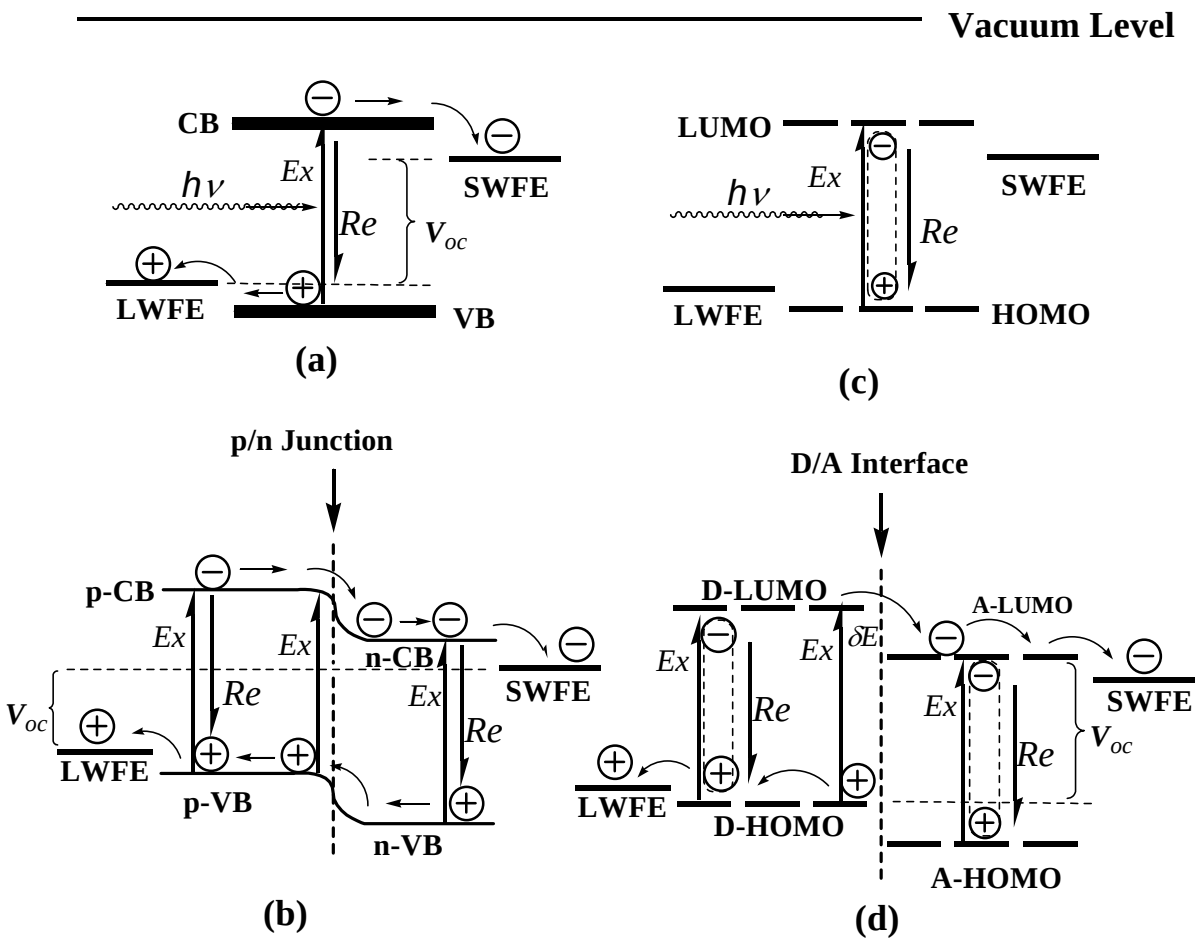


Figure 14.1 Frontier orbital/band energy level schemes of solar cells in (a) a single inorganic semiconductor cell (Fritz Cell); (b) an inorganic p/n junction solar cell (Bell Lab Cell); (c) an organic single material solar cell (Schottky Cell); (d) an organic donor/acceptor heterojunction solar cell (Tang Cell). *D* denotes an electron donor, and *A* denotes an electron acceptor. Ex denotes excitation, and Re denotes relaxation (or recombination). *dE* denotes the energy level offset between D-LUMO and A-LUMO.

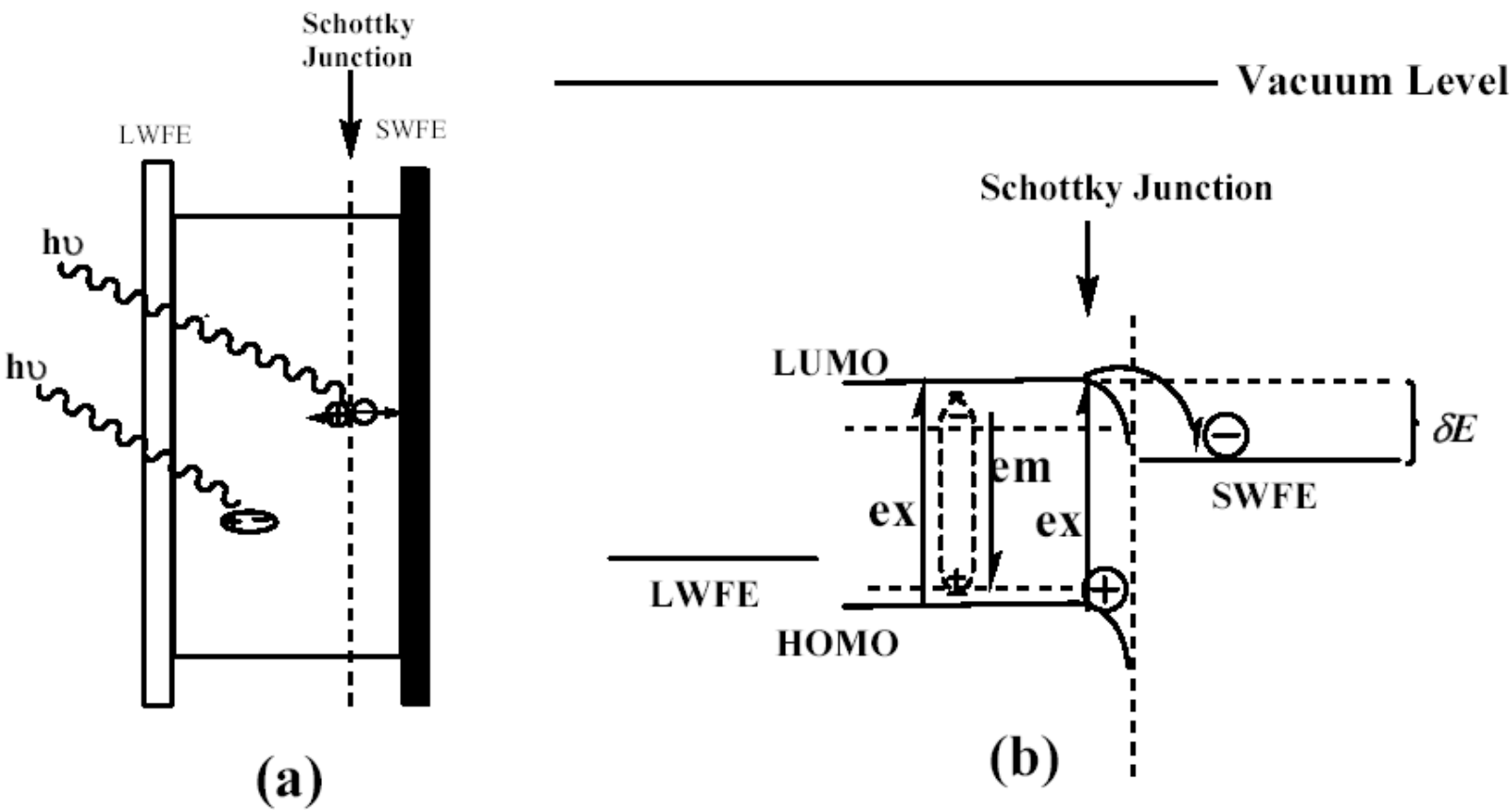


Figure 14.2 First generation single–material organic photovoltaic cell or 'Schottky cell' with (a) device structure and (b) energy diagram

