ELECTRONICS DEVICES & CIRCUITS

Chapter 8
OPTOELECTRONICS

8.1 Elementary Ideas of LED and LCD
8.2 Photodiode, Phototransistor and Solar Cell and their Applications

Detailed Notes • Diagrams • Tables • Solved Numericals
15 Multiple Choice Questions with Answer Key • 10 Broad Questions

Prepared for Engineering Students (Diploma / B.Tech – Electronics & Allied Branches)

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8.0 Introduction to Optoelectronics

Optoelectronics is the branch of electronics that deals with devices which either **emit** light, **detect** light, or **convert** light energy into electrical energy and vice versa. These devices work on the interaction between **photons** (particles of light) and **electrons** inside a semiconductor. Because light can carry information at very high speed and without electrical contact, optoelectronic devices are used everywhere – from TV remote controls and indicator lamps to optical-fibre communication, solar power plants and mobile-phone displays.

Light as a photon

Light behaves as a stream of energy packets called photons. The energy of one photon depends only on its frequency (or wavelength):

Photon energy

$E = hf = hc / \lambda$

In convenient units: E (eV) = 1.24 / λ (μm) or λ (nm) = 1240 / E (eV)

where $h = 6.626 \times 10^{-34}$ J·s (Planck's constant), $c = 3 \times 10^{8}$ m/s, 1 eV = 1.6×10^{-19} J.

Three basic processes between photons and electrons

Process	Meaning	Device that uses it
Emission (recombination)	An electron falls from the conduction band to the valence band and releases the energy as a photon.	LED, laser diode
Absorption (generation)	A photon of energy ≥ band-gap raises an electron from valence band to conduction band, creating an electron-hole pair.	Photodiode, phototransistor, LDR
Photovoltaic action	Photo-generated pairs are separated by the junction field and appear as a voltage / current without external battery.	Solar cell
Electro-optic modulation	An electric field changes the optical property (polarisation / transparency) of a material.	LCD

Band-gap decides the colour

The wavelength of light emitted or detected is fixed by the **energy band-gap** (E_g) of the semiconductor. Silicon and germanium have an *indirect* band-gap, so recombination gives mostly heat – they are poor light emitters. Compound semiconductors such as GaAs, GaP, GaAsP, GaN have a *direct* band-gap, in which recombination gives photons efficiently – therefore they are used for LEDs and lasers.

Colour	Wavelength (nm)	Photon energy (eV)
Infrared	> 750	< 1.65
Red	620 – 750	2.0 – 1.65
Orange / Yellow	570 – 620	2.2 – 2.0
Green	495 – 570	2.5 – 2.2
Blue	450 – 495	2.75 – 2.5
Violet / UV	< 450	> 2.75

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8.1 Elementary Ideas of LED and LCD

8.1.1 Light Emitting Diode (LED)

A **Light Emitting Diode (LED)** is a special p-n junction diode that **emits visible or infrared light when forward biased**. It converts electrical energy directly into light energy, a phenomenon called **electroluminescence**. It is a *solid-state* source: no filament, no vacuum, no heat-glow.

Principle of operation

- In forward bias, the battery pushes **electrons** from the n-side and **holes** from the p-side towards the junction.
- Electrons cross the junction and **recombine** with holes near the junction (in the p-region).
- During recombination, an electron falls from a high-energy conduction band to a lower-energy valence band; the difference in energy (E_g) is released as a **photon**.
- Wavelength of the emitted light: $\lambda = hc / E_g$. Hence the colour of LED depends on the semiconductor material, not on the plastic lens.
- In silicon or germanium diodes, the energy is released as heat (non-radiative); so LEDs use direct band-gap compound semiconductors.

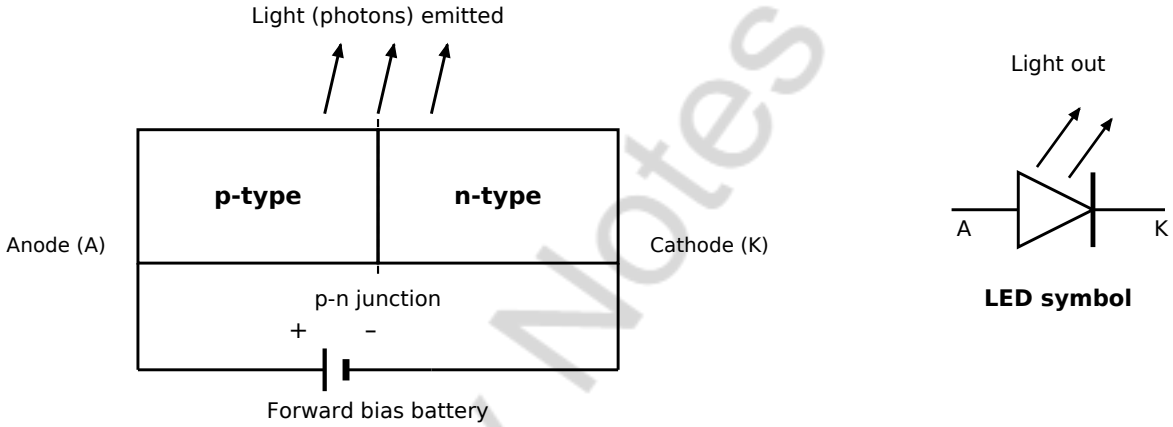


Fig. 8.1 Light emission in a forward-biased p-n junction and the LED symbol

Construction

- The p-n junction is formed by epitaxial growth of a thin **p-layer on a thick n-type substrate** (GaAs, GaP, GaAsP, GaN etc.).
- The top p-layer is made very thin and the top contact is small so that light can escape from the surface.
- The bottom surface carries a metal (back) contact that also acts as a **reflector** to send light upward.
- The chip is mounted in a **transparent / diffused epoxy dome** which protects the chip, acts as a lens and gives the LED its viewing angle.
- Two leads: the **longer lead is the anode (+)** and the shorter lead (with a flat edge on the body) is the **cathode (–)**.

