content in the film and improved stability against light-induced degradation compared with RF PECVD films [69]. The improved HWCVD a-Si has been incorporated in an *n-i-p* solar cell as the intrinsic layer and solar cells with ∼10% initial efficiency have been demonstrated [94, 95].

HWCVD is considered very promising. Although it has not yet been incorporated into any of today's large-scale manufacturing facilities, the ability to deposit a-Si and a-SiGe films at very high rate (∼up to 150–300 Å/s) [96, 97] has attracted tremendous interest. Another reason researchers are interested in HW CVD is its effectiveness in making microcrystalline and polycrystalline silicon films.

There are several concerns about incorporating HW processes in manufacturing. First, the uniformity of HW films is still poorer than that of RF PECVD films, although some companies have worked on this and made significant improvement [98]. Second, the filament needs to be improved to reduce the maintenance time in production. Third, HW-deposited solar cells have not yet achieved the same performance as cells prepared using low deposition rate, RF PECVD.

12.3.5 Other Deposition Methods

Beside PECVD and HW deposition methods, other deposition processes have been explored for depositing a-Si films. These include (1) reactive sputter deposition from silicon targets using a mixture of hydrogen and argon [99, 100]; (2) e-beam evaporation, assisted with various hydrogenation methods [101, 102], (3) spontaneous chemical vapor deposition [103], (4) photo-CVD [70, 71] using ultraviolet excitation and mercury sensitization, (5) remote plasma chemical vapor deposition [104], (6) electron cyclotron resonance (ECR) microwave deposition [105, 106], (7) pulsed laser deposition [107, 108], and (8) gas jet deposition [109]. Most of these deposition methods yield poorer a-Si films or solar cells compared with RF PECVD deposited films and devices, and therefore, are not (or not yet) used in large-scale a-Si PV production.

12.3.6 Hydrogen Dilution

Strong hydrogen dilution of the silane gas mixture during a-Si deposition has been found to reduce the density of defect states and improve the stability of the material against light-soaking effects [110–112]. Solar cells with *i*-layers deposited using strong H_2 dilution show improved performance and stability [113, 114]. There are two other important effects of hydrogen dilution. As the dilution is increased, the deposition rate declines. When hydrogen dilution is increased sufficiently, the thin silicon films that are deposited become microcrystalline.

Ferlauto *et al*. [115] have made a careful study of the "phase diagram" for silicon thin films deposited under varying levels of hydrogen dilution of silane. Some of their results, which are based on *in situ* spectroscopic ellipsometry of the growing film, are presented as Figure 12.13; this diagram pertains to a particular RF power level, substrate (c-Si), and substrate temperature. For lower dilutions ($R < 10$), films are invariably amorphous, but there is a transition to a "roughened" surface beyond a critical thickness. This roughening transition is suppressed as dilution is increased. For higher dilutions, the