USC University of Southern California

ECE 105: Introduction to Electrical Engineering

Lecture 8

Optoelectronics

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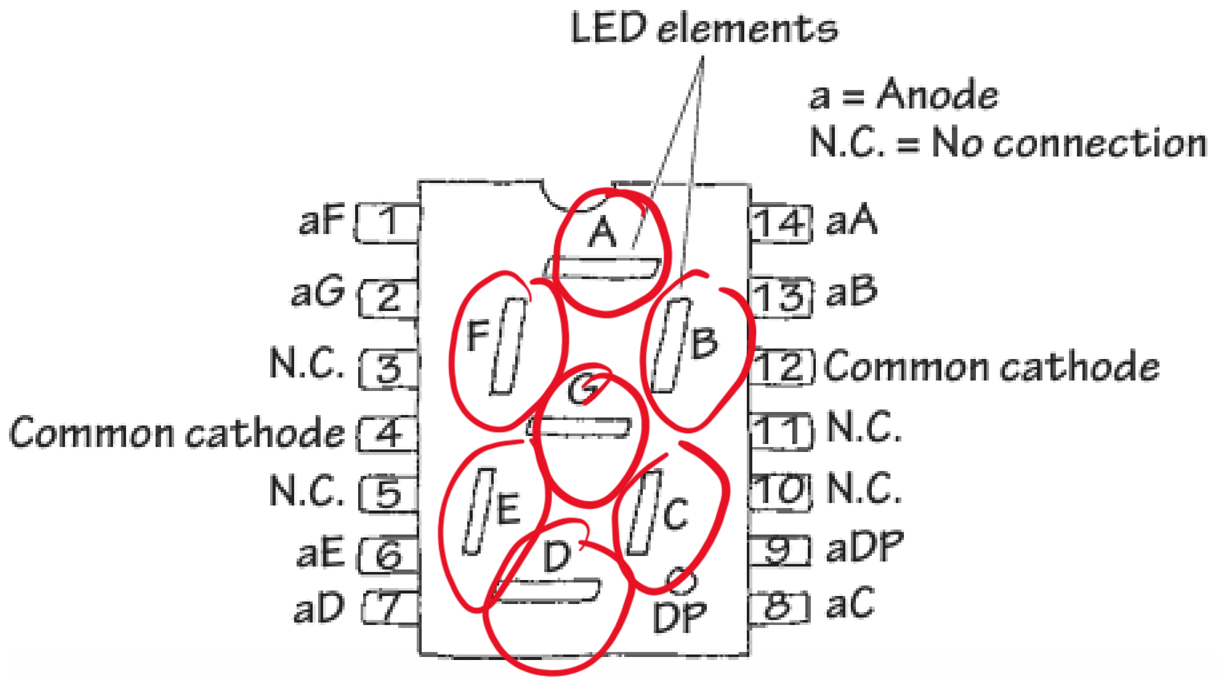
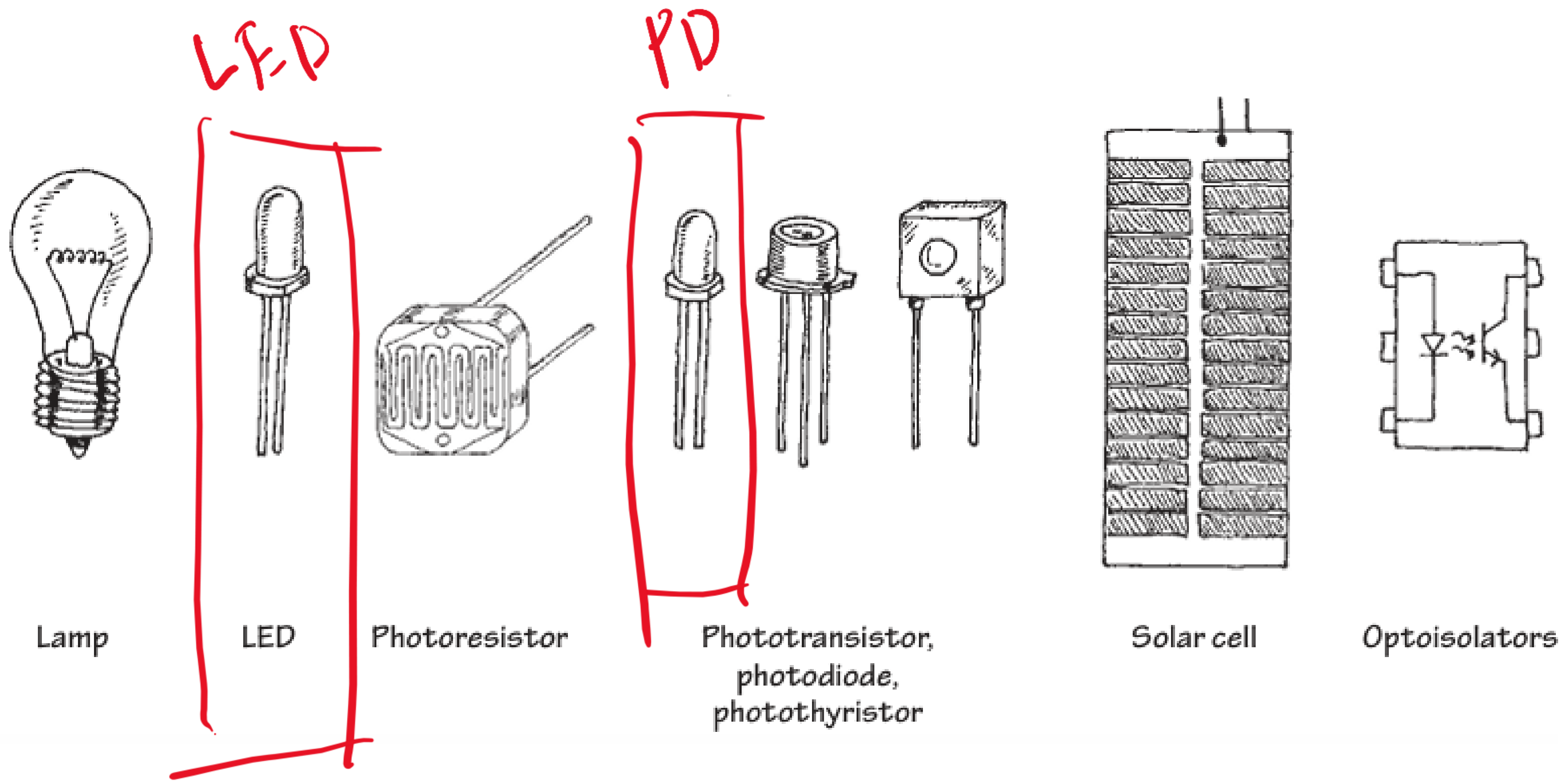
The seven-segment display

