could be caused by either space charge or interface recombination, depending on the device preparation.

Band gap gradients formed by controlled incorporation of Ga or S have been proposed as a means to increase device efficiency by separately reducing recombination and collection losses [19, 204–206]. A gradient in the conduction band from wide at the $Cu(InGa)Se_2$/Mo interface to narrow near the space charge region has been used to enhance minority-carrier collection [199, 206] and to reduce back surface recombination when the diffusion length is comparable to the film thickness [207]. Alternatively, a gradient from wide at the $Cu(InGa)Se_2$/CdS interface to narrow at the edge of the space charge region could reduce recombination and increase V_{OC}. In this case, the smaller band gap in the bulk portion of the device can still enable high optical absorption and J_{SC} [19, 206]. The most effective implementation of a surface band gap gradient may be the incorporation of S near the front surface [20] since the main effect is in lowering the valence band, instead of raising the conduction band as with Ga, and there should be less impact on collection of light-generated electrons.

13.6 MANUFACTURING ISSUES

The competitiveness of a PV technology will primarily be governed by its performance, stability, and costs. The best $Cu(InGa)Se_2$ cells and modules have demonstrated efficiency on a par with commercial crystalline silicon products. Long-term stability appears not to be a significant problem, as shown in field tests of prototype modules, but low-cost production remains to be demonstrated in practice.

It is evident that thin films have the potential to be produced at very low costs. Moisture barriers of aluminum films that are deposited on plastic foils to be used, for example, in potato chip bags cost less than 0.01 $\$/m^2$ to produce. This particular example is at the low end of production costs and more advanced functional coatings are in general substantially more expensive to manufacture. Thin film coatings on architectural glass cost on the order of 1 $\$/m^2$. Thus PV modules constructed from thin-film materials have the possibility for very low manufacturing costs. Whether $Cu(InGa)Se_2$ module production will be able to achieve this low-cost potential will depend on how well the process technology fulfills the requirements for material costs, throughput, and yield.

13.6.1 Processes and Equipment

Deposition processes can be either batch-type, in which a number of substrate plates are processed in parallel, or in-line, in which one substrate plate immediately follows the preceding one. In batch processing, a process step is completely finished before the next batch is started, whereas a substrate plate may enter an in-line process step before the previous substrate is finished in order to keep the line continuously running.

One common view on volume production is that in-line continuous processing is a prerequisite for low costs. Fabrication of large-area thin-film products with physical vapor deposition is often made in a continuous or quasi-continuous in-line system. However, the cost of a batch process can be equally low, provided the throughput is large enough. For manufacturing of $Cu(InGa)Se_2$ modules, this means that the CdS chemical bath deposition