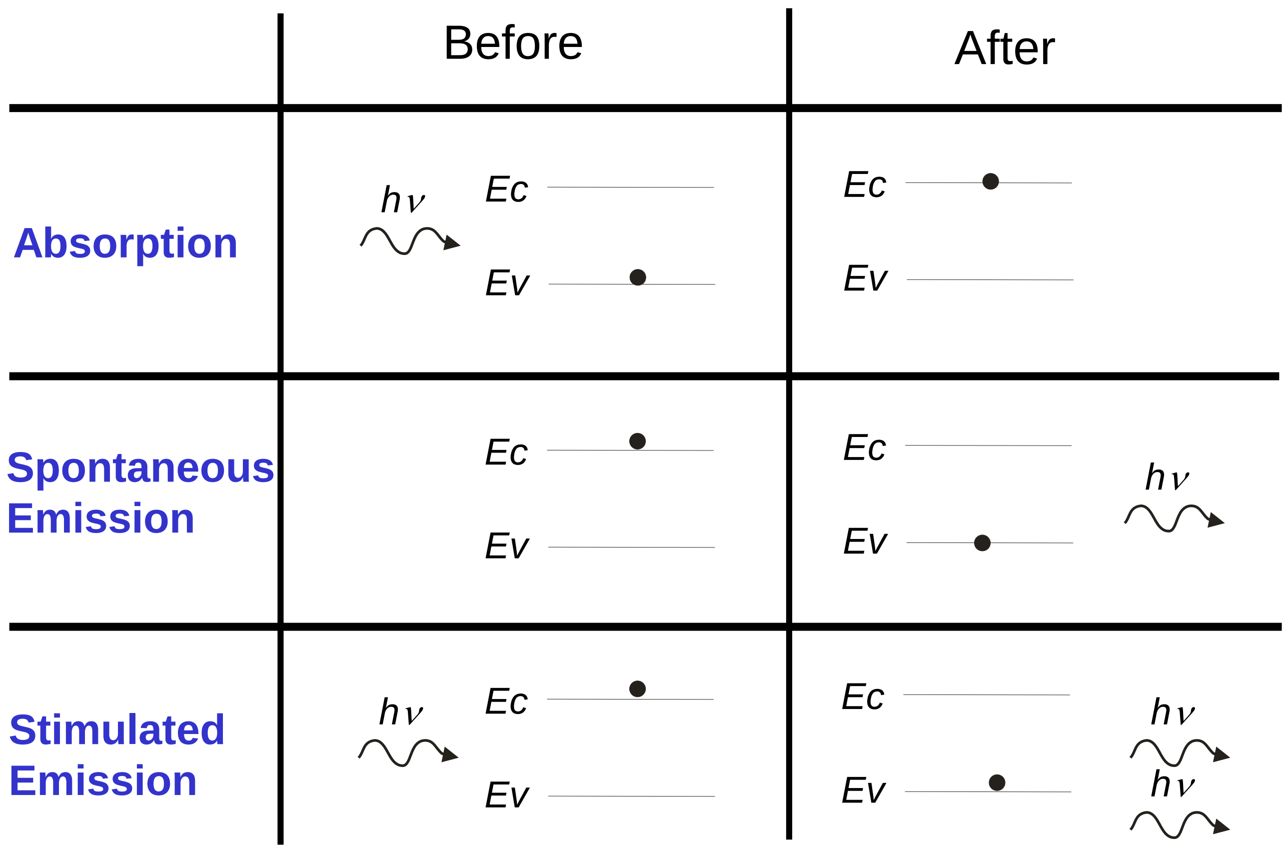
$$P_{\text{int}} = \eta_{\text{int}} \cdot \left(\frac{h\nu}{q}\right) \cdot I \qquad \text{- internal optical power}$$

$$P_{ext} = \eta_{ext} \cdot P_{\text{int}} = \eta_{ext}\eta_{\text{int}}\left(\frac{h\nu}{q}\right) \cdot I \qquad \text{- external optical power}$$

where Greek letter ν is photon frequency, q is electron charge, and I is the current injected to laser

Interactions between photons and electrons

- *absorption*, *spontaneous emission*, and *stimulated emission*.



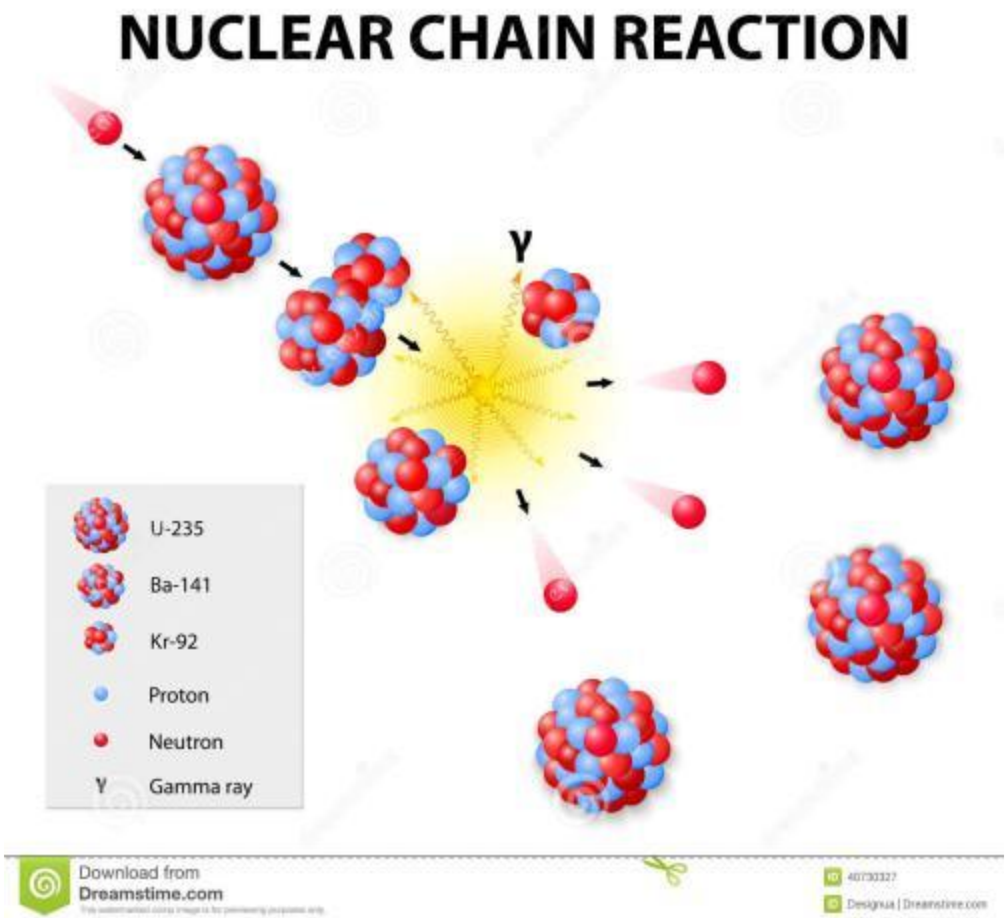
Electrons (carriers) in the valence band absorb energy from the incoming photons and are excited to the conduction band., leaving holes in the valence band.

Electrons in the conduction band recombine with the holes randomly.

Incoming photons stimulate the excited electrons in the conduction band to fall to valence band and recombine with the holes→ two emitted photons are *coherent*.

And these two phtotons further trigger other stimulated emission.

Stimulated emission is similar to NCR



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LED and Laser

- ***LED***: **l**ight **e**mitting **d**iode
- ***Laser:*** **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation

  First demonstrated of stimulated emission by Townes, Gordon and Zeiger in 1954. (maser)

  1st laser: Theodore H. Maiman, 1960 (also see ref: Bell labs and the first ruby laser)

Charles Hard Townes

Nicolay Gennadiyevich Basov

Aleksandr Mikhailovich Prokhorov

The Nobel Prize in Physics 1964

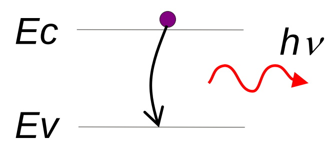
"for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"

(Ref: http://www.nobel.se/physics/laureates/1964/index.html)

LED and Laser (contd.)

- LEDs emit light by *spontaneous emission*.

  → incoherent light

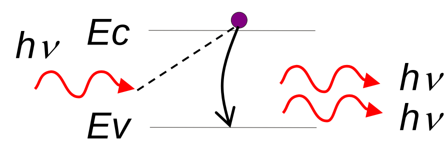
  

  – LED is a forward biased pn-junction without optical feedback.

  → wider linewidth (spectral width).

- Lasers emit light by *stimulated emission*.

  → coherent light

  – Semiconductor laser is a forward-biased p-n junction with a "Fabry-Perot cavity".

  → faster response time and narrower spectral width

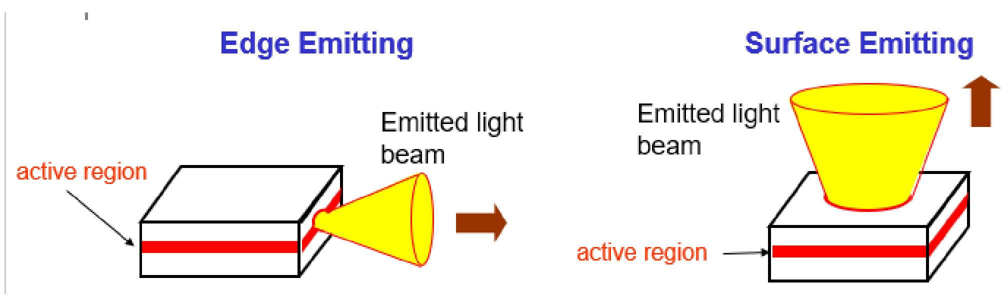
  (linewidth).

