AQA A-Level Physics

13.1 Discrete semiconductor devices

Flashcards

What is a semiconductor?

What is a semiconductor?

A device that only allows limited movement of charge carriers, they have a medium sized gap between the valence band and conduction band so the electrons need some energy to cross it.

How does a hole form in a semiconductor?

How does a hole form in a semiconductor?

The structure of a semiconductor is a crystalline lattice, when an electron is displaced by energy it leaves an atom with a missing electron called a hole. Holes can be passed between atoms in a semiconductor material. Holes are always in the valence band and act as particles with positive charge.

How can the electrical properties of semiconductors be controlled?

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Doping. Impurities are introduced to the semiconductor material to modify electrical conductivity. Intrinsic semiconductors are undoped, **extrinsic** are doped by adding charge carriers in a precise way e.g. to make diodes. Extrinsic semiconductors can be n-type or p-type.

What is an n-type semiconductor?

What is an n-type semiconductor?

An extrinsic semiconductor where the dopant atoms donate extra electrons to the material to increase conductivity, electrons are the majority charge carriers.

What is a p-type semiconductor?

What is a p-type semiconductor?

An extrinsic semiconductor that has been doped with acceptor atoms that create an excess of holes as the majority charge carriers.

What is a p-n junction?

What is a p-n junction?

Where an n-type and p-type semiconductor join, current only flows in 1 direction as electrons leave the n-type and go into holes in the p-type forming a depletion region with few charge carriers that acts as an insulator.

When does the depletion zone in a diode disappear?

When does the depletion zone in a diode disappear?

When the p.d across the diode is high enough, valence electrons in the depletion zone move freely across. This happens when the p-type side is connected to the positive potential and the n-type side to the negative, like this the diode is forward-biased.

What is meant by a reverse-bias diode?

What is meant by a reverse-bias diode?

When the p-type side (anode) is connected to the negative potential, and the n-type side (cathode) to the positive potential. Diffusion of electrons and holes at the junction increases the depletion region so current will not flow.

What happens when the reverse-bias voltage is at the breakdown voltage?

What happens when the reverse bias voltage is at the breakdown voltage?

The depletion region breaks down and a high reverse avalanche current flows. The diode is permanently damaged.

What is a transistor?

What is a transistor?

A 3 terminal semiconductor that can regulate current and voltage as well as acting as a switch.

What is the difference between a discrete component and an integrated circuit?

What is the difference between a discrete component and an integrated circuit?

A discrete component consists of 1 semiconductor device (e.g. 1 diode), whereas an integrated circuit consists of many individual devices which are interconnected on a single silicon chip.

What is the difference between a passive and an active device?

What is the difference between a passive and an active device?

Passive devices consume but do not produce energy and cannot control current flow in the circuit (e.g. resistors).

Active devices can electrically control current (e.g. transistors).

What does MOSFET stand for?

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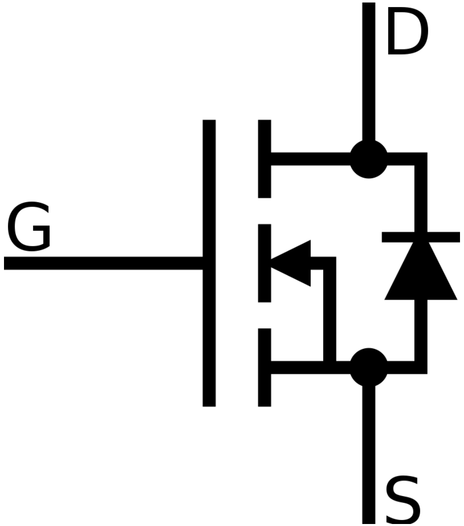
Metal Oxide Semiconductor Field Effect Transistor



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How does the MOSFET work?

How does the MOSFET work?

It varies the width of a conducting channel, along which (in n-channel MOSFETs) electrons flow from the source to the drain (so conventional current is from drain to source). The 3 terminals are the gate, the drain and the source.

Describe the simplified structure of the MOSFET

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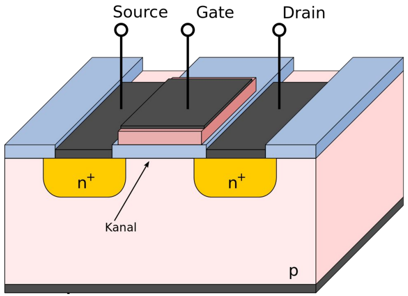
An underlying layer (substrate) of p-type material has 2 n-type regions diffused into one surface. A thin, insulating layer of metal oxide forms on the outside of the surface and aluminium electrodes form the gate, source and drain.



When the MOSFET is in operation, what is the effect of a positive voltage on gate G?

When the MOSFET is in operation, what is the effect of a positive voltage on gate G?

Holes in the p-type substrate are repelled into the substrate from the metal oxide layer creating an n-type conduction channel between the source and drain. Increasing this voltage means there’s more electrons in this channel.