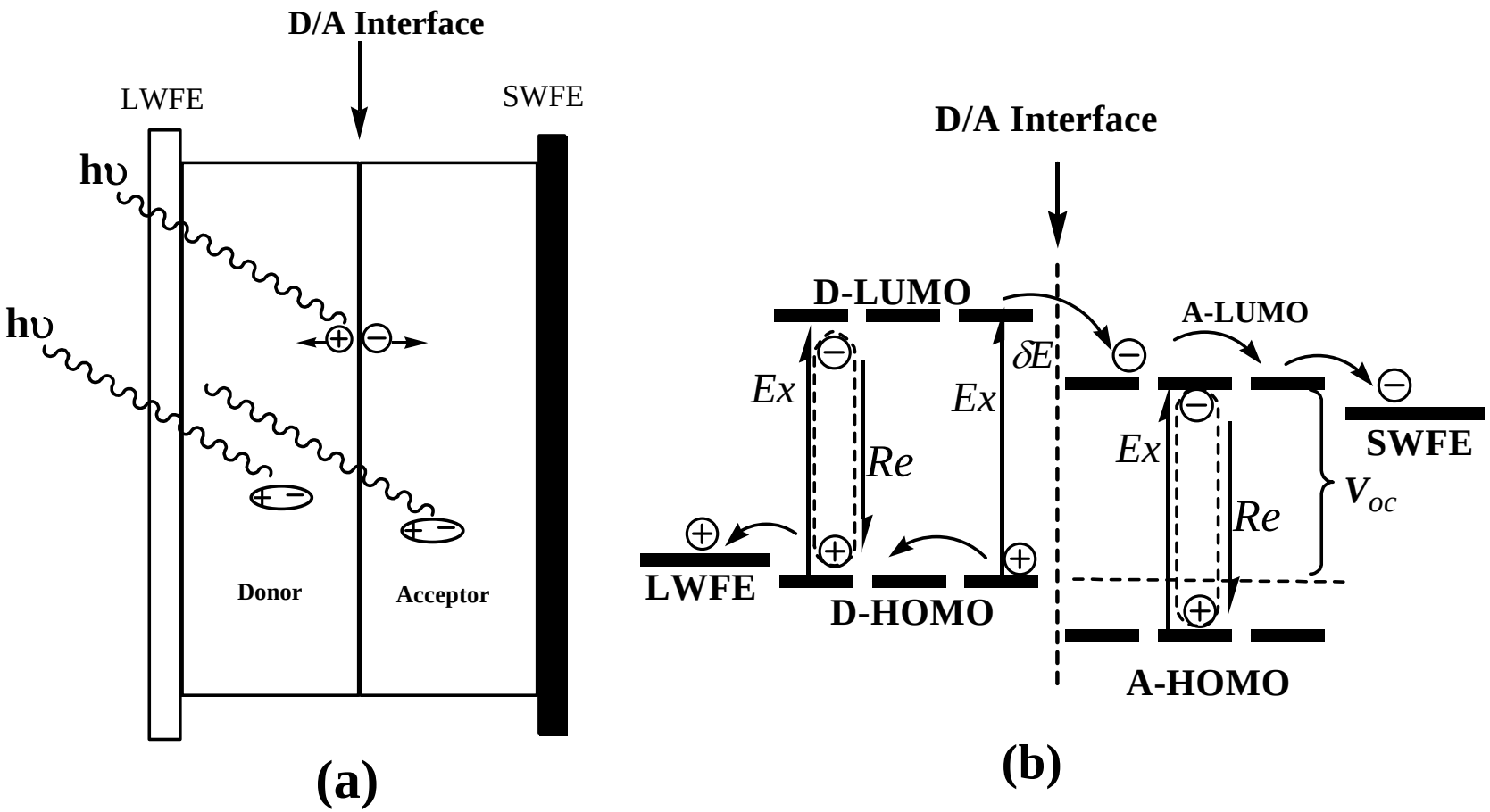


Figure 14.3 Second generation donor/acceptor bilayer heterojunction organic photovoltaic cell or ‘Tang cell’ with (a) device structure and (b) energy diagram

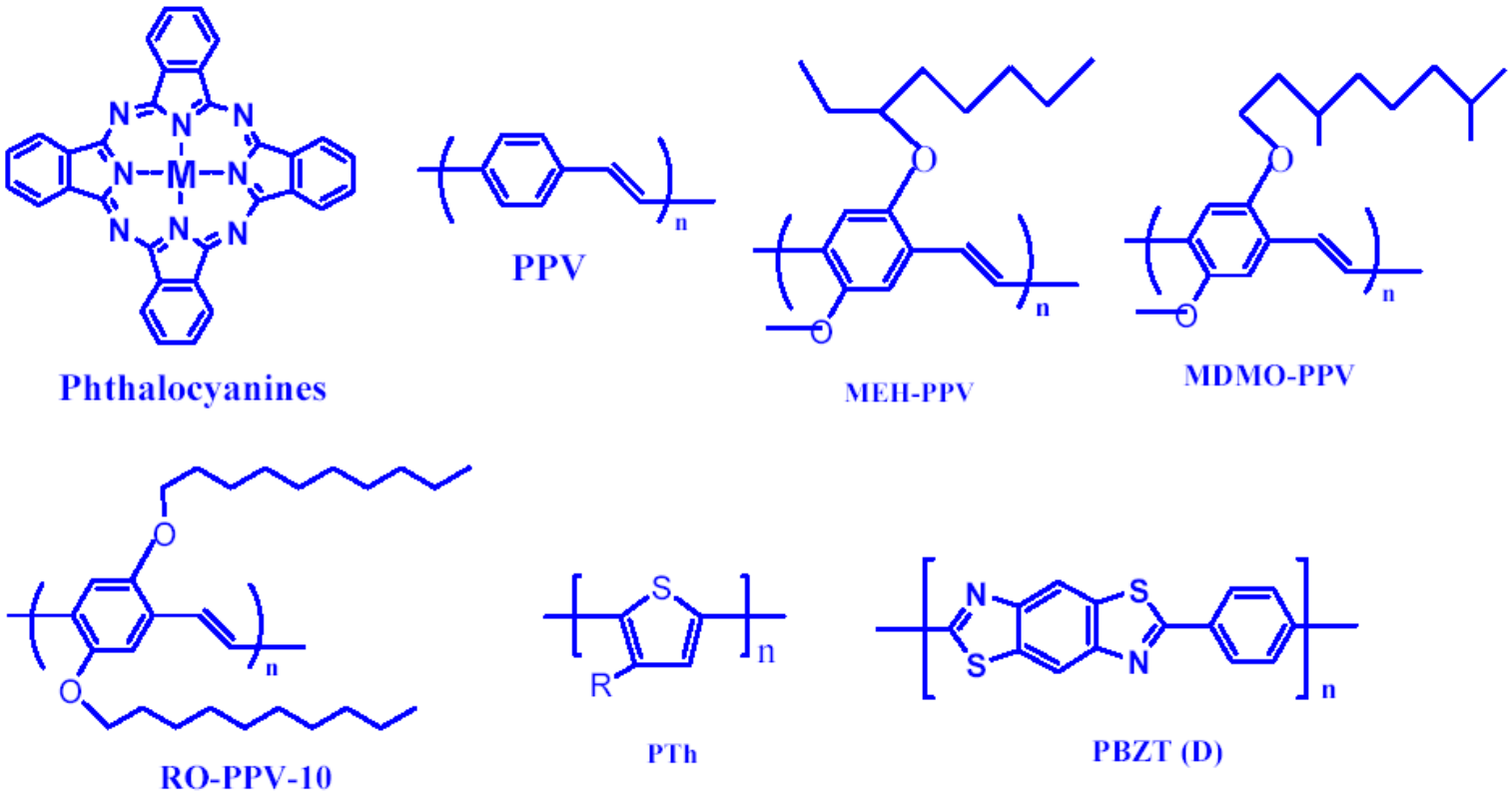


Figure 14.4 Representative organic/polymeric electron donors (p-type semiconductors). PPV = poly-p-phenylenevinylene, MEH-PPV = poly(2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylene vinylene), MDMO-PPV = poly [2-methoxy-5-(3',7'-dimethyloctyloxy)-1-4-phenylene vinylene], PBZT = poly(p-phenylene benzobisthiazole), PTh = polythiophene, RO-PPV-10 = poly(2, 5-didecyloxy-1,4-phenylene vinylene).