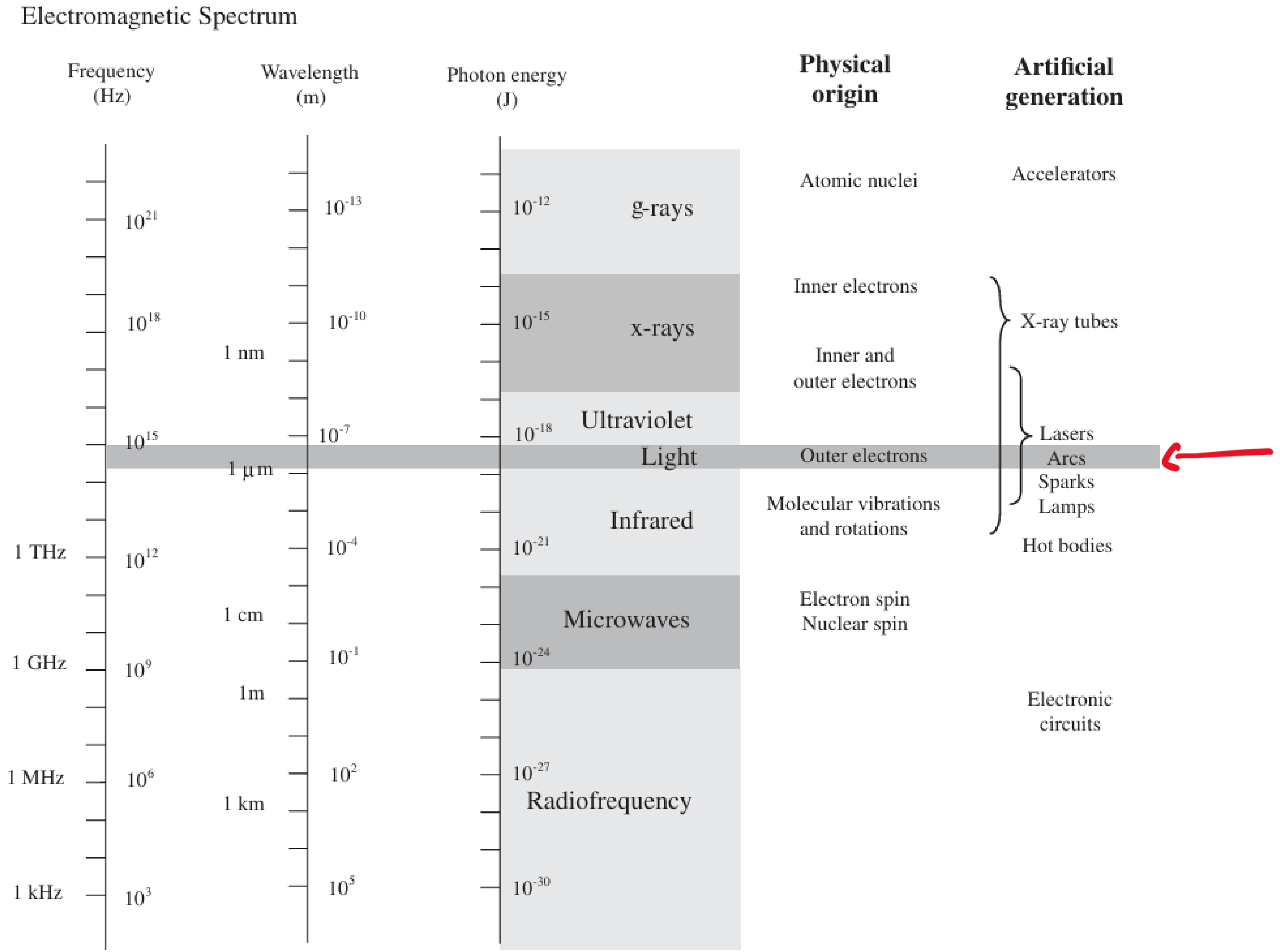
LED Displays



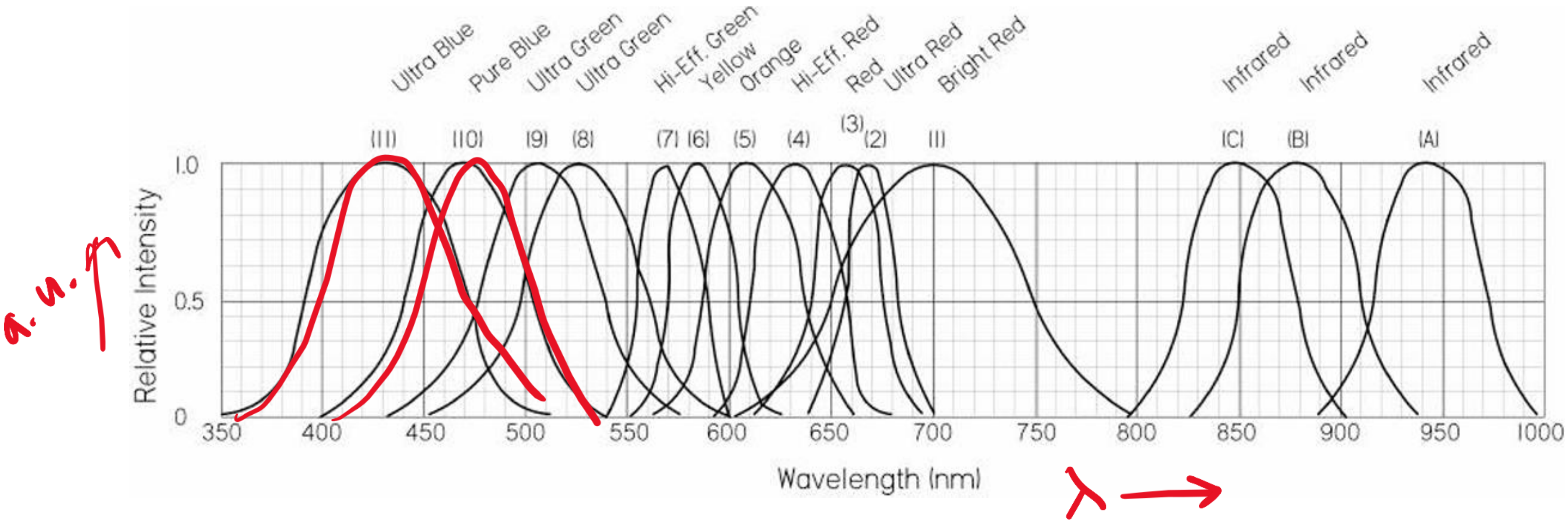
Light-based devices

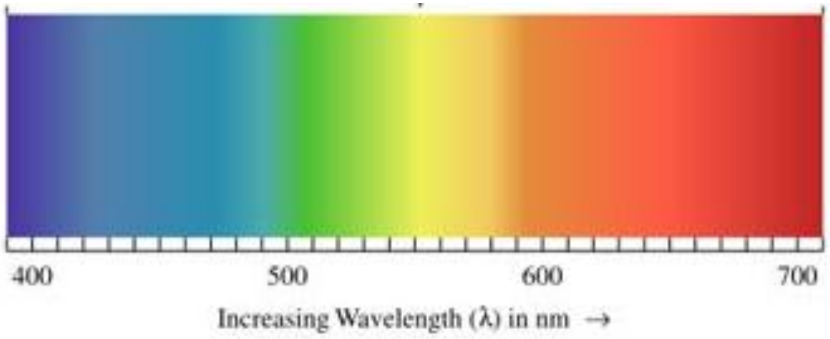


Artificially generating light

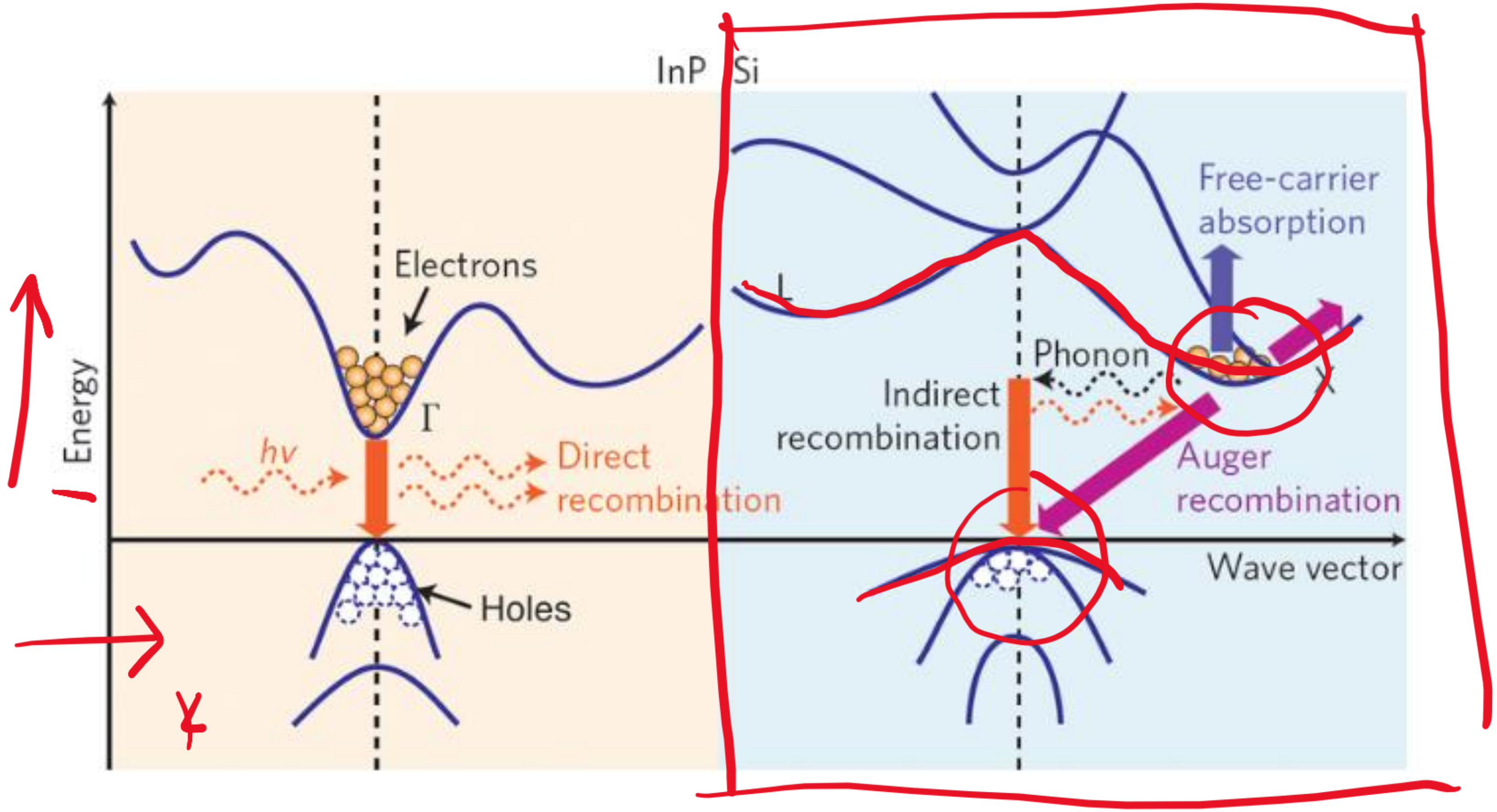


LED emission spectra





Direct vs indirect semiconductors



2 Energy band diagrams and major carrier transition processes in indium phosphide (direct bandgap) and silicon (indirect bandgap) crystals. Silicon, Germanium and some III/V compounds like GaP and AlAs are indirect bandgap semiconductors. InP, GaAs, GaN and other ternary (AlGaAs, InGaAs) and quaternary (InGaAsP, InAlAsP) compounds are direct bandgap semiconductors commonly used for photonic devices fabrication.

LEDs are made out of non-silicon semiconductors

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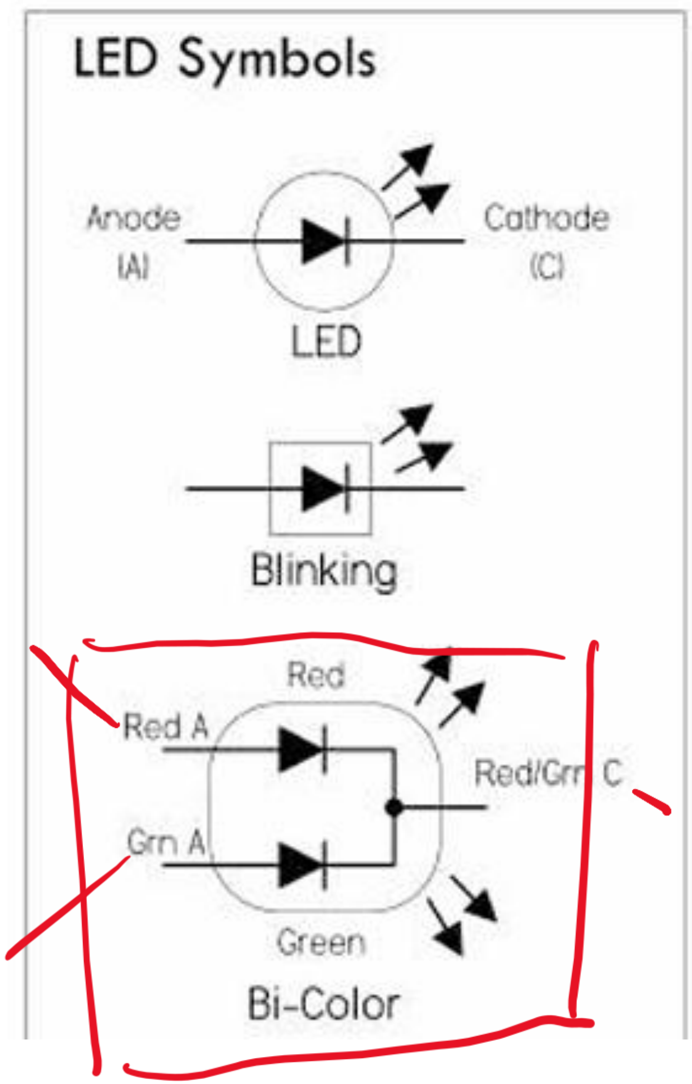
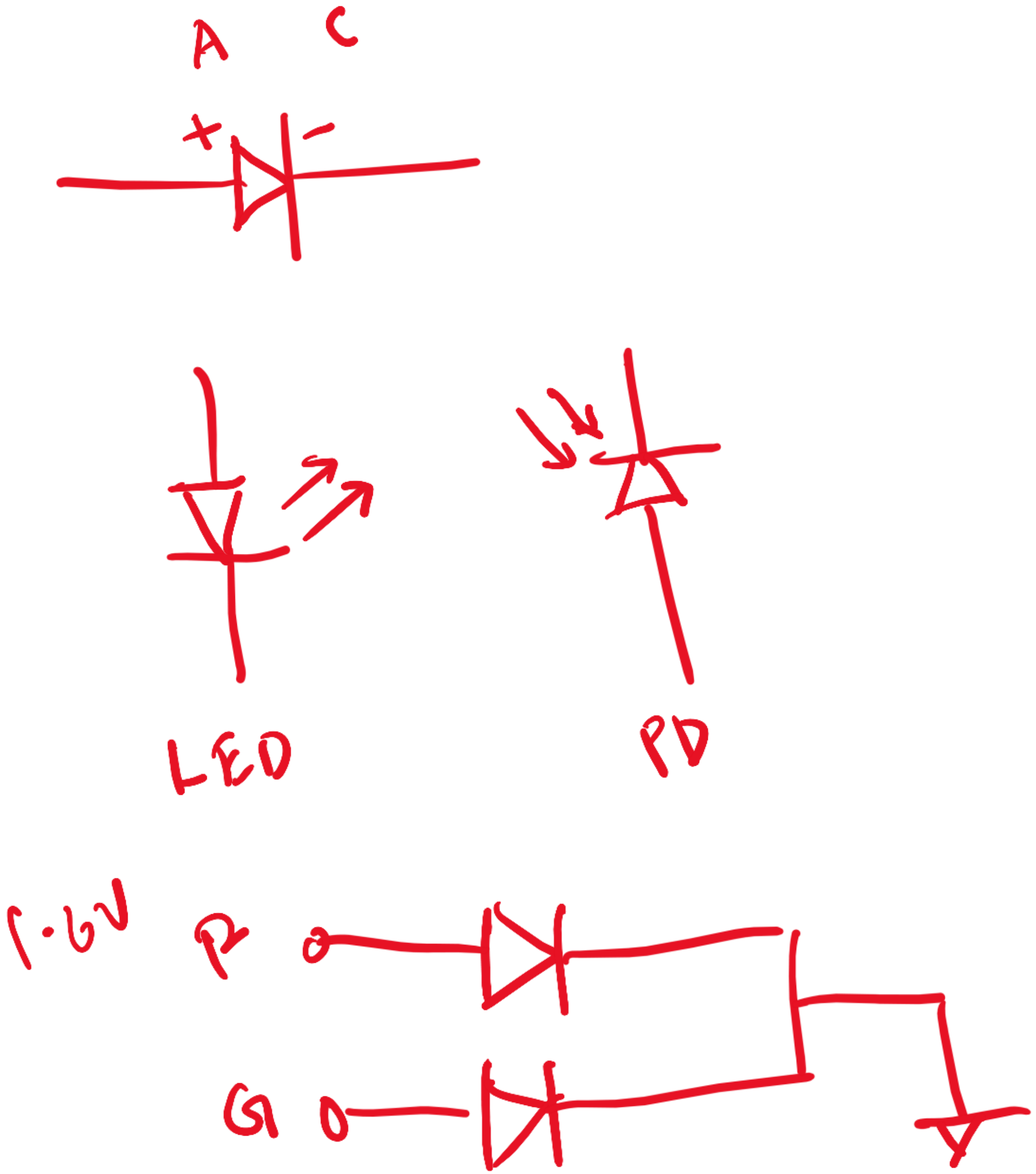
Color	Wavelength [nm]	Semiconductor material
Infrared	$\lambda > 760$	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
Red	$610 < \lambda < 760$	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	$590 < \lambda < 610$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	$570 < \lambda < 590$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	$500 < \lambda < 570$	**Traditional green:** Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP) **Pure green:** Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN)
Blue	$450 < \lambda < 500$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate—under development
Violet	$400 < \lambda < 450$	Indium gallium nitride (InGaN)
Purple	multiple types	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	$\lambda < 400$	Diamond (235 nm) Boron nitride (215 nm) Aluminium nitride (AlN) (210 nm) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)—down to 210 nm
Pink	multiple types	Blue with one or two phosphor layers: yellow with red, orange or pink phosphor added afterwards, or white with pink pigment or dye.
White	Broad spectrum	Blue/UV diode with yellow phosphor

