of hydrogen on the surface [117]. At the low temperature side (below 250°C), it again takes a higher hydrogen dilution to reach the transition between amorphous to microcrystalline [117]; this effect is likely due to the low surface diffusivity of hydrogen during growth. When a-Si is deposited at a lower temperature with higher H dilution, more H is incorporated and the material has a wider band gap. By following the edge of the transition curve (but staying on the amorphous side) while reducing the deposition temperature, wide-gap a-Si and single-junction a-Si n-i-p cells with 1.053 V open-circuit voltage were deposited [76, 118]. It was also observed that materials deposited near the edge of microcrystalline formation show intermediate-range structural order [119].

12.3.7 Alloys and Doping

As was discussed in Section 12.2.7, a-Si-based alloys can be deposited using a gas mixture of SiH_4 with other gases such as GeH_4, CH_4, O_2 (or NO_2), and NH_3 for obtaining a-$SiGe_x$, a-SiC_x, a-SiO_x and a-SiN_x, respectively. Among these alloy materials, a-SiGe has been explored extensively for PV applications as the narrow band gap absorber. As we see from Figure 12.10, the band gap E_G decreases with increasing Ge content. When E_G is decreased to below 1.4 eV, the defect density becomes so high that the materials can no longer be used as the intrinsic layer for solar cells. Various approaches have been explored to make a-SiGe or a-Ge with low band gap (below 1.3 eV) and low defect density [61]. Despite tremendous progress, device quality a-SiGe with low band gap (below 1.3 eV) has not been demonstrated.

Another related aspect for a-SiGe deposition is the deposition uniformity. Because of the different dissociation rates of germane (GeH_4) and of silane (SiH_4) in an RF plasma, the film deposited near the gas inlet side of the chamber has higher Ge content than the film near the exhaust. This nonuniformity makes it difficult to implement the process over large areas in manufacturing. By taking advantage of the approximately similar dissociation rate of GeH_4 and disilane (Si_2H_6), many research groups use a mixture of GeH_4 and Si_2H_6 for the fabrication of a-SiGe alloy and successfully obtain uniform film [52].

As discussed in Section 12.2.6, a-Si can be doped n-type by mixing phosphine (PH_3) with the gas mixture or doped p-type by mixing diborane (B_2H_6), BF_3, or trimethylboron [TMB, $B(CH_3)_3$] with the gas mixture during deposition. Because of the need for transparency in p-layers, which act as the "window" layer for sunlight, most cells have either μc-Si or a-SiC as the uppermost p-layer. Amorphous SiC p-layers are usually made using a mixture of SiH_4 and CH_4 strongly diluted in hydrogen [61]. The μc-Si p-layer is generally made in a PECVD process using high H dilution with high RF power at relatively low temperature. There have been suggestions that the optimum p-layer for a-Si solar cells is either nanocrystalline or is very close to the transition from amorphous to microcrystalline [120, 121].

12.4 UNDERSTANDING a-Si pin CELLS

12.4.1 Electronic Structure of a pin Device

Profiles showing electronic levels such as bandedges are an important tool in understanding device physics. Figure 12.14 illustrates the profiles of the bandedge levels E_C and E_V