Typical specification for light sources

(value needs to be updated)

	SE-LED	EE-LED	MM-LD	SM-LD
average power (dBm) in SMF in MMF	 -36 -13	 -30 -7	 >0 -	 >0 -
modulation speed (Mb/s)	100	200	300	>1000
spectral width (nm)	110	70	1-5	<1
mean life-time@50C (hr) (*1yr ~ 8760 hr)	100M	>1M	50-500K	50-500K
drive circuit	simple	simple	complex	complex
packaging	simple	>	>	complex
cost	low	<	<	high

SE-LED :surface emitter LED. EE-LED :edge emitter LED.
MM-LD: multimode Laser diode. SM-LD: single-mode Laser diode.

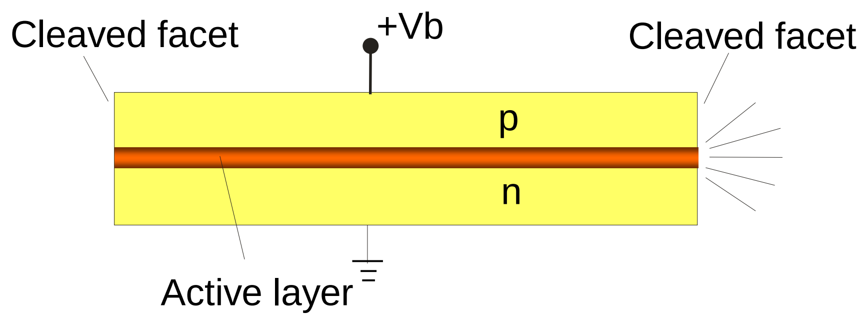


General requirements for a light source

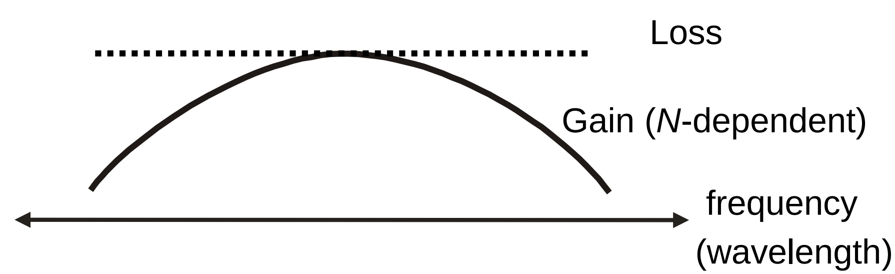
- output in single mode
- narrow spectral width (linewidth)
- emitting light in the desired transmission window (e.g. 1.3 or 1.55 μm)
- good current-to-light conversion efficiency : mW/mA
- fast modulation speed
- good linearity of P/I curve
- good heat dissipation (may need TE cooler)
- good stability of wavelength and output power with temperature
- low packaging (coupling) complexity
- good reliability (transmitter life time)
- low cost

Basic Laser Structure

- A semiconductor laser diode is basically an LED together with two cleaved facets (act as partial reflection mirrors) that form a Fabry-Perot cavity.

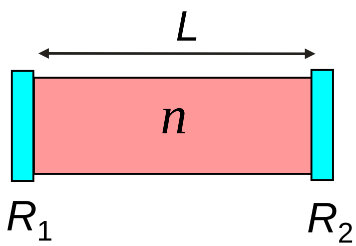


- Three conditions to lase (Lasing Principles)
  - population inversion, $N_2 > N_1$. (N_1 and N_2 are the carrier density in the valence band and conduction band, respectively.
  - gain $\geq$ loss,
  - feedback cavity

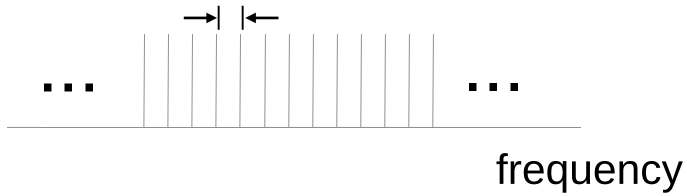


Fabry-Perot Cavity

- A *Fabry-Perot cavity* is formed by a cavity with two end mirrors.
- Only signals with frequencies equal to the harmonics of $c/(2nL)$ can exist inside this cavity. (n is the cavity's refractive index)



$\boxed{\Delta f = c/(2nL)}$



- At steady state in the laser cavity,

$$E_0 \exp[(g/2)2L]\sqrt{R_1R_2}\exp[-(\alpha_{\text{int}}/2)2L]\exp(2ikL) = E_0$$

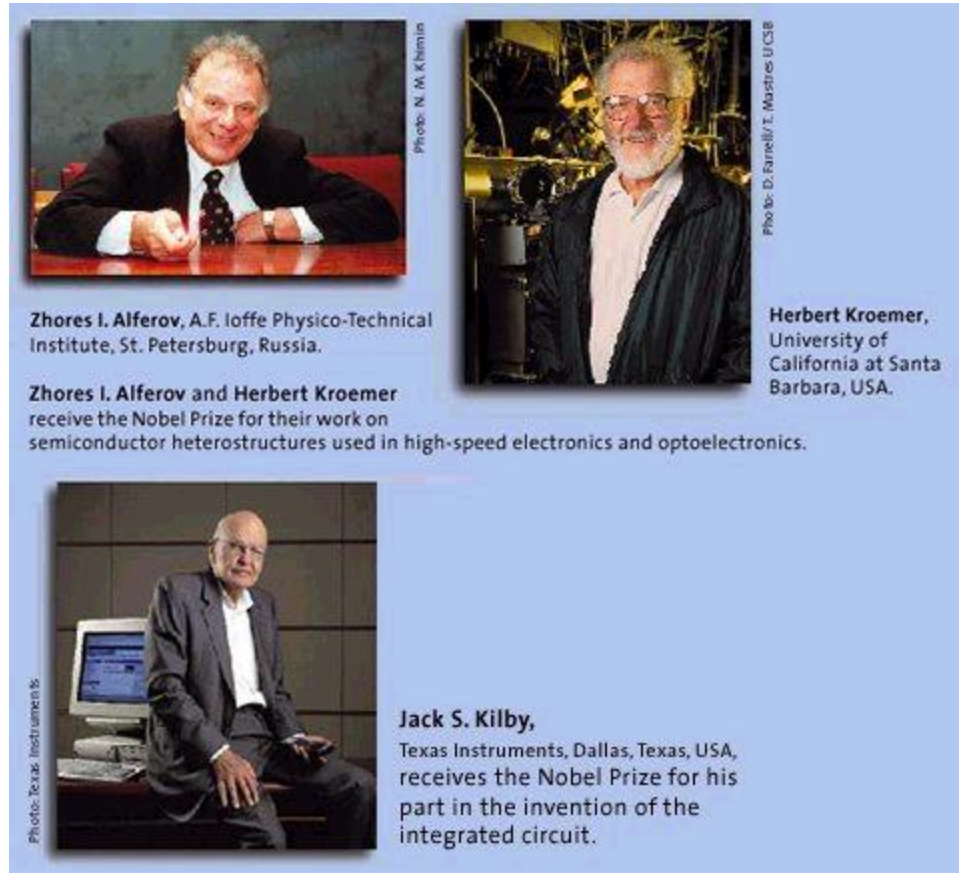
$$\rightarrow \begin{cases} g = \alpha_{\text{int}} + \dfrac{1}{2L}\ln\left(\dfrac{1}{R_1R_2}\right) = \alpha_{\text{int}} + \alpha_{mirror} = \alpha_{cavity} \\ 2kL = 2m\pi \qquad \text{or} \qquad \nu = \nu_m = m \cdot c/(2nL) \end{cases}$$

Only signals of these frequency can pass through this cavity.

g and α_{int} are cavity internal power gain and loss, respectively. Electric field's gain and loss are just half of those.

The Nobel Prize in Physics 2000

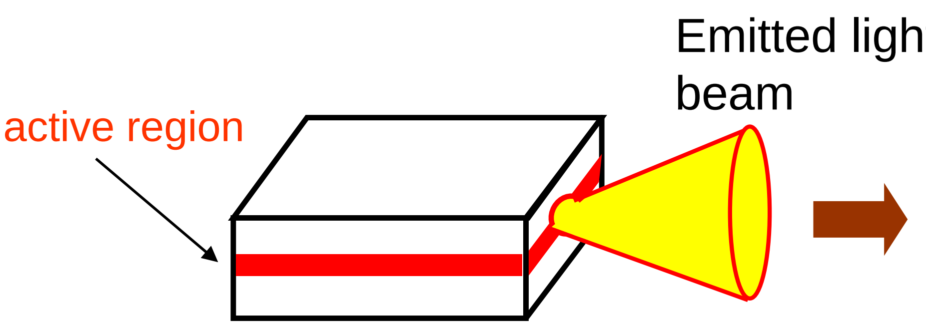
- Alferov$^{1/4}$ and Kroemer$^{1/4}$ –
  - "*for basic work on information and communication technology, specifically for developing semiconductor* ***heterostructures*** *used in high-speed-and opto-electronics*"
  - They proposed in 1963, independently of each other, the principle for the *heterostructure* laser
- Jack S. Kilby$^{1/2}$ –
  - "for basic work on information and communication technology, specifically for his part in the invention of the integrated circuit"



Ref: http://www.nobel.se/physics/educational/poster/2000/kroemer.html

Surface Emitting vs. Edge Emitting

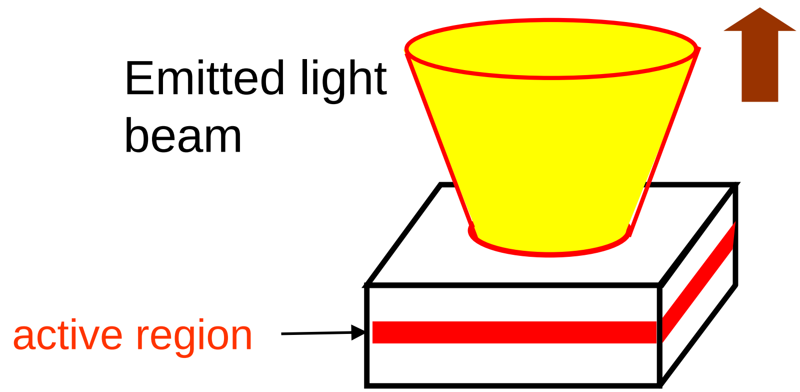
Edge Emitting



- Emitted light is parallel to the plane of the active layer
- Need to dice the laser out to do measurements →
  high manufacturing cost

- Narrower light beam width
- The generated photons may be reabsorbed along the active layer or lost at the facet (reflection).