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Materials and colours of LEDs

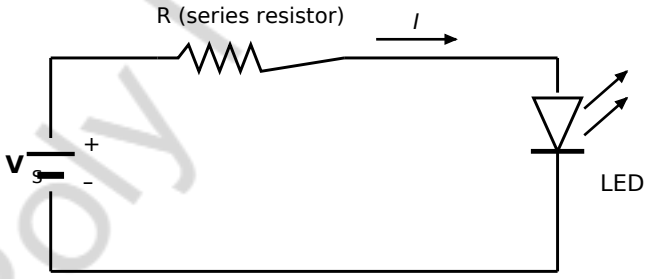
Semiconductor	Colour / Region	Approx. λ (nm)	Forward voltage V_F (V)
GaAs	Infrared	870 – 940	1.2 – 1.5
GaAsP	Red / Orange / Yellow	600 – 660	1.8 – 2.2
GaP (Zn-O / N doped)	Red / Green	565 – 700	2.0 – 2.2
AlGaInP	High-brightness red–amber	590 – 630	2.0 – 2.4
InGaN	Green / Blue	450 – 530	3.0 – 3.5
GaN + phosphor	White	Broad spectrum	3.0 – 3.6

Characteristics

- **I–V characteristic:** similar to an ordinary diode but with a higher knee (cut-in) voltage of about 1.2 V to 3.5 V depending on colour. Below the knee there is no light; above it, current rises sharply.
- **Light output vs current:** optical power is approximately **proportional to forward current** – so brightness is controlled by current, not by voltage.
- **Reverse breakdown voltage is low** (3–5 V). LEDs must never be reverse biased heavily.
- **Typical rating:** forward current 10–20 mA, power dissipation 50–150 mW, switching time in nanoseconds.
- **Spectral width:** narrow (≈ 20–40 nm) – almost monochromatic light.

Series resistor for an LED

Since the LED has a very small dynamic resistance after the knee, a **current-limiting resistor** is always connected in series. Without it, current rises uncontrollably and the LED burns out.



I = (VS – VF) / R

Fig. 8.2 LED driven through a series current-limiting resistor

Resistor formula
$R = (V_S - V_F) / I_F$
Example: V_S = 5 V, V_F = 2 V, I_F = 20 mA → R = (5 – 2) / 0.02 = **150 Ω** (use 150 Ω or the next higher standard value).

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Advantages and disadvantages

Advantages	Disadvantages
Low operating voltage and low power consumption	Light output varies with temperature
Very long life (≈ 50,000 – 100,000 hours)	Easily damaged by over-current or reverse voltage
Fast switching (ns); no warm-up time	Narrow viewing angle for simple types
Small, rugged, shock-proof, cheap	Blue / white LEDs are costlier than red
Many colours; can be dimmed using PWM	Needs a driver circuit for high power

Related ideas

- **Seven-segment display:** seven LEDs (a–g) plus a decimal point arranged as '8'. In *common-cathode* type, all cathodes are grounded and a segment glows when its anode is HIGH; in *common-anode* type, all anodes go to V_{CC} and a segment glows when its cathode is LOW.
- **Dot-matrix display:** LEDs in rows and columns (5×7, 8×8) used for alphanumeric characters and moving signboards.
- **Bi-colour / RGB LED:** two or three LED chips in one package; mixing red, green and blue gives any colour.
- **IR LED:** emits invisible infrared light, used in remote controls and proximity sensors.
- **OLED:** organic LED – a self-emitting thin-film display that needs no back-light; used in smartphones and TVs.
- **Laser diode:** an LED with an optical cavity that gives coherent, highly directional light (optical fibre, barcode readers, CD/DVD).

Applications of LED

- Indicator lamps in appliances, panels and instruments; seven-segment and dot-matrix displays.
- Remote controls (IR LED), optocouplers and optical-fibre transmitters.
- Energy-saving lighting – bulbs, street lights, torches, automobile head-lamps and tail-lamps.
- Traffic signals, signboards, large video screens and LED TV back-lighting.
- Sensors – object counting, proximity detection, security alarms.

8.1.2 Liquid Crystal Display (LCD)

A **Liquid Crystal Display (LCD)** is a flat, passive display that **does not emit light itself**; instead it **controls (modulates) the passage of ambient or back-light** using liquid crystals placed between two polarizers. Because it only controls light, it consumes extremely small power (microwatts per cm^2) – ideal for calculators, watches and battery-powered devices.

