

Research Skills: Task 2

The sun emits electromagnetic spectrum energy from infrared to ultraviolet light. Photons, the basic particle of electromagnetic force, are spin particles, so electromagnetic force is intrinsically handed in three dimensions, therefore altering the path of particles at any angle not parallel with it.

Therefore transverse waves can transmit across the vacuum between the sun and earth, conserving its frequency.

This energy is absorbed by an electrically charged particle which emits an electron, producing a potential difference. Semiconductors absorb the energy increasing with either bound (excitons) or separate hole-electron pairs.

Semiconductors are characterised by change in resistance under temperature, because unlike conductors, not only moving electrons but also moving valence shell spaces carry charge, so moving charge is not only negative but also positive. This arises when electrons escape bonds through energy absorption. Therefore below a threshold temperature, they are insulators, with charge that can be carried increasing with energy absorbed.

Because semiconductors have widely varying characteristics which can be engineered further, only silicon will be discussed.

(90% of solar cells use silicon doped with boron and phosphorus.)

Silicon and germanium atoms' outer shells can hold eight electrons but contain only four, so these four form covalent bonds, occupying the outer shells of two atoms each. This arranges them into a square grid, each atom having an electron 'on four sides'. [PIC]

When heat is absorbed, some electrons gain enough energy to break these bonds, leaving a positively-charged bound ion. This positive charge in the electron shell can attract free or neighbouring electrons, in turn leaving behind an empty valence shell space. These effectively mobile positive charges are called 'holes'.

Photovoltaic cells use semiconductor wafers or thin-films, usually silicon, N(negative)-type doped with phosphorus on front side and P(positive)-type doped with boron on the back. Excited by the sun's radiation, the positive side emits electrons creating a potential difference. Free electrons escape into the conduction band, [enabled by a diode tunnel between positive and negative poles],

free holes form in the valence band. Electrodes collect the positive and negative charge.

350~450um silicon wafer rods are cut to size, exposed to phosphorus vapour to form a 0.3~0.5um coating. Conducting material functioning as electrodes is applied as a liquid bottom and top. Glass on top with antireflective coating, frame beneath. Busbar welds connect cells into modules. Cells connected in series increase voltage whereas in parallel current is increased. Therefore the desired voltage and current dictates the arrangement of cells per module.

Solar inverters convert this for use.

String inverters convert modules in series, so maximum output is limited to the lowest module output but are cheap.

Modern converters are computers which track and transfer electricity output, use and storage.

Hybrid inverters connect and co-ordinate solar panels, supplying home and grid, feeding AC or DC battery storage. Grid-tie inverters can convert output to match grid phase, voltage & frequency AC for export to the grid and juggle local and grid energy.

Solar power stations usually use solar trackers guiding multi-axial photovoltaic-arrays. Solar inverters output AC to step-up transformers exporting to the grid.

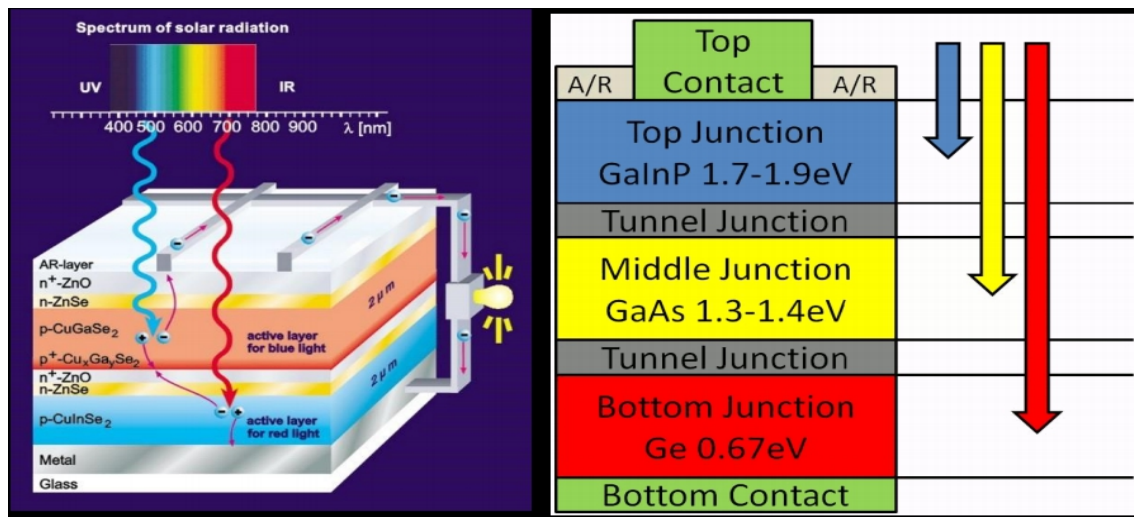
Problems are: efficiency, cost, toxicity, reliability.

