The term "bulk heterojunction" is used to describe a heterojunction composed of two different materials acting as electron- and a hole- transporters, respectively, which are mixed together in a bulk and thus containing several discrete interfaces.
Dye-sensitized nanocrystalline solar cells (DSSC)

The mesoporous TiO$_2$ photoanode in DSSCs is made of typically 10-15 nm-radius nanocrystalline particles, whose dimensions are smaller than the typical Debye length characterizing this material. As a consequence, no space charge layer is formed inside the particles and no electric field is formed at the oxide/adsorbed dye layer interface that could help separating photogenerated charges. The prevention of the carriers recombination (back electron transfer) must then rely on the kinetic competition between the various forward and back electron transfer processes (see next page).

SC = TiO$_2$
S = redox dye-sensitizer
D = redox mediator
Kinetic competition between ET processes in DSSC

Photoexcitation:
\[ \text{hv} \]
\[ \text{S I SC} \leftrightarrow \text{S*ISC SC} \]

Charge injection:
\[ \text{S*ISC} \rightarrow \text{e}^- (\text{SC}) + \text{S^+ISC} \]
35 fs - 15 ps

Dye regeneration:
\[ \text{S^+ISC} + D \rightarrow \text{SISC} + D^+ \]
0.1 - 30 \( \mu \)s

Charge recombination:
\[ \text{S^+ISC} + e^- \rightarrow \text{S I SC} \]
0.2 - 0.8 ms

Dark current:
\[ D^+ + e^- \rightarrow D \]
10 ms
Dye-sensitized nanocrystalline solar cells (DSSC)

DSSC Basics:
- Cell efficiency = 10-12%
- Module efficiency = 6-9%
- 0.3 year payback period
  \[
  \frac{32 \text{ kWh/m}^2}{(1700 \text{ kWh/m}^2 \cdot \text{yr}) \times 0.06}
  \]

Advantages of DSSC:
- Much less sensitive to angle of incidence (good in diffuse light)
- Can be designed for operation at very low light levels
- Efficiency is optimal at low light intensity of scattered light
- Wide range of optimal temperatures
- Much less sensitive to partial shading
- Manufacturing is cheap and easy, needs only commonly available processing equipment
- Significantly lower embodied energy than other solar cells
**DSSC vs Si cells under low light intensity**

Electron-hole recombination in Si and GaAs homojunction cells takes place essentially upon prior trapping of carriers. If the density of photogenerated carriers is low compared to the trap density (under low light intensity), recombination is very effective and the conversion efficiency thus tends to 0. Under high light intensities, trap states are filled up by the first carriers and recombination is minimized. As a result, conversion yields for such systems are generally higher under strong light irradiation.

Efficiency of DSSC under high light intensities is often limited by the conduction of the hole transporting material (ion transport in the electrolyte). Their conversion efficiency tends then to be maximum under moderate incident light intensity (1/10 Sun).
Solid-state double donor-acceptor heterojunction photovoltaic cells
Organic photovoltaics (OPV)

Donor-acceptor bilayer cells

C. W. Tang  

1) Exciton formation; 2) Exciton diffusion; 3) Charge separation; 4) Charge transport
Electron-donor material combines three functions:
1) light absorption, 2) exciton conduction, and 3) hole transport
Conjugated polymers are excellent candidates for use in low-cost electronics and photovoltaics. Polymer-based solar cells have reached power conversion efficiencies of 6% in recent reports. Deposition of organics by screen printing, doctor blading, inkjet printing, and spray deposition is possible because these materials can be made soluble. These techniques are required for the high-throughput roll-to-roll processing that will drive the cost of polymer-based PV down to a point where it can compete with current grid electricity. Additionally, these deposition techniques all take place at low temperature, which allows devices to be fabricated on plastic substrates for flexible devices.
Small molecule-based OPV

F. A. De Castro et al.
2009, 11, 8886-8894
Convergence of 1st, 2nd and 3rd generation photovoltaic technologies

p-n junction: Si, GaAs (1G)
Thin-film CIGS, CdTe (2G)

OPV: polymer, small molecule-based (3G)

DSSC: liquid electrolyte, solid HTM-based (3G)

Evolution of Silicon Solar Cell Design

Space silicon cell design developed in the early 1960s, which became a standard design for over a decade. Chemically textured non-reflecting "black" cell (so called because of their almost zero reflectivity) in the early 1980s, and exhibited efficiencies of up to 17%.