Surface Emitting

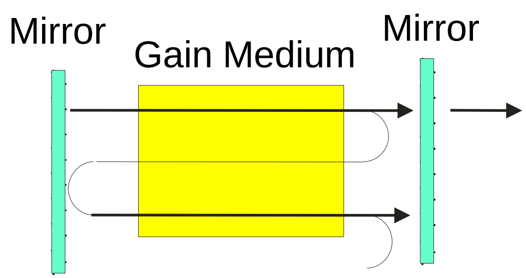


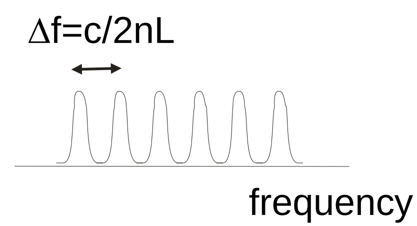
- Emitted light is perpendicular to the plane of the active layer
- No need to dice the laser chips out of the waver to do measurements→ facilitate laser testing and reduce manufacturing cost
- Wider light beam width → easier to couple to fiber (but the efficiency is lower); lower packaging cost

Laser modes

- Only certain frequencies (the Fabry-Perot modes) are allowed in the laser cavity.
- The mode spacing is $\Delta f = c\,/(2\,nL)$

  where c, n, and L are the light velocity, refractive index inside cavity and cavity length, respectively.





Fabry-Perot Cavity Mode

$$E_0 \exp[(g/2)2L]\sqrt{R_1R_2}\exp[-(\alpha_{\text{int}}/2)2L]\exp(2ikL) = E_0$$

$$\equiv$$

$$\rightarrow \begin{cases} g = \alpha_{\text{int}} + \dfrac{1}{2L}\ln\left(\dfrac{1}{R_1R_2}\right) = \alpha_{\text{int}} + \alpha_{mirror} = \alpha_{cavity} \\ 2kL = 2m\pi \qquad \text{or} \qquad \nu = \nu_m = m\cdot c\,/\,(2nL) \end{cases}$$

g and α_{int} are cavity internal power gain and loss, respectively. Electric field's gain and loss are just half of those.

Only signals of these frequency can pass through this cavity.

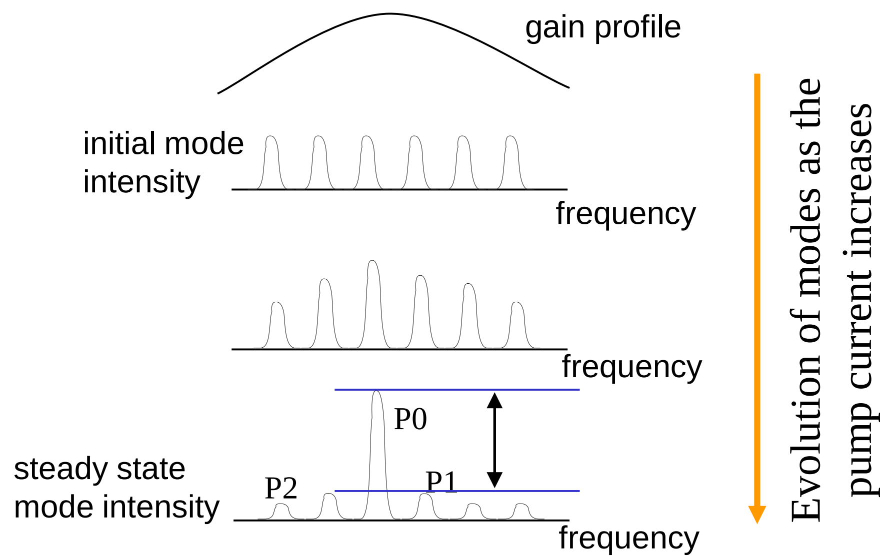
Side mode suppression ratio (SMSR or MSR)

- The gain medium that provides optical gain is *wavelength-dependent*. The mode that is closer to the gain maximum grows faster than the other modes, and it depletes the gain after several round trips of reflection.

  → *The rich gets richer, the poor gets poorer.*

$$\boxed{\mathrm{SMSR} \equiv P_0 \;/\; P_1}$$

For single-mode operation, typically SMSR > 20 dB.



The mode spacing is $\Delta f = c/(2\,nL)$

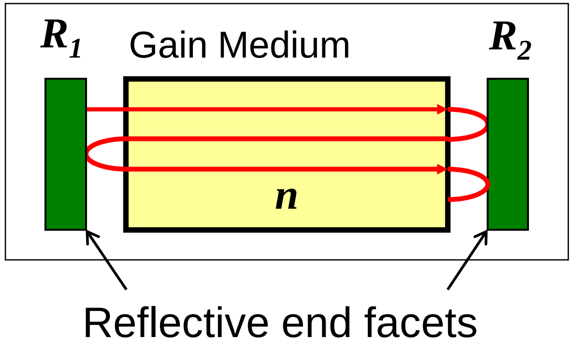
Q: What are the problems with multimode laser operation?

Q: How to achieve better SMSR?

Types of Laser Diodes

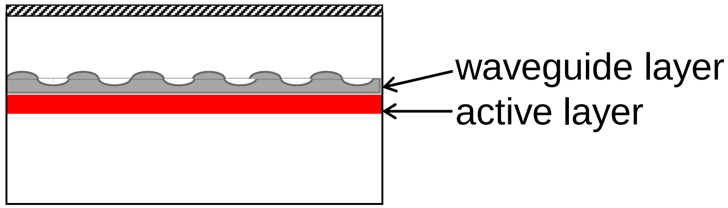
Fabry-Perot (FP) Lasers

- *MSR* ~10 - 20 dB
- usually support multi-longitudinal mode operation



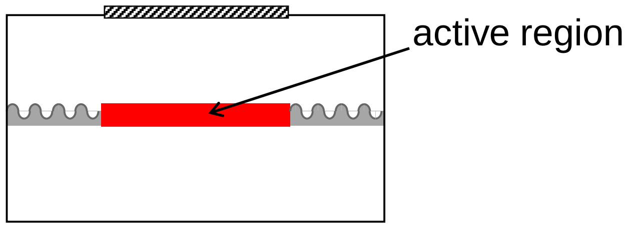
Distributed Feedback (DFB) Lasers

- *MSR* > 30dB
- wavelength selection by integrated distributed gratings over the whole active layer



Distributed Bragg Reflector (DBR) Lasers

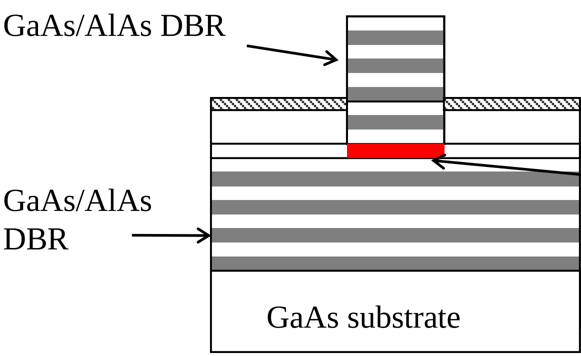
- *MSR* > 30dB
- wavelength selection by integrated distributed gratings as Bragg reflector <u>outside</u> the active layer

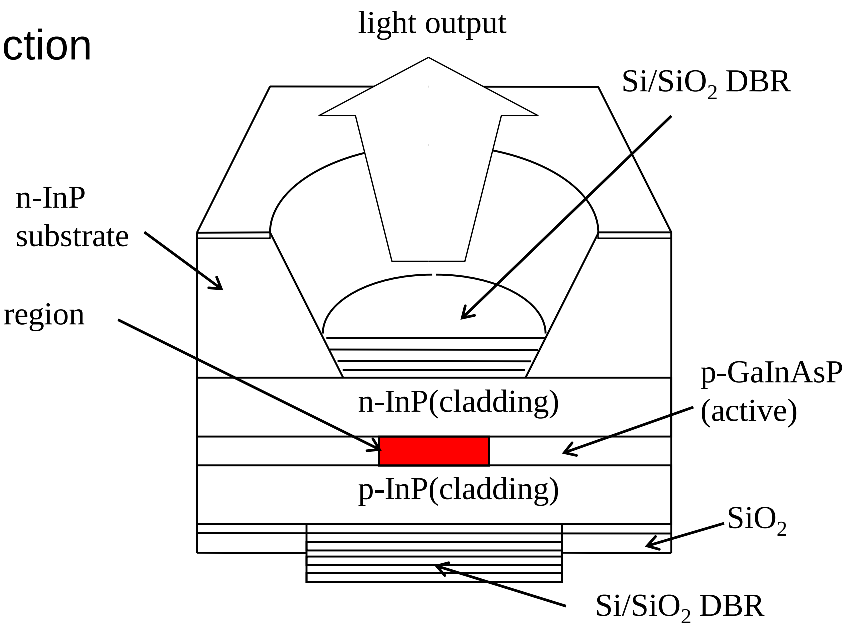


Types of Laser Diodes (2)

Surface Emitting Lasers (SEL)