Efficiency is

$\text{capacity factor} = \frac{\text{actual production}}{\text{maximum production}}$

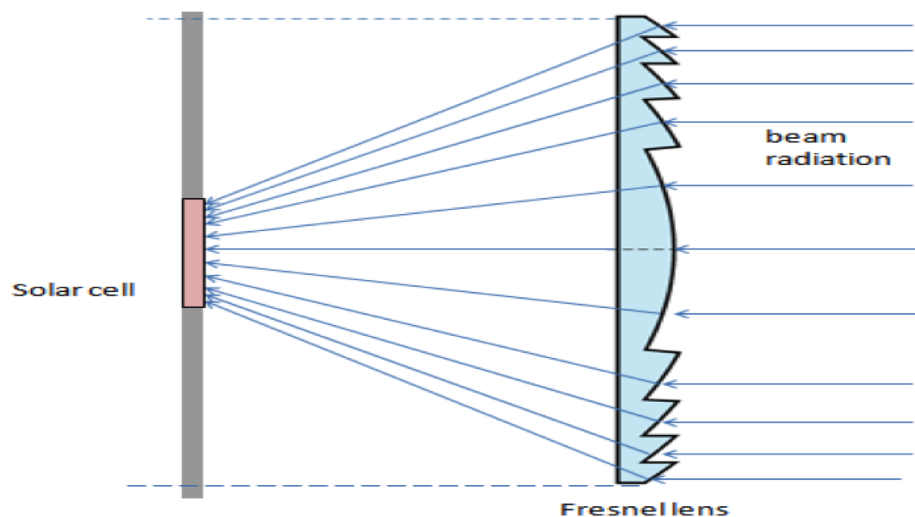
maximised by increasing light absorbed and utilised. Glass has very low reflectance and is treated with antireflective coating so maximum photons penetrate. Because silicon has quite high reflectance, the surface is pyramidized (mattified) reducing reflectance from 35% to 11%.

Simple cells only generate electricity above the band gap. To increase efficiency, “multijunction” cells are made of layers of semiconductors excited at decreasing frequencies, each layer absorbing higher energy photons but transmitting lower energy ones to lower layers, with a “tunnel diode” enabling electron transmission.



