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DIGITAL COMMUNICATION

- Prof. N. B. Kanirkar

Good Morning

- Light Sources & Detectors in Fiber Optics

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Light Sources for Fiber Optics

Light sources for fiber optics act as light transmitters and must meet certain requirements if they are to be acceptable for the purpose. First, the light produced must be as nearly monochromatic (single frequency) as possible. Most light sources are not single frequency, but emit light at many frequencies distributed over a band or portion of the spectrum, which may be quite broad. A few sources such as gas ionization lamps, light emitting diodes, and lasers emit light over a much narrower band. But even these sources are not truly monochromatic and do emit at several frequencies over a narrow band. The emission spectra of some typical light transmitters are compared in Fig.

Next, the light source should have a high-intensity output so that sufficient energy is transmitted on a fiber to overcome the losses encountered during transmission. Also the sources must be capable of being easily modulated. Although most sources presently available are capable of analog modulation (for example, amplitude modulation), binary on/off modulation with PCM is usually used since it gives good results with much better noise immunity than other methods.

Finally, the devices must be small and easily coupled to fibers so that excessive coupling losses do not occur. They must also be relatively inexpensive to manufacture.

Light emitting diodes and semiconductor lasers are both extensively used for this application. Both emit narrow-band light at fixed center wavelengths as the result of the recombination of hole–electron pairs in the junction area of the diode. Each such recombination is accompanied by the release of a photon of light with a fixed energy content that corresponds to the wavelength of light emitted and to the energy required to free a valence electron from its parent atom in the semiconductor.

Each photon contains an amount of energy that is related to the corresponding electromagnetic frequency by the expression

$$E = hf$$

where E is the energy in joules, h is Planck's constant (6.625×10^{-34} J-s) and f is the frequency in hertz. Light is usually designated by its wavelength instead of frequency. Wavelength is related to frequency by

$$f = \frac{c}{\lambda}$$

where c is the velocity of light in free space (300 Mm/s) and λ is the wavelength in meters. The energy is usually stated in electron voits (eV) found by dividing the energy in joules by the electronic charge q (1.602×10^{-19} C/electron), or

$$E_q = \frac{E}{q}$$

Combining these relationships gives the eV energy in terms of the wavelength as

$$E_q = \frac{hc}{q}\frac{1}{\lambda} = \frac{1.241}{\lambda\,(\mu\text{m})}$$

Fiber-optic Communications

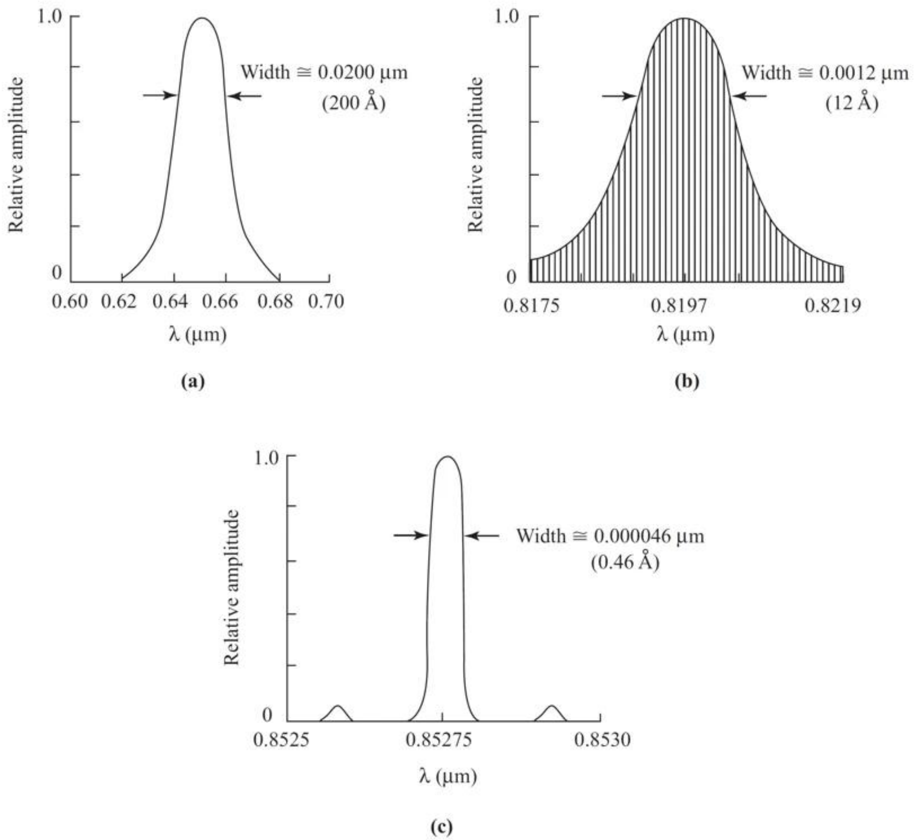


Figure Light emission spectra for typical light transmitters. (a) LED operating at 0.65 μm. (b) Broad-spectrum laser diode at 0.8197 μm. (c) Narrow-spectrum laser diode at 0.85275 μm.

Three semiconductor diodes are made using materials that have energy band gaps of 1.9, 1.46, and 0.954 eV. Find the wavelengths and frequencies of the light produced by them.

SOLUTION (a) The wavelength is

$$\lambda = \frac{1.241}{\text{eV}} = \frac{1.241}{1.9} = 0.6532\ \mu\text{m} \quad (= 6532\ \text{angstroms})$$

which emits in the orange-red portion of the visible spectrum. The frequency of this light is

$$f = \frac{c}{\lambda} = \frac{300\ \text{Mm/s}}{0.6532\ \mu\text{m}} - \mathbf{459.3\ THz}$$