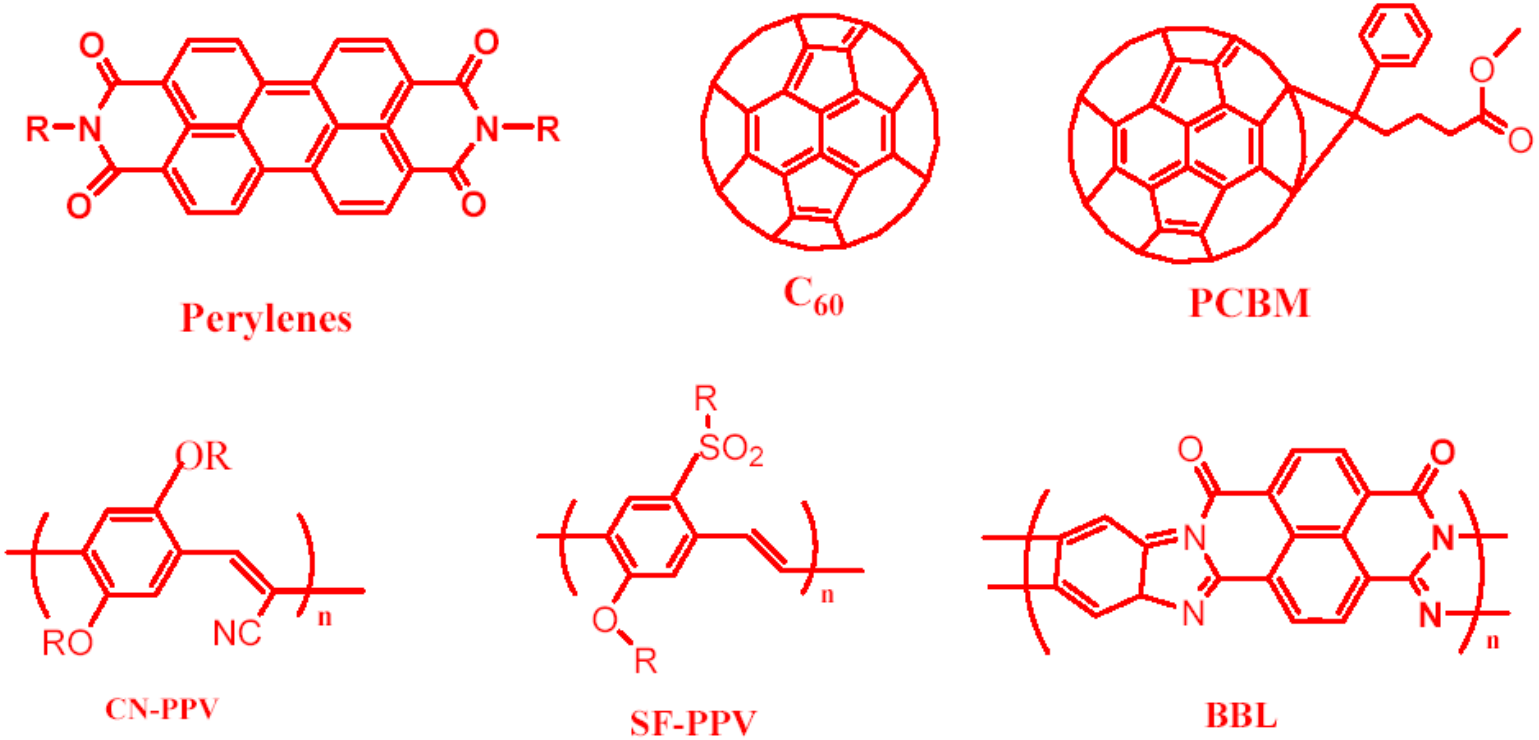


Figure 14.5 Representative organic/polymeric electron acceptors (n-type semiconductors). CN-PPV = poly(2,5,2',5'-tetraalkoxy-7,8'-dicyanodi-p-phenylenevinylene), BBL = poly(benzamidazobenzo phenanthroline), PCBM = [6,6]-phenyl-C61-butyric acid methyl ester, and SF-PPV = poly[2-alkoxy-5-alkanesulfonyl-1-4-phenylene vinylene].

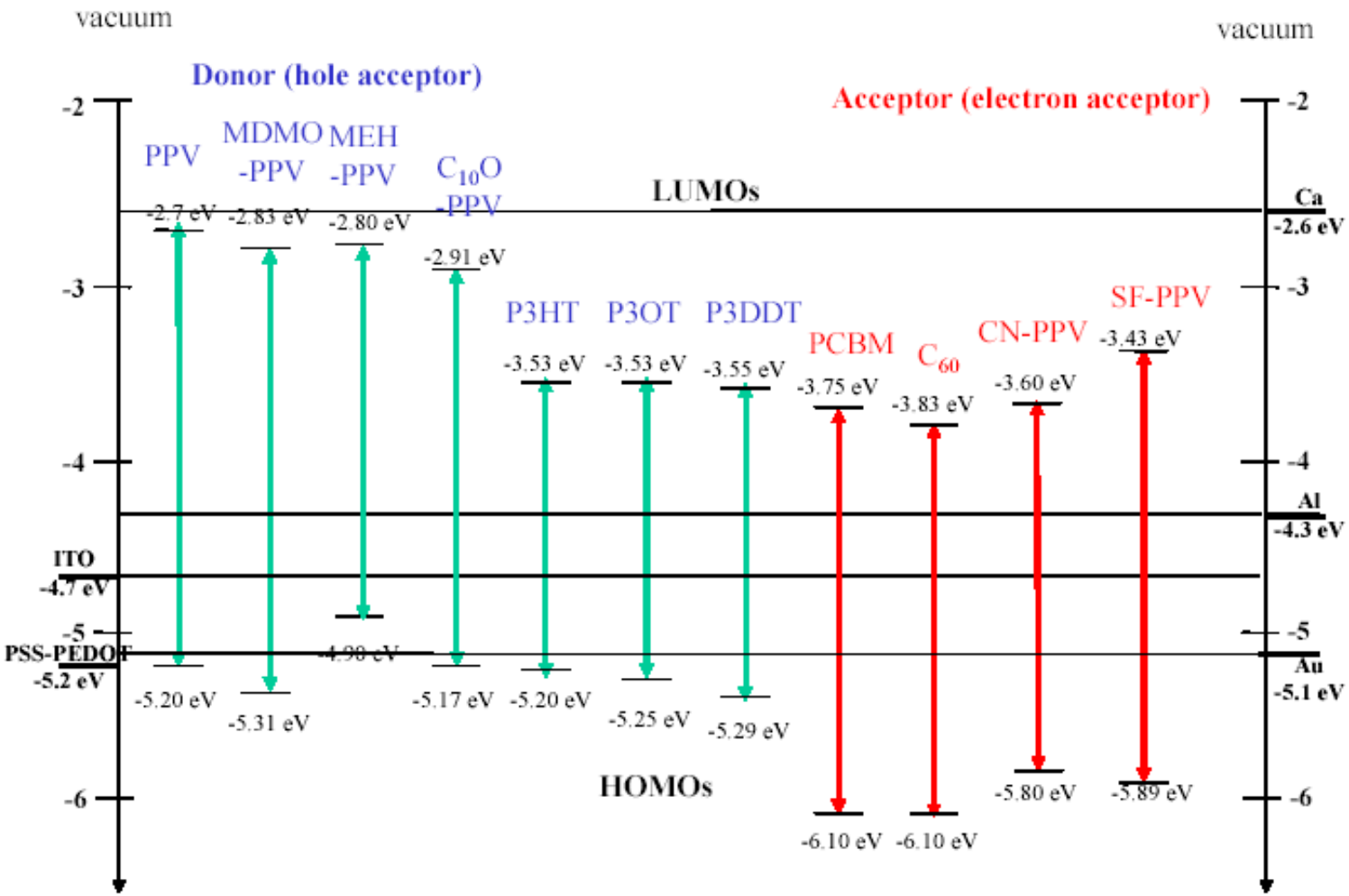


Figure 14.6 Frontier orbital levels of representative polymeric electron donors and acceptors; the work functions of several representative electrodes are also shown on the sides. P3HT = poly(3-hexylthiophene), P3OT = poly(3-octyl thiophene), P3DDT = Poly(3-dodecylthiophene).