$E = h\nu$

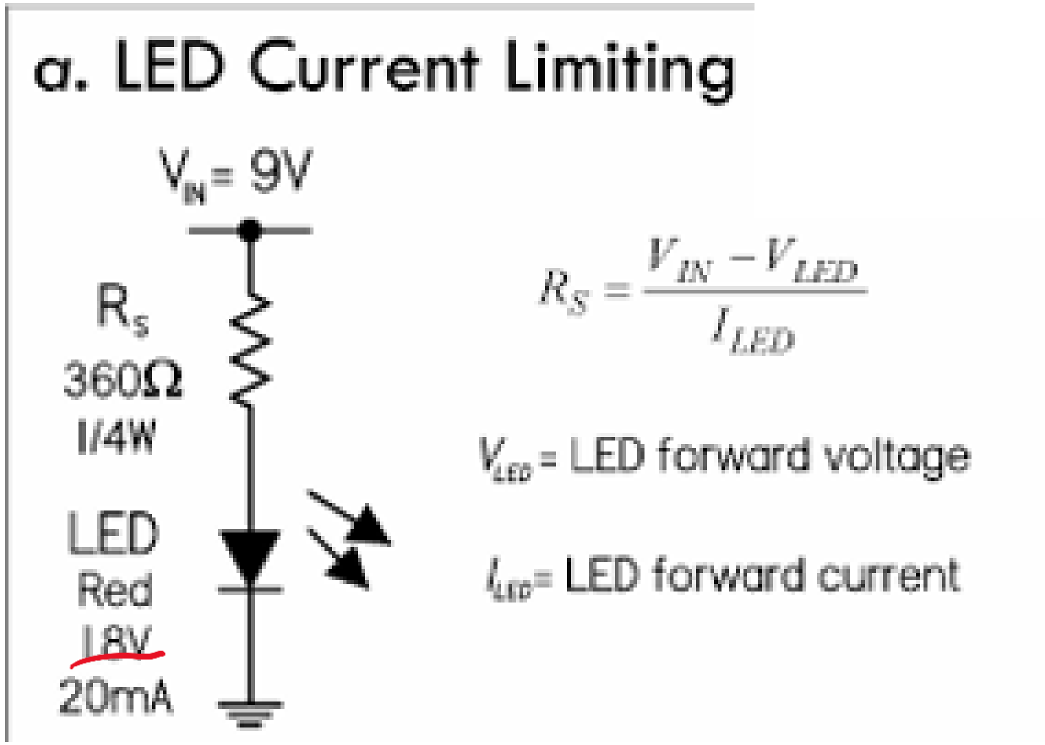
Color LED	Name Color	Wavelength nm = 1x10^{-9}	Voltage Drop (Forward Voltage)
	White	395 - 530 nm	3 - 5 V
	Ultraviolet	< 400 nm	3.1 - 4.4 V
	Violet	400 - 450 nm	2.8 - 4.0 V
	Blue	450 - 500 nm	2.5 - 3.7 V
	Green	500 - 570 nm	1.9 - 4.0 V
	Yellow	570 - 590 nm	2.1 - 2.2 V
	Orange	590 - 610 nm	2.0 - 2.1 V
	Red	610 - 760 nm	1.6 - 2.0 V
	Infrared	> 760 nm	< 1.9 V

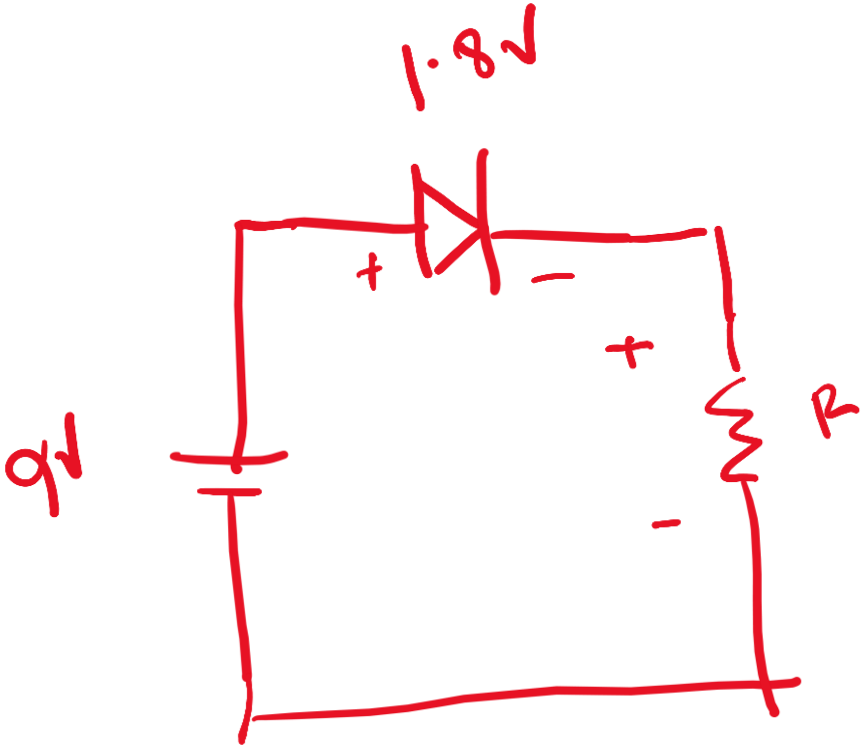
LED symbols


LED Symbols
Anode (A)
Cathode (C)
LED
Blinking
Red
Red A
Red/Grn C
Grn A
Green
Bi-Color