What is meant by the MOSFET operating in enhancement mode?

What is meant by the MOSFET operating in enhancement mode?

Applying a voltage between the drain and source whilst there is a conduction channel allows current to flow through the MOSFET. Increasing the voltage increases the channel size and current – this is enhancement mode.

Define V_{DS}, V_{GS}, V_{th}, I_{DS} and I_{DSS}

Define V_{DS}, V_{GS}, V_{th}, I_{DS} and I_{DSS}

V_{DS}: voltage between drain and source

V_{GS}: voltage between gate and source

V_{th}: the minimum V_{GS} value needed to form a conducting channel between the drain and source

I_{DS}: current between drain and source

I_{DSS}: leakage current between drain and source when V_{GS}= 0V

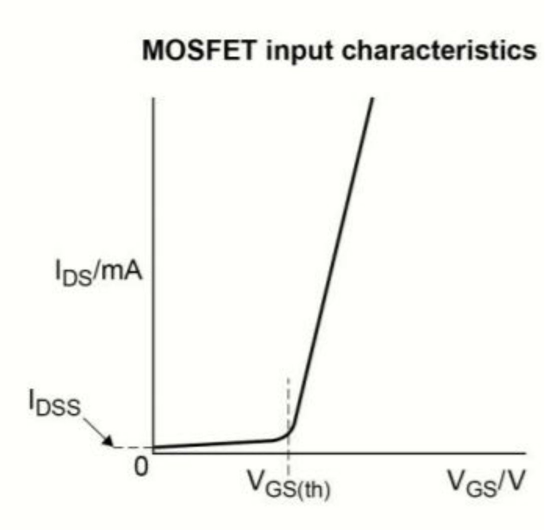
When will the MOSFET turn on?

When will the MOSFET turn on?

When the voltage V_{GS} between the MOSFET gate and the source exceeds a threshold value ($V_{GS(th)}$). This is the gate voltage at which the n-type channel is just closed so the device is just off.

Draw a characteristic curve for a MOSFET input

Draw a characteristic curve for a MOSFET input



I_{DSS} is the drain current that flows when the device is fully off as the gate voltage is 0. It changes with temperature. The input resistance is very high, > $10^{12}\Omega$

Image: AQA

Define saturation region

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The constant current region on a graph of I_{DS} against V_{DS}, where there is almost 0 increase in current when V_{DS} is increased.

Summarise the 3 operation regions for an enhancement mode MOSFET

Summarise the 3 operation regions for an enhancement mode MOSFET

1. Cut-off region: MOSFET switched off
2. Ohm's law region: MOSFET acts as variable resistor
3. Saturation region: MOSFET in constant current region and maximum I_{DS} flows

Define transconductance, g_m

Define transconductance, g_m

$$g_m = \text{change in } I_{DS} \,/\, \text{change in } V_{GS}$$

What risk is there if the gate on a MOSFET is left unconnected?

What risk is there if the gate on a MOSFET is left unconnected?

Static charges can accumulate on the oxide layer between the gate and source, which acts as a capacitor. The gate must be connected so the charge can flow off to the ground.

What is a zener diode?

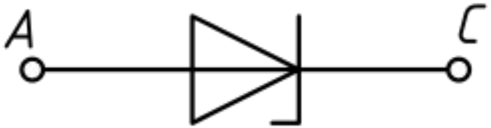

Image: Wikimedia

What is a zener diode?

A semiconductor p-n junction that allows current to flow in the forward direction, and also the reverse direction when the reverse-bias voltage is above a certain value (V_z). They can be operated continuously in breakdown mode.

What is the effect on the current when the zener diode operates above the zener breakdown voltage, V_z?

What is the effect on the current when the zener diode operates above the zener breakdown voltage V_z?

The diode has a controlled internal breakdown so an avalanche current flows. V_z remains constant regardless of the current through it. The diode needs a minimum operating current to work in breakdown mode, and it has a maximum avalanche current, above which it will be damaged by overheating.

Draw the characteristic curve for zener breakdown voltage and state its minimum operating current

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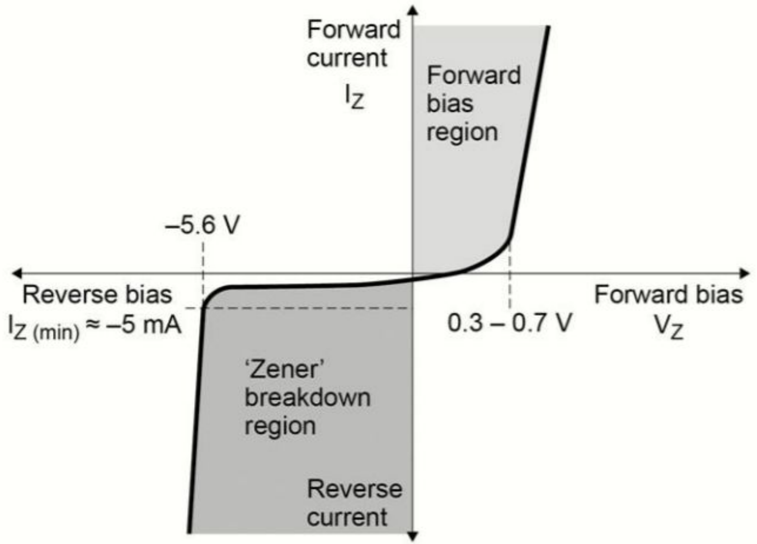