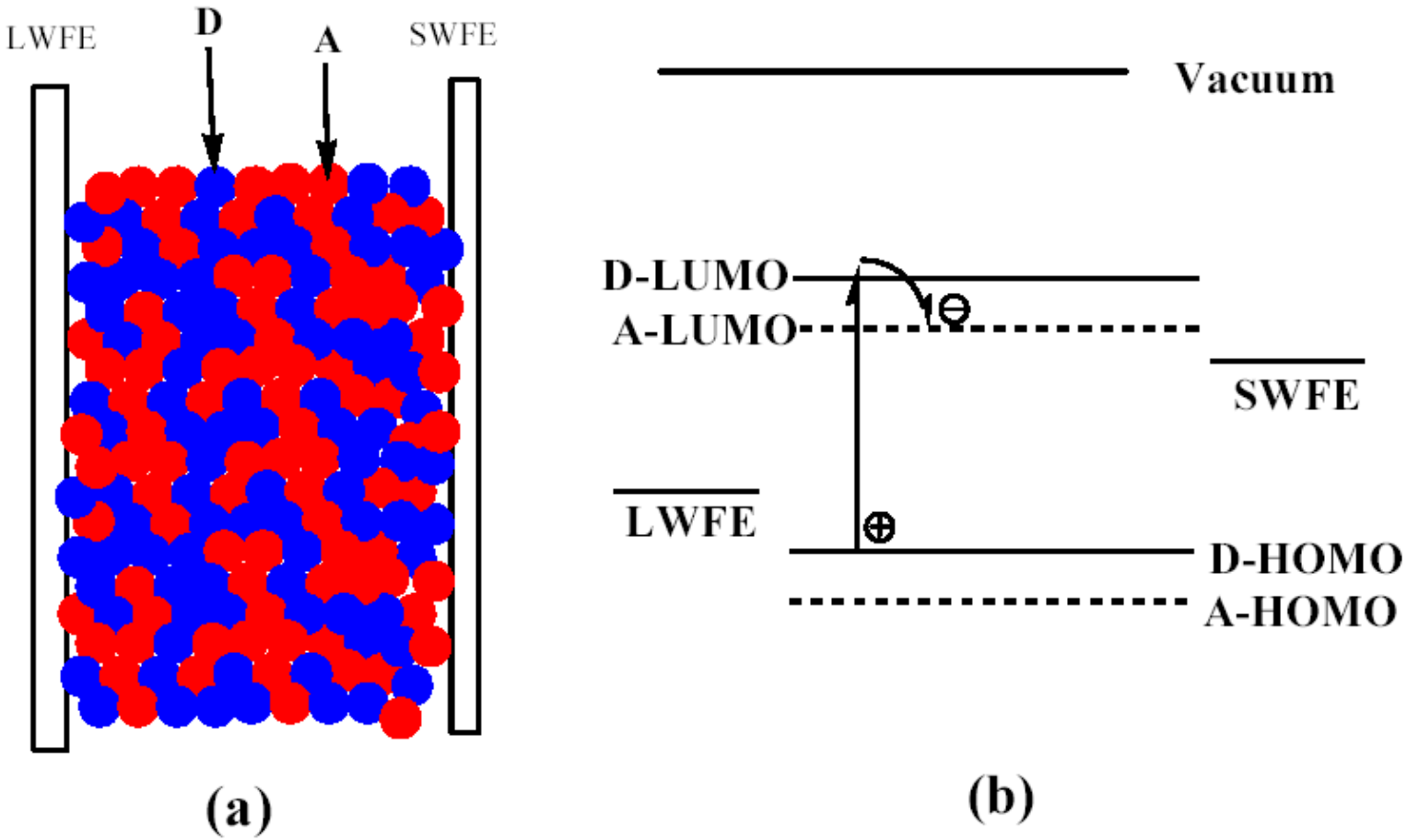


Figure 14.7 Third generation donor/acceptor blend type organic photovoltaic cells or 'bulk heterojunction cells' with (a) device structure and (b) energy diagram.

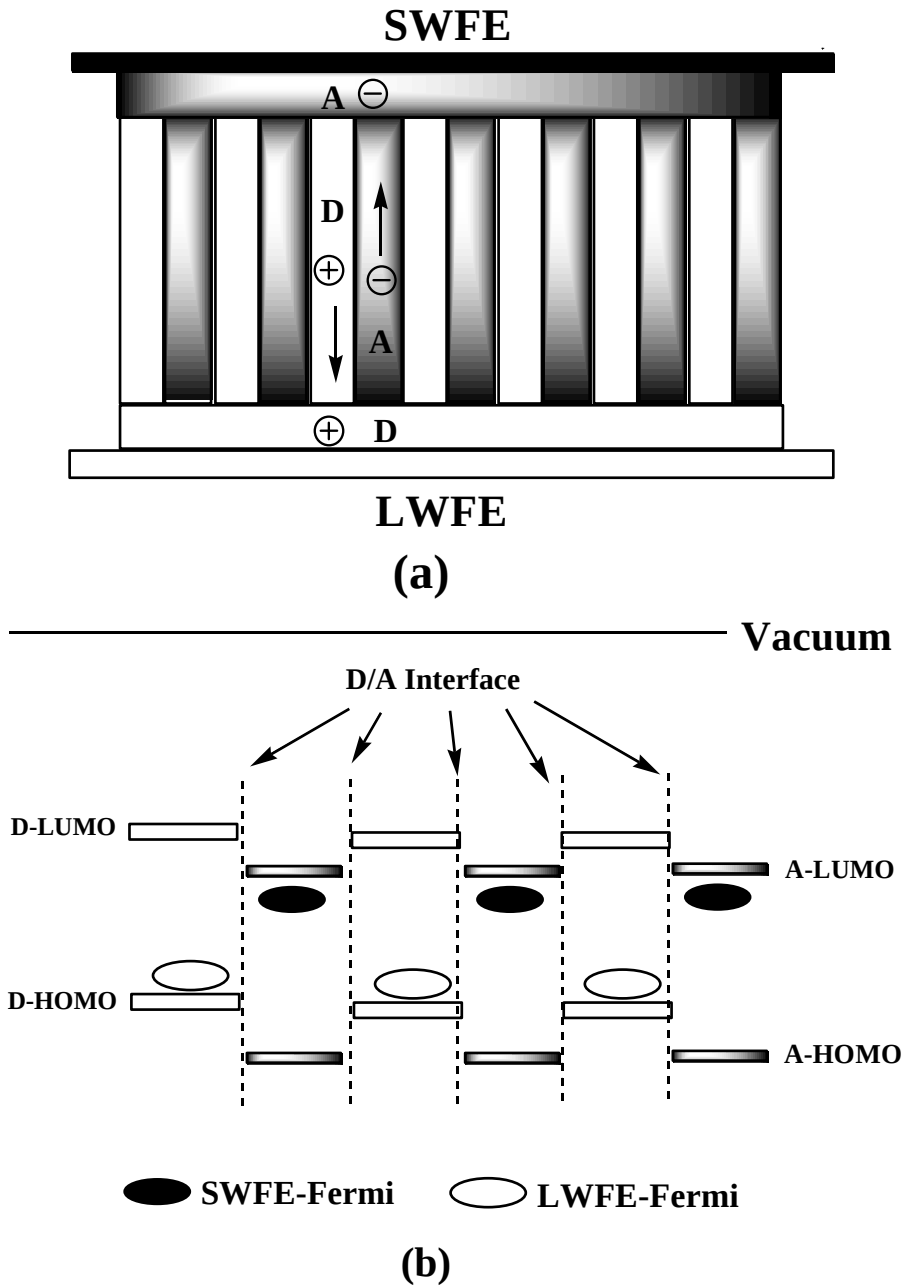


Figure 14.8 Fourth generation donor/acceptor bicontinuous ordered nano structure type photovoltaic cells or 'BONS cells' with (a) device structure and (b) energy diagram. The vertically aligned donor or acceptor columns shown in (a) can be inorganic semiconductor nanorods, nanowires, carbon nanotubes, conjugated semiconducting polymers, or discotic type stacked organic small molecules.

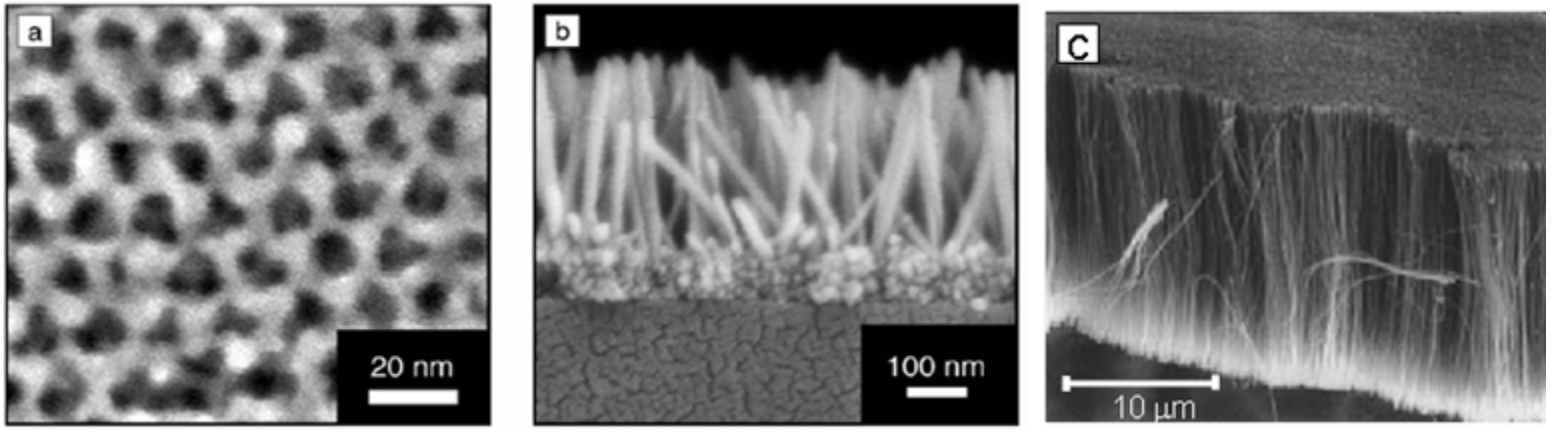


Figure 14.9 Scanning electron microscope images of (a) mesoporous titania (plane view) [21] and (b) a brush of zinc oxide nanowires (cross-section view) respectively [courtesy of S. Shaheen, *National Renewable Energy Lab*], and (c) is a typical transmission electron microscopic image of carbon nanotube coaxial nanowires produced by pyrolysis of FePc [3].