- Edge-emitting lasers have the problem that the output light beam from the narrow aperture is highly divergent due to diffraction; also large cavity size → harder to fabricate high-density laser array on a single chip
- Emitting direction can be changed by *output grating coupler* or by *angular reflector*
- *Vertical cavity surface emitting lasers (VCSEL)*
  - shorter cavity length
  - DBR stacks for wavelength selection



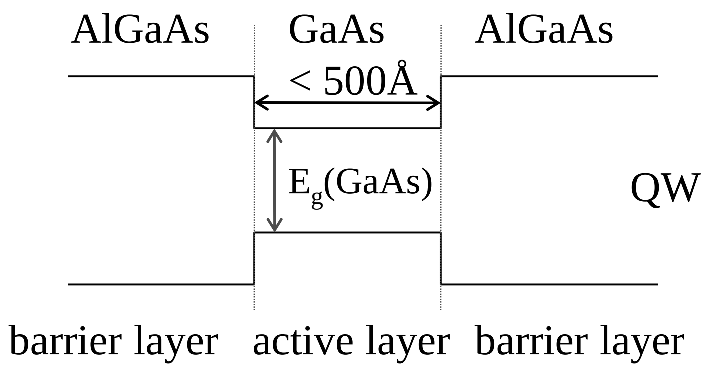


*Types of Laser Diodes (3)

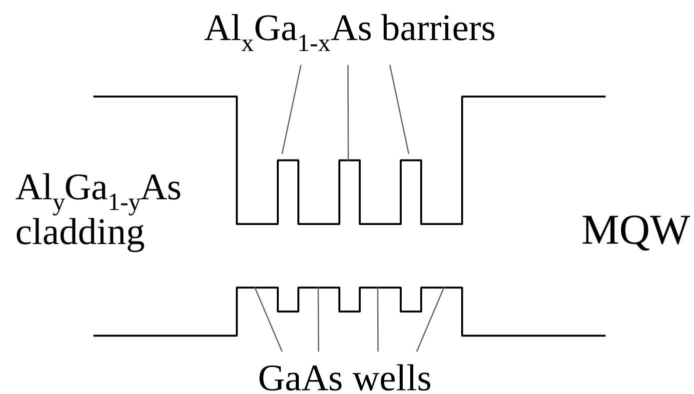
Quantum-Well (QW) Lasers

(Also see the Nobel Lecture of Zhores I. Alferov)

- similar to double heterostructure, but the thickness of the active layer is extremely small (< 500 Å) (1 Å=0.1nm)
- carriers are confined in a finite potential well



- multiple active-barrier layers are joined together to form the active region
  → ***Multiple Quantum Wells (MQW)***
  ⇒ carriers not captured by the first well can be captured by a subsequent one
  ⇒ good carrier confinement
  → low threshold current



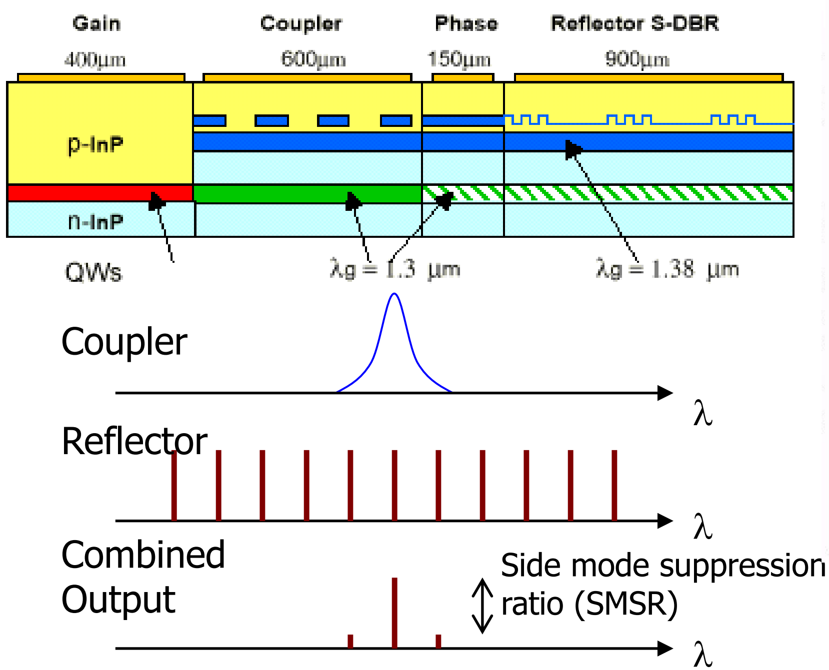
Types of Laser Diodes (4)

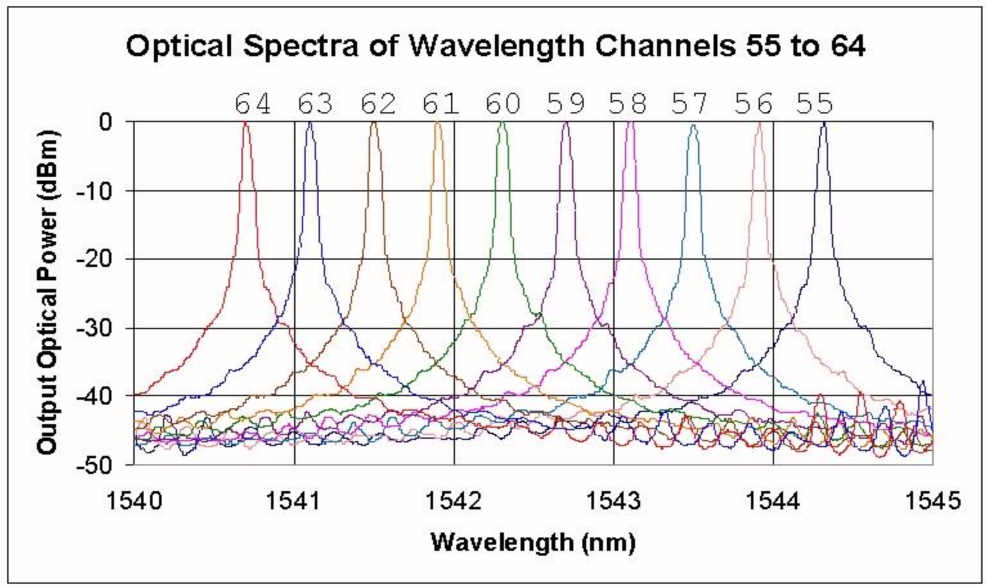
Tunable Lasers

→ Wavelength Tunability can be achieved by, e.g.,

- multi-section laser → use pump current to control gain, phase and grating separately
- external cavity with electro-optic/acousto-optic filters

Example: **Grating-assisted co-directional Coupler with Sampled grating Reflector (GCSR) Laser**





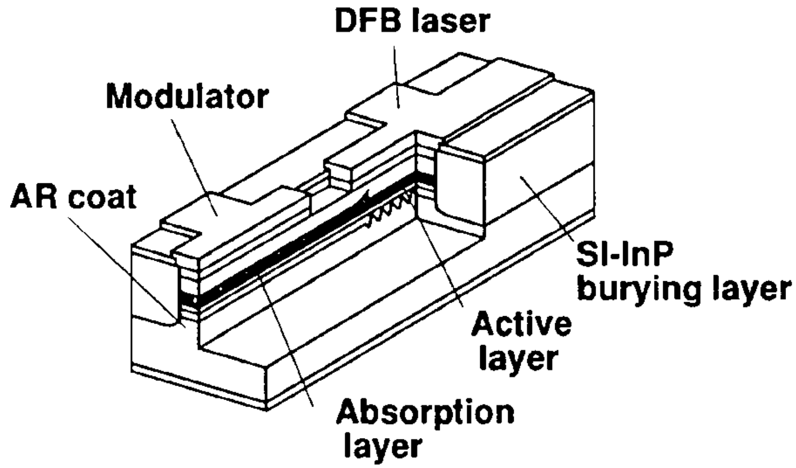
Tuning Range: 40-60 nm @1550nm

SMSR >30dB, output power ~ 0 dBm

Types of Laser Diodes (5)

Integrated Lasers

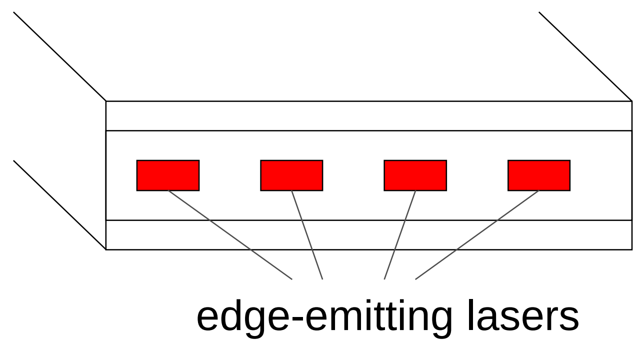
- *DFB laser integrated with electroabsorption modulators*



Q: advantage?

