Conversion of Photon Energy to Other Forms

Overview

Photons are particles of quantized energy and, because they interact with electrons, this energy can be converted into other forms through a number of different processes.

Photovoltaics or solar cells convert photon energy into electrostatic potential energy, or convert power supplied by a flow of photons into electrical power.

Photosynthesis is the process by which the energy of a photon is converted into chemical energy.

Photochemisty is used to convert molecules from a low energy form to a high energy form, which can subsequently be used as a fuel.

Photoelectrochemistry can be used to convert photon energy to chemical energy (H_2) in an electrochemical cell.

Thermophotoelectric effect allows the conversion of electromagnetic radiation from a hot source to electric power.

Basic concepts

Conceptual conversion of the energy of a photon using atoms and molecules

After excitation to a bound state, the energy of the H atom is untappable.

Photoionization separates the positive and negative charges, but they cannot be directed to wires.

Individual molecules suffer from the same problems.

Two different molecules can act as a charge donor-acceptor pair after photoexcitation. One can imagine bonding this different molecules to different wire which are closely spaced. There are practical problems with this.

Photosynthesis uses this charge separation concept and follows it with a conversion to chemical energy. Bacterial photosynthesis differs from algal and plant photosynthesis.

Artificial photosynthetic schemes can be imagined.

Crystals and photons

Vast number of atoms leads to the energy band structure of a crystal. The valence band contains electrons involved in bonds holding the crystal together, and the conduction band contains fewer electrons which are free to roam throughout the crystal.

There is a band gap, which is a range of energy for which no states of the crystal exist. No electron can have an energy in this range.

A photon with an energy greater than the band gap can excite or promote an electron to the conduction band, thereby creating a hole in the valence band.

Excited electrons quickly lose energy to "drop", in the energetic sense, to the bottom of the conduction band. This energy is lost as heat to the crystal.

Both the conduction band electron and the valence band hole are free to move through the crystal.

In a short time, holes and electrons with recombine, the energy being lost as heat to the crystal.

Excited electrons can be created anywhere within the crystal, as the photon flux decreases statistically with penetration depth into the crystal.

Connecting wires to a crystal does not lead to extraction of the energy because there are no preferred directions for the movements of electrons and holes.

A directionality must be built into a crystal.

Semiconductors and PN junctions

Semiconductors are crystals which have a gap in the range of 1 to 3 eV and which can be doped to provide some conductivity.

Doping with an n-type dopant such as phosphorus leads to an extra electron in the crystal which must occupy the conduction band. Doping with a p-type dopant such as boron leads to a hole in the valence band.

At the interface between p and n type regions (the pn junction region), some electrons will cross from the n region into the p region. The result is a very thin region ($< 1\mu m$) which has an electric field built in.

When a photon is absorbed in this depletion region, the electron is rapidly driven into the n material and the hole is driven into the p material by the electric field.

Attachment of wires to the n and p sides now results in a flow of electrons trying to recombine with the holes.

Photovoltaic cells

Absorption of an above band gap photon yields a separated electron-hole pair with an electrostatic potential energy approximately equal to the band gap energy, such as 2 eV.

The available potential difference is just this energy divided by e, such as 2 V.

If the absorbed photon has an energy greater than the band gap, the potential difference is still the same.

The current is given by the number of electrons multiplied by the charge of the electron in coulombs, so the current is proportional to the number of photons absorbed per second.

The power is current times potential difference, so the power is proportional to the band gap energy and the number of photons per second.

To efficiently use the solar spectrum, cells with different band gaps must be stacked so that the highest energy photons are absorbed in the top cell, slightly lower energy photons are absorbed in the next cell, and so forth.