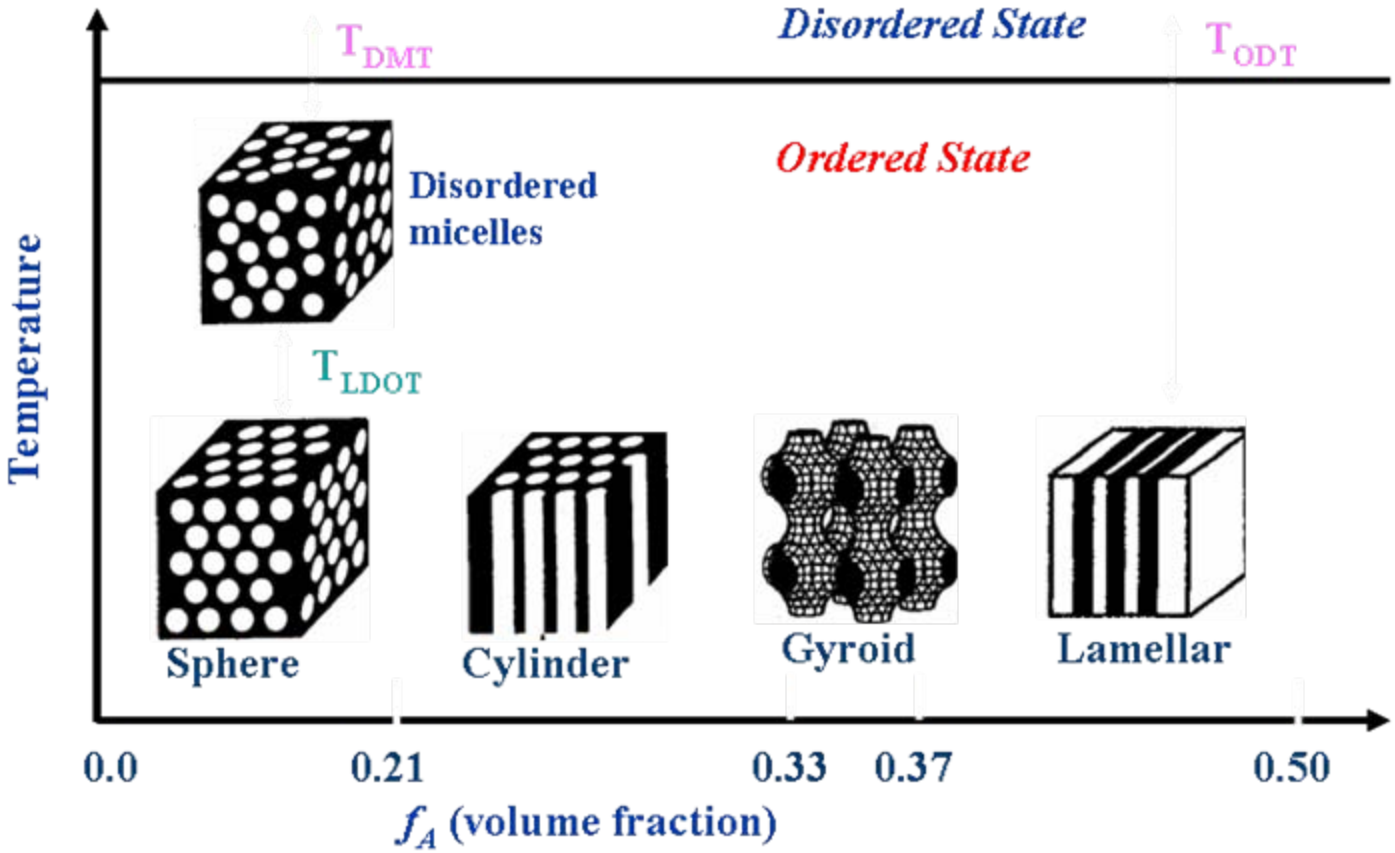
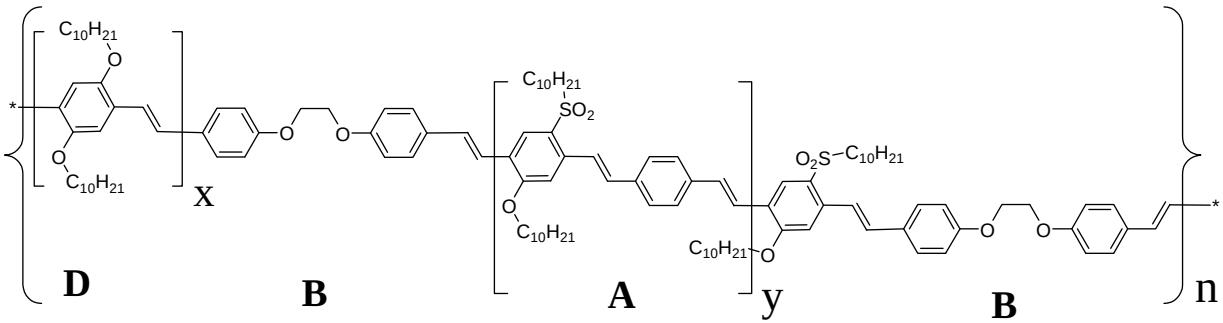
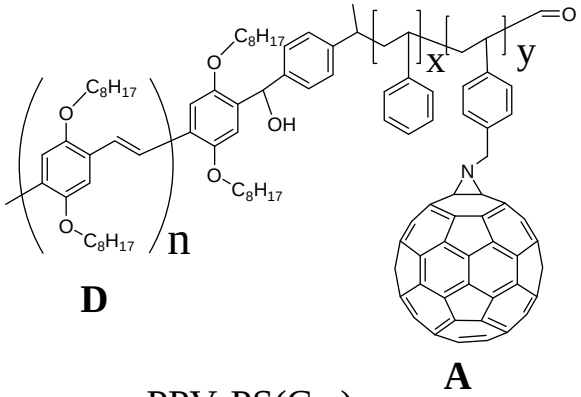


Figure 14.10 Some representative self-assembly structures of diblock copolymers.



$(DBAB)_n$



PPV-PS(C_{60})

Figure 14.11 Two representative donor/acceptor block copolymer systems studied.

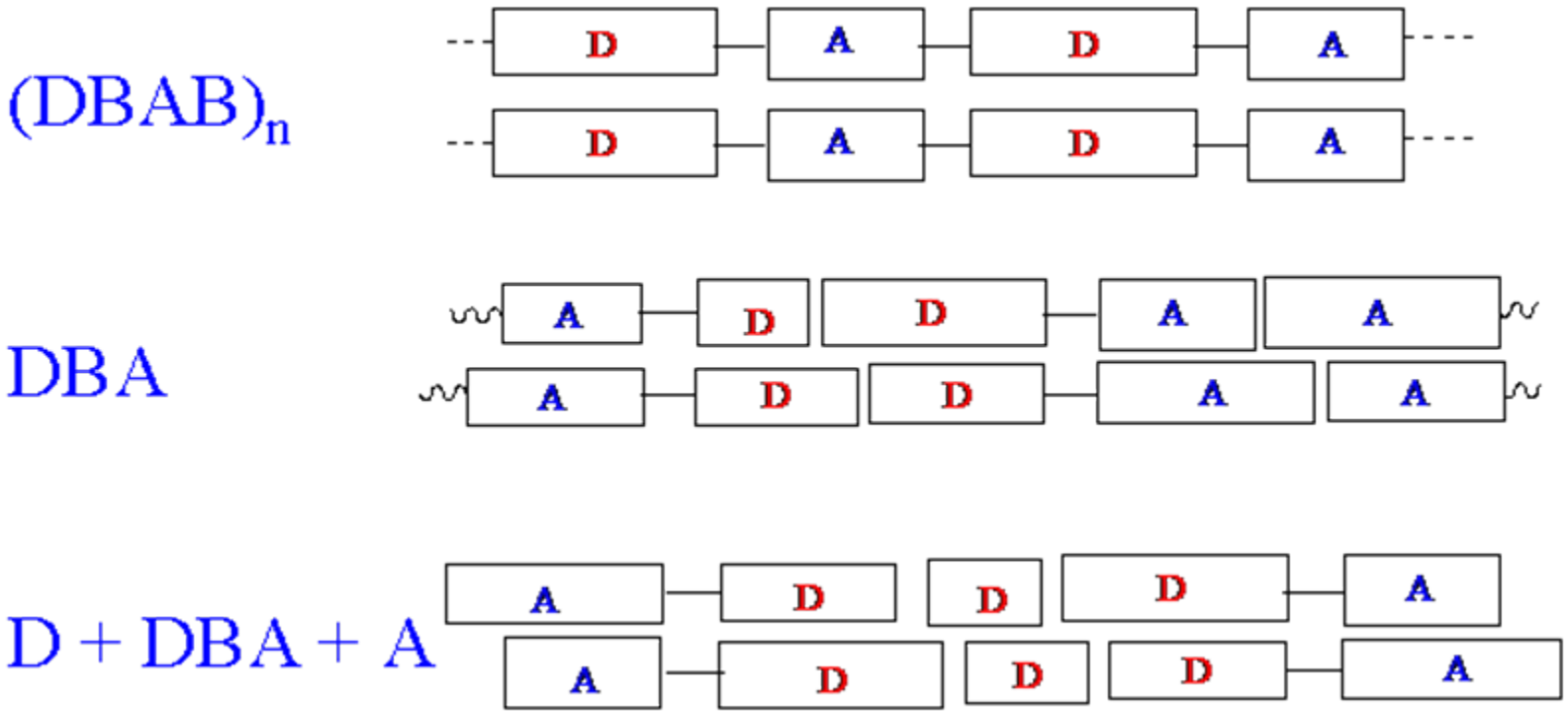


Figure 14.12 Different stacking possibilities of $(DBAB)_n$ and DBA block copolymers (See text for details)