Liquid crystals

A liquid crystal is a substance that has properties between a **liquid** (it flows) and a **solid crystal** (its molecules have an ordered, directional arrangement). Its molecules are rod-shaped and an applied electric field can reorient them, which changes the way light passes through. Three common phases are:

Phase	Molecular arrangement	Use
Nematic	Rod-like molecules lie parallel to each other, no layers; free to slide	Twisted-nematic (TN) displays – most common
Smectic	Molecules arranged in distinct layers	Memory / ferro-electric displays

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Phase	Molecular arrangement	Use
Cholesteric	Layers of nematic type, each slightly rotated – a helical structure	Thermometers, colour-changing films

Construction of a twisted-nematic (TN) LCD cell

1. Two glass plates, each coated on its inner surface with a thin **transparent conducting electrode** (indium tin oxide, ITO), shaped as the digits / segments to be displayed.
2. On top of the electrodes a thin **alignment layer** is rubbed in one direction. The two rubbing directions are kept **90° apart**.
3. A thin film (≈ 5–10 µm) of **nematic liquid crystal** is sealed between the plates. Its molecules follow the rubbing direction at each plate, so they form a **90° twist** from one plate to the other.
4. Two **polarizers** are attached on the outer surfaces, with their polarisation axes crossed (perpendicular to each other).
5. A **reflector** (reflective type) or a **back-light** (transmissive type) is placed behind the rear polarizer.

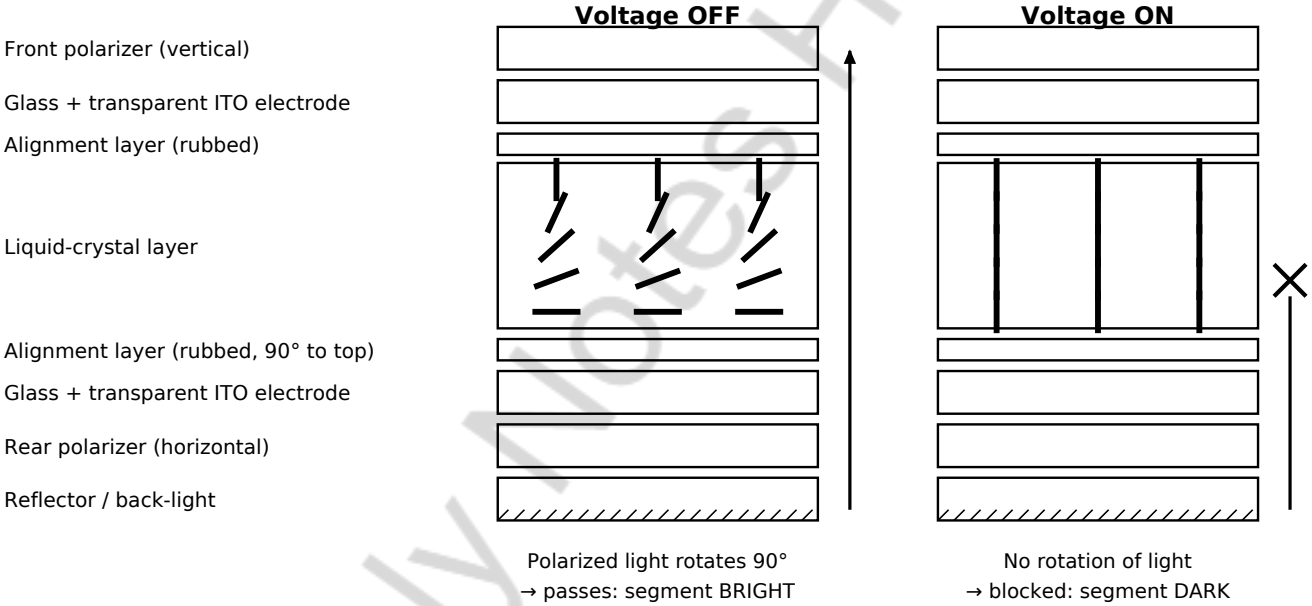


Fig. 8.3 Twisted-nematic LCD cell: OFF (bright) and ON (dark) states

Working principle

- **No voltage (OFF state):** Light from the front enters through the first polarizer and becomes polarized. The twisted liquid crystal **rotates the plane of polarization by 90°**, so light can pass through the second (crossed) polarizer, hits the reflector and returns. The segment appears **bright / transparent** (background colour).
- **Voltage applied (ON state):** An electric field between ITO electrodes **untwists** the molecules and aligns them along the field. The light is no longer rotated, so it is **blocked by the second polarizer**. The segment appears **dark**.
- By applying voltage only to chosen segments, digits and characters are formed as dark patterns on a bright background.
- **Drive voltage:** an **AC** signal (≈ 3–5 V, 30–100 Hz) is used. DC would cause electrolysis and damage the liquid crystal and shorten its life.

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Types of LCD

Type	Description
Reflective	Uses ambient light reflected from a mirror at back; no back-light, lowest power. Used in calculators, watches.
Transmissive	Uses a back-light (LED / CCFL) behind the cell; readable in dark. Used in monitors, TVs, mobiles.
Trans-reflective	Works with both ambient light and back-light; used in outdoor handheld devices.
Dynamic scattering (DSM)	Applied current makes the liquid crystal turbulent and light-scattering (milky); older, higher power.
Passive matrix / Active matrix (TFT)	Passive – row and column grid drives pixels. Active – each pixel has its own thin-film transistor (TFT) for sharp, fast, high-contrast images.

Advantages and disadvantages

Advantages	Disadvantages
Very low power consumption	Does not emit light – needs external / back-light
Thin, light, flat; operates at low voltage	Limited viewing angle for simple types
Good readability in bright light (reflective type)	Slow response at low temperature
Low cost for small displays	Needs AC drive; temperature range limited

Applications of LCD

- Digital watches, calculators, multimeters, panel meters and instruments.
- Mobile phones, laptops, computer monitors, LCD televisions and projectors.
- Medical equipment, ATM and POS machines, automobile dashboards and avionics displays.