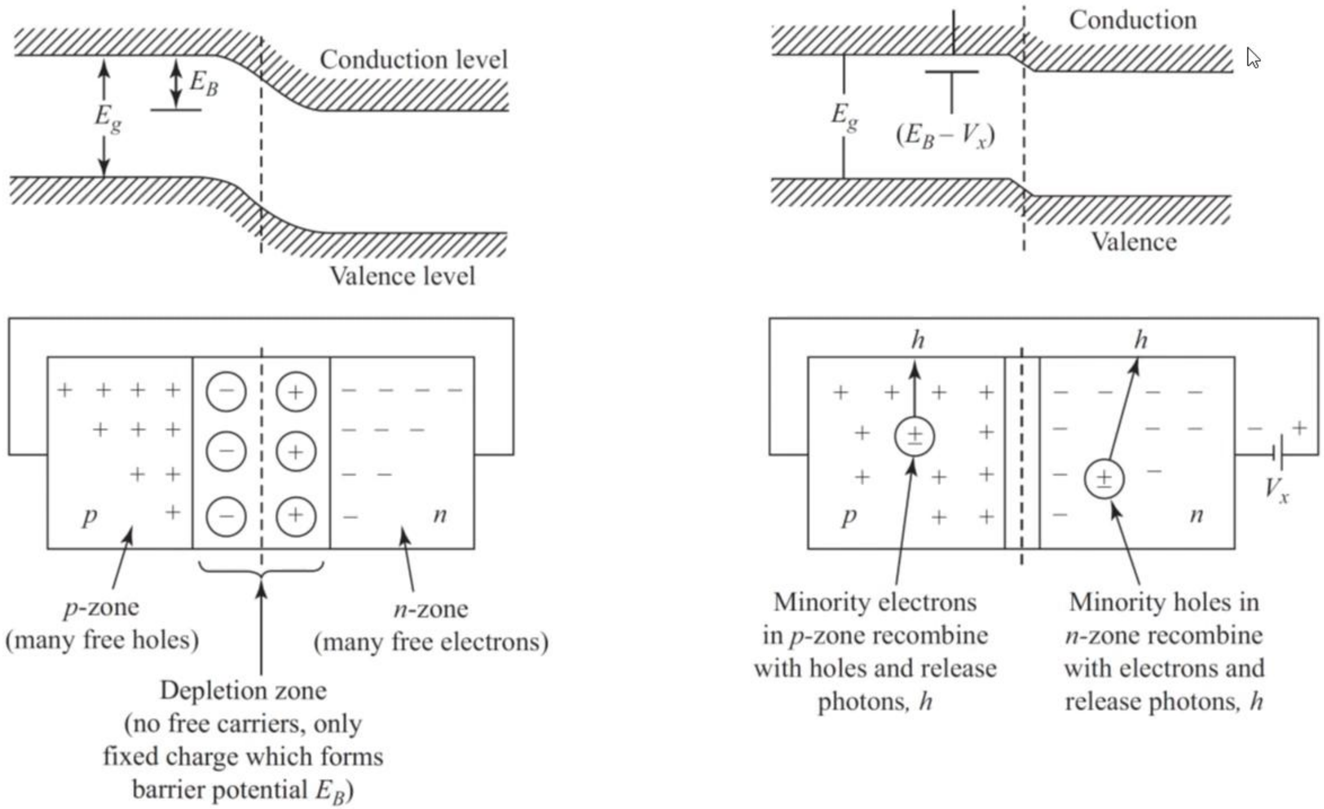
(b) $\lambda = 0.850\ \mu\text{m}$ and $f =$ **352.9 THz,** which produces light in the 0.8-μm loss window of silica fibers.
(c) $\lambda = 1.300\ \mu\text{m}$ and $f =$ **230.6 THz,** which produces light in the 1.3-μm loss window of silica fibers.

Light Emitting Diodes

A *light emitting diode* (LED) works by the process of spontaneous emission when it is forward biased and conducting current. One side of the diode junction is *p*-type material containing mostly holes (broken covalent bonds with missing electrons). The other side of the junction is *n*-type material containing mostly free electrons.

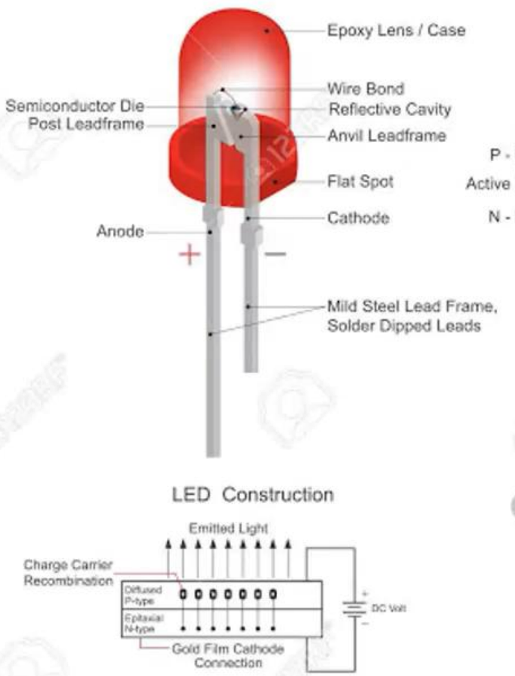
At zero bias a depletion zone separates the *p* and *n* regions as shown in Fig. . The depletion zone has had all free electrons and holes removed, uncovering two layers of fixed charges of opposite polarities that form a potential barrier across the depletion zone.

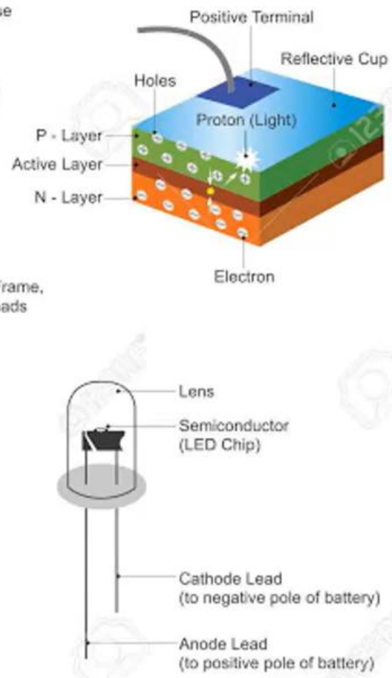
When forward bias is applied, the barrier potential is reduced and the depletion zone is narrowed until holes and electrons are free to cross the barrier to conduct current, as shown in Fig. Holes injected into the *n* region quickly encounter free electrons and recombine. Electrons injected into the *p* region encounter holes and recombine. External current flow replenishes the lost holes and electrons.