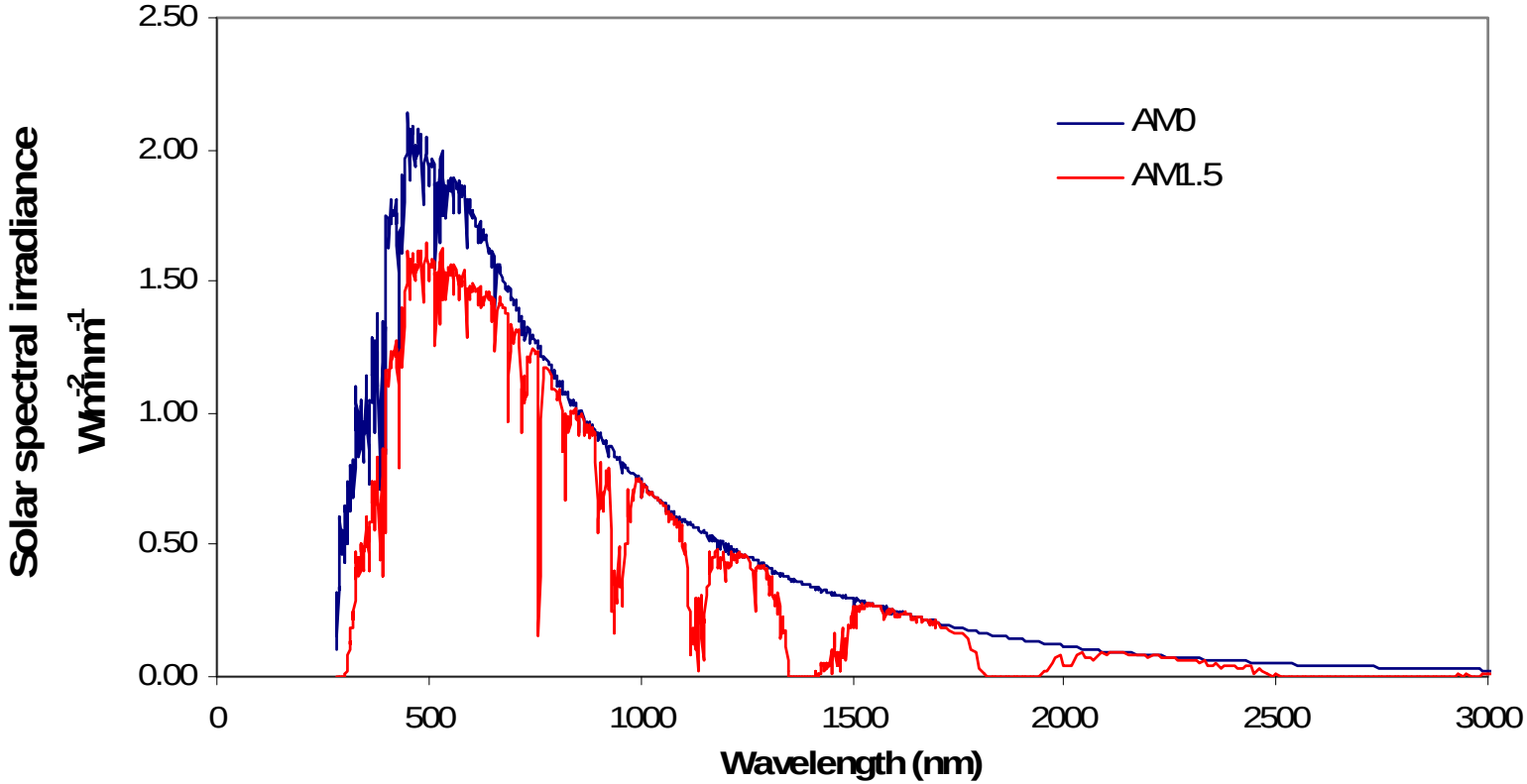


Figure 14.13 Standard solar spectral irradiance above the atmosphere (AM0, extra-terrestrial, top curve) and under the reference air mass 1.5 conditions (ASTM G173-03, 2003, bottom curve. See rredc.nrel.gov/solar/spectra/am1.5 or www.astm.org/): Conditions for the terrestrial standard: An air mass of 1.5 (solar zenith angle 48.19°s), a turbidity of 0.27, and the receiving surface is at 37° tilt toward the equator, facing the sun (*i.e.*, the surface normal points to the sun, at an elevation of 48.81° above the horizon). These conditions are representative of average conditions in the 48 contiguous states of the US. In real life, a large range of atmospheric conditions can be encountered, resulting in more or less variations in atmospheric extinction.

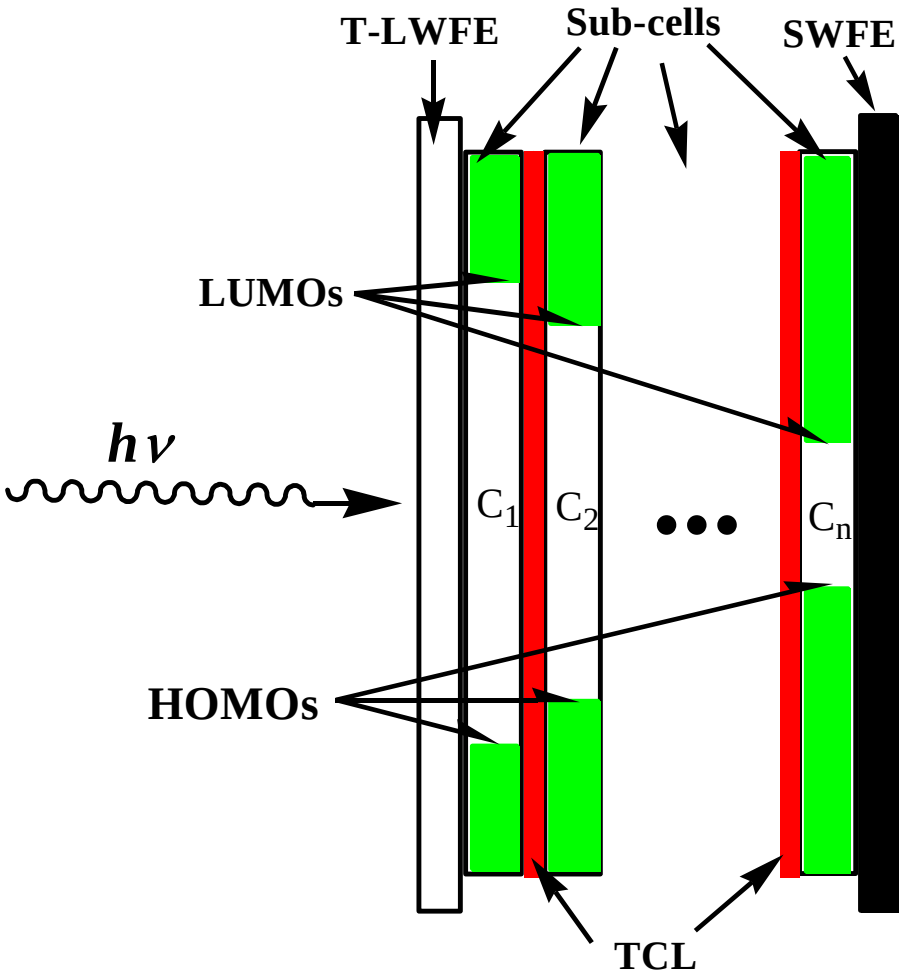


Figure 14.14 Scheme of a tandem style stacked sub-cells with excitation energy gaps grading from large to small along the light propagation direction. TCL denotes transparent conducting layer. T-LWFE denotes transparent large work function electrode.