8.1.3 Comparison of LED and LCD

Parameter	LED	LCD
Nature	Active – emits light	Passive – only modulates light
Principle	Electroluminescence (recombination)	Electro-optic effect (rotation of polarization)
Power consumption	Higher (mW range)	Very low (µW range)
Visibility in dark	Good (self-luminous)	Needs back-light
Drive signal	DC (forward current)	AC voltage
Operating voltage	1.2 – 3.5 V	3 – 5 V (AC)
Response time	Nanoseconds	Milliseconds
Life	Very long	Long (limited by back-light and ageing)
Cost for large area	Higher per display	Lower
Typical use	Indicators, 7-segment, lighting	Calculators, watches, monitors, TVs

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8.2 Photodiode, Phototransistor and Solar Cell

The devices in this section are **photo-detectors / photo-converters**: they respond to incident light by producing a current or a voltage. All three use the **internal photoelectric effect** – absorbing a photon of energy $\geq E_g$ generates an electron-hole pair inside the semiconductor, which then contributes to current.

8.2.1 Photodiode

A **photodiode** is a p-n junction diode specially constructed so that light can fall on the junction region. It is normally operated in **reverse bias**; the reverse current is then proportional to the intensity of incident light. It is therefore a **light-controlled current source**.

Construction

- A p-n junction in silicon (400–1100 nm), germanium (800–1800 nm) or InGaAs (900–1700 nm) with a **transparent window / lens** on top.
- The p-layer is thin so that light reaches the depletion region. An **anti-reflection coating** improves absorption.
- Packaged in a metal can with a glass window or in a clear plastic case; the cathode is marked by a tab or a longer lead.

Working principle

1. In the **dark**, a small reverse saturation current (the **dark current**, nA range) flows due to thermally generated minority carriers.
2. When light of energy $hf \geq E_g$ falls on the junction, it generates **electron-hole pairs** in and near the depletion region.
3. The strong electric field in the depletion region (increased by reverse bias) sweeps electrons to the n-side and holes to the p-side.
4. This extra **photocurrent** I_P adds to the dark current. Total reverse current: $I = I_D + I_P$, with $I_P \propto$ light intensity.
5. The voltage drop across the load R_L ($= I_P R_L$) gives an output voltage that follows the light.

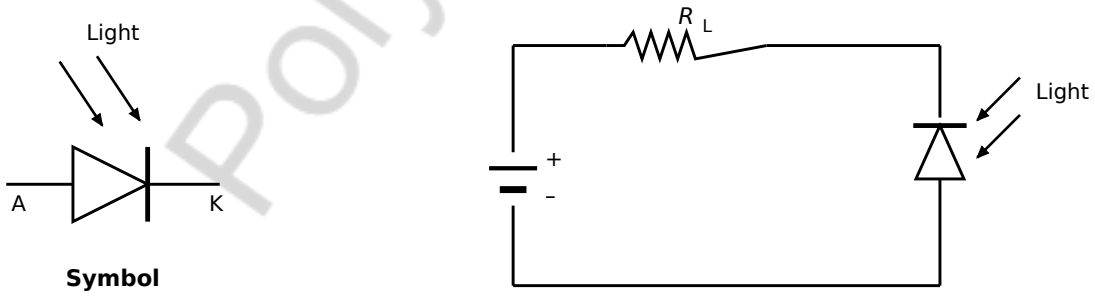


Fig. 8.4 Photodiode symbol and reverse-biased circuit

Modes of operation

Mode	Bias	Features	Use
Photoconductive	Reverse	Wide depletion layer, low capacitance, **fast response**, linear; more dark current / noise	Optical communication, detectors, sensors
Photovoltaic	Zero (no bias)	Generates its own voltage (like a tiny solar cell); very low noise, slower	Light meters, precision measurement, solar cells

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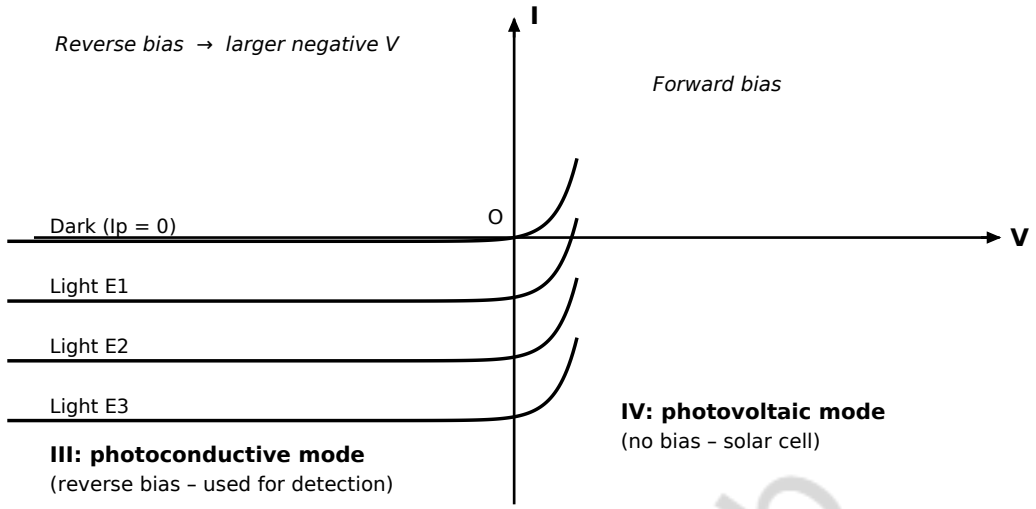