A
C
+
-
LED
PD
1.6V
R
G

LED driver circuit





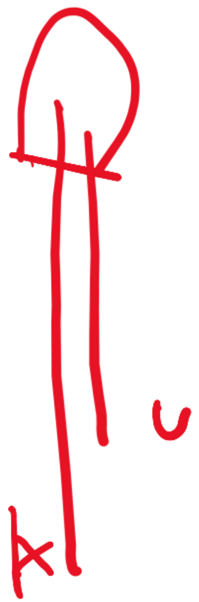
$$V_S = V_{LED} + I R$$

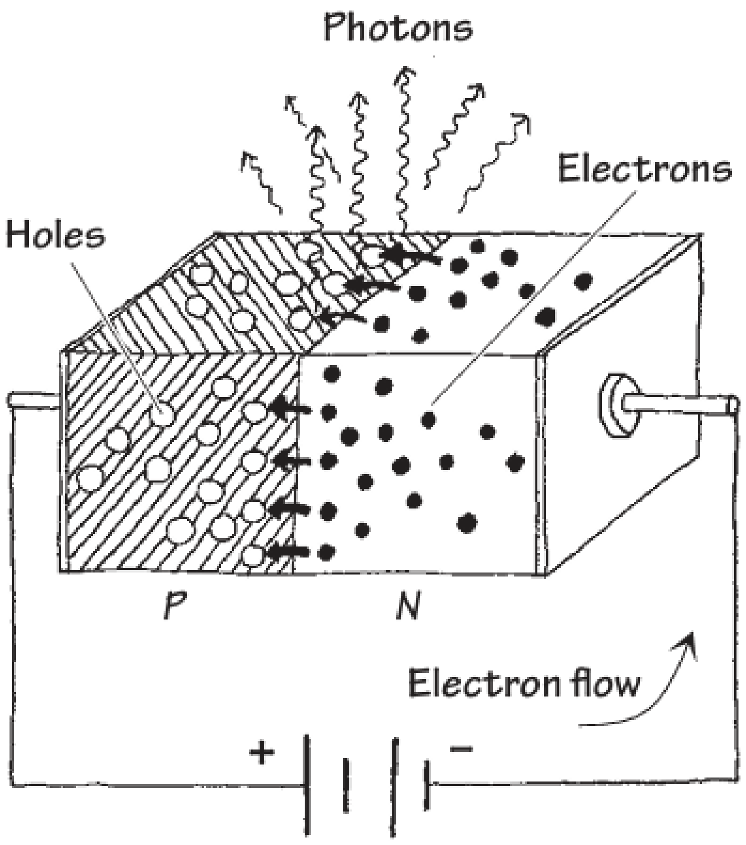
$$9V = 1.8 + 20mA \, R$$

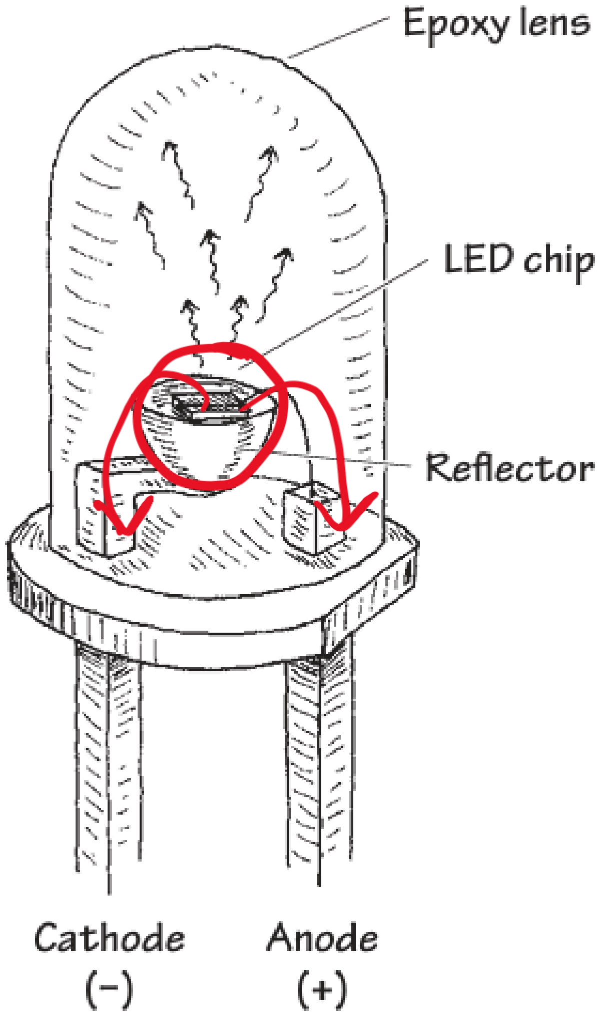
$$7.2V = 20mA \cdot R$$

$$R = \frac{7.2}{20m} = 360\Omega$$

LED is a diode

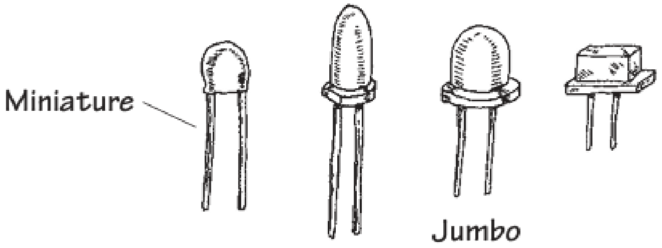




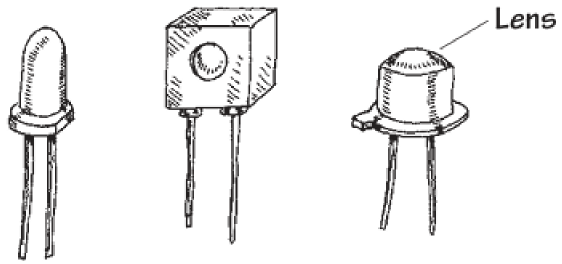


LED packages

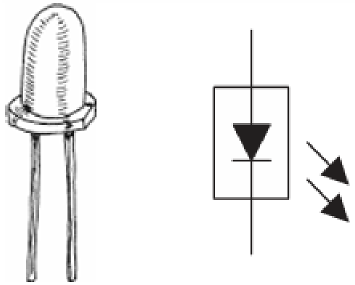
Visible-Light LEDs



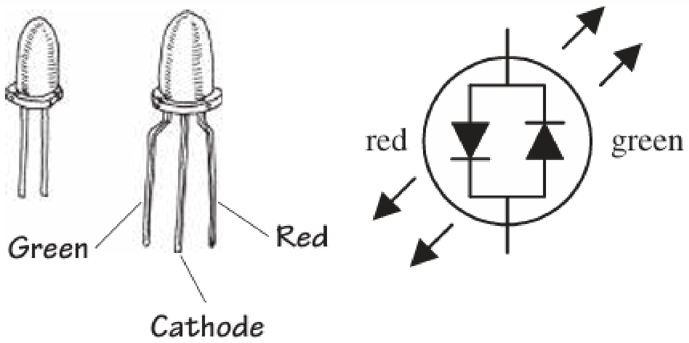
Infrared LEDs



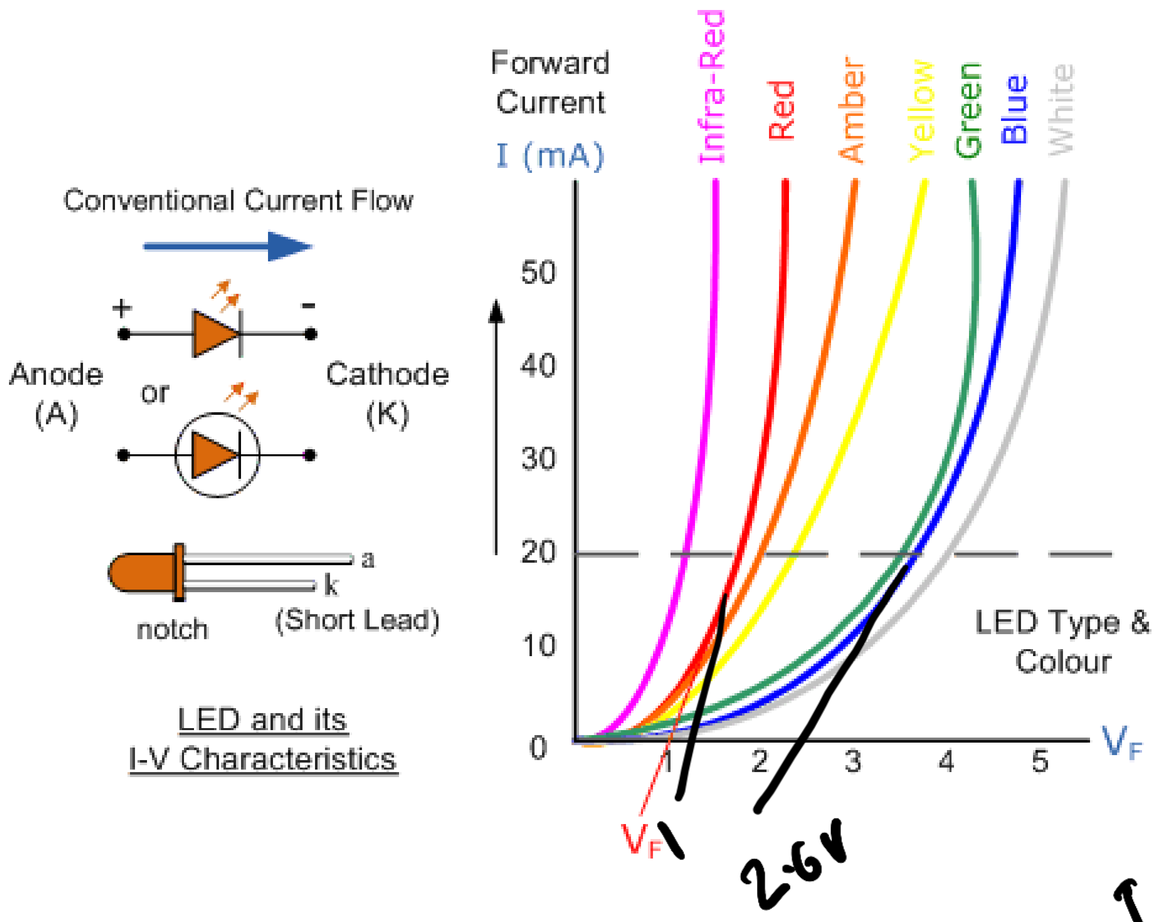
Blinking LEDs

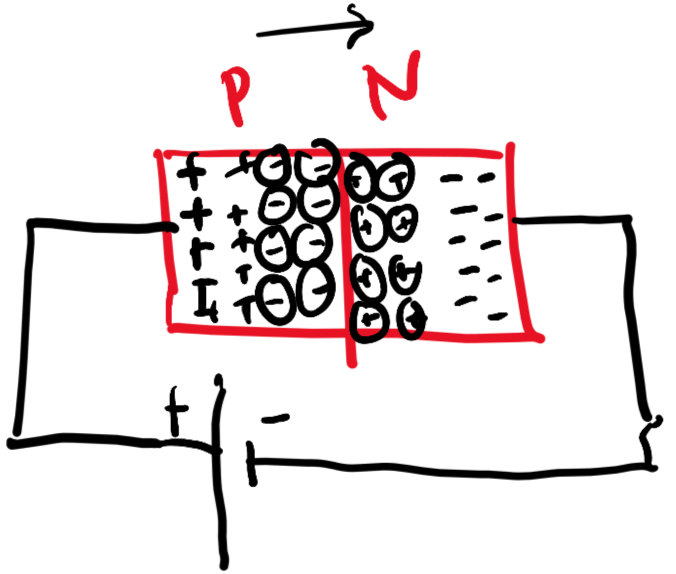


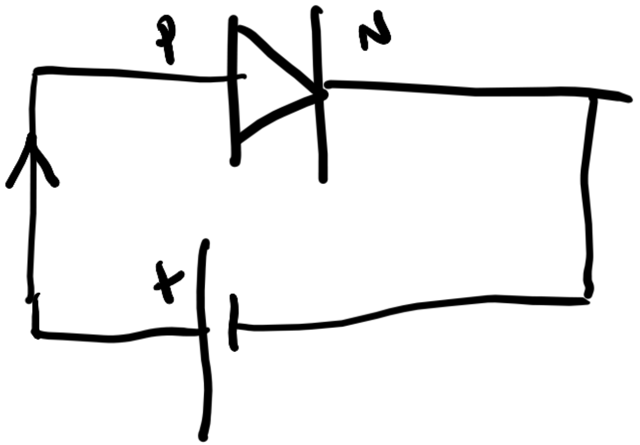
Multicolor LEDs

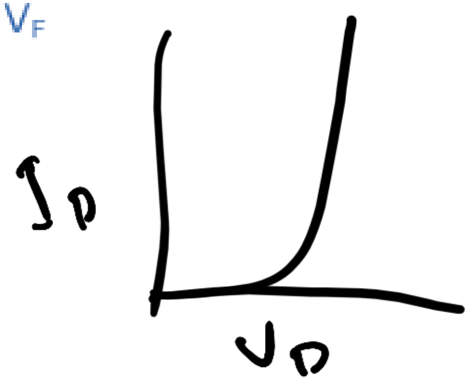


