Tunnel diode(Esaki Diode)

• It was introduced by Leo Esaki in 1958.

• Heavily-doped p-n junction

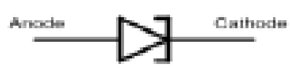
Impurity concentration is 1 part in 10^3 as compared to 1 part in 10^8 in p-n junction diode

• Width of the depletion layer is very small (about 100 A).

• It is generally made up of Ge and GaAs.

• It shows tunneling phenomenon.

• Circuit symbol of tunnel diode is :

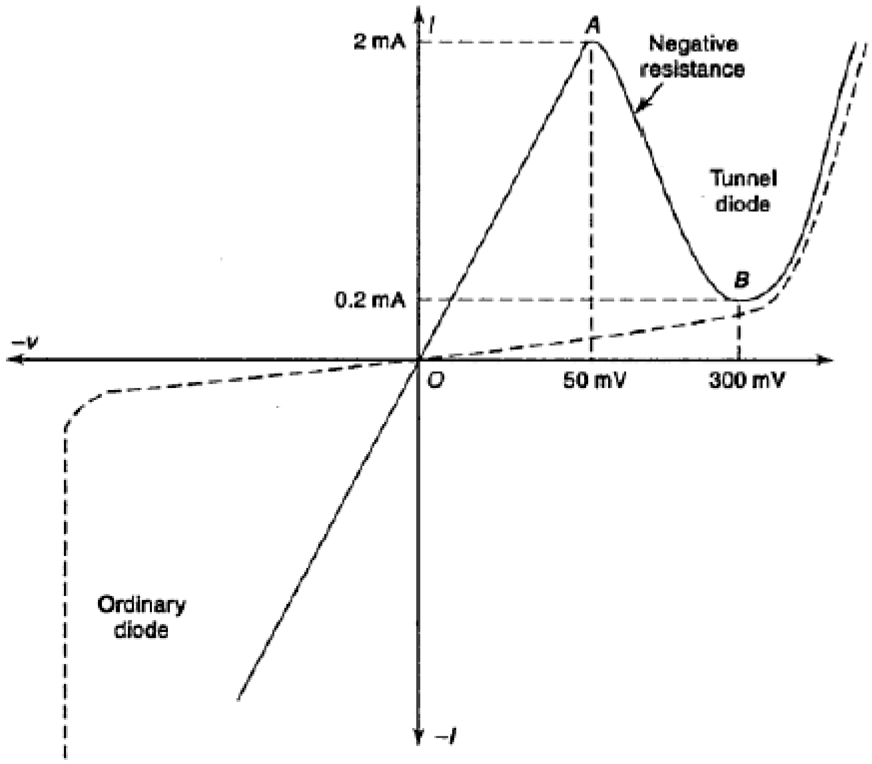


Tunnelling Effect

• Classically, carrier must have energy at least equal to potential-barrier height to cross the junction .

• But according to Quantum mechanics there is finite probability that it can penetrate through the barrier for a thin width.

• This phenomenon is called tunneling and hence the Esaki Diode is known as Tunnel Diode.



V–I characteristic of tunnel diode

ENERGY BAND DIAGRAM

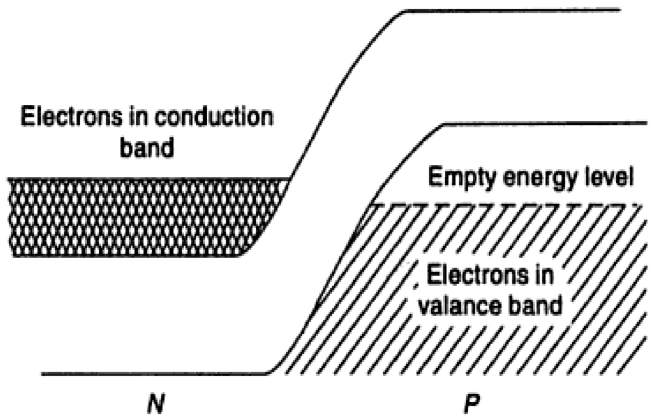
Energy-band diagram of pn junction in thermal equilibrium in which both the n and p region are degenerately doped.