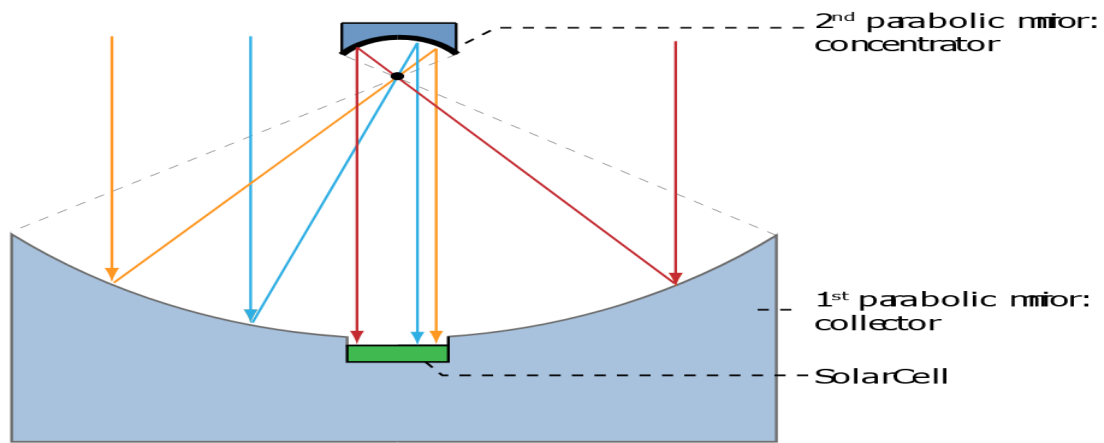
NASA Multijunction cells (2022)

Concentrating photovoltaics (CVP) focuses more light on cells to increase efficiency. They require direct beam radiation not diffuse light² and can overheat the cell and damage it. It is measured by its factor increase eg 2x.



Fedkin, M. *Fresnell lens* (2018)

Methods include mirror reflector funnel embrasures, Fresnell lenses which are lightweight with short focal length and large aperture fitted to each cell or an a frame matching the array, parabolic mirrors fitted in pairs



Baumgaertner, J. *Parabolic Mirrors* (2016)

and luminescent film concentrators. Transparent internally reflective layers absorb light-waves, trap and concentrate them onto contained photovoltaic cells, increasing efficiency up to threefold.

Passive cooling (thermoceramics) or active (liquid metal) can prevent overheating damage, increasing efficiency by allowing PV use under higher solar energy that would otherwise damage materials.

Sun tracking increases efficiency and prolongs generating period, increasing reliability, but increases maintenance, wastes space to allow manoeuvrability without shadows being cast when PVCs move, consumes power and increases maintenance costs.

Solutions to cost increase pollution and vice versa.

Semiconductor film applied to glass or plastic is cheaper but less efficient with short lifespan.

Organic photovoltaics addresses toxicity problems. Carbon-based chemical structures have low relative permittivity, so doping or charge carriers donated by electrodes are needed to make them semiconducting. Instead of a bandgap between layers in crystalline semiconductors, the energy difference between the highest (HOMO) and lowest (LUMO) molecular orbitals absorbs and emits solar energy. Changing the electron orbitals in carbon molecules ('conjugation') makes the band gap small enough for visible light to excite electrons from HOMO to LUMO. But the energy difference between the valence and conduction bands is 2.5-5eV instead of 1-2eV in crystal semiconductors.

Holes bind with electrons forming excitons, releasing them requires overcoming this exciton-

binding energy (E_b). Room-temperature thermal energy c.26meV is sufficient to overcome crystalline exciton bonds/release a hole-electron pair, but not 2.5-5eV bonds. Therefore two or more OSCs whose energy difference is higher than the E_b are sandwiched so that one donates and one accepts an electron.

The Seebeck effect increases temperature or electrical differences across materials causing a gradient in electron distributions which can also create current, increasing efficiency.

This energy $E = h \times \nu(\text{frequency})$ and $p = h / \lambda(\text{wavelength})$

Inconstant generation requires maximally polluting “standby” usage of polluting power generation. Solutions include smart grids, large battery storage, independent power generation, and thermal storage.

Concentrated solar power (CSP) heats water to drive conventional steam turbines. Combined thermal storage (usually as molten salts) energy can be released when needed.

Solar water heating systems either heat water directly or heat antifreeze which heats water heat exchanger heats water (this prevents freezing in colder climates).

Direct solar heating combined with internal ventilation, such as in Trombe walls, address cost and efficiency, within individual buildings.

Illustrations

Fedkin, M. (2018) Fresnel Lens

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