IV characteristics for LEDs



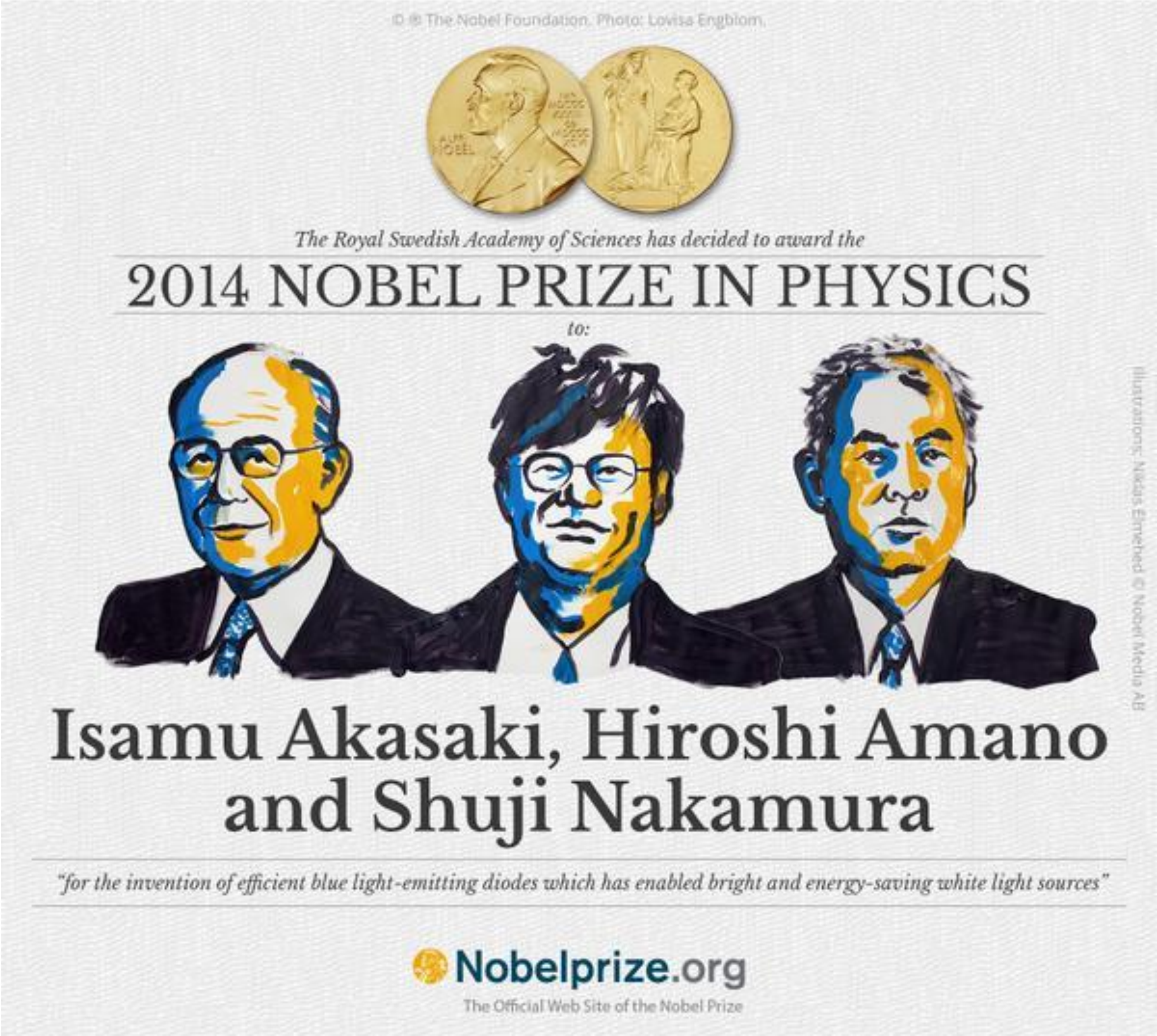


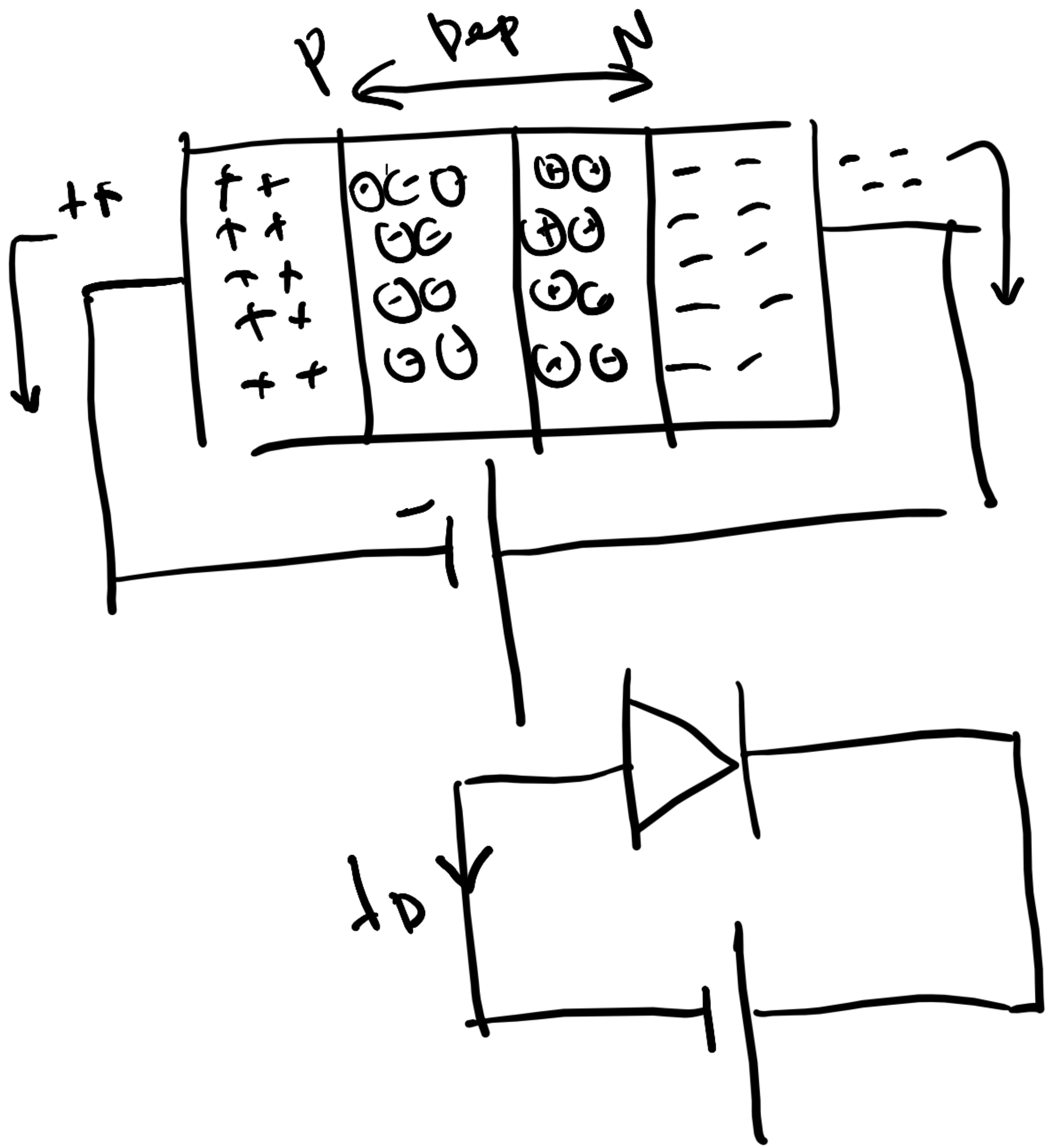




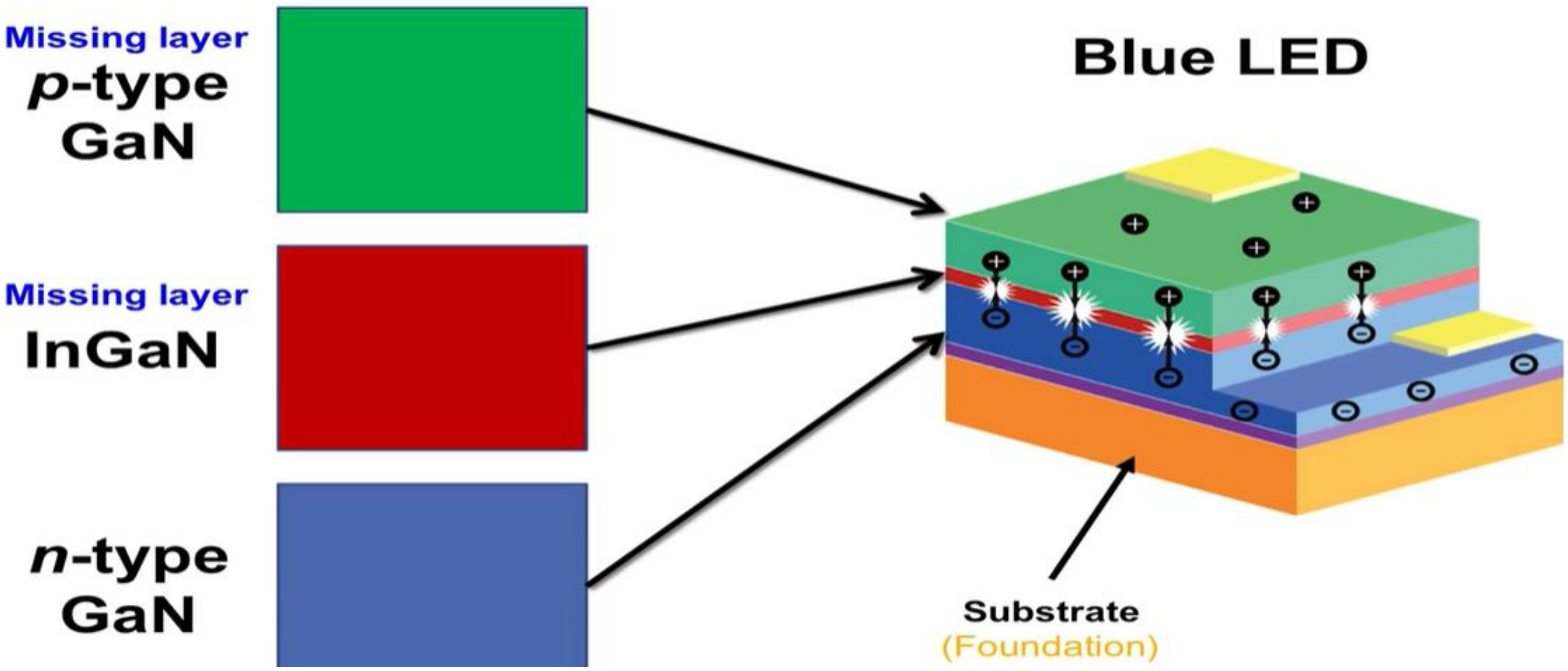
Forward bias

Blue LED won the 2014 Nobel in Physics

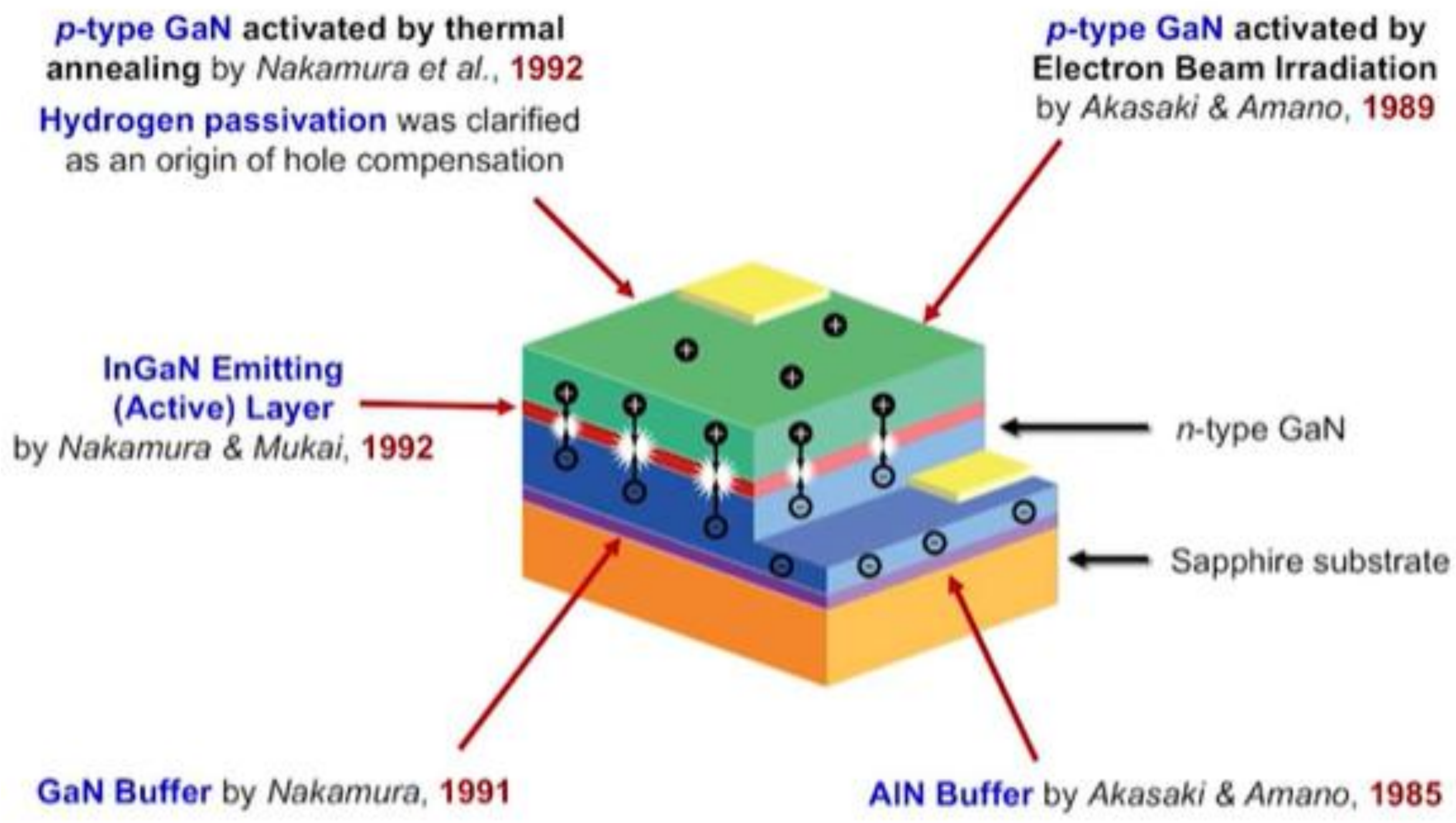



P
Dep
N
I_D

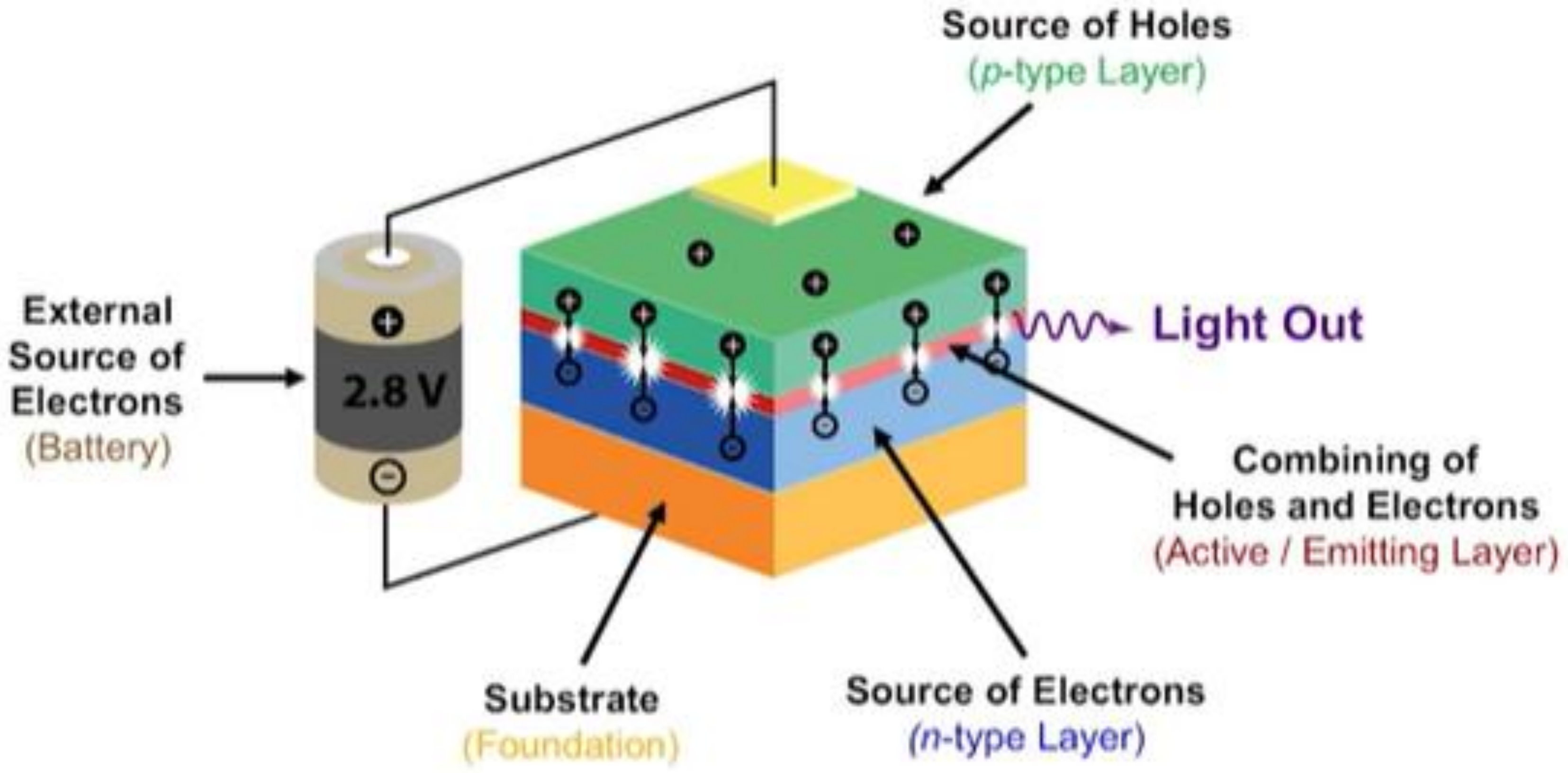
Steps to get the Blue LED



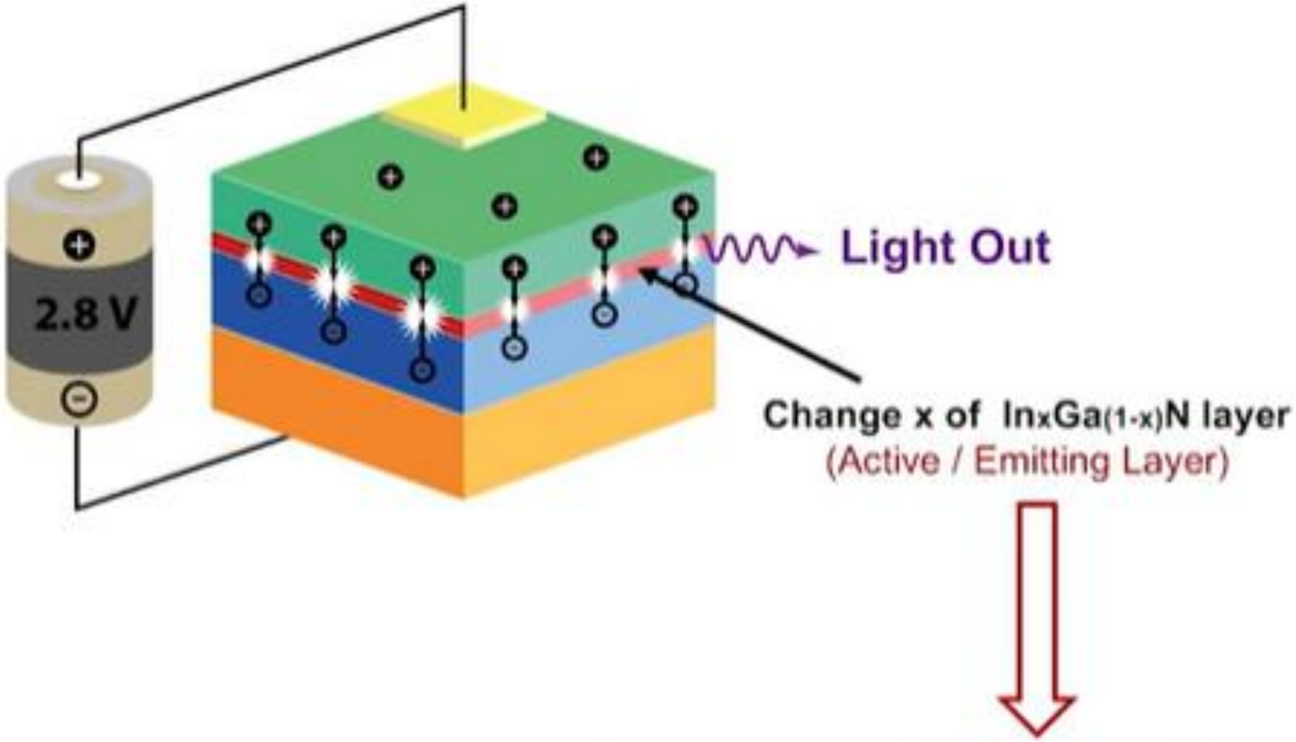
InGaN LEDs

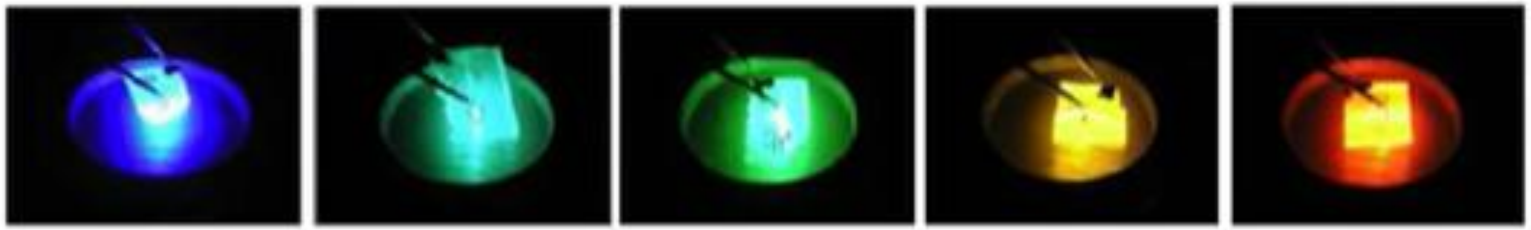

p-type GaN activated by thermal annealing by Nakamura et al., 1992
Hydrogen passivation was clarified as an origin of hole compensation
p-type GaN activated by Electron Beam Irradiation by Akasaki & Amano, 1989
InGaN Emitting (Active) Layer by Nakamura & Mukai, 1992
