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VCE Physics Unit 3

Area Of Study 2, Electronics And Photonics, Study Notes 3

Photonics is the area of physics dealing with the combination of light and electronics. It's founded on the concept of the "photo-electric effect", which most basically shows that some materials release electrons when struck by particles of light ("photons"). Photonic devices usually have the purpose of enabling **communication** (transmitting and receiving data). Data can be **analogue** (continuously varying, like a wave) or **digital** (a set of discrete numbers). Digital data is more usual, because current technology allows discrete numbers to be processed at speeds allowing accurate enough representation of analogue data. The conversion of analogue data into digital allows much simpler circuitry, because every number can be represented as a series of "ons" and "offs" ("1"s and "0"s; "**binary** code"), rather than as continuously varying voltage and current (which leads to many complications).

Light Dependant Resistors (LDRs); Further Detail

Alternative to photodiodes and phototransistors (explained below). Non Ohmic resistors. Level of resistance depends on intensity of light. Light intensity measured in **Lux**. Log-log intensity/resistance graph makes log-log relationship appear linear, so be careful when interpreting these graphs. Made from a single type of semiconductor material. Generally:

- Low light intensity (dark) → High resistance
- High light intensity (bright) → Low resistance

Most commonly used as either R_1 or R_2 in series with a fixed resistor as part of a voltage dividing circuit. Output characteristics are reversed when LDR is R_2 instead of R_1.

If used as R_1:

- V_{OUT} (across R_2) is relatively **high** (closer to $V_{OUT} = V_{SUPPLY}$) when $R_{LDR} < R_2$ (probably high light intensity).
- V_{OUT} (across R_2) is relatively **low** (closer to $V_{OUT} = 0V$) when $R_{LDR} > R_2$ (probably low light intensity).

If used as R_2:

- V_{OUT} (across LDR) is relatively **low** (closer to $V_{OUT} = 0V$) when $R_{LDR} < R_1$ (probably high light intensity).
- V_{OUT} (across LDR) is relatively **high** (closer to $V_{OUT} = V_{SUPPLY}$) when $R_{LDR} > R_1$ (probably low light intensity).

- **Relatively large** (in comparison to a photodiode or phototransistor).
- **Slower response** than either photodiode or phototransistor. Too slow for use for communication of digital data.
- A more gradual change in resistance than either a photodiode or phototransistor.
- Useful for varying voltage and current, but not so much for only switching it on and off.

Photodiodes

Alternative to LDR and phototransistor (explained below). Made from a p-n junction (p-type and n-type semiconductor materials joined).

"Photovoltaic": big word for "solar cell". Light causes voltage between n-type to p-type materials, creating current when forward biased in a circuit.

"Photoconductive": reverse biased to power supply in circuit. Light above a specific intensity decreases resistance, allowing increase in leakage current. Operates as light activated switch in this way.

- No light → no (hardly any) current (due to reverse biasing).
- Light → "breakdown voltage" → very little resistance = current.

- Can be very small.
- **Lower current** than phototransistor (one photon → one electron).
- **Less sensitive** than phototransistor.
- **Faster response** than phototransistor or LDR.

Phototransistors

Alternative to LDR and photodiode. Made from two p-n junctions (p-type and n-type semiconductor materials joined). Like a regular BJT, can be npn or pnp. B (base) is usually not connected, as it's the photosensitive part.

"Photoconductive": power supply connected across C and E in circuit. Light above a specific intensity activates B, allowing current to flow from C to E. Operates as light activated switch in this way.

- No light → no (hardly any) current (due to reverse biasing of C to B and no current at B).
- Light → current at B → current from C to E.

- **Higher current** than photodiode (it's a transistor, which "amplifies" current; small current form B to E → large current from C to E; one photon → many electrons).
- **More sensitive** than photodiode.
- **Slower response** than photodiode.

An small integrated circuit (IC) containing a photodiode activating the base of a transistor amplifier is often used in modern circuitry to accommodate "the best of both worlds" between the pros and cons of photodiodes and phototransistors.

Light Emitting Diodes (LEDs); Further Detail

Operates in the reverse way to a photodiode. Current across the forward biased p-n junction causes the emission of photons, rather than the absorption of photons causing current. Wavelength of light is determined by the semiconductor materials used in construction.

LASER Diodes (LDs)

Alternative to LEDs. Can be switched on and off more rapidly. Intensity does not decrease with distance, because light does not disperse. Due to "coherent" generation of light (waves of light all oscillate on same axis). Better for applications involving multiple sources, and distant and unenclosed (not isolated from other light sources) transmission receivers.

Optical Isolators ("Opto-Isolators" or "Opto-Couplers")

So called because it can be seen either as a method of isolating two associated circuits from each other, or as a method of coupling two circuits together, but without the need for a physical connection.