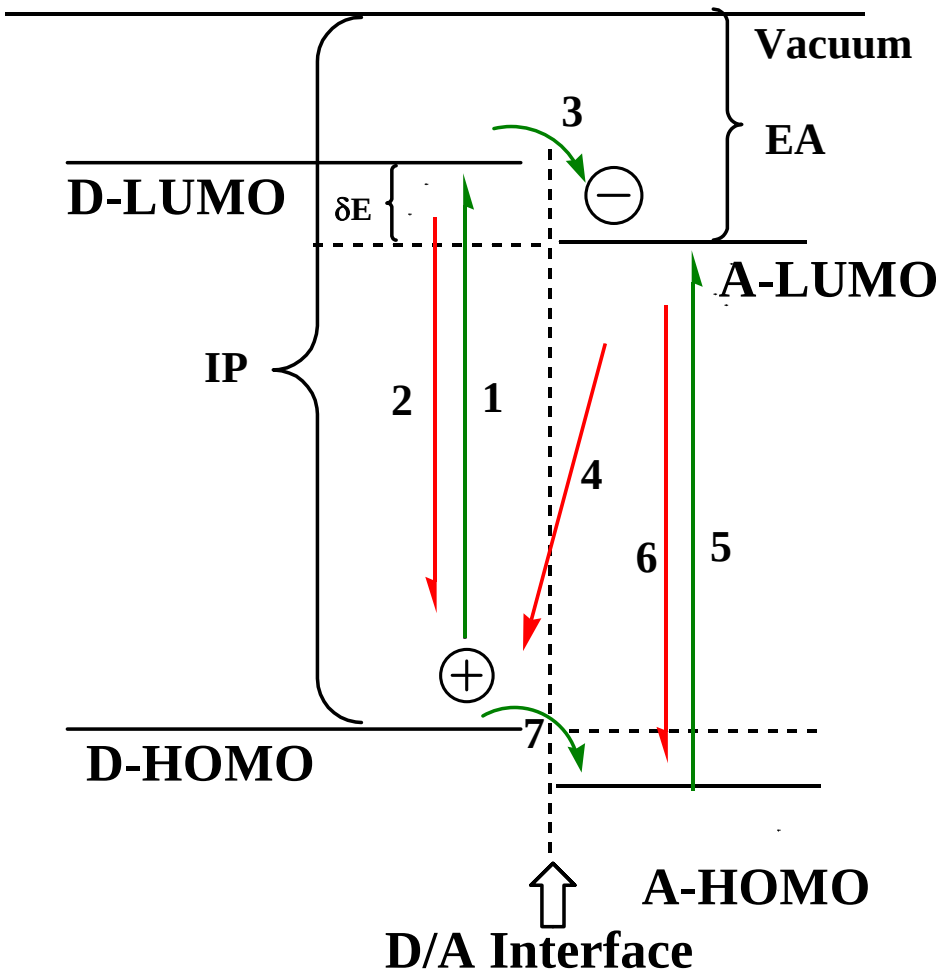


Figure 14.15 Scheme of molecular frontier orbitals and photo-induced electron transfer processes in a donor/acceptor binary heterojunction solar cell. *dE* denotes energy offset between donor-LUMO (D-LUMO) and acceptor-LUMO (A-LUMO). *IP* denotes ionization potential of the donor, and *EA* denotes electron affinity of the acceptor.

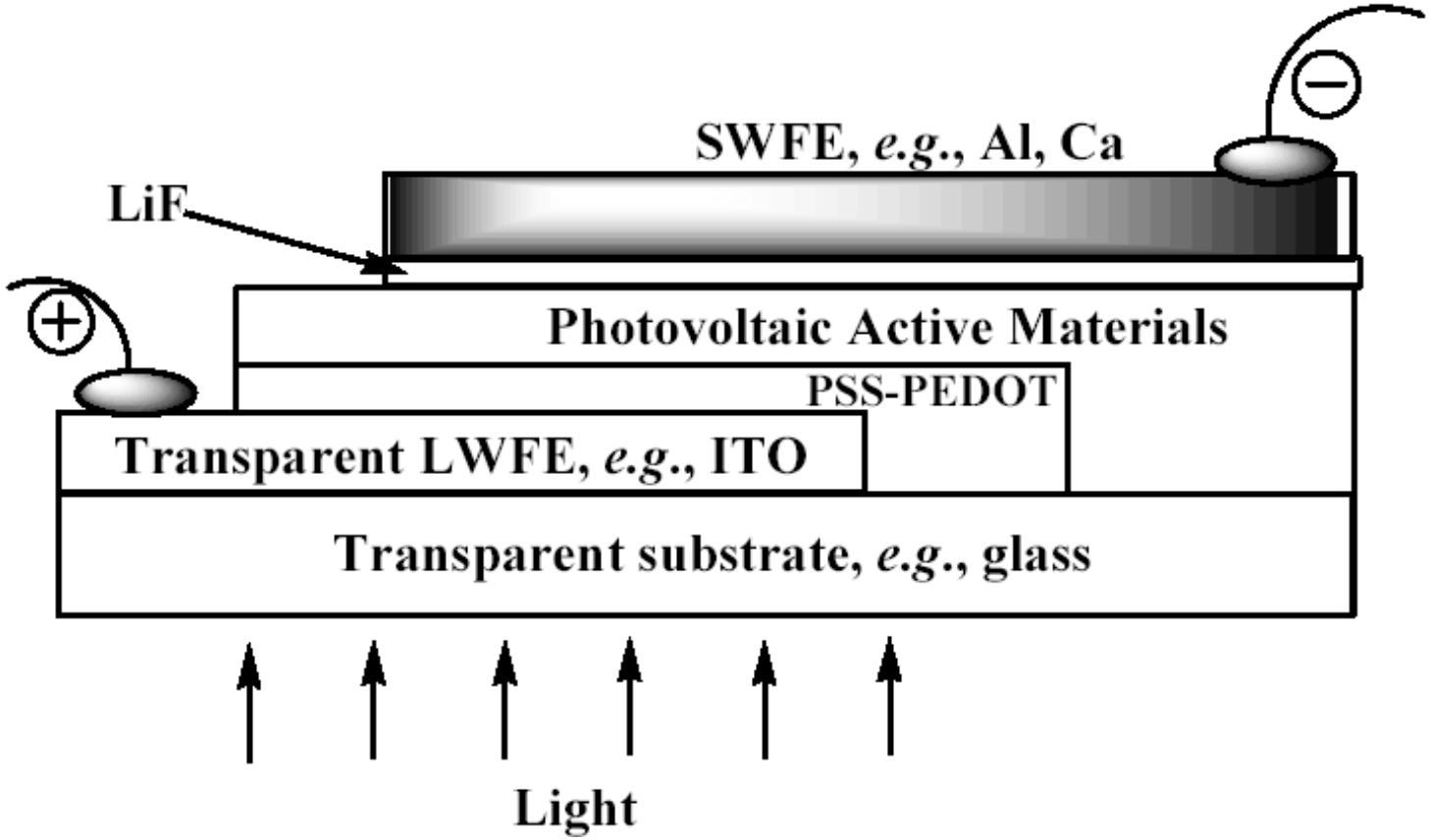


Figure 14.16 General scheme of an organic/polymer photovoltaic cell with buffer layers