n-type GaN
Sapphire substrate
GaN Buffer by Nakamura, 1991
AlN Buffer by Akasaki & Amano, 1985

LED colors – single color from on LED



Changing emission colors – can you change color?

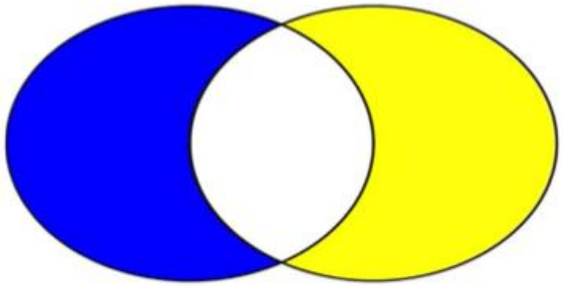




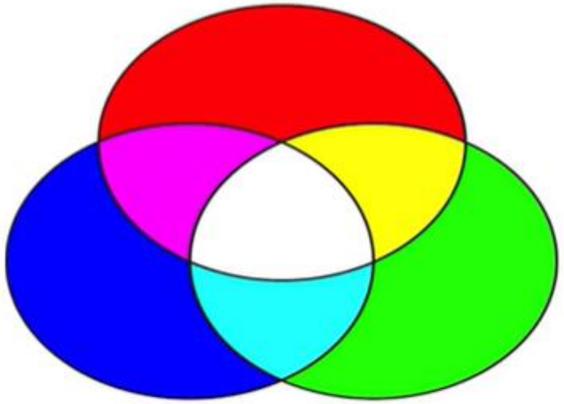
How to get white light

One LED can only produce **one color**
(red, orange, yellow, green, blue, or violet)

To achieve white light, need to **combine colors**:



Blue + Yellow
(Easiest)



Blue + Green + Red
(Highest Quality)

The LED in our demo board

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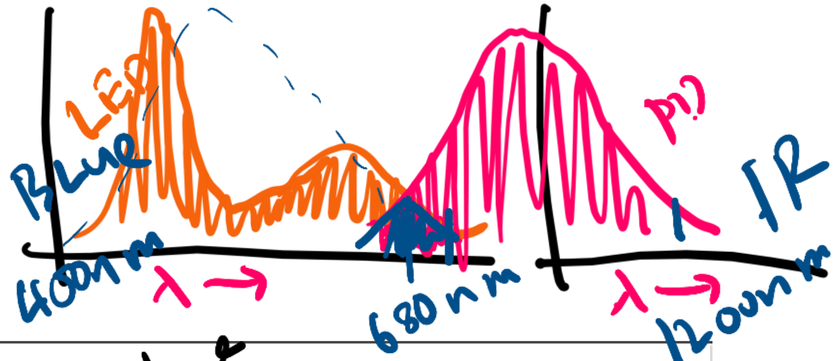
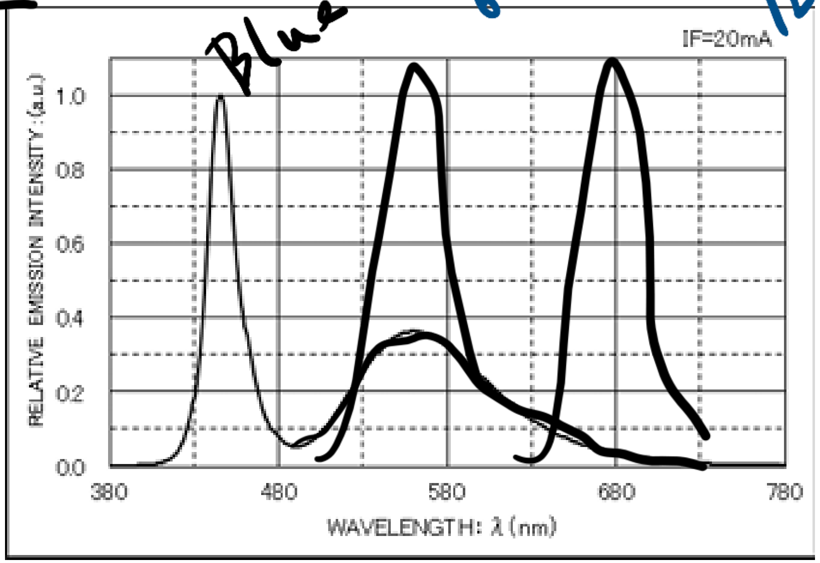
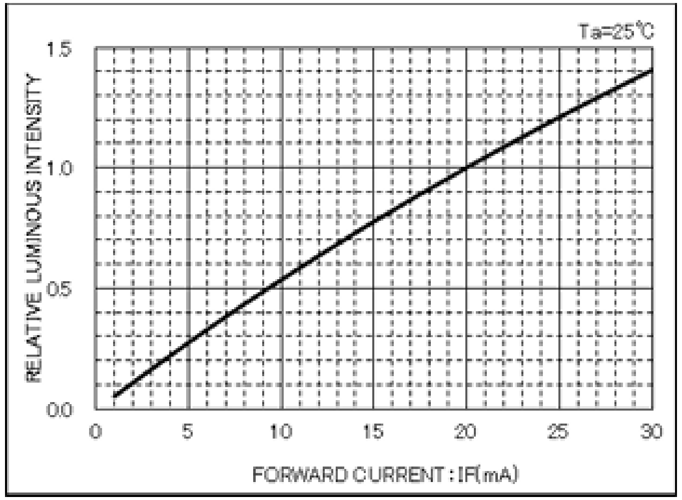