Fig. 8.5 V–I characteristics of a photodiode for different light intensities (E3 > E2 > E1)

Characteristics – reading the graph

- With no light (dark curve), the diode behaves like an ordinary diode with a very small reverse current.
- With increasing illumination, the curves shift **downward** – the reverse current grows in equal steps for equal steps of light intensity (linearity).
- In the **reverse-bias** region the curves are almost **flat** – the current depends on light, not on the voltage. This makes the photodiode a good constant-current light sensor.
- In the 4th quadrant (zero or small forward bias) the diode delivers power: the **photovoltaic** region.

Important parameters

Parameter	Meaning / typical value
Responsivity (R)	Photocurrent per unit optical power: $R = I_P / P$ (A/W). Typical 0.4 – 0.6 A/W for silicon at 800–900 nm.
Quantum efficiency (η)	Number of carriers collected per incident photon (%). $R = \eta q\lambda / hc$.
Dark current (I_D)	Reverse current with no light (pA – nA). It limits the weakest detectable light.
Response (rise) time	Time to rise from 10% to 90% of final output; ns for PIN / APD, µs for ordinary diode.
Spectral response	Range of wavelengths detected; silicon peaks near 900 nm.
Noise equivalent power (NEP)	Light power giving signal equal to noise; lower NEP = better detector.
Junction capacitance	Smaller capacitance gives faster response; falls with higher reverse voltage.

Special types of photodiodes

- **PIN photodiode:** an intrinsic (i) layer between p and n widens the depletion region – lower capacitance, higher speed, better sensitivity at long wavelengths.
- **Avalanche photodiode (APD):** operated near breakdown; impact ionisation multiplies carriers (gain 50–200) – very sensitive, used in long-distance fibre links and LIDAR.
- **Schottky photodiode:** metal-semiconductor junction; responds well in the ultraviolet range.

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Applications of photodiode

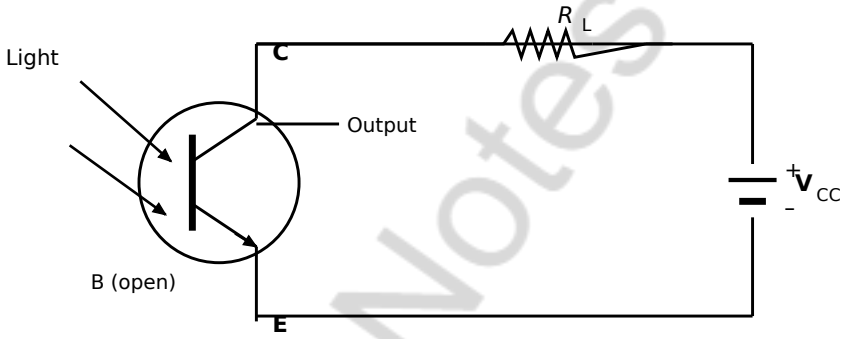
- Optical-fibre communication receivers and remote-control (IR) receivers.
- Light meters in cameras, automatic street-light and brightness control.
- Smoke detectors, burglar alarms, object counters, barcode and CD/DVD pick-up.
- Medical instruments – pulse oximeter, CT scanner; position sensing and encoders.
- Solar-energy measurement, spectrometers, optocouplers.

8.2.2 Phototransistor

A **phototransistor** is a bipolar junction transistor (usually n-p-n) whose **base-collector junction is exposed to light**. The light plays the role of base current; so the device gives a **built-in amplification** of the photocurrent. It is more sensitive than a photodiode, but slower.

Construction

- Similar to a BJT but with a **transparent window or lens** over the large-area base-collector junction.
- Most devices have only two leads (collector and emitter); the **base is left open** because light supplies base drive. Some types bring out a third base lead to set bias or reduce noise.
- Made from silicon (visible – near IR) or germanium.



Symbol (n-p-n) **Typical phototransistor circuit**

Fig. 8.6 Phototransistor symbol and a typical circuit

Working principle

1. The collector-base junction is **reverse biased** (V_{CC} applied across C–E with base open).
2. Light falling on the base-collector junction generates electron-hole pairs; the junction field separates them, producing a **photocurrent** I_P that acts like a base current.
3. The transistor amplifies it: $\mathbf{I_C = (\beta + 1)\, I_P \approx \beta\, I_P}$, where β is the dc current gain.
4. The collector current flows through R_L; the output voltage is $V_{out} = V_{CC} - I_C R_L$. As light increases, I_C rises and V_{out} falls.

Characteristics

- $\mathbf{I_C - V_{CE}}$ **curves:** look like normal transistor output curves, but the parameter is **light intensity** (mW/cm^2) instead of base current.
- In the active region I_C is nearly independent of V_{CE} and proportional to light.
- The device may be used as a **linear amplifier** (active region) or as a **switch** (saturation and cut-off – ON in light, OFF in dark).
- **Dark current** I_{CEO} is larger than that of a photodiode (leakage is also amplified).

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- Typical response time is microseconds (limited by the large base-collector capacitance – the Miller effect).