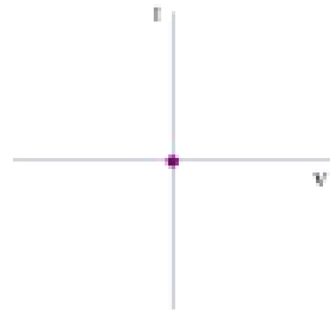
AT ZERO BIAS

Simplified energy-band diagram and I-V characteristics of the tunnel diode at zero bias.

- Zero current on the I-V diagram;

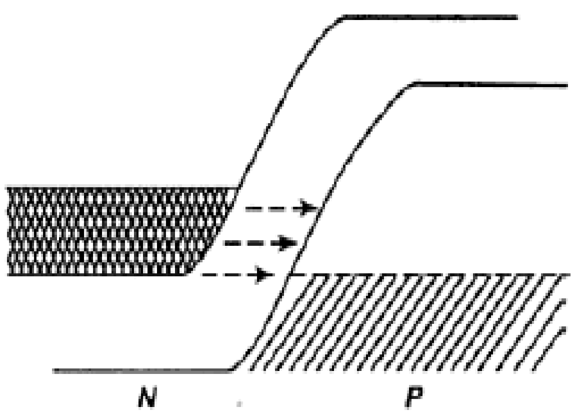
- All energy states are filled below EF on both sides of the junction;

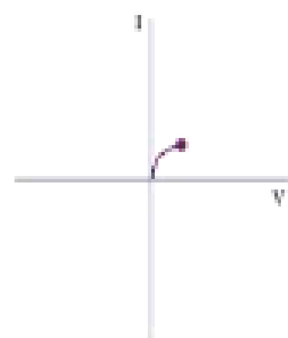




AT SMALL FORWARD VOLTAGE

Simplified energy-band diagram and I-V characteristics of the tunnel diode at a slight forward bias





- Electrons in the conduction band of the n region are directly opposite to the empty states in the valence band of the p region.

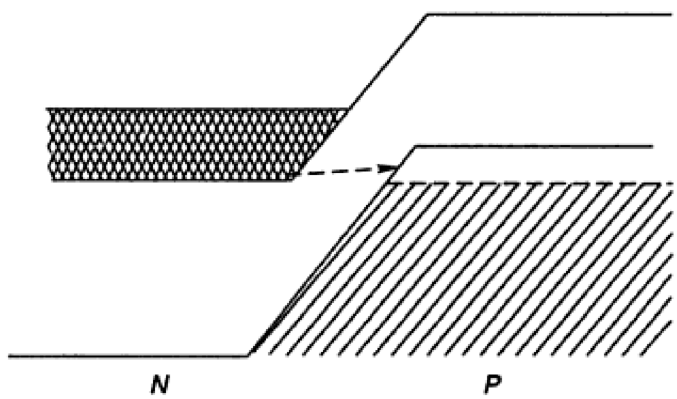
So a finite probability that some electrons tunnel directly into the empty states resulting in forward-bias tunneling current.

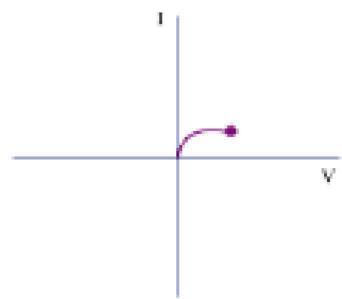
AT MAXIMUM TUNNELING CURENT

Simplified energy-band diagraam and I-V characteristics of the tunnel diode at a forward bias producing maximum tunneling current.