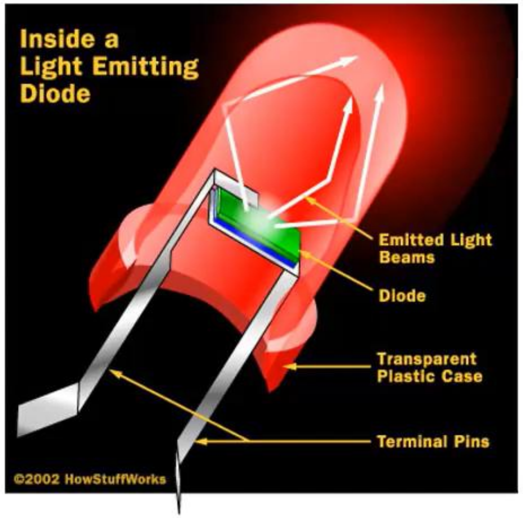


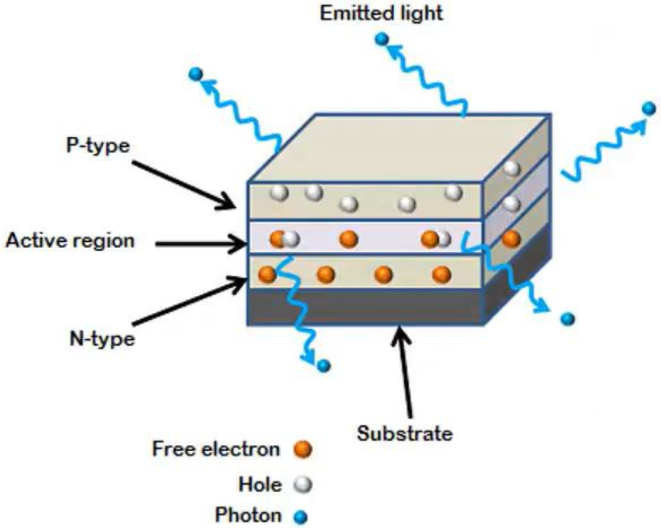
Energy band diagram and carrier distribution within a *pn* diode
(a) with zero bias and (b) with forward conducting bias.

A Light-Emitting Diode (LED)

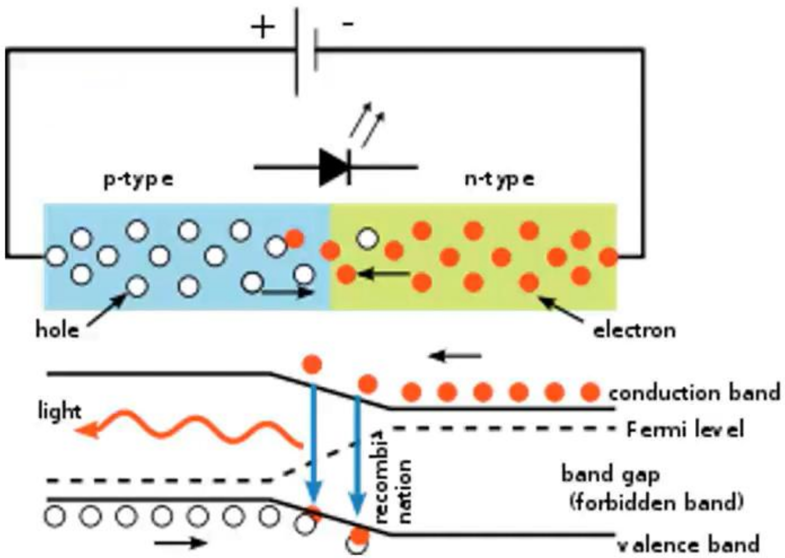








Construction of LED



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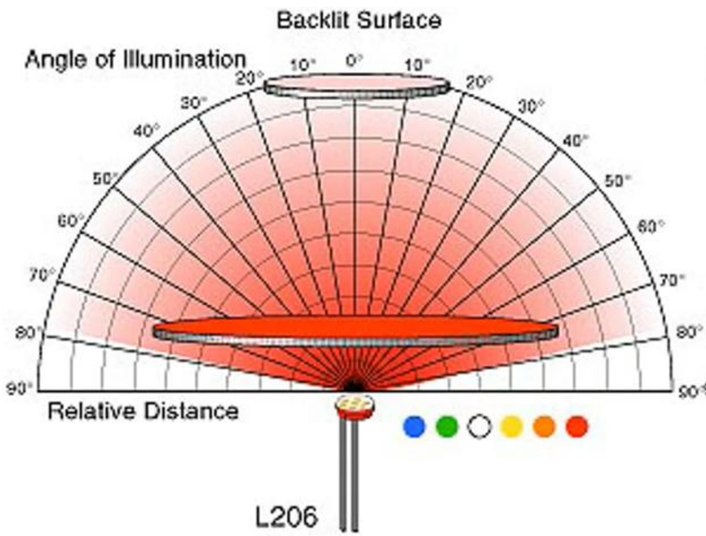
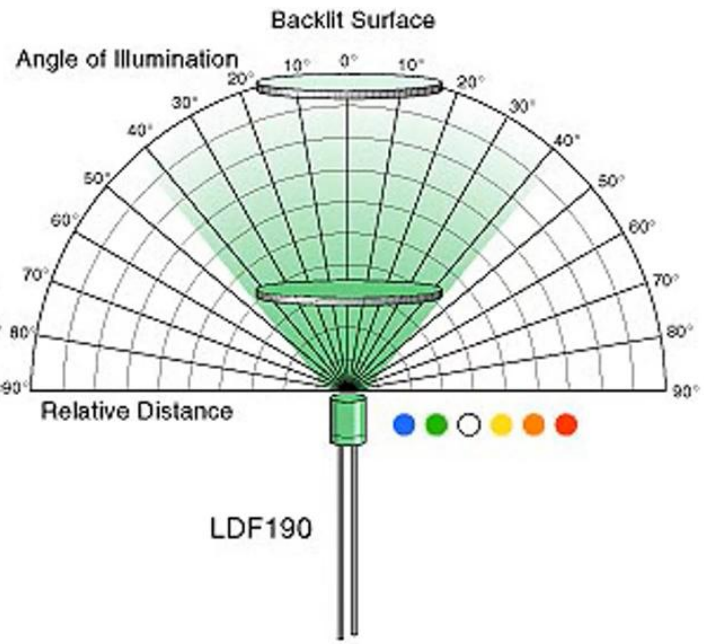