Laser Array

- multiple (edge emitting or surface emitting) lasers are fabricated on a single substrate
- need to consider coupling among the laser modes
- useful in interconnections in optical computing (optical backplane)



Consideration of tunable lasers:

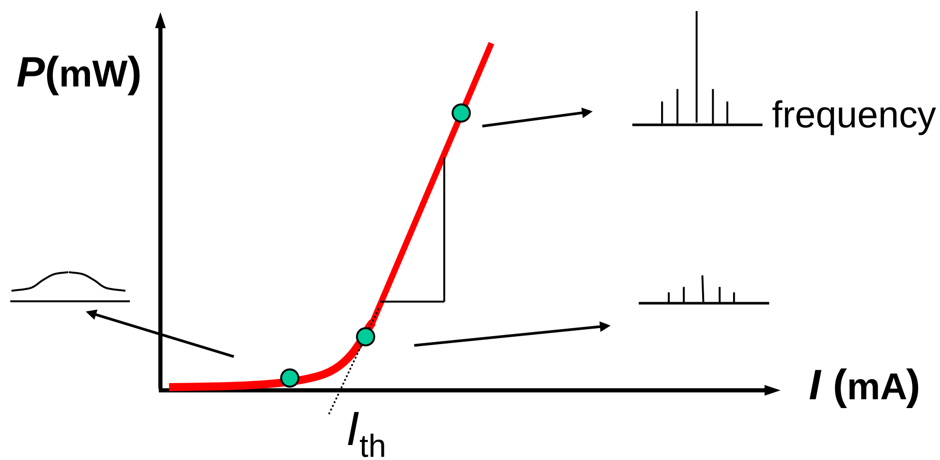
- *tuning range*
- *tuning speed*
- *linewidth*
- *stability* (wavelength and power stability)

	Ext. Cavity	DBR	2-section DFB	AO	GCSR
tuning range	70 nm	4nm(quasi cont.) 10nm(cont.)	2.1nm(cont.)	>70nm	60nm
tuning speed	>1ms	~ ns	~ ns	~ μs	~ ns

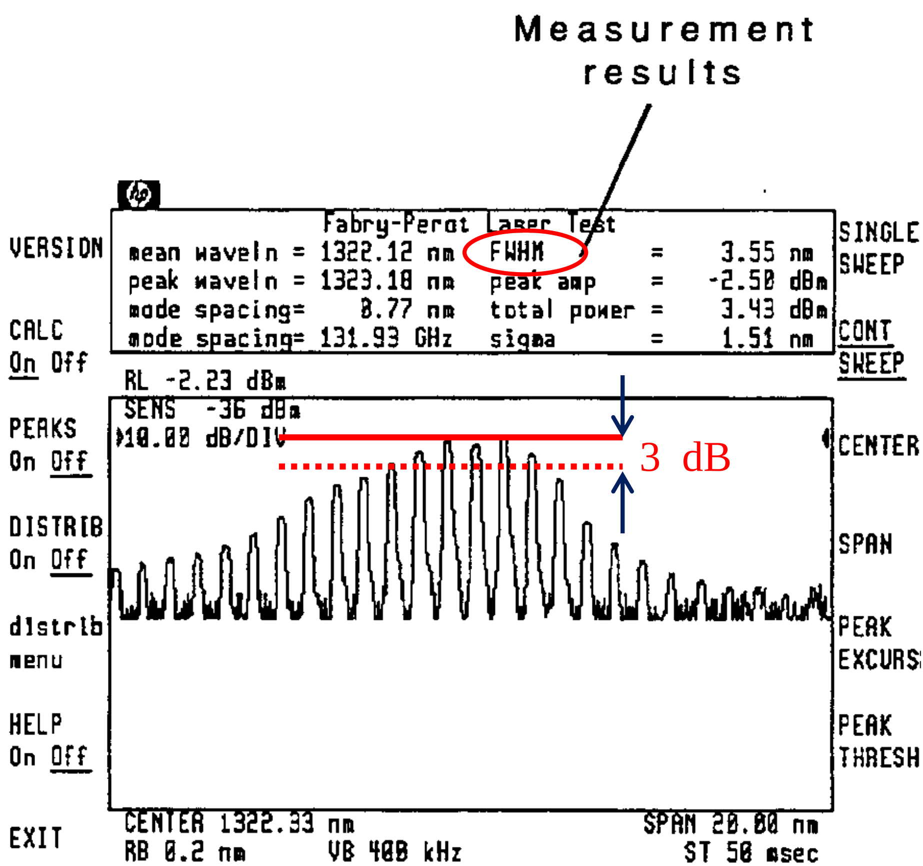
cont: continuous tuning of wavelength)
AO: acousto-optic

Laser *P-I* curve

- The laser output characteristic is governed by the *P-I* (output optical power versus input current) curve.
- From the *P-I* curve, important parameters of a particular laser, such as the *threshold current*, *laser linearity* (dP/dI, and d^2P/dI^2), can be obtained.
- When different bias current is applied, the laser has different spectral characteristics.
  - When I < threshold current $\rightarrow$ spontaneous emission
  - When I > threshold current $\rightarrow$ stimulated emission

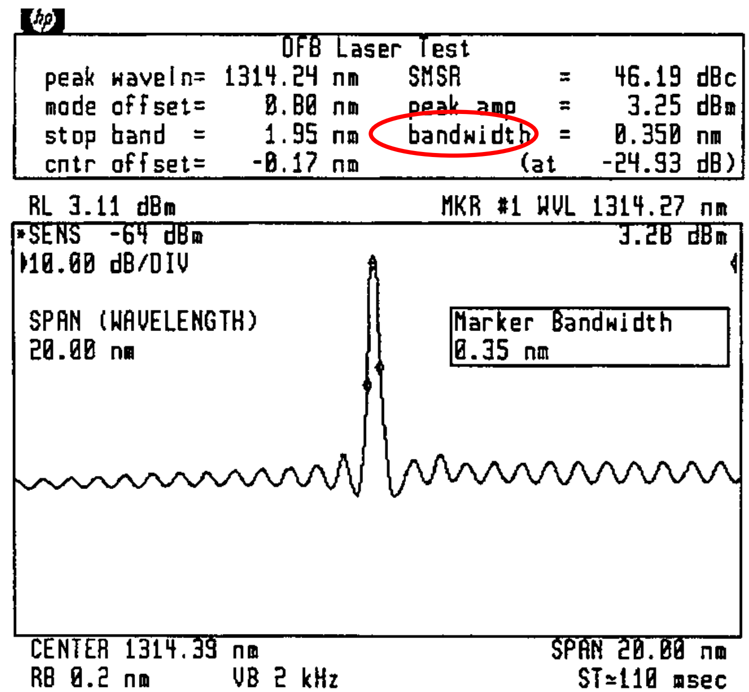


Laser Spectral width Measurement



Typical measurement results

(a) FP laser

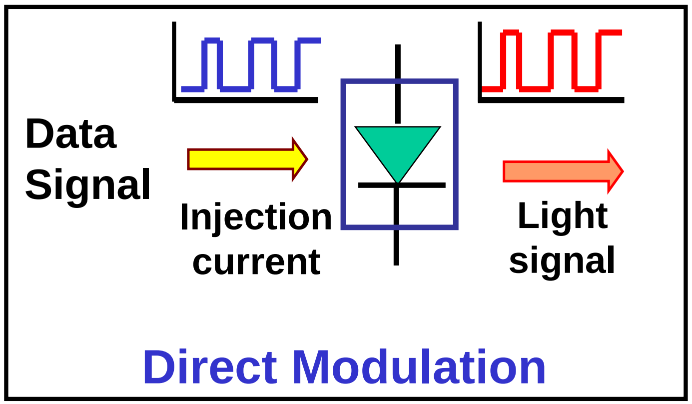


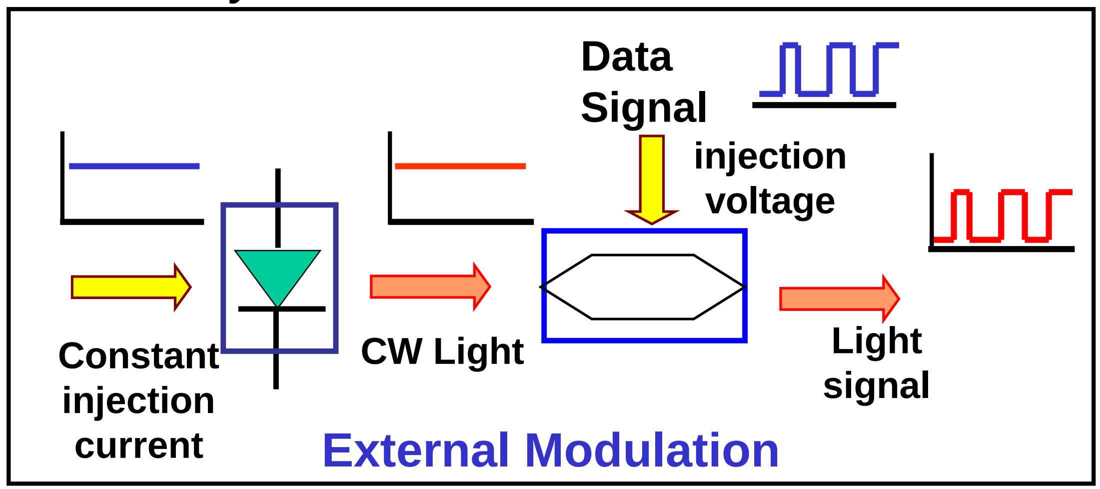
20 nm span.

(b) DFB laser

Direct/External Modulation of Laser

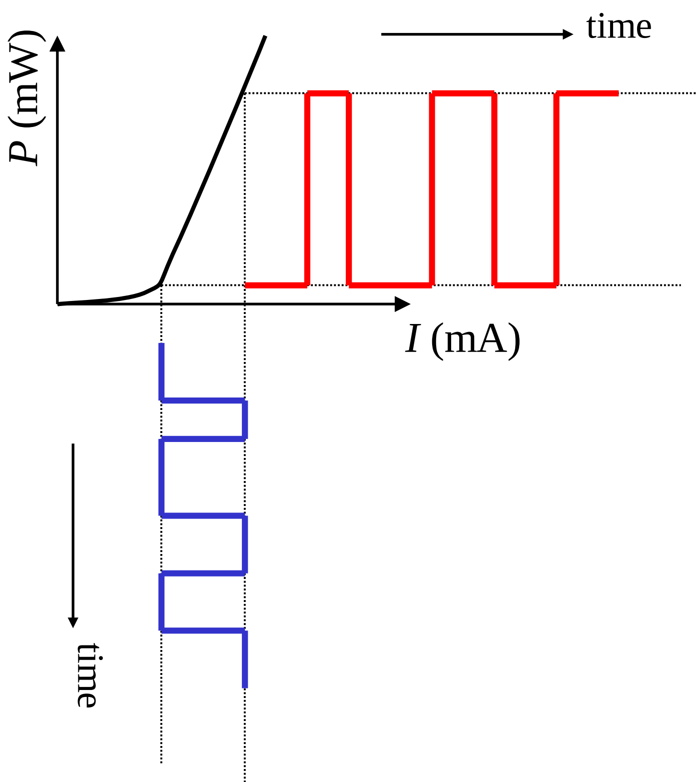
- **CW** (continuous wave) signal does not carry information. Light source needs to be modulated (amplitude, frequency, or phase) to convey information.
- The max. modulation frequency determines the max. information capacity that this transmitter can carry.



