14.2.1 Condensation/Reaction of Cd and Te_2 Vapors on a Surface

14.2.1.1 Physical vapor deposition (PVD)

The basis for vapor deposition of CdTe is the equilibrium between Cd and Te_2 vapors and CdTe solid, $Cd + 1/2Te_2 \Leftrightarrow CdTe$. As a consequence, CdTe can be deposited by coevaporation from elemental sources, by direct sublimation from a CdTe source or by vapor transport using a carrier gas to entrain and deliver Cd and Te_2 vapors from either elemental or CdTe sources. Congruent sublimation of the CdTe compound fixes the gas-phase composition for deposition from a CdTe source, and the relatively low vapor pressure of CdTe compared to elemental Cd and Te facilitates the deposition of single-phase solid films over a wide range of substrate temperatures (refer to Figure 14.3(b)). Similar considerations allow coevaporation from multiple II-VI binary sources to deposit alloys in pseudobinary systems such as $CdZn_{1-x}Te_x$ and $CdTe_{1-x}S_x$.

Evaporation can be carried out from open crucibles or from Knudsen-type effusion cells, with the latter providing superior control over beam distribution and utilization. For effusion-cell evaporation, the deposition rate and uniformity of the species arriving at the substrate are controlled by source temperature, effusion-cell geometry, source to substrate distance, and total pressure [93, 94]. Within the effusion cell, mass transport to the nozzle exit occurs in a transitional flow regime, between free molecular flow and diffusion-limited flow. Effusion cells are typically constructed of boron nitride or graphite and are radiatively heated. For deposition in moderate vacuum, $\sim 10^{-6}$ Torr, with a CdTe source effusion cell with 0.5-cm-diameter orifice and a temperature of 800°C, at a source to substrate distance of 20 cm, a deposition rate of ~ 1 µm/min is obtained on a substrate at a sufficiently low temperature (~ 100°C) for Cd and Te sticking coefficients to approach unity. At higher substrate temperatures, the sticking coefficients of impinging Cd and Te decrease, resulting in a lower deposition rate, imposing a practical limit to substrate temperature of less than 400°C for modest CdTe utilization. As-deposited films exhibit (111) preferred orientation and normal grain-size distribution with a mean grain diameter that depends on film thickness and substrate temperature; for 2-µm-thick films, the mean grain diameter ranges from ~ 100 nm at 100°C to ~ 1 µm at 350°C. The physical vapor deposition (PVD) process has been investigated by university (Stanford University [95], Institute of Energy Conversion at University of Delaware [96]) and industrial (Canrom and Central Research Laboratory at Japan Energy Corporation [97]) groups.

14.2.1.2 Close-space sublimation (CSS)

To evaporate CdTe films onto substrates at temperatures above 400°C, reevaporation of Cd and Te from the growing CdTe surface limits the deposition rate and utilization. This can be mitigated by depositing at higher total pressure, ~ 1 Torr, but mass transfer from the source to the substrate becomes diffusion-limited, so the source and substrate must be brought into close proximity. For close-space sublimation (CSS), the CdTe source material is supported in a holder having the same area as the substrate; the source holder and substrate cover serve as susceptors for radiative heating and conduct heat to the CdTe source and the substrate, respectively. An insulating spacer allows thermal isolation of the source from the substrate, so that a temperature differential can be sustained throughout the duration of the deposition. The ambient for deposition typically contains a nonreactive