13.5.3 The Cu(InGa)Se_2/CdS Interface

It may seem surprising that recombination at the Cu(InGa)Se_2/CdS interface does not limit V_{OC} since, in processing Cu(InGa)Se_2 solar cells, no special efforts are made to match lattices or reduce interface defects and the devices are typically exposed to air between the Cu(InGa)Se_2 and CdS depositions. This can be explained by type inversion of the near-junction region of the Cu(InGa)Se_2 induced by the band alignment and doping [169, 182–184]. In this case, the Fermi level at the interface is close to the conduction band so that electrons in the near surface region of the Cu(InGa)Se_2 are effectively majority carriers and there is an insufficient supply of holes available for recombination through the interface states. It has alternatively been proposed that doping due to Cd diffusion during the chemical bath deposition of CdS results in the formation of an n-type emitter and a p–n homojunction in the Cu(InGa)Se_2 [136]. This would require the junction to remain very close to the Cu(InGa)Se_2/CdS interface to minimize recombination of carriers generated near the interface, and would therefore be very process-specific.

The Cu(InGa)Se_2/CdS band diagram shown in Figure 13.19 demonstrates that the conduction-band offset ΔE_C between the CdS and the Cu(InGa)Se_2 is critical for creating the type inversion in the Cu(InGa)Se_2. In this diagram, the bulk Cu(InGa)Se_2 layer is p-type with E_g depending on the relative Ga concentration, the CdS layer is n-type with $E_g = 2.4$ eV and is totally depleted, and the bulk ZnO n^+-layer has $E_g = 3.2$ eV. A thin HR ZnO layer between the n^+-ZnO layer and the CdS is also assumed to be depleted. Positive ΔE_C indicates a spike in the conduction band, that is, the conduction-band minimum in the CdS is at higher energy than the conduction-band minimum of the Cu(InGa)Se_2. Figure 13.19 shows the case with $\Delta E_C = 0.3$ eV and a -0.3 eV conduction-band offset between the ZnO and the CdS [52]. Models of current transport and recombination have considered the effect of ΔE_C [184–187]. These models show that if ΔE_C is greater than about 0.5 eV, collection of photogenerated electrons in the Cu(InGa)Se_2 is impeded and

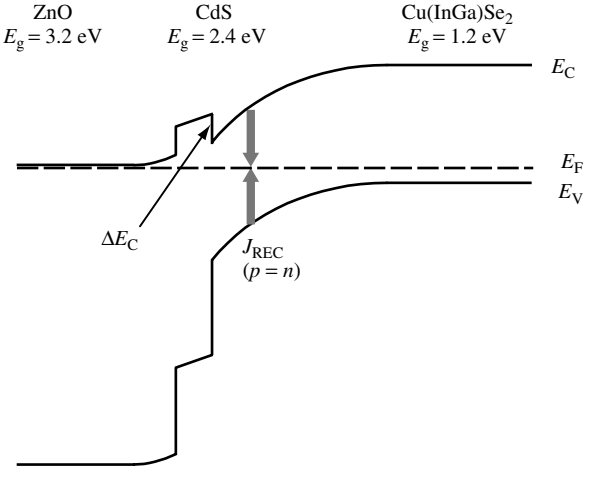

Figure 13.19 Band diagram of a ZnO/CdS/Cu(InGa)Se_2 device at 0 V in the dark. Note that the recombination current J_{REC} is greatest where $p = n$ in the space charge region of the Cu(InGa)Se_2 and not at the interface