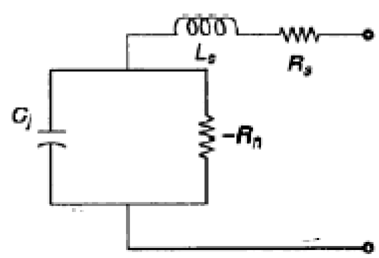
- The maximum number of electrons in the n region are opposite to the maximum number of empty states in the p region.

- Hence tunneling current is maximum.





TUNNEL DIODE EQUIVALENT CIRCUIT



Equivalent circuit of tunnel diode

• This is the equivalent circuit of tunnel diode when biased in negative resistance region.
• At higher frequencies the series R and L can be ignored.
• Hence equivalent circuit can be reduced to parallel combination of junction capacitance and negative resistance.

Applications

- As logic memory storage device
- As microwave oscillator
- In relaxation oscillator circuit
- As an amplifier
- As an ultra-high speed switch

Advantages

- Low noise
- Ease of operation
- High speed
- Low power

Disadvantages

- Voltage range over which it can be operated is 1 V less.
- Being a two terminal device there is no isolation between the input and output circuit.

Laser diode:

A laser diode, or LD, is an electrically pumped semiconductor laser in which the active medium is formed by a p-n junction of a semiconductor diode similar to that found in a light-emitting diode.The laser diode is the most common type of laser produced. Laser diodes have a very wide range of uses that include, but are not limited to, fiber optic communications, barcode readers, laser pointers, CD/DVD/Blu-ray reading, laser printing, scanning and increasingly directional lighting sources.

A laser diode is electrically a P-i-n diode. The active region of the laser diode is in the intrinsic (I) region, and the carriers, electrons and holes, are pumped into it from the N and P regions respectively. While initial diode laser research was conducted on simple P-N diodes, all modern lasers use the double-heterostructure implementation, where the carriers and the photons are confined in order to maximize their chances for recombination and light generation. Unlike a regular diode used in electronics, the goal for a laser diode is that all carriers recombine in the I region, and produce light. Thus, laser diodes are fabricated using direct bandgap semiconductors. The laser diode epitaxial structure is grown using one of the crystal growth techniques, usually starting from an N doped substrate, and growing the I doped active layer, followed by the P doped cladding, and a contact layer. The active layer most often consists of quantum wells, which provide lower threshold current and higher efficiency.

Laser diodes form a subset of the larger classification of semiconductor *p*-*n* junction diodes. Forward electrical bias across the laser diode causes the two species of charge carrier – holes and electrons – to be "injected" from opposite sides of the *p*-*n* junction into the depletion region. Holes are injected from the *p*-doped, and electrons from the *n*-doped, semiconductor. (A depletion region, devoid of any charge carriers, forms as a result of the difference in electrical potential between *n*- and *p*-type semiconductors wherever they are in physical contact.) Due to the use of charge injection in powering most diode lasers, this class of lasers is sometimes termed "injection lasers," or "injection laser diode" (ILD). As diode lasers are semiconductor devices, they may also be classified as semiconductor lasers. Either designation distinguishes diode lasers from solid-state lasers.

Another method of powering some diode lasers is the use of optical pumping. Optically pumped semiconductor lasers (OPSL) use a III-V semiconductor chip as the gain medium, and another laser (often another diode laser) as the pump source. OPSL offer several advantages over ILDs, particularly in wavelength selection and lack of interference from internal electrode structures.[2][3]

When an electron and a hole are present in the same region, they may recombine or "annihilate" with the result being spontaneous emission — i.e., the electron may re-occupy the energy state of the hole, emitting a photon with energy equal to the difference between the electron and hole states involved. (In a conventional semiconductor junction diode, the energy released from the recombination of electrons and holes is carried away as phonons, i.e., lattice vibrations, rather than as photons.) Spontaneous emission gives the laser diode below lasing threshold similar properties to an LED. Spontaneous emission is necessary to initiate laser oscillation, but it is one among several sources of inefficiency once the laser is oscillating.