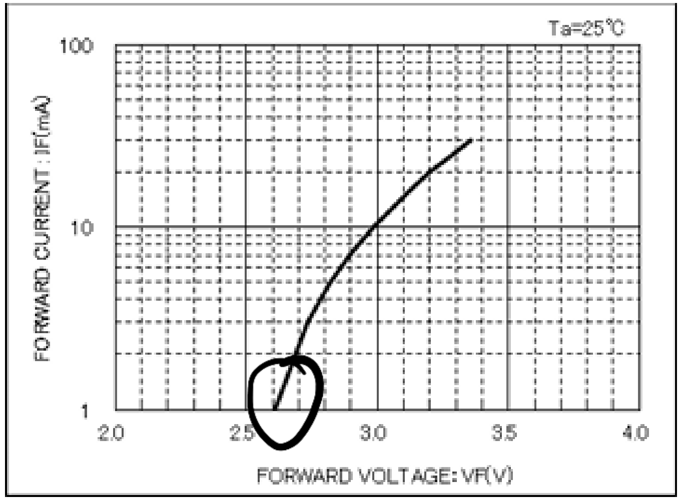
SPECTRUM



RELATIVE LUMINOUS INTENSITY - FORWARD CURRENT



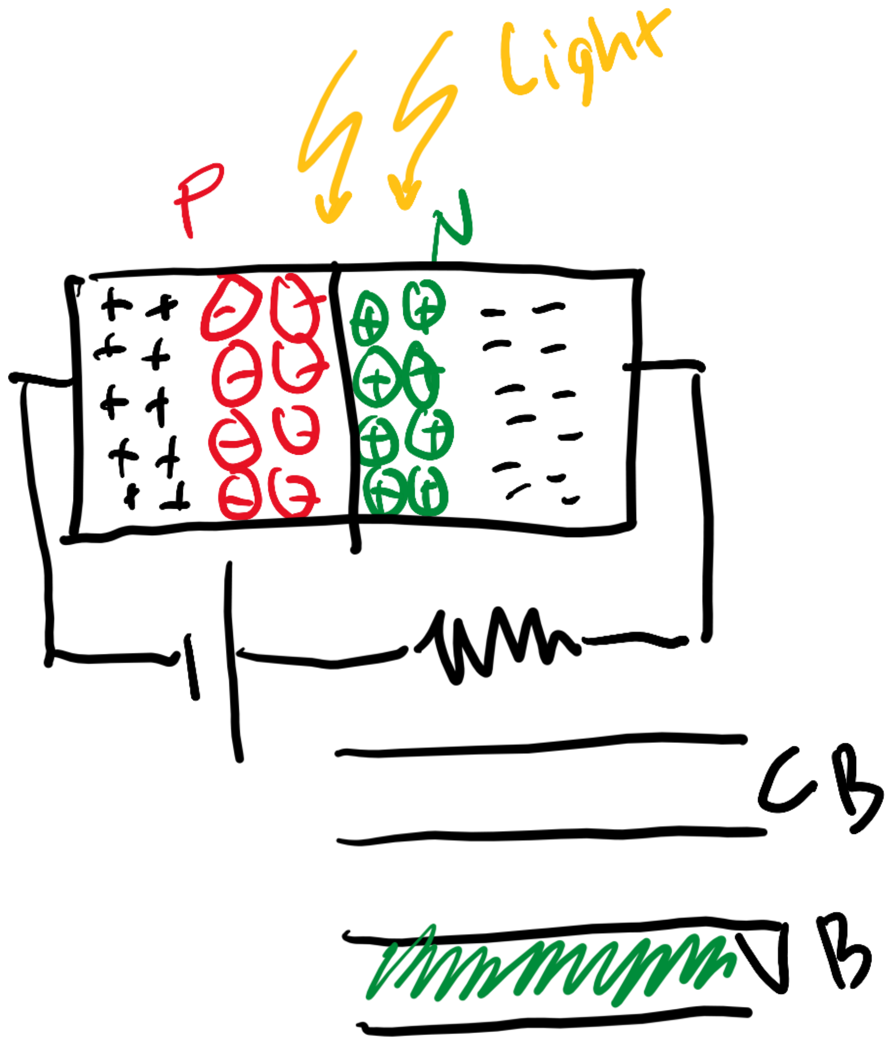
FORWARD CURRENT - FORWARD VOLTAGE

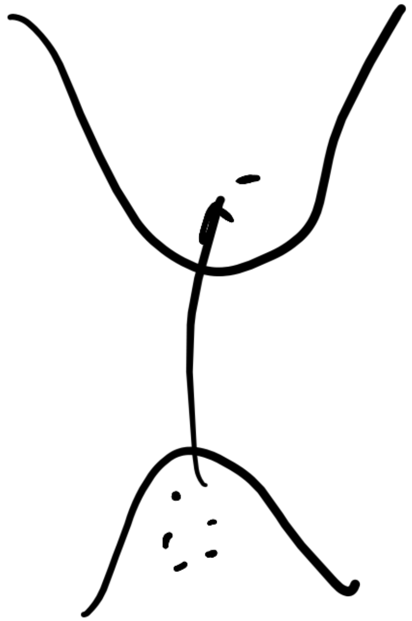


2.6V

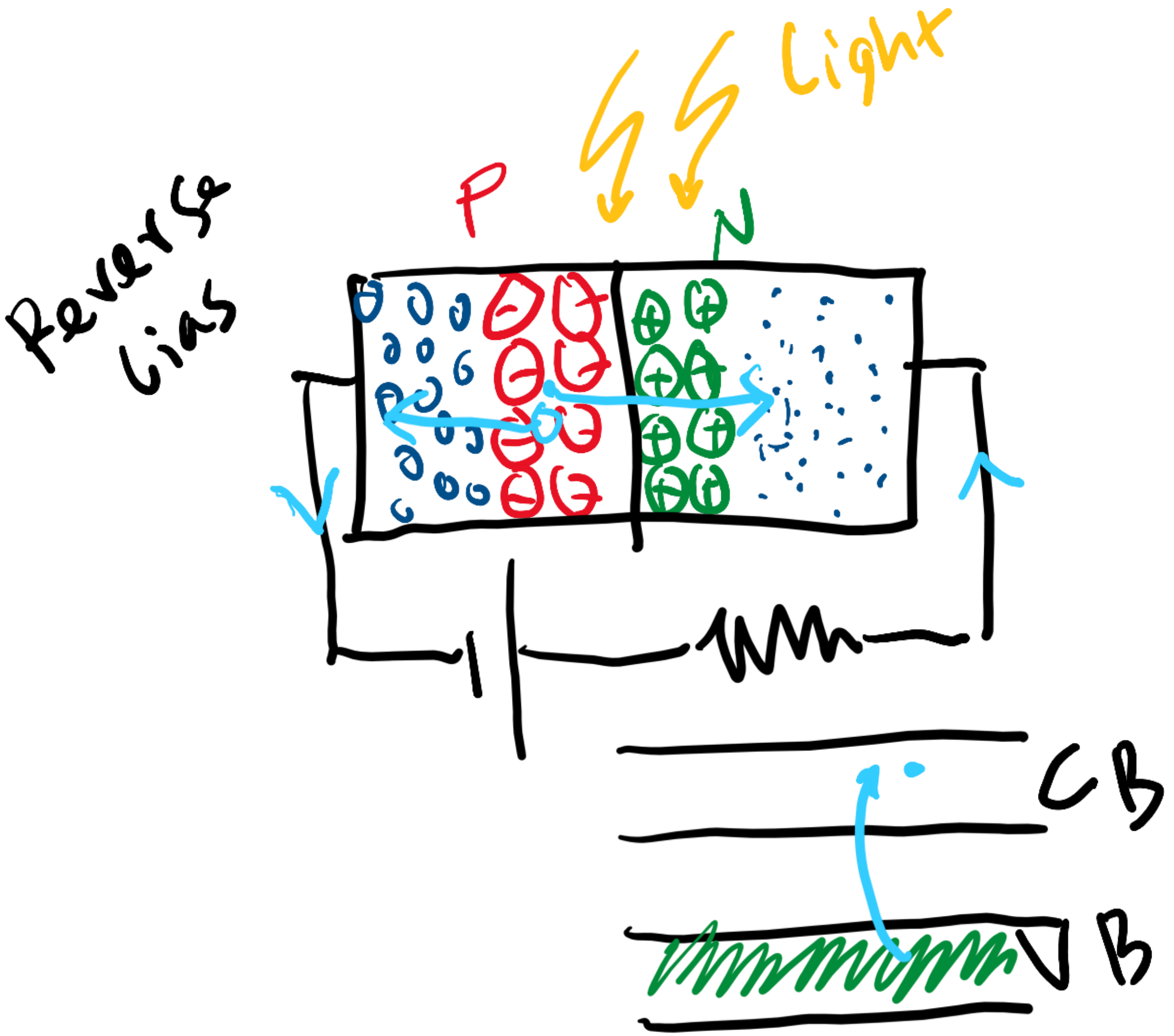
https://fscdn.rohm.com/en/products/databook/datasheet/opto/led/chip_mono/csl0416wbcw1-e.pdf