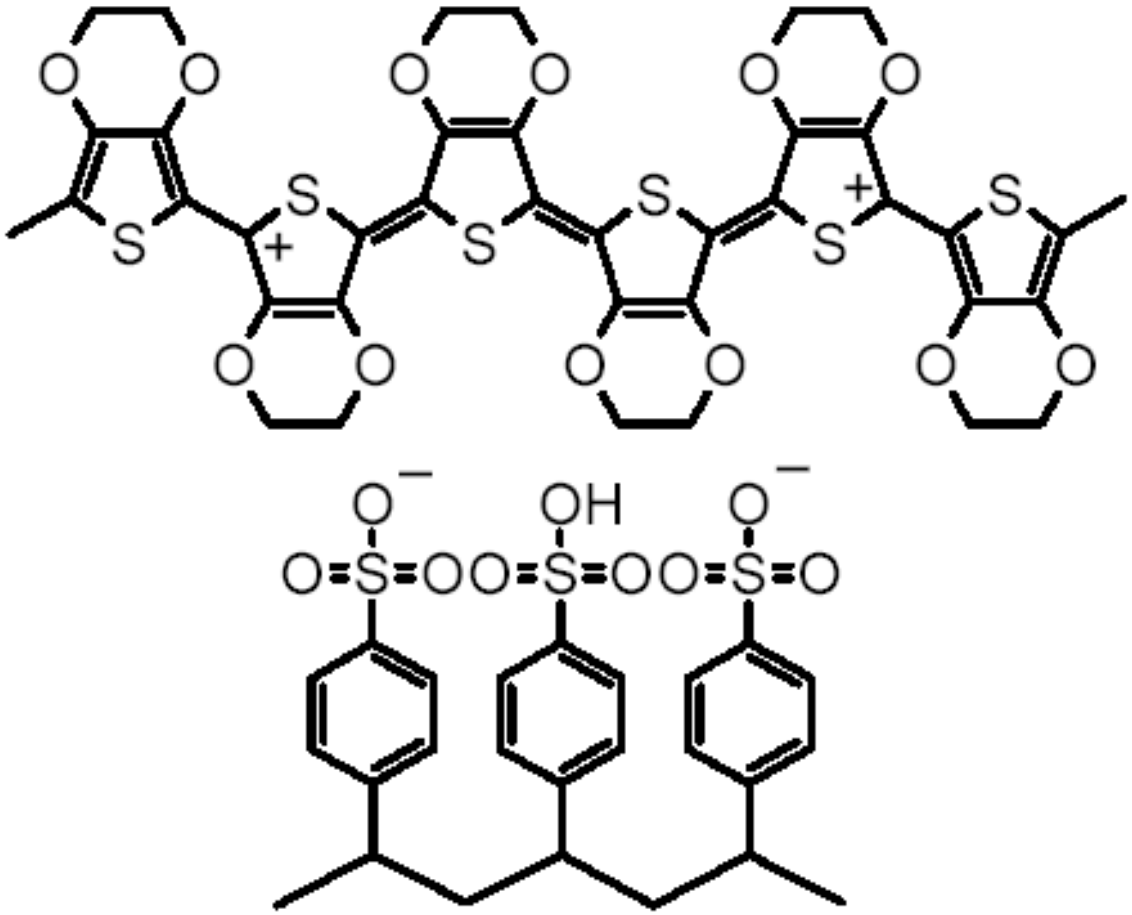


Figure 14.17 Chemical structure of PSS-PEDOT

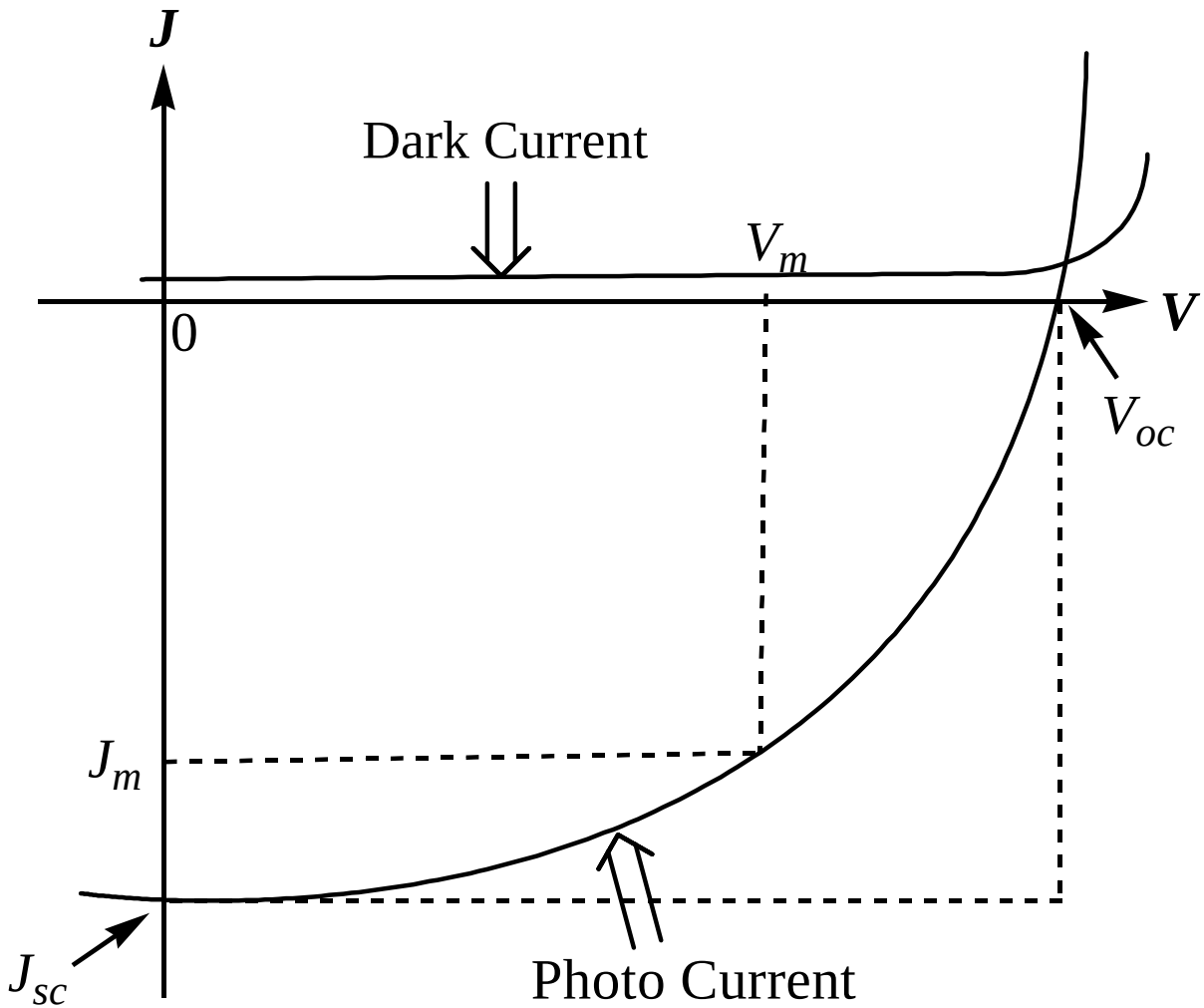


Figure 14.18 A schematic current density-voltage (*J-V)* plot of a photovoltaic cell in the dark and under illumination

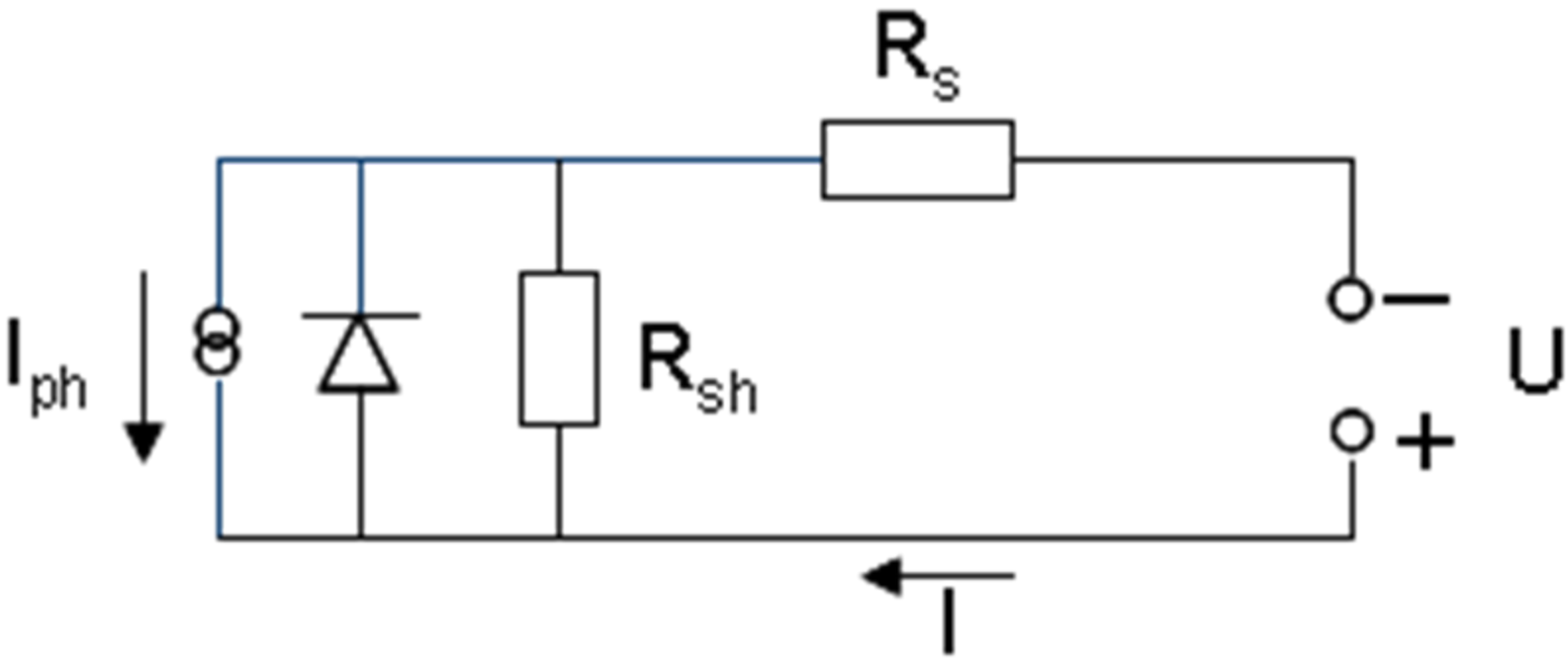


Figure 14.19 Equivalent circuit for a solar cell described by equation (4)