gap decreases about 0.7 eV as the Ge ratio $x$ increases from 0 to 1. The band gap increases with atomic fraction of hydrogen $h$. Figure 12.10(b) should be viewed as a useful approximation; in particular, the atomic fraction $h$ is only one aspect of the hydrogen microstructures in a-SiGe alloys, and quantitative deviations from the contour plot are likely. Additionally, only some of the materials represented in the figure are useful as absorber layers. In particular, as the Ge ratio $x$ rises to about 0.5, the optoelectronic properties become so poor that these alloys are no longer useful in solar cells [54]. Similarly, only limited ranges of the atomic fraction of hydrogen $h$ yield useful absorber layers.

It might be thought that a-SiC would be equally useful as a wider band gap absorber; despite some promising research [55], this material is not being used as an absorber layer by manufacturers. B-doped a-SiC is used extensively as a $p$-type, window layer [56]. a-SiO and a-SiN are used as insulators in thin-film transistors [57], but are not major components in solar cells.

# 12.3 DEPOSITING AMORPHOUS SILICON

## 12.3.1 Survey of Deposition Techniques

The first preparations of a-Si:H by Chittick *et al.* [58] and by Spear and LeComber [59] used a silane-based glow discharge induced by radio frequency (RF) voltages; the method is now often termed plasma enhanced chemical vapor deposition (PECVD). Since this pioneering work, many deposition methods have been explored with the intention of improving material quality and deposition rate. Among these methods, PECVD using 13.56-MHz excitation is still the most widely used today in research and manufacturing of a-Si-based materials. However, emerging film deposition methods, mostly toward higher deposition rate or toward making improved microcrystalline silicon films, have been extensively explored in recent years. Table 12.1 summarizes the most extensively studied deposition processes used as well as some of their advantages and disadvantages. Among these, PECVD with very high frequency (VHF) and hot-wire (HW) catalytic deposition

**Table 12.1** Various deposition processes used for depositing amorphous silicon–based materials

| Processes | Maximum rate[a] [Å/s] | Advantages | Disadvantages | Manufacturers | References |
|---|---|---|---|---|---|
| RF PECVD | 3 | High quality uniform | Slow | Many | [60–62] |
| DC PECVD | 3 | High quality uniform | Slow | BP Solar | [63, 64] |
| VHF PECVD | 15 | Fast | Poor uniformity | None | [65, 66] |
| Microwave PECVD | 50 | Very fast | Film quality not as good | Canon | [67] |
| Hot-wire | 50 | Very fast | Poor uniformity | None | [68, 69] |
| Photo-CVD | 1 | High quality | Slow | None | [70, 71] |
| Sputtering | 3 | | Poor quality, slow | None | [72, 73] |

[a] Maximum deposition rate: The deposition rate beyond which the film quality deteriorates rapidly; these numbers are empirical, not fundamental limits, and represent current results at the time of publication