Another potential reason for using an HR ZnO buffer layer is to add protection of the interface region from sputter damage induced during deposition of the TCO layer which typically requires more harsh conditions. This seems to be particularly important for some alternative Cd-free buffer layers or with dc magnetron–sputtered TCO layers [162].

13.4.7 Device Completion

In order to contact laboratory test cells, a metal contact is deposited onto the TCO layer. It is shaped as a grid with minimum shadow area in order to allow as much light as possible into the device. Solar cell measurement standards recommend a minimum cell area of 1 cm^2, but many labs routinely use cells in the order of 0.5 cm^2. The metal grid contact can be made by first depositing some tens of nanometers of Ni to prevent the formation of a high resistance oxide layer, and subsequently depositing a few micrometers of Al. Evaporation through an aperture mask is a suitable deposition method.

After deposition of the metal grid, the total cell area is defined by removing the layers on top of the Mo outside the cell area by mechanical scribing or laser patterning. Alternatively, just the layers on top of the Cu(InGa)Se_2 can be removed, by photolithography and etching, since the lateral resistance of the Cu(InGa)Se_2 prevents collection outside the cell area.

The only significant difference in the device layers between lab cells and modules is the thickness of the TCO. Modules normally do not have any grid that assists in current collection over the cell area, so a substantially thicker TCO layer, that is, higher sheet conductivity, is needed in order to keep resistive losses low. A TCO layer with higher sheet conductivity may also have lower optical transmission in the infrared due to increased free-carrier absorption resulting in a decreased photocurrent.

13.5 DEVICE OPERATION

Cu(InGa)Se_2 solar cells have achieved efficiencies approaching 20%, the highest of any thin-film solar cells, largely by empirical processing improvements and in spite of relatively poor understanding of the underlying mechanisms and electronic defects that control the device behavior. However, a more complete picture of the device operation is emerging to enable both a better understanding of the devices and identification of pathways to further improvements.

The operation of Cu(InGa)Se_2/CdS solar cells is characterized by high quantum efficiency (QE) and short-circuit current. The open-circuit voltage increases with the band gap of the absorber layer and is insensitive to grain boundaries and defects at the Cu(InGa)Se_2/CdS interface. A basic device model can be constructed in which the voltage is limited by recombination through bulk trap states in the space charge region of the Cu(InGa)Se_2 absorber layer. Recombination at the Cu(InGa)Se_2/CdS interface is minimized by proper doping and band alignment or surface treatment to create an effective n-type inversion layer in the near-junction region of the absorber layer.

The device operation can be described by identifying loss mechanisms. These can be divided into three categories. The first are optical losses that limit generation of carriers and therefore the device current. The second are recombination losses that limit