Extra wide illumination angle (160°)
Very short illumination distance



Wide illumination angle (120°)
Short illumination distance

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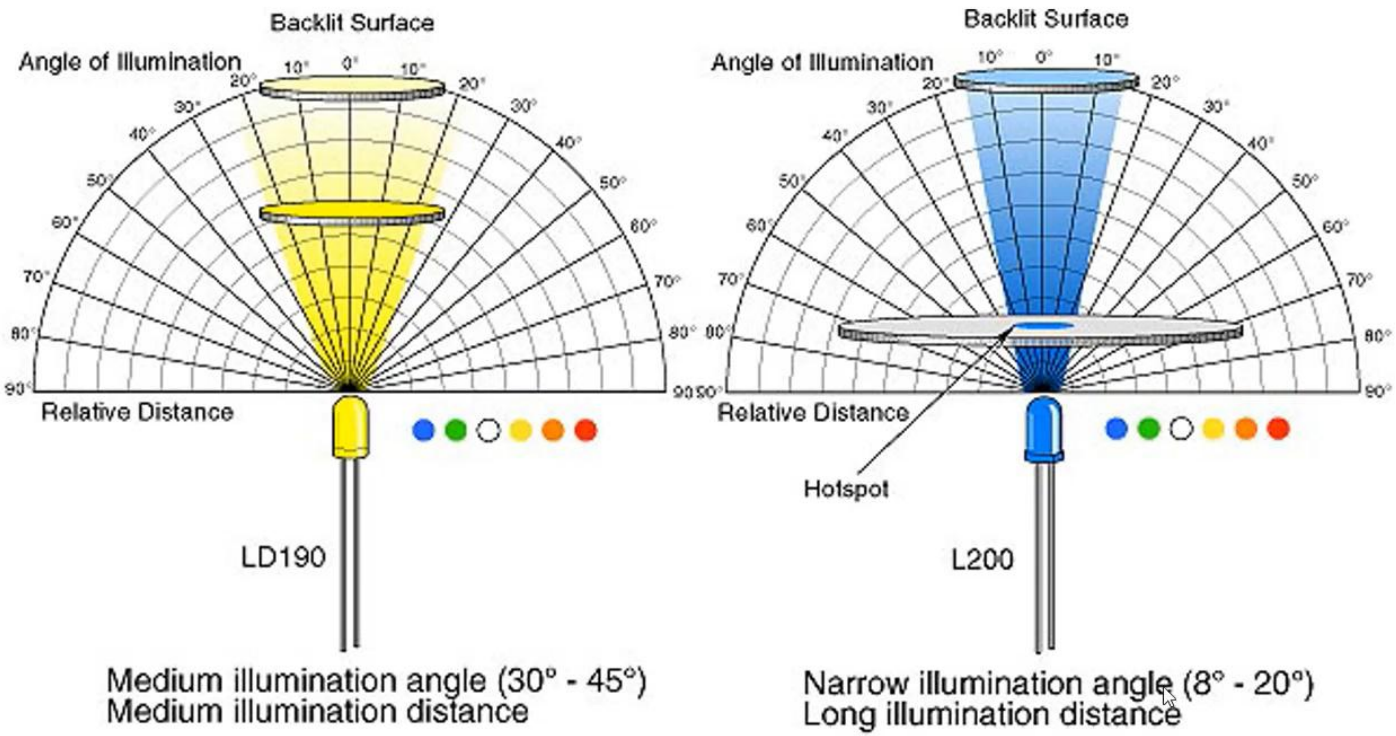
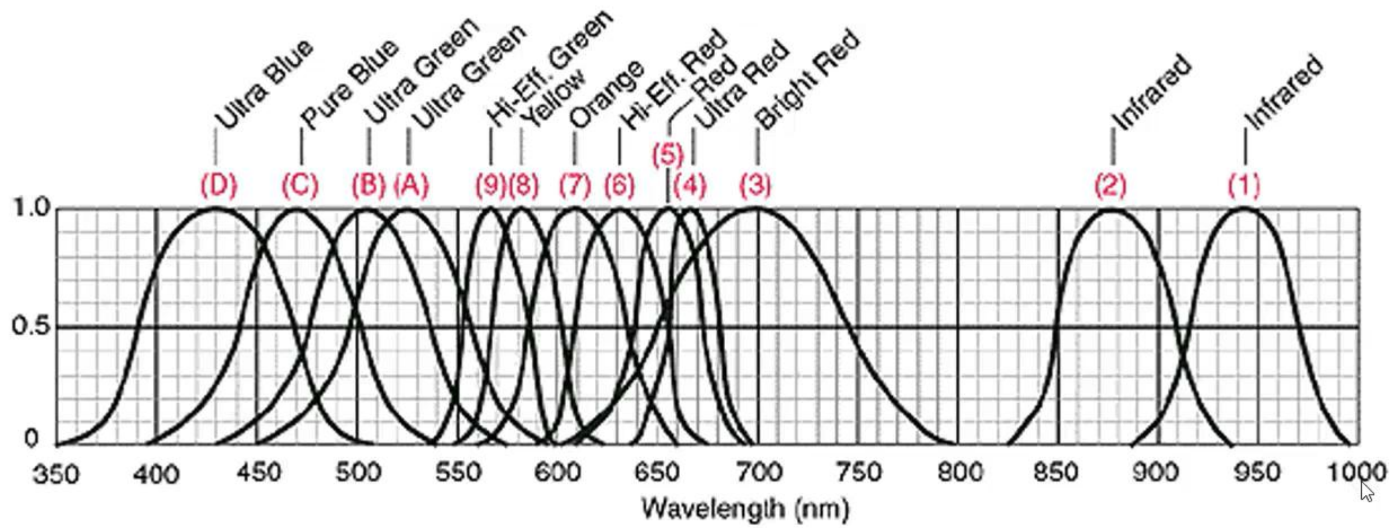

Backlit Surface
Angle of Illumination
Relative Distance
LD190
Medium illumination angle (30° - 45°)
Medium illumination distance
Backlit Surface
Angle of Illumination
Relative Distance
Hotspot
L200
Narrow illumination angle (8° - 20°)
Long illumination distance

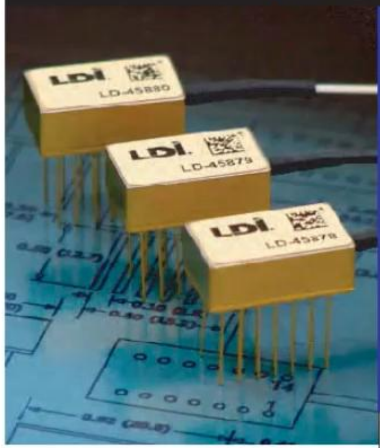

Ultra Blue
Pure Blue
Ultra Green
Ultra Green
Hi-Eff. Green
Yellow
Orange
Hi-Eff. Red
Red
Ultra Red
Bright Red
Infrared
Infrared
(D)
(C)
(B)
(A)
(9)
(8)
(7)
(6)
(5)
(4)
(3)
(2)
(1)
1.0
0.5
0
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
Wavelength (nm)