How does a photodiode work

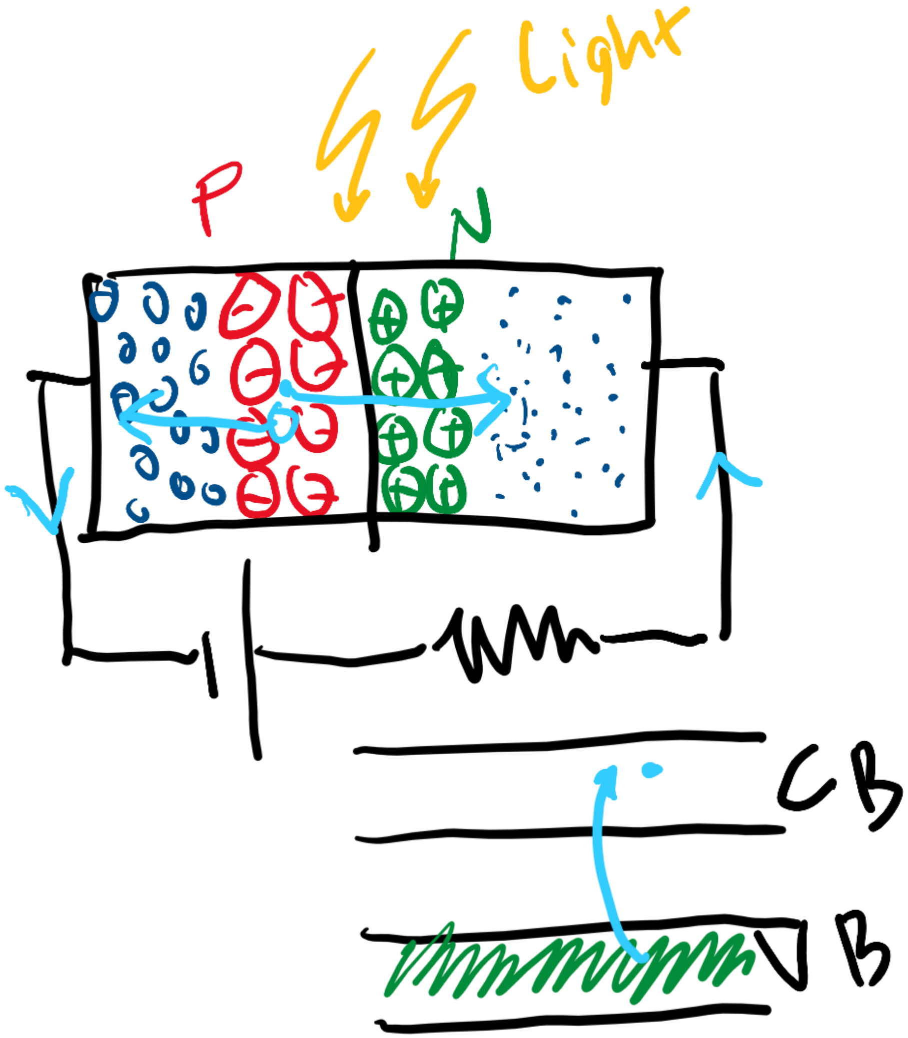


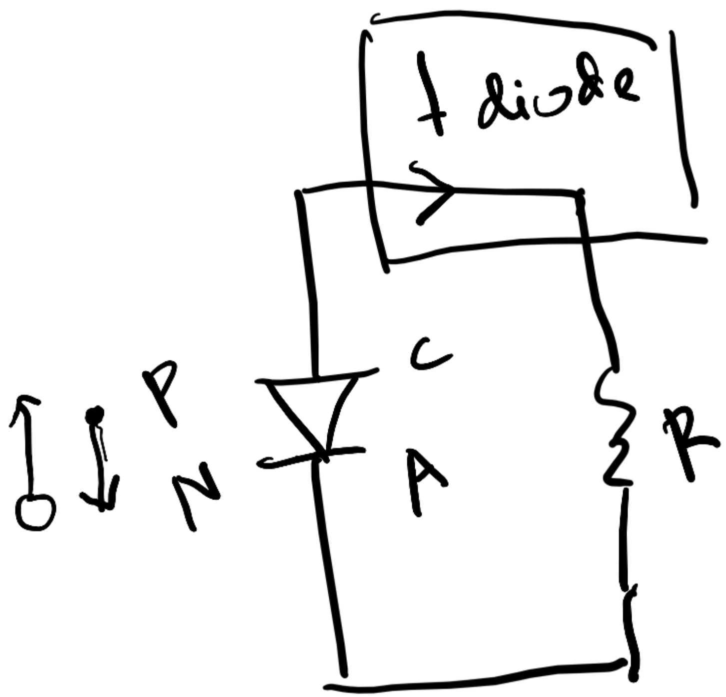


How does a photodiode work

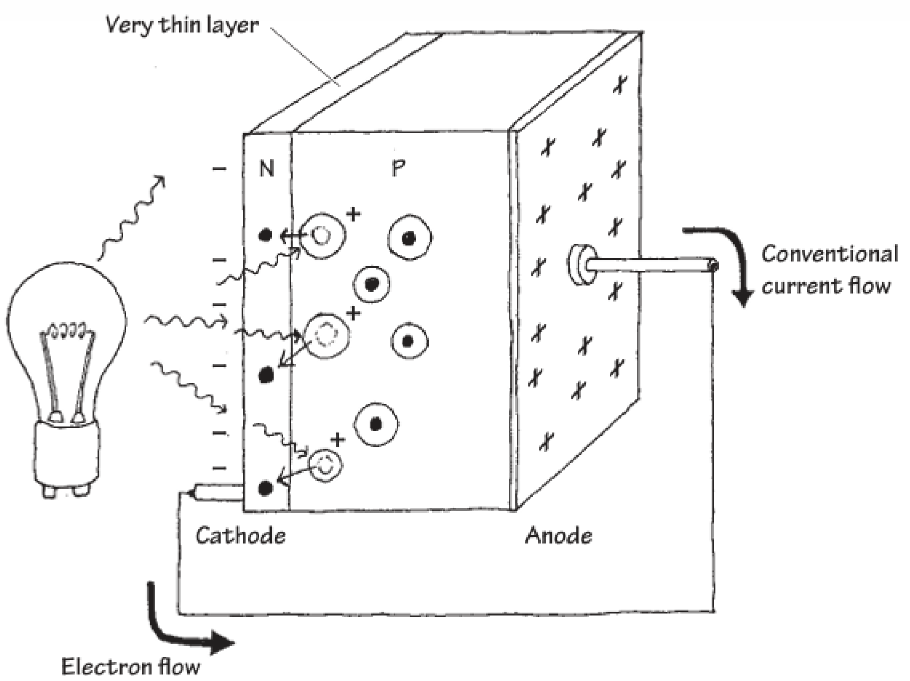


How does a photodiode work

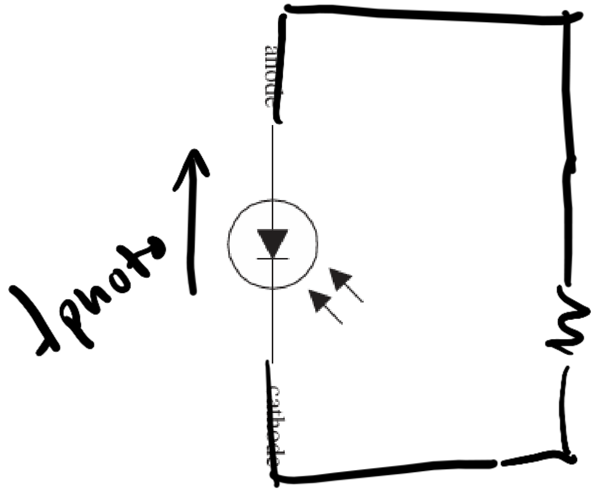


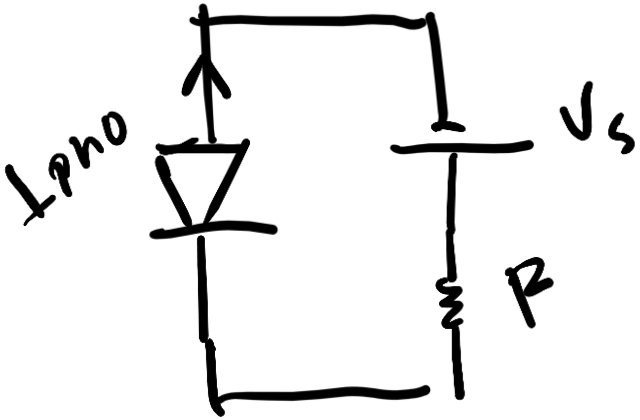


Photodiode

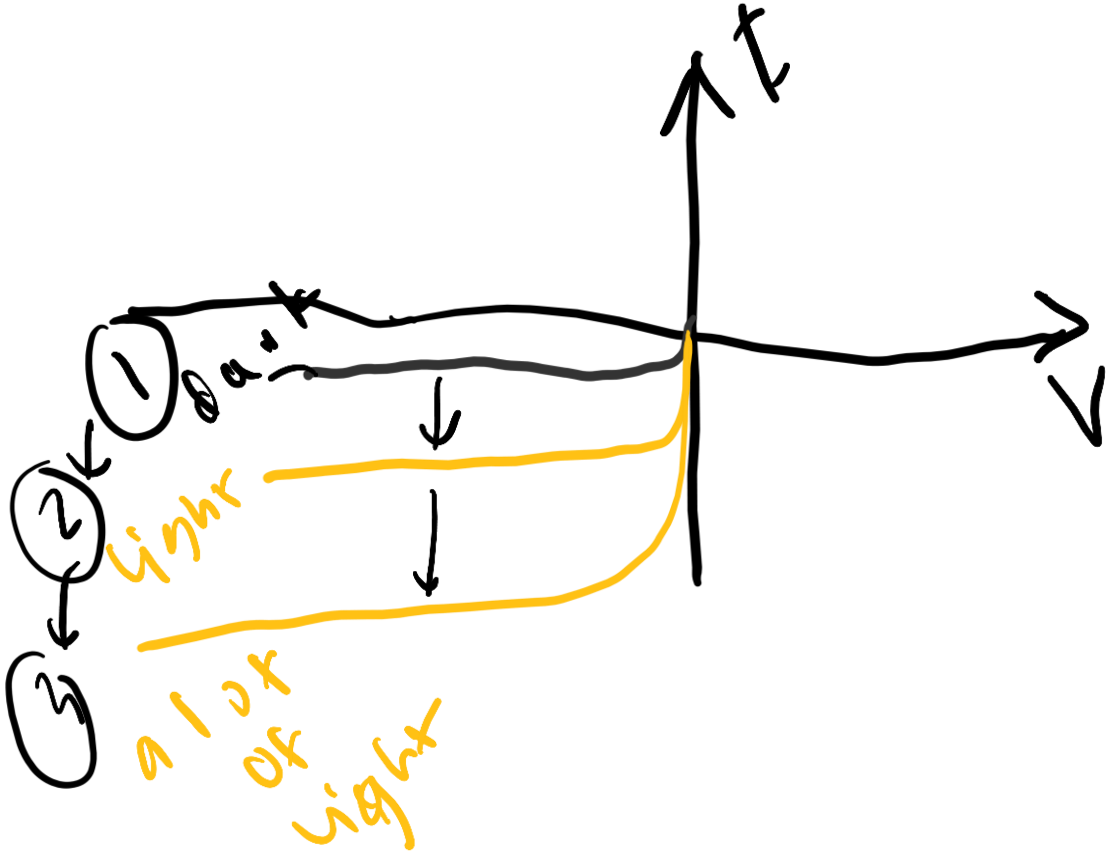


Reverse bias





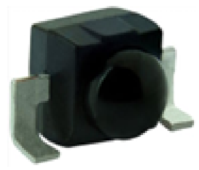
IV of photodiode



The PD in our demo board

https://www.vishay.com/docs/83493/vemd2023slx01.pdf

Silicon PIN Photodiode



DESCRIPTION

VEMD2023SLX01 is a high speed and high sensitive PIN photodiode in a miniature side looking, surface mount package (SMD) with dome lens and daylight blocking filter. Filter is matched with IR emitters operating at wavelength of 830 nm to 950 nm. The photo sensitive area of the chip is 0.23 mm².

FEATURES

- Package type: surface mount
- Package form: side view
- Dimensions (L x W x H in mm): 2.3 x 2.55 x 2.3
- AEC-Q101 qualified
- High radiant sensitivity
- Daylight blocking filter matched with 830 nm to 950 nm IR emitters
- Fast response times
- Angle of half sensitivity: φ = ± 35°
- Package matched with IR emitter series VSMB2943SLX01
- Floor life: 4 weeks, MSL 2a, acc. J-STD-020
- Lead (Pb)-free reflow soldering
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

AUTOMOTIVE GRADE
Pb-free
e3
RoHS COMPLIANT
HALOGEN FREE
GREEN

APPLICATIONS

- High speed photo detector
- Infrared remote control
- Infrared data transmission
- Photo interrupters
- IR touch panels

PRODUCT SUMMARY			
COMPONENT	I_{ra} (μA)	φ (deg)	$\lambda_{0.5}$ (nm)
VEMD2023SLX01	10	± 35	750 to 1050

Note

- Test conditions see table "Basic Characteristics"

ORDERING INFORMATION			
ORDERING CODE	PACKAGING	REMARKS	PACKAGE FORM
VEMD2023SLX01	Tape and reel	MOQ: 3000 pcs, 3000 pcs/reel	Side view

Note

- MOQ: minimum order quantity

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Reverse voltage		V_R	60	V
Power dissipation	$T_{amb} \leq 25$ °C	P_V	215	mW
Junction temperature		T_j	100	°C
Operating temperature range		T_{amb}	- 40 to + 100	°C
Storage temperature range		T_{stg}	- 40 to + 100	°C
Soldering temperature	Acc. reflow solder profile fig. 7	T_{sd}	260	°C
Thermal resistance junction/ambient	Acc. J-STD-051	R_{thJA}	250	K/W

PD characteristics

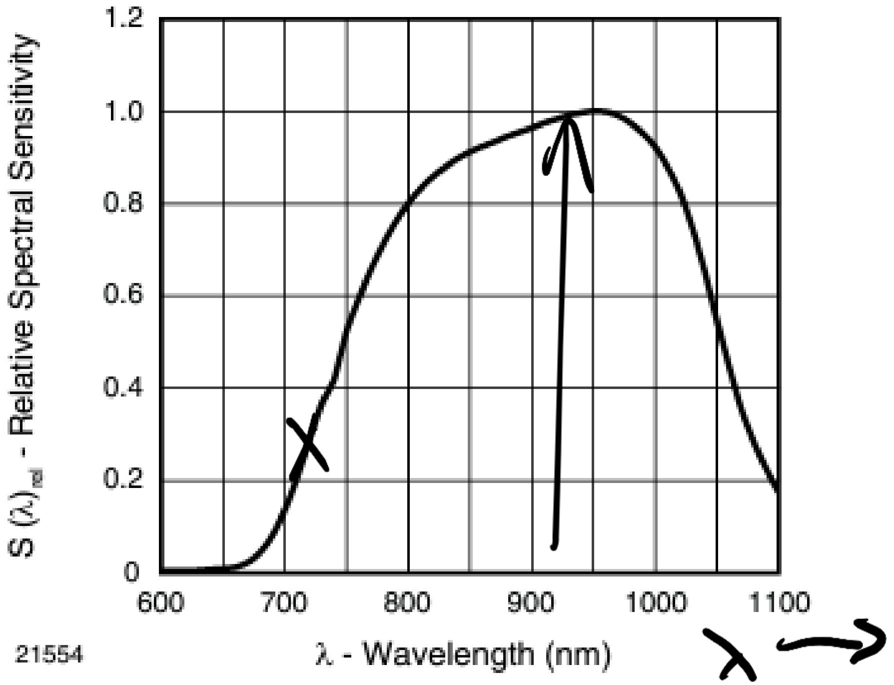


Fig. 5 - Relative Spectral Sensitivity vs. Wavelength

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

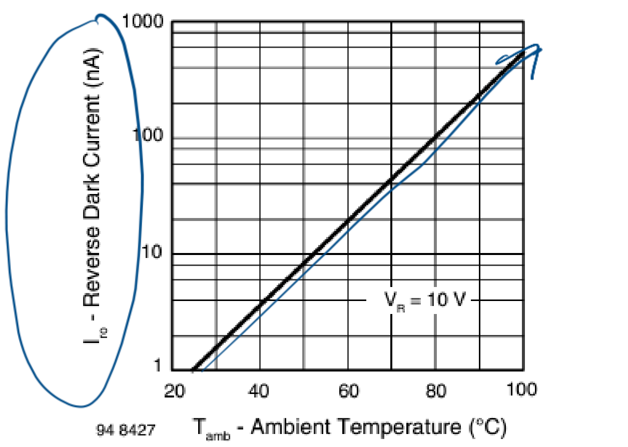


Fig. 1 - Reverse Dark Current vs. Ambient Temperature

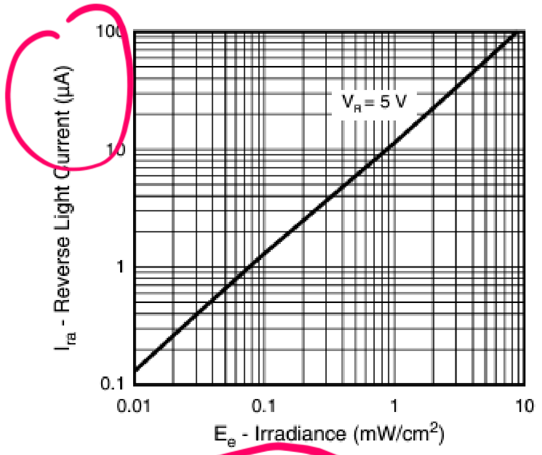
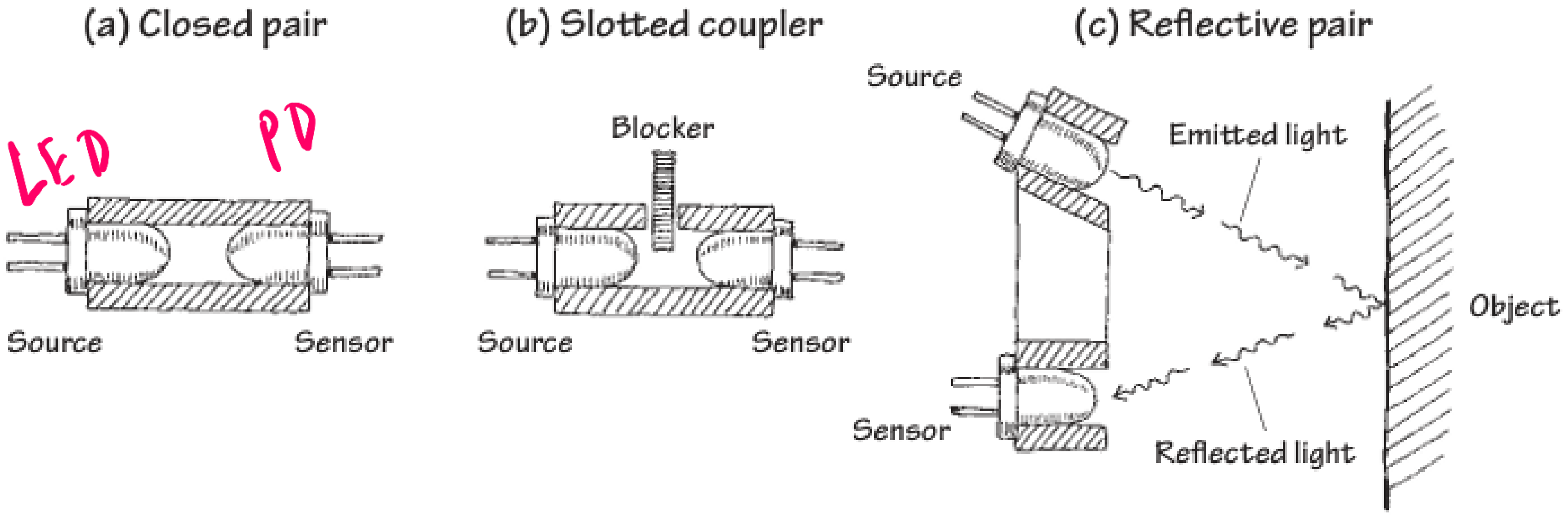


Fig. 3 - Reverse Light Current vs. Irradiance

LED-PD combo



(a) Closed pair
LED
PD
Source
Sensor
(b) Slotted coupler
Blocker
Source
Sensor
(c) Reflective pair
Source
Emitted light
Object
Sensor
Reflected light