gas such as N_2, Ar, or He. A small partial pressure of O_2 appears to be crucial for obtaining good film density and solar cell junction quality. As-deposited CSS films deposited above 550°C exhibit nearly random orientation and normal grain size distribution with mean grain size that is comparable to film thickness. The CSS process has been intensively investigated by groups at Kodak [98], USF [99, 100], NREL [101], Matsushita [102], and Antec [103, 104] and has yielded the highest small-area cell performance of any process shown in Figure 14.6. Commercial development is presently under way at Antec, GmbH.

14.2.1.3 Vapor transport deposition (VTD)

VTD allows high-rate deposition at high substrate temperature at pressures approaching 0.1 atm onto moving substrates. While CSS is diffusion-limited, VTD works by convective transfer of a vapor stream saturated with Cd and Te to the substrate, where supersaturation of the Cd and Te vapors results in condensation and reaction to form CdTe. The CdTe source consists of a heated chamber containing solid CdTe in which the carrier gas mixes with the Cd and Te vapors and is exhausted through a slit over or under the moving substrate at a distance on the order of ~1 cm. The geometrical configuration of the source influences the uniformity and utilization of the vapors in the carrier gas. The carrier-gas composition can be varied, as with CSS, to include N_2, Ar, He, and O_2. As-deposited VTD films are similar to CSS films, with nearly random orientation and normal grain size distribution with mean grain size that is comparable to film thickness [105]. The VTD process can provide a very high deposition rate onto moving substrates and is currently being investigated by the Institute of Energy Conversion and is under development by First Solar, LLC [106].

14.2.1.4 Sputter deposition

CdTe films have been deposited by radio-frequency magnetron sputtering from compound targets. Mass transfer of Cd and Te occurs via ablation of the CdTe target by Ar^+, followed by diffusion to the substrate and condensation. Typically, deposition is carried out at a substrate temperature less than 300°C and at pressures ~10 mTorr. As-deposited films 2-μm-thick deposited at 200°C exhibit mean grain diameter ~300 nm and nearly random orientation. The sputter-deposition technique has been investigated by groups at the University of Toledo [107] and NREL [108].

14.2.2 Galvanic Reduction of Cd and Te Ions at a Surface

14.2.2.1 Electrodeposition

Electrodeposition of CdTe consists of the galvanic reduction of Cd and Te from Cd^{+2} and $HTeO_2^+$ ions in acidic aqueous electrolyte. The reduction of these ions utilizes six electrons in the following reactions:

$$HTeO_2^+ + 3H^+ + 4e^- \rightarrow Te^o + 2H_2O,\ E_o = +0.559\ V$$

$$Cd^{+2} + 2e^- \rightarrow Cd^o,\ E_o = -0.403\ V$$

$$Cd^o + Te^o \rightarrow CdTe$$