Tyco Electronics/LDI
2 Olsen Avenue
Edison, New Jersey 08820 USA
Voice: 732-549-9001
Fax: 732-906-1559
Internet: www.laserdiode.com
E-mail: sales@laserdiode.com

tyco / Electronics
Fiber Optic Business Unit

LDI.
Laser Diode Incorporated

1300nm Edge-Emitting LED

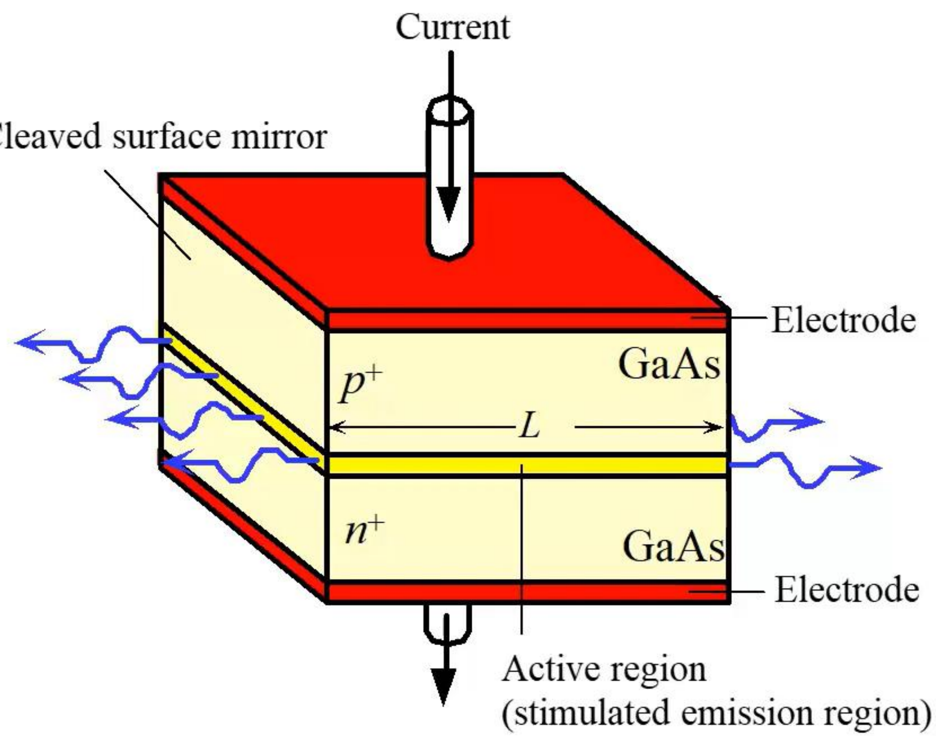


- High stability
- Fast rise time
- Singlemode and multimode pigtail
- Hermetic 14-pin DIL packages
- Thermoelectric cooler option
- Military-qualifiable package
- High reliability coupling

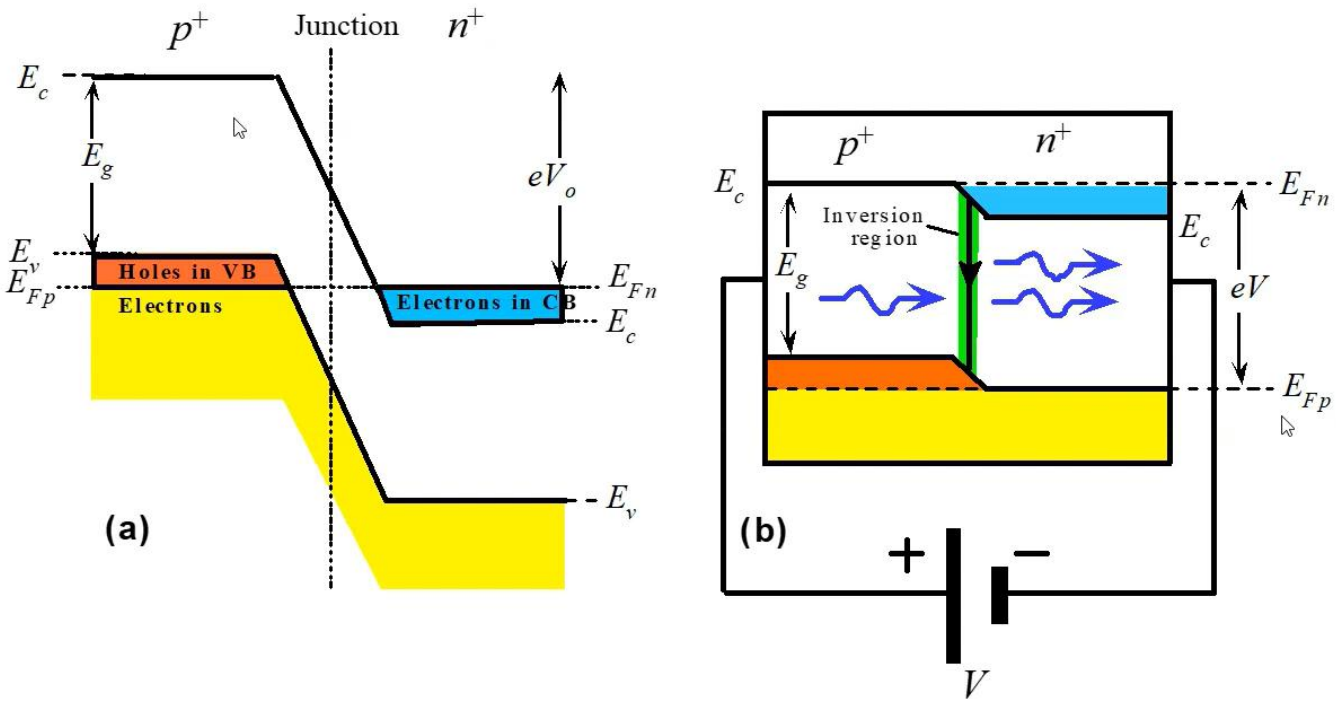
Laser Diode Incorporated's 1300nm edge-emitting LEDs (light-emitting diode) feature stable power and spectral characteristics over temperature.

LDI's MOCVD-grown InGaAsP devices are aligned to either a singlemode or multimode optical fiber in a stable, 14-pin dual-in-line package (DIP). Two versions of the DIP are offered. The standard package with a long-horn flange is configured either with or without a thermistor and a Peltier-effect thermoelectric cooler (cooler package). A second uncooled, low-profile package without a flange is also available for applications where space is limited and temperature control is not required.