An LED or LD is used as the digital output of one circuit. A photodiode or phototransistor is used as the input to another circuit. Digital data is passed from one circuit to the other without the need for an electrical connection.

Optical Switches

Very similar in construction and operation to an optical isolator. Most commonly used for reading digital information from a CD or DVD.

At regular intervals of time, light (usually infra-red) from a laser diode is either reflected or not reflected from the surface of the CD or DVD. If reflected during an interval of time, it's received by a photodiode or phototransistor and registered as "on" (or a "1"). If not reflected, it's not received by anything (as there's nothing to be received) and registered as "off" (or a "0").

The binary code (the stream of 1s and 0s [ons and offs]) is interpreted by a processor and decoded into something that makes sense to a human user at the output (an analogue signal, probably images on a screen or sounds from loudspeakers).

Optical Fibres

Optical fibres, or “fibre-optics”, are solid tubes of transparent material (usually a type of glass) that carry light from one place (possibly a LASER diode somewhere) to another (possibly a photodiode somewhere else, possibly a long way away).

Advantages Over Wire Cables

Optical fibres have major advantages over the transmission of data electronically along wire cables. Data transmitted as light in optical fibres encounters very little signal degradation. Data transmitted as current through wire cables encounters resistance that increases with the length of the cable, and generates a detectable magnetic field. Data transmitted as AC (alternating current) encounters resistance increasing with the diameter of the wire cable. It tends to move only on the surface of the wire. This is known as “**surface effect**” or “**skin effect**”, and can only be reduced by using more and thinner wires, all of which have a tendency to corrode over time. This dramatically increases the cost.

Refraction, Critical Angle and Total Internal Reflection

Refraction is when light changes the direction of its path as it moves from one medium to another. The “**Refractive Index**” of a medium tells the extent to which light deviates from its original path as it moves from a vacuum into the medium. When light moves into a medium of **lower** refractive index it refracts **away** from the “**normal**”. The “normal” is an imaginary line perpendicular to the barrier between the two media. The “angle of incidence” is **less than** the “angle of refraction”. **The angles are measured from the normal**.

When light moving into a medium of lower refractive index has an angle of incidence such that the angle of refraction is **90°**, the light’s path is along the barrier between the two media. The angle of incidence at which this occurs is called the **critical angle**. When the angle of incidence is **greater than** the critical angle, light doesn’t refract out of the medium, but instead **reflects** back into the medium. This is called **T**otal **I**nternal **R**eflection, or **TIR**. Reflection occurs such that the **angle of incidence equals the angle of reflection**.

Optical fibre has a greater refractive index than the medium surrounding it (usually either air or water), so **if** light exits it will refract away from the normal. The diameter of an optical fibre is such that light can’t enter without striking the first internal surface at greater than the critical angle. It therefore reflects back into the fibre, continuously striking the internal barriers at greater than the critical angle, and hence continuously internally reflecting along the fibre. This is how optical fibres work to transmit light from one place to another.

Coherent And Incoherent Bundles

Optical fibres are usually bundled together, so that many signals can be transmitted simultaneously. Coherent optical fibre bundles have the same relative position of the fibres at each end, allowing images to be reflected along the bundle. This kind of optical fibre is used for the insertion of tiny camera lenses during “keyhole” surgery. Non-coherent optical fibre bundles have no relationship between the position of the fibres at each end and are therefore only useful for data transmission.

Cladding

Especially when bundled, light “leaks” out from optical fibres where some of it refracts outwards (into adjoining fibres) as well as reflecting inwards. This results in the intensity of light decreasing with distance, and is reduced by “**cladding**” each fibre with materials of decreasing refractive index.

Dispersion In Optical Fibres

Dispersion means “scattering” or “spreading-out”. This can happen with pulses of light as they travel through optical fibres. Over long distances, this causes the output light to be different from the input, in that the output pulses are closer together, further apart, or in the wrong order. This can lead to jumbled data at the receiving end. There are two types of dispersion:

Material Dispersion.

The refractive index of transparent materials such as optical fibres is actually slightly different for different wavelengths (colours) of light, as demonstrated by white light being “split” into its component colours as it passes through a prism. This causes variation in the arrival time of pulses at the output if the input light consists of multiple wavelengths.

Material Dispersion can be overcome by the use of single coloured LASERs (emitting light with only one, single and constant wavelength) at the input.

Modal Dispersion

There are multiple paths that pulses of light can take as they travel (zig-zagging) through an optical fibre. Joins and bends in the fibres increase the possible number of path lengths. Pulses of light taking a longer path length arrive later at the output than pulses taking a shorter path length.

Modal dispersion can be overcome by the use of very thin “single mode” fibres (limiting the difference between path lengths). The deficiency of these is that the intensity of the light is lost quicker, so amplification is required about every 100km. “Multi-mode” fibres are thicker, less consistently manufactured, and used for shorter distances.