The difference between the photon-emitting semiconductor laser and conventional phonon-emitting (non-light-emitting) semiconductor junction diodes lies in the use of a different type of semiconductor, one whose physical and atomic structure confers the possibility for photon emission. These photon-emitting semiconductors are the so-called "direct bandgap" semiconductors. The properties of silicon and germanium, which are single-element semiconductors, have bandgaps that do not align in the way needed to allow photon emission and are not considered "direct." Other materials, the so-called compound semiconductors, have virtually identical crystalline structures as silicon or germanium but use alternating arrangements of two different atomic species in a checkerboard-like pattern to break the symmetry. The transition between the materials in the alternating pattern creates the critical "direct bandgap" property. Gallium arsenide, indium phosphide, gallium antimonide, and gallium nitride are all examples of compound semiconductor materials that can be used to create junction diodes that emit light.

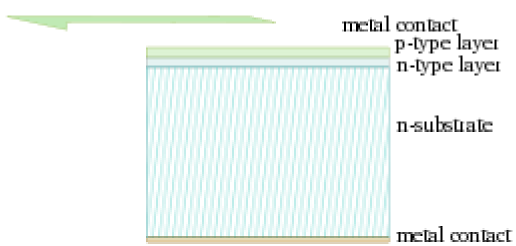


Diagram of a simple laser diode, such as shown above; not to scale

In the absence of stimulated emission (e.g., lasing) conditions, electrons and holes may coexist in proximity to one another, without recombining, for a certain time, termed the "upper-state lifetime" or "recombination time" (about a nanosecond for typical diode laser materials), before they recombine. Then a nearby photon with energy equal to the recombination energy can cause recombination by stimulated emission. This generates another photon of the same frequency, travelling in the same direction, with the same polarization and phase as the first photon. This means that stimulated emission causes gain in an optical wave (of the correct wavelength) in the injection region, and the gain increases as the number of electrons and holes injected across the junction increases. The spontaneous and stimulated emission processes are vastly more efficient in direct bandgap semiconductors than in indirect bandgap semiconductors; therefore silicon is not a common material for laser diodes.

As in other lasers, the gain region is surrounded with an optical cavity to form a laser. In the simplest form of laser diode, an optical waveguide is made on that crystal surface, such that the light is confined to a relatively narrow line. The two ends of the crystal are cleaved to form perfectly smooth, parallel edges, forming a Fabry–Pérot resonator. Photons emitted into a mode of the waveguide will travel along the waveguide and be reflected several times from each end face before they are emitted. As a light wave passes through the cavity, it is amplified by stimulated emission, but light is also lost due to absorption and by incomplete reflection from the end facets. Finally, if there is more amplification than loss, the diode begins to "lase".

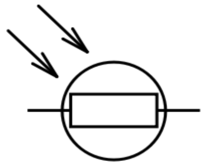
Some important properties of laser diodes are determined by the geometry of the optical cavity. Generally, in the vertical direction, the light is contained in a very thin layer, and the structure supports only a single optical mode in the direction perpendicular to the layers. In the transverse direction, if the waveguide is wide compared to the wavelength of light, then the waveguide can support multiple transverse optical modes, and the laser is known as "multi-mode". These transversely multi-mode lasers are adequate in cases where one needs a very large amount of power, but not a small diffraction-limited beam; for example in printing, activating chemicals, or pumping other types of lasers.

In applications where a small focused beam is needed, the waveguide must be made narrow, on the order of the optical wavelength. This way, only a single transverse mode is supported and one ends up with a diffraction-limited beam. Such single spatial mode devices are used for optical storage, laser pointers, and fiber optics. Note that these lasers may still support multiple longitudinal modes, and thus can lase at multiple wavelengths simultaneously.

The wavelength emitted is a function of the band-gap of the semiconductor and the modes of the optical cavity. In general, the maximum gain will occur for photons with energy slightly above the band-gap energy, and the modes nearest the gain peak will lase most strongly. If the diode is driven strongly enough, additional *side modes* may also lase. Some laser diodes, such as most visible lasers, operate at a single wavelength, but that wavelength is unstable and changes due to fluctuations in current or temperature.