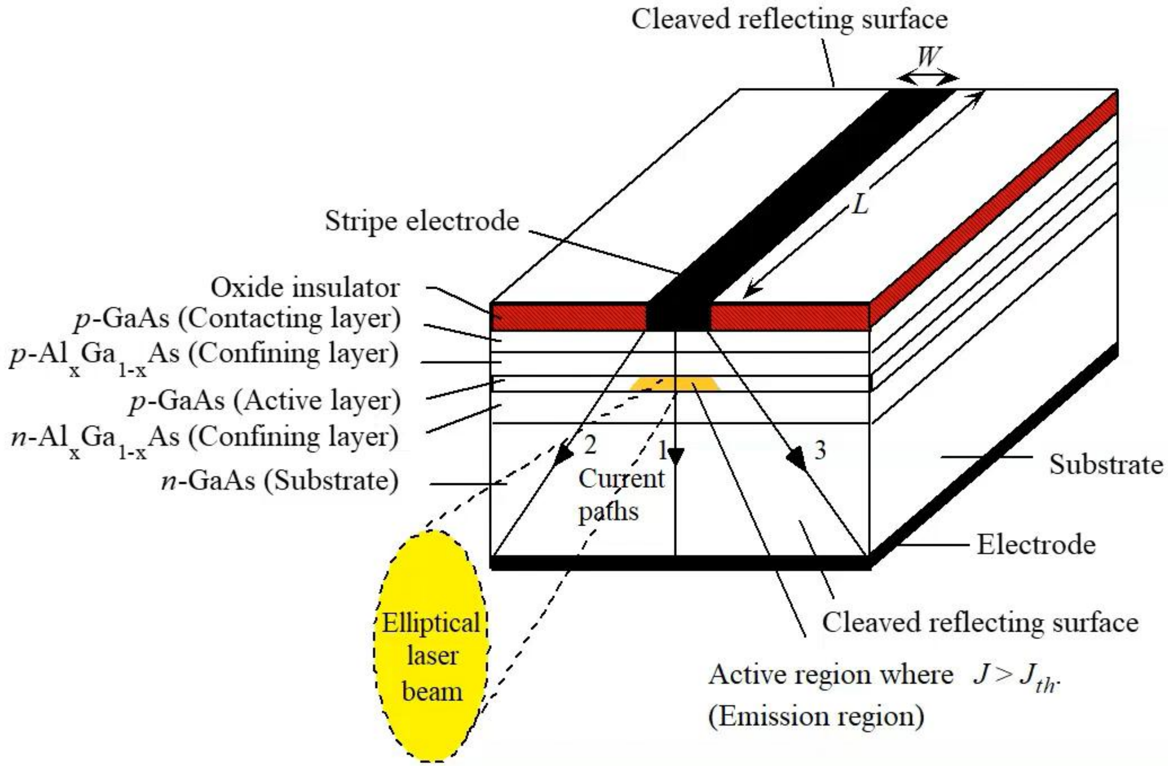
10-4400-0009 Rev. A



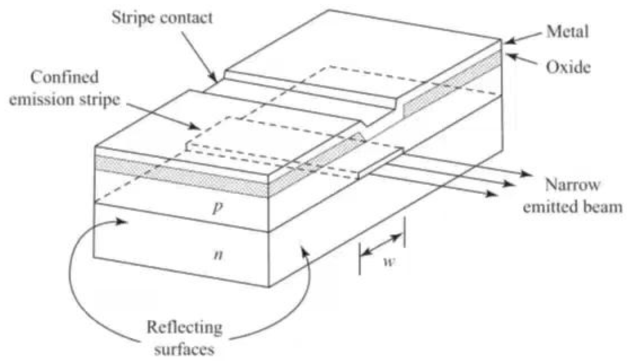
A schematic illustration of a GaAs homojunction laser diode. The cleaved surfaces act as reflecting mirrors.



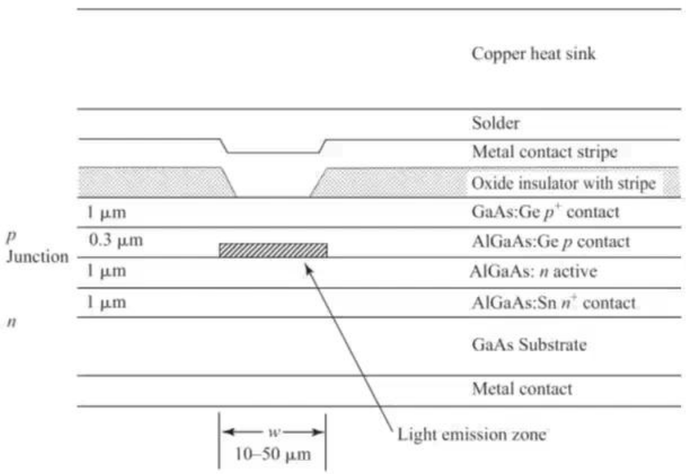
The energy band diagram of a degenerately doped *p-n* with no bias. (b) Band diagram with a sufficiently large forward bias to cause population inversion and hence stimulated emission.



Schematic illustration of the the structure of a double heterojunction stripe contact laser diode

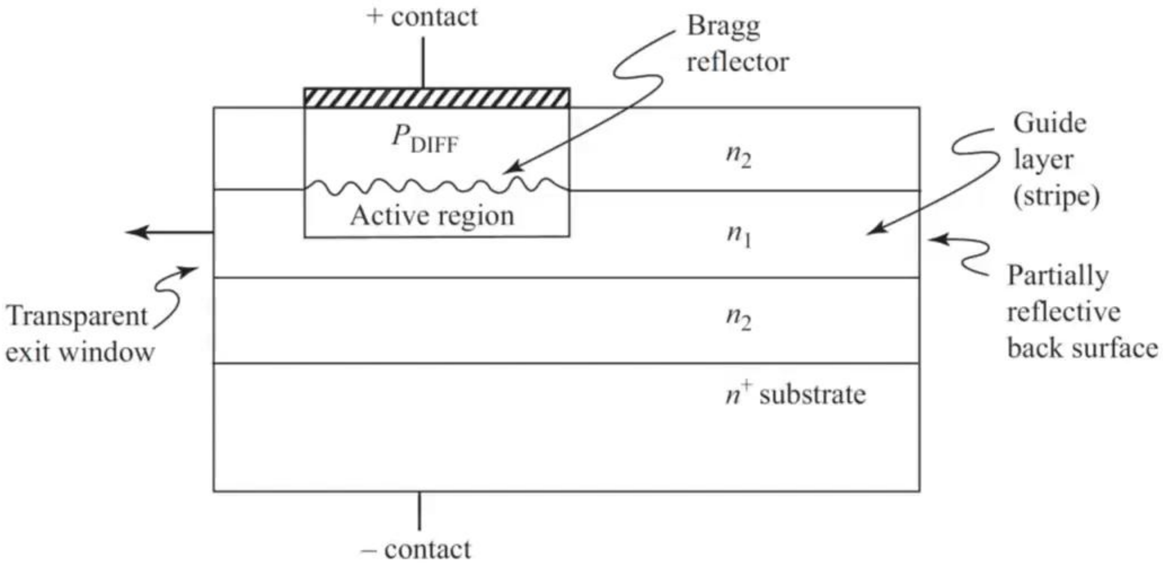


(a)



(b)

(a) Gain-guided stripe laser diode,
(b) Cross section of a double-heterostructure laser showing the various layers.



Distributed feedback laser diode.