Photodarlington

A phototransistor driving another transistor in Darlington connection gives a total gain of $\beta_1\beta_2$ (thousands) – extremely sensitive to light, but still slower (tens of μs) – used for detecting very dim light.

Photodiode versus phototransistor

Parameter	Photodiode	Phototransistor
Junctions	One p-n junction	Two junctions (n-p-n / p-n-p)
Gain	No internal gain (APD excepted)	Internal gain = β (typ. 100 – 1000)
Sensitivity	Lower	Higher (about β times)
Response speed	Very fast (ns)	Slower (μs)
Linearity	Excellent	Fair
Dark current	Very small (nA)	Larger (amplified leakage)
Output current	μA	mA
Preferred use	Fast, precise detection, communications	Switching, sensing, simple low-cost circuits

Optocoupler (opto-isolator)

An **optocoupler** contains an LED and a phototransistor (or photodiode / photo-Darlington / photo-triac) sealed in one package, facing each other. An electrical signal at the input makes the LED glow; the phototransistor detects the light and produces an output signal. The only link between input and output is **light**, so the two circuits are **electrically isolated** (several kV isolation).

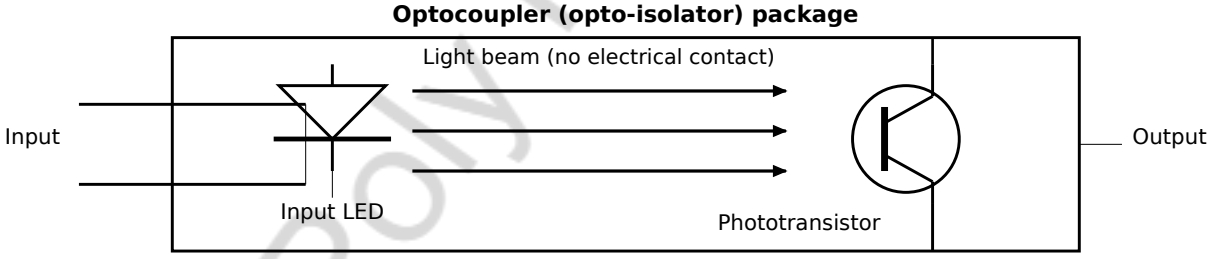


Fig. 8.7 Optocoupler: LED and phototransistor in one package

Applications of phototransistor

- Optocouplers for isolating microcontrollers from high-voltage / noisy circuits (SMPS, motor drives).
- Light-operated switches and relays, automatic street lights, twilight switches.
- Object detection and counting, slotted opto-switches in printers, mice and encoders.
- Punched-card / tape readers, shaft-speed measurement, safety light curtains.
- Infrared receivers in remote-control and security systems; smoke detectors.

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8.2.3 Solar Cell (Photovoltaic Cell)

A **solar cell** is a p-n junction device that **converts light (solar) energy directly into electrical energy** by the **photovoltaic effect**. Unlike a photodiode, it is used **without any external bias** and delivers power to a load.

Construction

- A thin **n-type emitter layer** (≈ 0.3 – 0.5 μm) is diffused on a thick **p-type silicon base** (≈ 200–300 μm), forming a large-area p-n junction.
- A **metal grid** (fingers and busbars) on the front collects current while leaving most of the surface open to light.
- An **anti-reflection coating** (SiN or TiO_2) reduces reflection loss from about 30 % to less than 5 %.
- A continuous **metal back contact** forms the other electrode; textured surface traps more light.

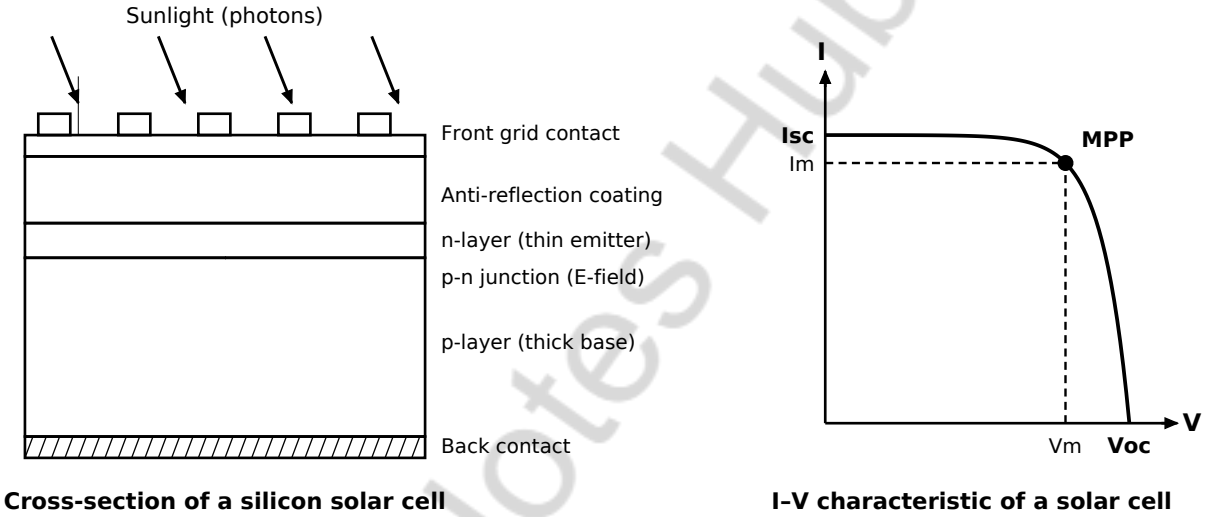


Fig. 8.8 Structure of a silicon solar cell and its I–V characteristic

Working principle

1. Sunlight photons with energy ≥ E_g (1.1 eV for Si) are absorbed, generating electron-hole pairs near the junction.
2. The **built-in electric field** of the junction pushes electrons to the n-side and holes to the p-side.
3. Separation of charge builds up an **open-circuit voltage** (about 0.5 – 0.7 V for Si) across the cell.
4. When a load is connected, electrons flow from the n-side through the external circuit to the p-side – a **direct current** flows and power is delivered.
5. Photons with energy < E_g are not absorbed; those with much larger energy waste the excess as heat – these are the basic efficiency limits.