Image: AQA

The minimum zener current is about 5mA. Above this, the reverse breakdown voltage becomes almost independent of the reverse current.

Why are the properties of zener diodes useful?

Why are the properties of zener diodes useful?

Zener diodes maintain a constant voltage when in the breakdown region so they can be used as constant voltage sources, reference voltages and to smooth fluctuating voltages when the zener diode is connected in the reverse-bias.

Why must a zener diode be connected in series with a resistor?

Why must a zener diode be connected in series with a resistor?

To keep the current through the diode between the minimum operating current and the maximum avalanche current.

What is a photodiode?

What is a photodiode?

A p-n junction diode that converts incident light energy to electrical energy (a current).

When is a photodiode able to produce a photocurrent?

When is a photodiode able to produce a photocurrent?

To be in photoconductive mode, it must be reverse-biased. When light photons are incident on the depletion region, electron-hole pairs form. The holes move to the anode and the electrons move to the cathode, so a reverse photocurrent flows. The size of the photocurrent is proportional to the light intensity.

What is meant by the spectral response of a photodiode?

What is meant by the spectral response of a photodiode?

Photodiodes respond differently to different wavelengths of light

Photosensitivity = photocurrent generated / power incident

Units = AW^{-1}

How can a photodiode be used in a smoke alarm?

How can a photodiode be used in a smoke alarm?

A pulsing LED is the only light source in a chamber. When smoke enters the chamber, the light is scattered, some of which goes to the photodiode. A photocurrent is generated and then amplified to sound the alarm.

What is a scintillator?

What is a scintillator?

A device that flashes when an ionising particle or high energy photon passes through it.

The intensity of this flash can be worked out from the magnitude of the current made by a photodiode near it.

How can the efficiency of a scintillator be calculated?

How can the efficiency of a scintillator be calculated?

$$E = \frac{\text{total energy of light photons produced in scintillator}}{\text{Energy deposited by photons or particles in scintillator}}$$

What is the hall effect?

What is the hall effect?

The production of a voltage (Hall voltage) perpendicular to a current carrying semiconductor/conductor in a magnetic field. The size of the voltage is proportional to the flux density (B) of the field.

What is a hall sensor?

What is a hall sensor?

A sensor with 3 terminals that uses the hall effect to vary its output voltage in response to a varying magnetic field. The direction and flux density of the field can be found.

Draw the hall sensor characteristic curve of Hall voltage against magnetic flux density

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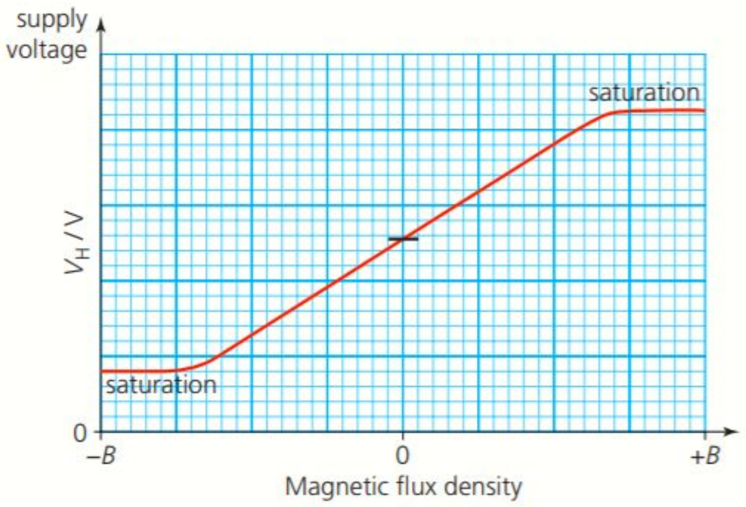

Figure 28 *Hall sensor characteristic curve*

Image: Collins

How can a Hall sensor be used to determine the angle of an object to the magnetic field (attitude)?

How can a hall sensor be used to determine the angle of an object to the magnetic field (attitude)?

The component of B perpendicular to the Hall sensor changes.

What are tachometers and how can Hall sensors be used in them?

What are tachometers and how can Hall sensors be used in them?

Tachometers measure rotational speed. The Hall sensor can produce an output each time it passes a fixed magnet or each time the magnetic field changes.