Photodetectors

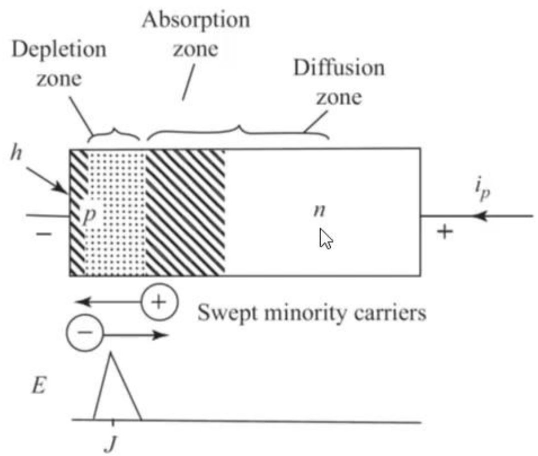
Introduction

Several types of photosensitive devices may be used as detectors for use with fiber optics. These include silicon photodiodes, phototransistors, and photo resistors. Not all of them have the speed of response and high sensitivity needed for useful communications application. Those that do include the *pin* diode and the avalanche diode.

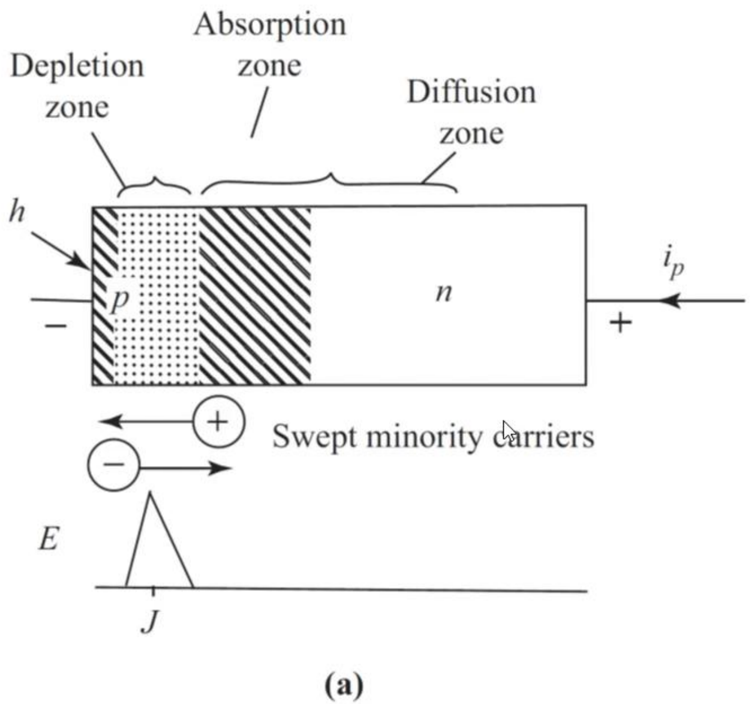
pn Photodiode

An ordinary *pn* diode may be used as a photodetector. It has sufficient speed, but its sensitivity is very low. Figure shows the structure of a *pn* photodiode. It has a *p* layer deposited on an *n* substrate so that light enters the junction through the *p* layer. The reverse-bias junction depletion zone is relatively thin. Photons of light entering the depletion zone ionize hole–electron pairs when they encounter atoms within the crystal structure. The mobile holes and electrons are swept out of the depletion zone by the electric field due to the reverse bias and contribute to the leakage current. The resulting leakage is proportional in magnitude to the incident light intensity.

Many of the photons entering the junction depletion zone of the *pn* diode pass through into the *n* region without ionizing an atom. Hole–electron pairs generated within the *n* region are not affected by the junction electric field and do not contribute to the photocurrent. As a result, the *responsivity* or conversion efficiency of the diode is quite low. However, since the depletion zone is quite thin, the carrier lifetime within the depletion zone is short so that the diode responds to rapid changes in light intensity.



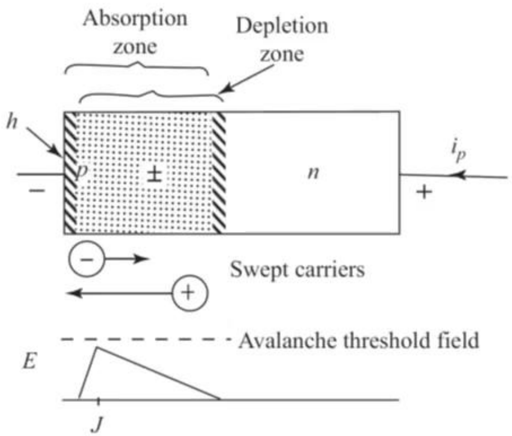
(a)



Photodiode structures with field distribution patterns.
(a) *pn* photodiode without multiplication

pin Photodiode

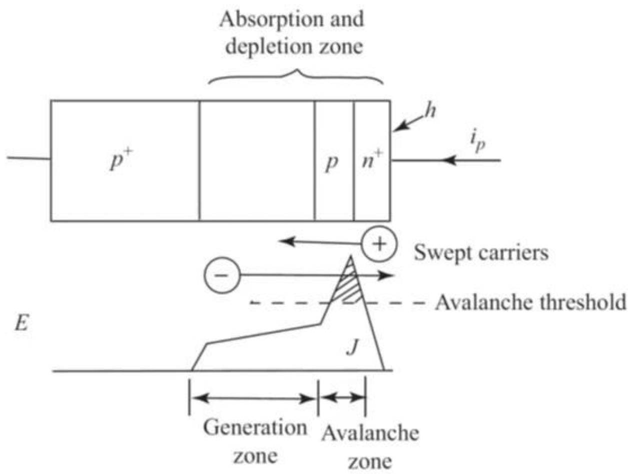
The sensitivity of the *pn* photodiode can be improved by including a lightly doped (or almost intrinsic) *n*-layer between the junction and the more heavily doped *n*-contact region to form the *pin* diode. The intrinsic layer, shown in Fig. is made thick enough so that most of the photons that pass through the junction without ionizing are absorbed within this layer. The junction electric field extends deep into this region, and any holes produced by the photons are swept across the junction to add to the photocurrent. This more complete use of the incident photons results in a larger photocurrent than would be the case without the intrinsic layer and a much higher sensitivity. However, the carriers produced within the intrinsic layer have farther to travel to cross the junction, so the response of the *pin* diode is slower than that of the *pn* diode. Sensitivity is gained at the expense of speed.