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Key parameters

Parameter	Definition	Typical value (Si cell)
Open-circuit voltage V_{oc}	Voltage across the cell with no load (I = 0)	0.5 – 0.7 V
Short-circuit current I_{sc}	Current when output is shorted (V = 0); proportional to light intensity and area	30 – 40 mA/cm^2
Maximum power point (V_m, I_m)	Operating point where output power $P_{max} = V_m I_m$ is largest	$V_m \approx 0.8\ V_{oc}$
Fill factor (FF)	$FF = P_{max} / (V_{oc}\ I_{sc})$; shows how 'square' the I–V curve is	0.70 – 0.85
Efficiency (η)	$\eta = P_{max} / P_{in} = (FF \cdot V_{oc} \cdot I_{sc}) /$ (irradiance × area)	15 – 24 % (commercial)

Reading the I–V curve

- The curve is nearly flat at I_{sc} (cell acts as a constant-current source) and then drops sharply near V_{oc} (constant-voltage source).
- Power = V × I is zero at both ends and maximum at the 'knee' – the **maximum power point (MPP)**. Solar inverters use **MPPT** circuits to keep the cell at this point.
- With higher light intensity, I_{sc} rises in proportion while V_{oc} rises only slightly (logarithmically).
- With higher temperature, V_{oc} falls (≈ –2 mV/°C per cell) and efficiency reduces.

Cells, modules and arrays

- One cell gives only ≈ 0.5 V; so **cells are connected in series** to raise voltage (36 or 72 cells ≈ 12 V / 24 V panel) and **in parallel** to raise current.
- A group of cells in a frame forms a **module (panel)**; modules combine to form an **array**.
- **Bypass diodes** protect shaded cells from hot-spots; **blocking diodes** prevent battery discharge through the panel at night.

Types of solar cells

Type	Material	Efficiency (approx.)	Remarks
Monocrystalline	Single-crystal Si	18 – 24 %	Highest efficiency, costlier
Polycrystalline	Multi-crystal Si	15 – 19 %	Cheaper, bluish look
Thin film	a-Si, CdTe, CIGS	8 – 18 %	Light, flexible, low cost
Multi-junction	GaAs / InGaP / Ge stack	30 – 40 %	Space satellites, concentrators
Perovskite / organic	Emerging materials	up to 25 % (lab)	Under development

Advantages and limitations

Advantages	Limitations
Renewable, clean, silent, no moving parts	Works only in sunlight; needs battery / grid backup
Low maintenance, long life (25+ years)	Low efficiency; large area needed
Usable in remote areas, scalable from mW to MW	High initial cost; output falls with heat and dust

Applications of solar cells

- Rooftop and utility-scale power plants, grid-tied and off-grid systems, solar water pumps.

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- Solar street lights, traffic signals, garden lamps, and battery chargers.
- Calculators, watches, small consumer gadgets.
- Satellites and space stations, remote telecom towers, weather stations.
- Electric vehicle charging, solar cookers / heaters (with power electronics), light sensors.

8.3 Comparison of Optoelectronic Devices

Device	Function	Bias	Key property
LED	Electrical → light	Forward	Brightness ∝ forward current
LCD	Controls light passage	AC field	Very low power, non-emissive
Photodiode	Light → current	Reverse (or zero)	Fast, linear
Phototransistor	Light → amplified current	C–E supply, base open	High sensitivity, medium speed
Solar cell	Light → electrical power	None (self-generating)	Large area, delivers power
Optocoupler	Signal transfer by light	LED forward; output biased	Electrical isolation

Important formulae

- Photon energy: E (eV) = 1240 / λ (nm)
- LED resistor: $R = (V_S - V_F) / I_F$
- Photodiode responsivity: $R = I_P / P$ (A/W)
- Phototransistor: $I_C \approx \beta I_P$
- Solar cell: FF = $P_{max} / (V_{oc} I_{sc})$; η = $P_{max} / P_{in} \times 100$ %

Solved numericals

Example 1. A GaAs LED has band-gap 1.42 eV. Find the wavelength of emitted light.
Solution: λ = 1240 / 1.42 = **873 nm** (infrared region).

Example 2. A red LED (V_F = 1.8 V, I_F = 15 mA) is to be driven from a 9 V supply. Find the series resistance.
Solution: R = (9 – 1.8) / 0.015 = **480 Ω**. Use the next standard value, 510 Ω (or 470 Ω with a small current margin).

Example 3. A photodiode produces 5 µA photocurrent for 10 µW incident power. Find its responsivity.
Solution: R = 5 µA / 10 µW = **0.5 A/W**.