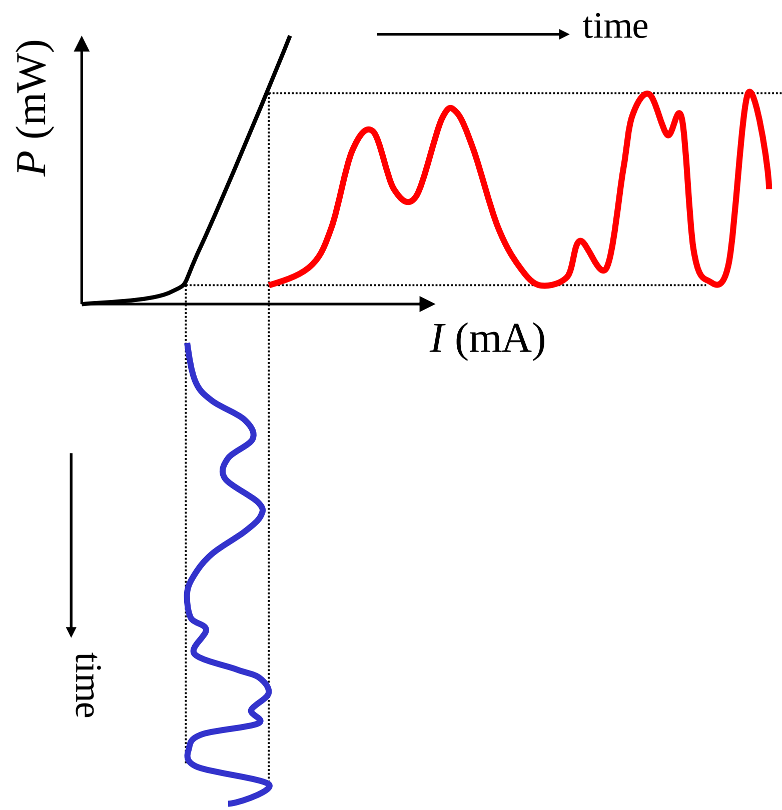


- For modulation at higher data rate, external modulation can be used.
- For the overall system capacity, additional bandwidth degradations due to non-zero laser linewidth and fiber dispersion have to be considered.

Analog and Digital Modulation



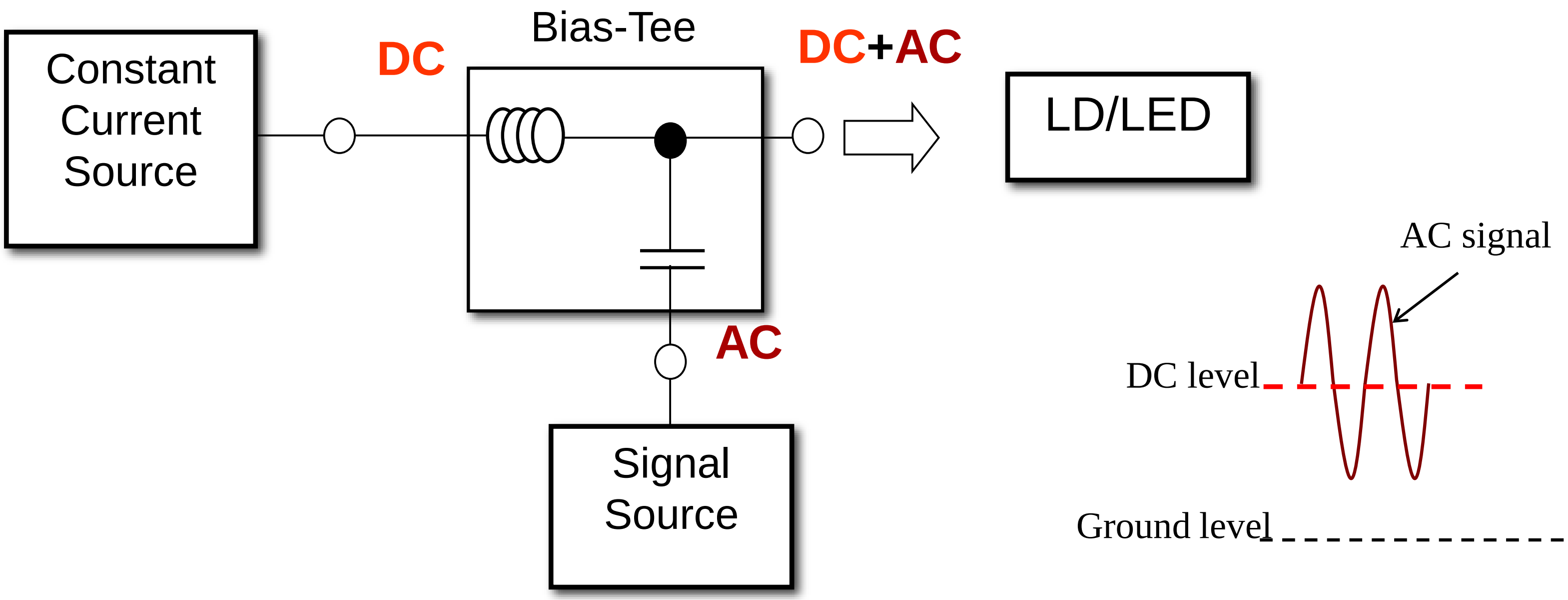
(a) Digital modulation



(b) Analog modulation

Direct Modulation of Optical Sources

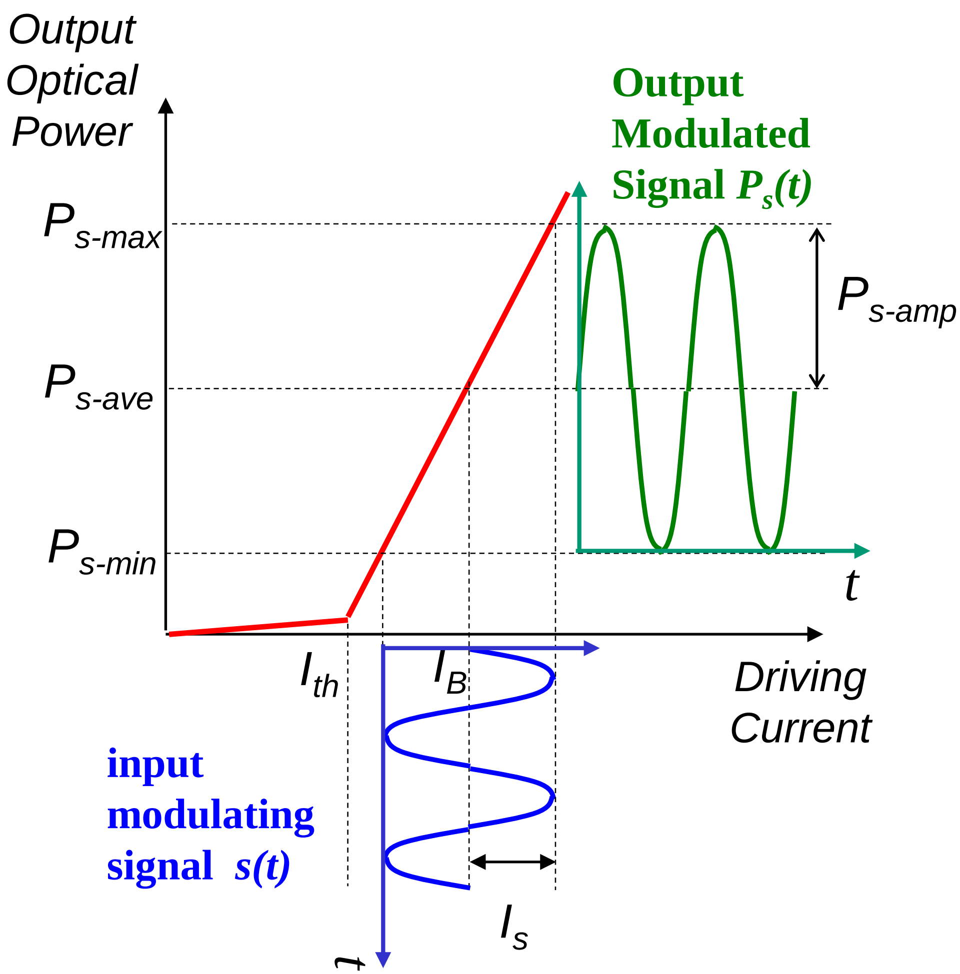
Current/signal biasing in laser diode and light-emitting diode



- The data signal has to be biased to a certain DC level in direct modulation of the optical source.
- Bias-Tee is used to combine the DC biased current and the AC data signal.
- The inductor in the bias-tee is to remove AC components (noises) from the constant current source while the capacitor in the bias-tee is to remove the original DC level of the data signal from signal source.

