

The large difference in reduction potential necessitates limiting the concentration of the more positive species, Te, to maintain stoichiometry in the deposit. In practice, the low Te species concentration ( $10^{-4}$  M) limits the CdTe growth rate due to Te depletion in the solution at the growing surface and subsequent mass transport. To overcome this, the electrolyte is vigorously stirred, and different methods of Te replenishment are employed. Thickness and deposition area are limited by the ability to maintain deposition potential over the entire surface of the growing film. As-deposited films can be fabricated as stoichiometric CdTe, Te-rich (by increasing Te species concentration in the bath) or Cd-rich (by depositing at low potentials with limited Te species concentration). As-deposited electrodeposited CdTe films on CdS thin-film substrates exhibit strong (111) orientation with columnar grains having a mean lateral diameter of 100 to 200 nm. The basis for this technology has been formalized in the open literature [109]. Electrodeposition of CdTe has been intensively studied by the group at Monosolar [110], Ametek [111], and the University of Texas [112]. In the 1980s, the Monosolar process was transferred to SOHIO and thence to BP Solar, where commercial development took place at the factory in Fairfield, California. In the early 1990s, the Ametek process was transferred to the Colorado School of Mines in Golden Colorado.

### 14.2.3 Precursor Reaction at a Surface

#### 14.2.3.1 *Metal organic chemical vapor deposition (MOCVD)*

MOCVD is a nonvacuum technique for depositing CdTe films at moderately low temperature from organic Cd and Te precursors such as dimethylcadmium and diisopropyltellurium in hydrogen carrier gas. The substrates are supported on graphite susceptors and can be heated radiatively or by coupling to a radio frequency generator. Deposition occurs by pyrolytic decomposition of the source gases and reaction of the Cd and Te species. As a consequence, the growth rate depends strongly on the substrate temperature, which typically ranges from 200 to 400°C. As-deposited films 2- $\mu$ m-thick deposited at 400°C exhibit columnar grain structure with lateral grain diameter  $\sim 1$   $\mu$ m. The MOCVD process has been investigated by groups at SMU/USF [113] and Georgia Institute of Technology [114].

#### 14.2.3.2 *Spray deposition*

Spray deposition is a nonvacuum technique for depositing CdTe from a slurry containing CdTe, CdCl<sub>2</sub>, and a carrier such as propylene glycol. The slurry can be sprayed onto unheated or heated substrates, after which a reaction/recrystallization treatment is performed. The application of spray deposition to CdTe films was developed by John Jordan (Photon Energy Corporation) during the 1980s. The company was sold to Coors in 1995 and had its name changed to Golden Photon. Cells with >14% efficiency were fabricated, but commercial development ceased in 1997. In this process, the mixture was sprayed onto the substrates at room temperature and baked at 200°C, followed by a bake in the presence of O<sub>2</sub> at 350 to 550°C, a mechanical densification step, and a final treatment at 550°C. Films produced by this method vary in morphology, grain size, and porosity, but films used to make high-efficiency cells exhibited a 1- to 2- $\mu$ m-thick dense region near the CdTe–CdS interface, a relatively porous back surface region, and random crystallographic