Example 4. A phototransistor with β = 200 receives light that creates photocurrent 2 µA. Find the collector current and the output voltage across R_L = 10 kΩ with V_{CC} = 12 V.
Solution: I_C = 200 × 2 µA = 400 µA; drop across R_L = 0.4 mA × 10 kΩ = 4 V; V_{out} = 12 – 4 = **8 V**.

Example 5. A solar cell of area 100 cm^2 has V_{oc} = 0.6 V, I_{sc} = 3.5 A, FF = 0.78 under 1000 W/m^2 sunlight. Find its efficiency.
Solution: P_{max} = 0.78 × 0.6 × 3.5 = 1.638 W. P_{in} = 1000 W/m^2 × 0.01 m^2 = 10 W. η = 1.638 / 10 × 100 = **16.4 %**.

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8.4 Multiple Choice Questions

Q1. An LED emits light because of

(A) Recombination of electrons and holes in forward bias
(B) Thermal heating of its filament
(C) Avalanche breakdown in reverse bias
(D) Rectification of AC current

Q2. An LED is normally operated in

(A) Reverse bias
(B) Forward bias
(C) Zero bias only
(D) Breakdown region

Q3. The semiconductor commonly used for blue LEDs is

(A) Ge
(B) Si
(C) InGaN / GaN
(D) GaAs

Q4. Which statement about an LCD is correct?

(A) It emits its own light
(B) It controls the passage of light and is a passive display
(C) It works only on DC
(D) It needs a very high voltage

Q5. The liquid-crystal phase used in the twisted-nematic display is

(A) Smectic
(B) Cholesteric
(C) Isotropic
(D) Nematic

Q6. A photodiode is generally operated in

(A) Reverse bias
(B) Forward bias
(C) Open circuit only
(D) Zener region only

Q7. The small current in a photodiode when no light falls on it is called

(A) Photo current
(B) Saturation voltage
(C) Dark current
(D) Leakage voltage

Q8. An LED (V_F = 2 V, I_F = 20 mA) is connected to a 9 V supply. The series resistor required is

(A) 150 Ω
(B) 350 Ω
(C) 450 Ω
(D) 700 Ω

Q9. In a phototransistor, the collector current is approximately

(A) I_P / β
(B) I_P
(C) βI_P
(D) β / I_P

Q10. Which device is based on the photovoltaic effect?

(A) LED
(B) Solar cell
(C) LCD
(D) Zener diode

Q11. Fill factor of a solar cell is defined as

(A) $V_{oc} I_{sc} / P_{max}$
(B) $P_{max} \times V_{oc}$
(C) $P_{max} / (V_{oc} I_{sc})$
(D) I_{sc} / V_{oc}

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Q12. Open-circuit voltage of a single silicon solar cell is about

(A) 0.1 V (B) 0.6 V

(C) 5 V (D) 12 V

Q13. An optocoupler is mainly used to provide

(A) Voltage amplification (B) Frequency multiplication

(C) Rectification (D) Electrical isolation between circuits

Q14. The wavelength of light emitted by a semiconductor with band-gap 1.24 eV is

(A) 620 nm (B) 1240 nm

(C) 1000 nm (D) 500 nm

Q15. Compared with a photodiode, a phototransistor has

(A) Higher sensitivity but lower speed (B) Lower sensitivity and higher speed

(C) No light sensitivity (D) Lower output current

Answer Key

Q	Ans	Q	Ans	Q	Ans
1	A	6	A	11	C
2	B	7	C	12	B
3	C	8	B	13	D
4	B	9	C	14	C
5	D	10	B	15	A

Hints: Q8: R = (9 – 2)/0.02 = 350 Ω. Q14: λ = 1240 / 1.24 = 1000 nm.

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8.5 Broad Questions

Q1. Explain the construction and working principle of a Light Emitting Diode (LED) with a neat diagram. Why are Si and Ge not used for making LEDs?

Q2. List the materials used to make LEDs of different colours. Draw and explain the characteristics of an LED and derive the expression for its series resistor.

Q3. What are liquid crystals? Describe the construction and working of a twisted-nematic LCD with a labelled diagram. Why is AC used to drive an LCD?

Q4. Compare LED and LCD displays on the basis of principle, power, drive, visibility, speed and applications.

Q5. Explain the principle and working of a photodiode. Draw and discuss its V–I characteristics for different light intensities.

Q6. Describe the photoconductive and photovoltaic modes of a photodiode. Define responsivity, dark current and response time. Write a note on PIN and avalanche photodiodes.

Q7. Explain the construction, working and characteristics of a phototransistor. Compare it with a photodiode.

Q8. What is an optocoupler? Explain its construction and working with a diagram and give its applications.

Q9. Explain the principle, construction and working of a solar cell. Draw its I–V curve and define V_{oc}, I_{sc}, maximum power point, fill factor and efficiency.

Q10. Write the applications of LED, LCD, photodiode, phototransistor and solar cell. Solve: a solar cell of 50 cm^2 area has V_{oc} = 0.62 V, I_{sc} = 1.7 A and FF = 0.75 under 100 mW/cm^2 light – find P_{max} and efficiency.

Answer for Q10 numerical (self-check): $P_{max} = 0.75 \times 0.62 \times 1.7 = 0.79$ W; $P_{in} = 100$ $mW/cm^2 \times 50$ $cm^2 = 5$ W; $\eta = 0.79 / 5 \times 100 \approx$ **15.8 %**.

— End of Chapter 8: Optoelectronics —

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