Direct Modulation of Optical Sources

Two Important Parameters in Direct Modulation



RF Modulation Index:

$$m = \frac{\text{Signal peak amplitude}}{\text{DC bias current - Threshold current}}$$

$$= \frac{I_s}{I_B - I_{th}}$$

$$P_s(t) = P_{s-ave}\left[1 + m\hat{s}(t)\right]$$

Normal operation: $0 < m \leq 1$

$\hat{s}(t)$:normalized version of ***s(t)*** (with unit amplitude)

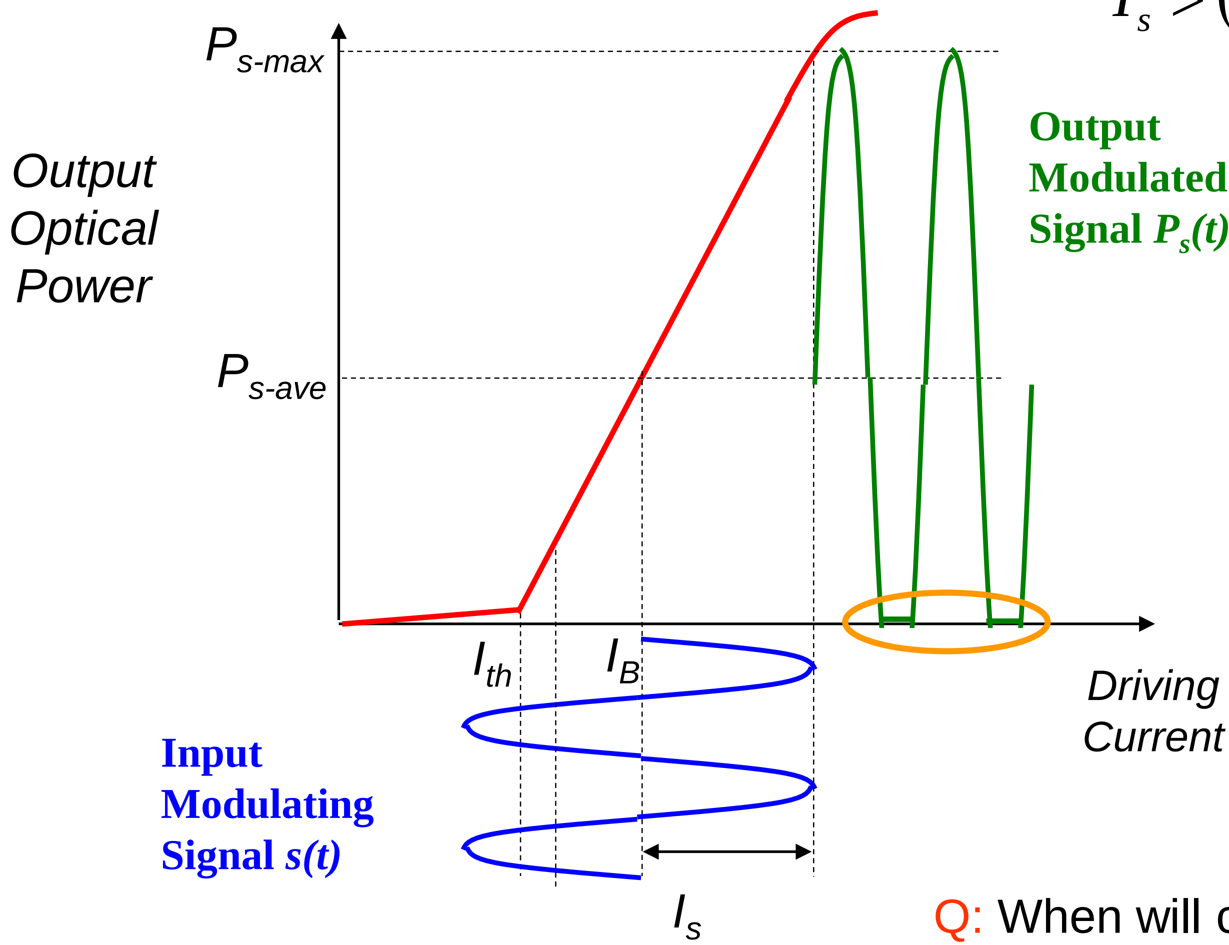
Optical Modulation Depth:

$$OMD = \frac{P_{s-amp}}{P_{s-ave}}$$

Direct Modulation of Optical Sources

When m > 1 → Clipping occurs

$$I_s > (I_B - I_{th}) \Rightarrow m = \frac{I_s}{I_B - I_{th}} > 1$$



The output light signal is clipped

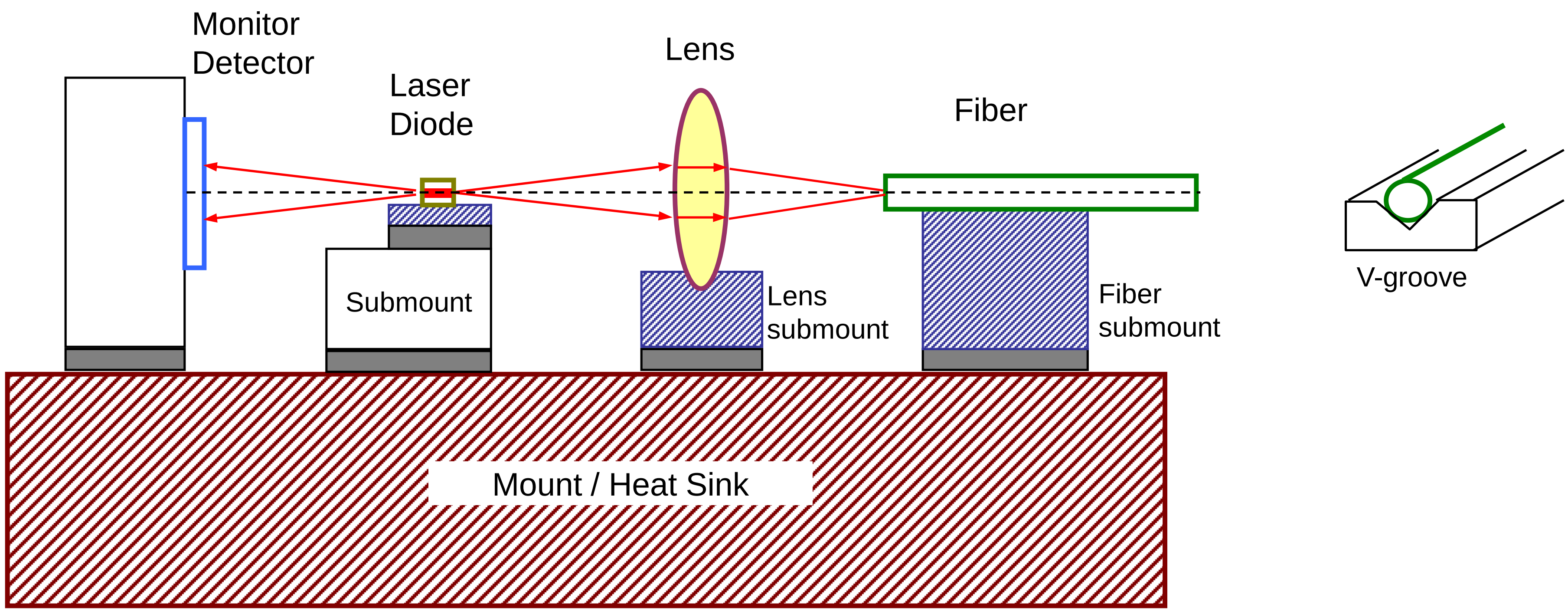
→ Output waveform is distorted

→ Clipped portion will create extra frequency components

→ distortions

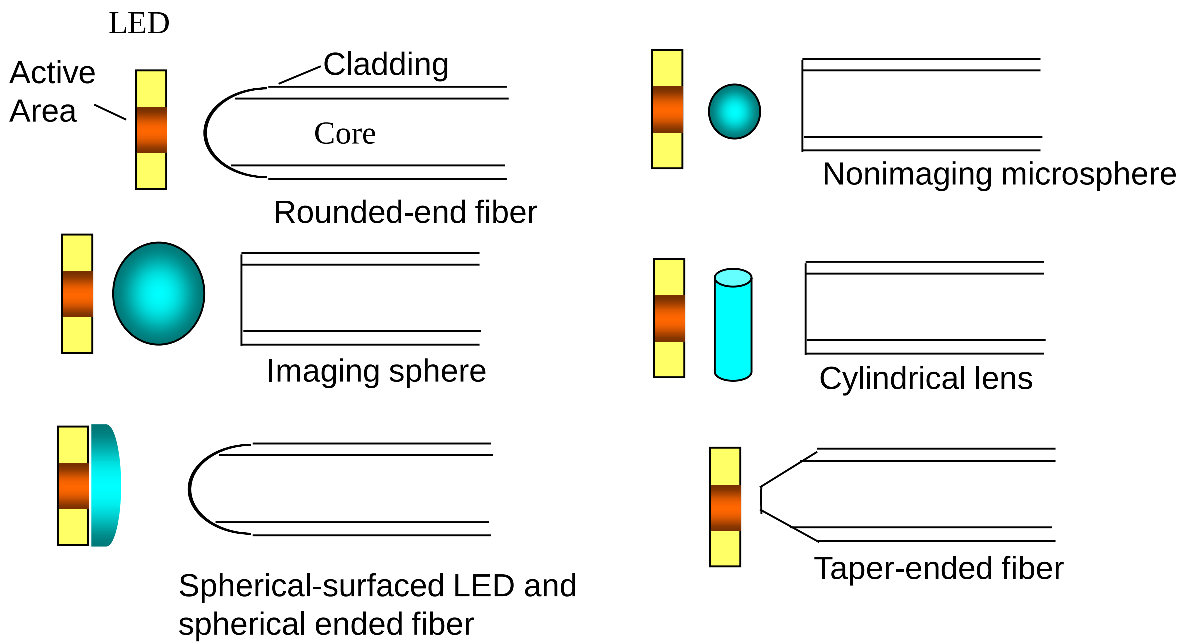
Q: When will clipping occur in real applications?

Laser Diode Packaging: Optics



Coupling improvement by lensing scheme

- Several types of micro lens can be used to improve the coupling efficiency when the fiber core is greater than the emitting area.