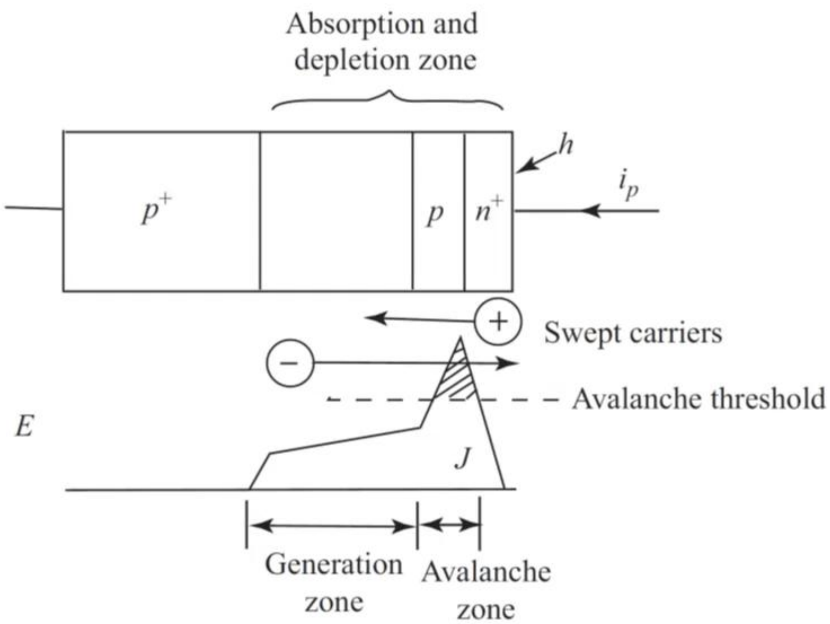
(b)

Avalanche Photodiode (APD)

If the negative reverse-bias voltage applied to the *pin* diode is increased, a threshold will be reached beyond which the field intensity at the junction becomes high enough so that electrons being accelerated through the depletion zone will create secondary hole–electron pairs when they collide with atoms. One photoelectron can result in many additional secondary electrons being created, resulting in an *avalanche multiplication effect*. The number of carriers generated by the avalanche effect is exponentially related to the field intensity so that high gains can be obtained with modest reverse bias voltages. All the additional carriers produced by the avalanche contribute to the photocurrent, so much higher conversion efficiencies are possible than without it.



(c)



(c)

Photodiode structures with field distribution patterns.
(*c*) *pipn* avalanche photodiode with multiplication.

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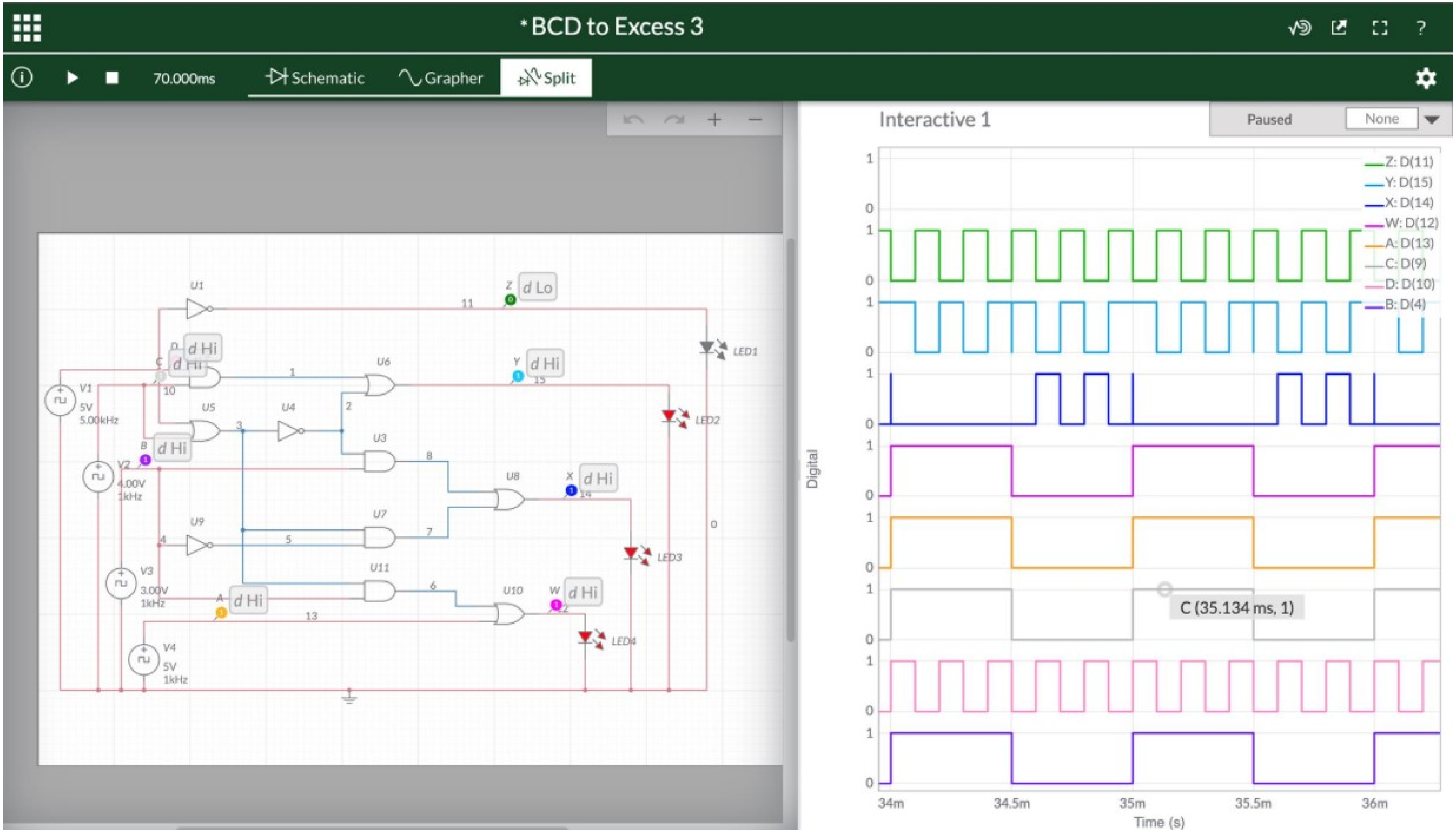

*BCD to Excess 3
70.000ms
Schematic
Grapher
Split
Interactive 1
Paused
None
Z: D(11)
Y: D(15)
X: D(14)
W: D(12)
A: D(13)
C: D(9)
D: D(10)
B: D(4)
C (35.134 ms, 1)
Digital
Time (s)
34m
34.5m
35m
35.5m
36m
U1
U3
U4
U5
U6
U7
U8
U9
U10
U11
LED1
LED2
LED3
LED4
V1
5V
5.00kHz
V2
4.00V
1kHz
V3
3.00V
1kHz
V4
5V
1kHz
d Lo
d Hi