Due to diffraction, the beam diverges (expands) rapidly after leaving the chip, typically at 30 degrees vertically by 10 degrees laterally. A lens must be used in order to form a collimated beam like that produced by a laser pointer. If a circular beam is required, cylindrical lenses and other optics are used. For single spatial mode lasers, using symmetrical lenses, the collimated beam ends up being elliptical in shape, due to the difference in the vertical and lateral divergences. This is easily observable with a red laser pointer.

LDR:



A photoresistor or light-dependent resistor (LDR) or photocell is a resistor whose resistance decreases with increasing incident light intensity; in other words, it exhibits photoconductivity.A photoresistor is made of a high resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance.A photoelectric device can be either intrinsic or extrinsic. An intrinsic semiconductor has its own charge carriers and is not an efficient semiconductor, for example, silicon. In intrinsic devices the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire bandgap. Extrinsic devices have impurities, also called dopants, added whose ground state energy is closer to the conduction band; since the electrons do not have as far to jump, lower energy photons (that is, longer wavelengths and lower frequencies) are sufficient to trigger the device. If a sample of silicon has some of its atoms replaced by phosphorus atoms (impurities), there will be extra electrons available for conduction.

This is an example of an extrinsic semiconductor. There are many types of photoresistors, with different specifications and models. Photoresistors can be coated with or packaged in different materials that vary the resistance, depending on the use for each LDR.

Applications

Photoresistors come in many types. Inexpensive cadmium sulphide cells can be found in many consumer items such as camera light meters, street lights, clock radios, alarm devices, night lights, outdoor clocks, solar street lamps and solar road studs, etc.They are also used in some dynamic compressors together with a small incandescent lamp or light-emitting diode to control gain reduction.

The use of CdS and CdSe photoresistors is severely restricted in Europe due to the RoHS ban on cadmium.Lead sulphide (PbS) and indium antimonide (InSb) LDRs (light- dependent resistor) are used for the mid-infrared spectral region. Ge:Cu photoconductors are among the best far-infrared detectors available, and are used for infrared astronomy and infrared spectroscopy.

Gallium Arsenide Device:

Gallium arsenide (GaAs) is a compound of the elements gallium and arsenic. It is a III/V semiconductor, and is used in the manufacture of devices such as microwave frequency integrated circuits, monolithic microwave integrated circuits, infrared light-emitting diodes, laser diodes, solar cells and optical windows.GaAs is often used as a substrate material for the epitaxial growth of other III-V semiconductors including: InGaAs and GaInNAs.

Some electronic properties of gallium arsenide are superior to those of silicon. It has a higher saturated electron velocity and higher electron mobility, allowing gallium arsenide transistors to function at frequencies in excess of 250 GHz. Unlike silicon junctions, GaAs devices are relatively insensitive to heat owing to their wider bandgap. Also, GaAs devices tend to have less noise than silicon devices, especially at high frequencies. This is a result of higher carrier mobilities and lower resistive device parasitics. These properties recommend GaAs circuitry in mobile phones, satellite communications, microwave point-to-point links and higher frequency radar systems. It is used in the manufacture of Gunn diodes for generation of microwaves.

Another advantage of GaAs is that it has a direct band gap, which means that it can be used to emit light efficiently. Silicon has an indirect bandgap and so is very poor at emitting light. Nonetheless, recent advances may make silicon LEDs and lasers possible.

As a wide direct band gap material with resulting resistance to radiation damage, GaAs is an excellent material for space electronics and optical windows in high power applications.

Because of its wide bandgap, pure GaAs is highly resistive. Combined with the high dielectric constant, this property makes GaAs a very good electrical substrate and unlike Si provides natural isolation between devices and circuits. This has made it an ideal material for microwave and millimeter wave integrated circuits, MMICs, where active and essential passive components can readily be produced on a single slice of GaAs.