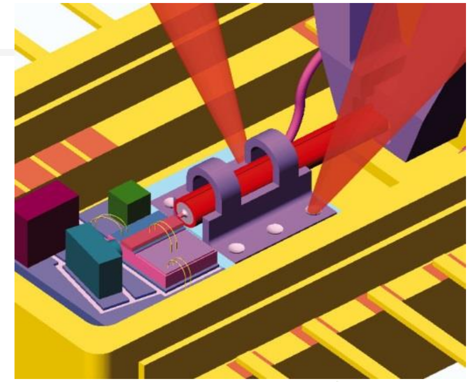


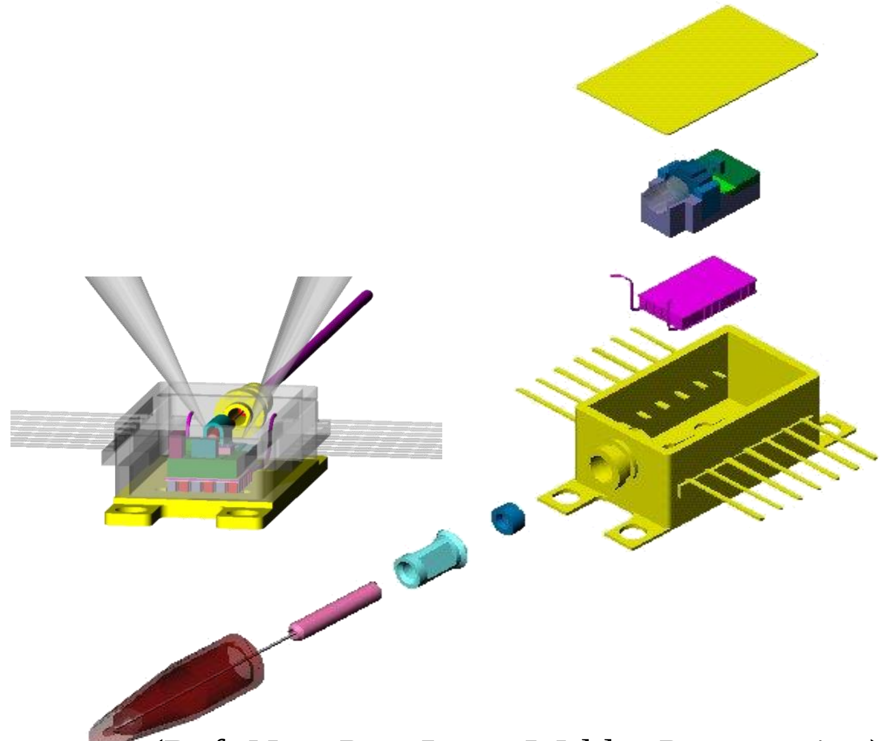
- problems: fabrication difficulty and stability

Laser Packaging [#]

- Packaging will ultimately affect the performance and the cost.
  - speed, output power, yield, reliability
- Require consistent packaging technique

  $\rightarrow$ automation
- Automation considerations
  - Package and Component Design
  - Bonding Technology
  - Component Parts Consistency
  - Process Maturity





(Ref: New Port Laser Welder Presentation)

Alcatel 1915 LMI

WDM direct modulation

1.55 µm digital Laser Module with optical Isolator

Description

This laser module contains an Alcatel SLMQW DFB laser with 25 Ω impedance matching designed for use in Wavelength Division Multiplexed (WDM) systems, direct modulation applications up to 2.5 Gbit/s. The module incorporates a thermoelectric cooler, precision thermistor, and optical isolator for stable operation under all conditions.

Features

- High output power
- Wavelength selection according to ITU-T G.692
- 50 GHz spacing available

- Optimized for direct modulation at 2.5 Gbit/s
- Low dispersion penalty
- 25 Ω RF impedance matching and DC bias RF filtering
- > 28 dB optical isolation
- Internal TEC and monitor photodiode
- InGaAsP Distributed FeedBack SLMQW (DFB) laser

Applications

- STM-16 and OC-48 high-speed WDM transmission systems
- WDM submarine terminal digital transmission systems
- Instrumentation

Optical characteristics

Parameter	Condition	Symb	Min	Typical	Max	Unit
Threshold current		Ith	3	5	15	mA
Output power	Twave = 25 to 40 °C	P_{Peak}	2			mW
Forward voltage	P_{Peak}, pin 3 & 11	Vf		1.2	2.0	V
Slope efficiency	@ 25 °C	η	0.04		0.07	mW / mA
Serial resistance	P_{Peak}, pin 11 & 12	Rs	23		27	Ω
Emission wavelength		λm		See table 1		
Δ(Emitted-Target) Wavelength	[4]	Δλe	- 0.1		+ 0.1	nm
Laser chip temperature range for tunability	[4]	Tλ	25		40	°C
Spectral width	FWHM	Δλ			30	MHz
Side-mode supression ratio	[2]	SMSR	32			dB
Dispersion penalty	[2], [3]	ΔS		0.6	2	dB
Tracking error	ACC, [P(25 °C) - P (65 ° C)]/ P (25 ° C)	TR	- 10		+ 10	%
Photodiode monitor current	P_{Peak}, V = - 5 V	Im	0.1		1	mA
Photodiode dark current	V = - 5 V	Id			100	nA
Wavelength drift vs Tcase		Δλ/ΔTc		0.2	0.5	pm / °C
Thermistor resistance		R_{th}	9.7		10.3	kΩ
Thermistor temperature coefficient		Rt	- 3		- 5	% / K
TEC current	[1]	It		0.7	1	A
TEC voltage	[1]	Vt		1.6	2	V

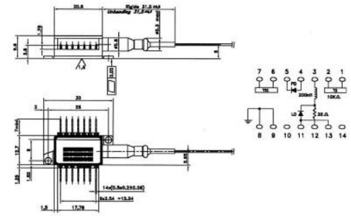
Notes : All measurements start of life, Tsubmount = 25 °C, Tcase = 25 °C, monitor bias - 5 V, P_{Peak} = 2 mW, unless otherwise stated.
[1] Tsubmount = 25 °C, Tcase = 65 °C
[2] 2.5 Gbit/s direct modulation, 2^{23}-1 PRBS, 14 ± 1% extinction ratio, NRZ line code at P_{Peak}
[3] 1900 ps/nm chromatic dispersion, BER = 10^{10}
[4] Tsubmount = Tλ. Tλ is chip temperature required to meet target wavelength (see Table1)

Absolute maximum ratings

Parameter	Min	Max	Unit
Operating case temperature	- 5	65	°C
Storage temperature	- 40	85	°C
Laser forward current		150	mA
Laser reverse voltage		2	V
Photodiode forward current		1	mA
Photodiode reverse voltage		20	V
TEC voltage		2.8	V
TEC current		1.4	A
ESD applied to PIN detector (pin 4&5) [1]		100	V
ESD applied on all other pins [1]		2000	V
Lead soldering time (at 260 °C)		10	s
Package mounting screw torque		0.2	Nm

[1] Human body model Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. These are absolute stress ratings only.

Mechanical details



Pin out

N°	Description
1	Thermistor
2	Thermistor
3	Laser DC bias (-)
4	Photodetector Anode (-)
5	Photodetector Cathode (+)
6	TEC (+)
7	TEC (-)
8	Case Ground
9	Case Ground
10	Not Connected
11	RF common (+)
12	Laser RF input (+)
13	RF common (+)
14	Not Connected

λ	THz	Last letter ##	Connector
1530,33	195,9	FB	FC/PC
1531,11	195,8	FC	FC/PC
1531,89	195,7	FD	FC/PC
1532,68	195,6	FE	FC/PC
1533,46	195,5	FF	FC/PC
1534,25	195,4	FG	FC/PC
1535,03	195,3	FH	FC/PC
1535,82	195,2	FJ	FC/PC
1536,61	195,1	FK	FC/PC
1537,39	195	FL	FC/PC
1538,18	194,9	FM	FC/PC
1538,97	194,8	FN	FC/PC
1539,76	194,7	FP	FC/PC
1540,55	194,6	FQ	FC/PC
1541,35	194,5	FR	FC/PC
1542,14	194,4	FS	FC/PC
1542,93	194,3	FT	FC/PC
1543,73	194,2	FU	FC/PC
1544,52	194,1	FV	FC/PC
1545,32	194	FW	FC/PC
1546,11	193,9	FX	FC/PC
1546,91	193,8	FY	FC/PC
1547,71	193,7	FZ	FC/PC
1548,51	193,6	GA	FC/PC
1549,31	193,5	GB	FC/PC
1550,11	193,4	GC	FC/PC
1550,91	193,3	GD	FC/PC
1551,72	193,2	GE	FC/PC
1552,52	193,1	GF	FC/PC
1553,32	193	GG	FC/PC
1554,13	192,9	GH	FC/PC
1554,94	192,8	GJ	FC/PC
1555,74	192,7	GK	FC/PC
1556,55	192,6	GL	FC/PC
1557,36	192,5	GM	FC/PC
1558,17	192,4	GN	FC/PC
1558,98	192,3	GP	FC/PC
1559,79	192,2	GQ	FC/PC
1560,60	192,1	GR	FC/PC
1561,41	192	GS	FC/PC
1562,23	191,9	GT	FC/PC
1563,04	191,8	GU	FC/PC
1563,86	191,7	GV	FC/PC
1530-1560		AA	FC/PC

Table 1, All wavelengths referenced to vacuum Tsubmount = 25 °C.

Standards

ITU-T G.652 optical fiber
IEC 68-2 and MIL STD 883 environment

Ordering information

Alcatel 1915 LMI

Description	Part number
1900 ps/nm	3CN 00154 ##
3200 ps/nm	3CN 00155 AA

defines the wavelength according to the table1 above

September 99
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Customized versions are available for large quantities.

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