localized electronic states within the band gap, E_g. It is customary to refer to states having ionization energy $\sim E_g/2$ as "deep" and states having ionization energy near the bands as "shallow." The types of defects controlling electronic properties include native defects, chemical impurities, and complexes thereof; native defects and impurities can occur substitutionally or interstitially. For example, cadmium vacancy, V_{Cd}, gives rise to shallow acceptor states, while cadmium substitution on a tellurium site, Cd_{Te}, gives rise to shallow acceptor states. Interstitial cadmium, Cd_i, gives rise to a relatively shallow donor state, while tellurium, Te_i, gives rise to deep states. A selected group of native, impurity, and complex defect levels in CdTe is shown in Figure 14.5.

Present-generation high-efficiency CdTe solar cells are based on *p*-type CdTe and *n*-type CdS. The desired electrical properties are obtained by activation treatments that incorporate specific impurities into the CdTe and CdS layers such as postdeposition treatments that introduce $CdCl_2$, O_2, and Cu into CdTe, which may activate or passivate native defects [61]. The specific effects of these agents on grain surfaces and the intragrain bulk properties must be considered separately to account for the enhanced *p*-type conductivity and the electrical passivation of grain boundaries in films after treatment. A comprehensive review of bulk diffusivities of group I, II, and III impurities in CdTe is given in Reference [62].

The polycrystalline aspect of cell fabrication gives rise to critical challenges for the development of *thin-film* photovoltaics: (1) separating intragrain from grain-boundary

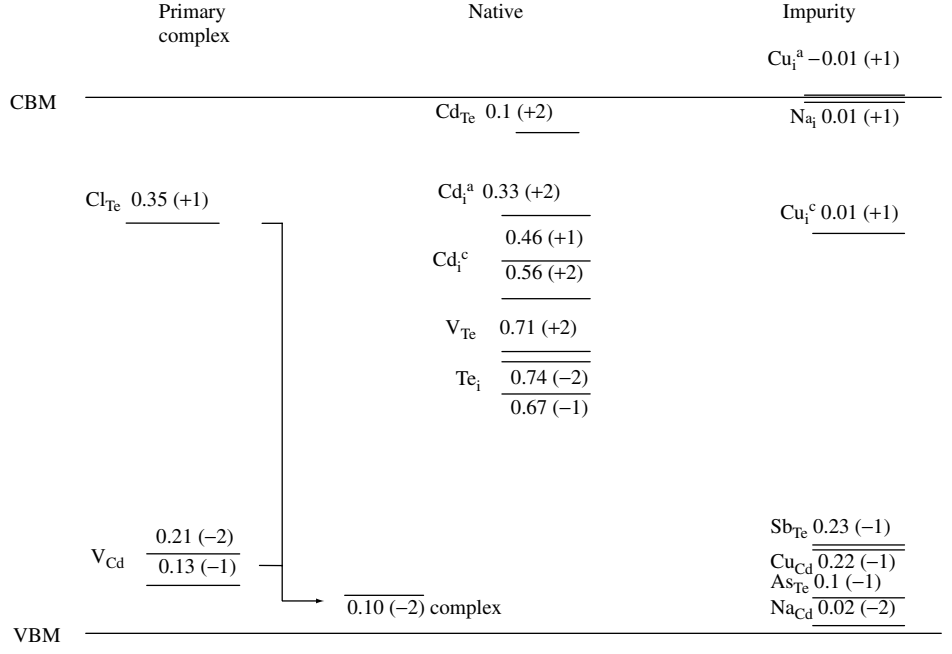

Figure 14.5 CdTe band structure with doping and defect levels. Charge states are in parentheses; energy is in electron volts measured from the conduction band for donor (positive) states and valence band for acceptor (negative) states. The superscripts a and c represent alternative interstitial sites. (Adapted from Wei S, Mtg. Record, National CdTe R&D Team Meeting (2001) Appendix 9 [60])