9.5.9.2 Concentration dependence of efficiency

Equation (9.13) shows that, for each decade of increase in J_{SC} due to a corresponding increase in the incident light flux, V_{OC} will increase by $(kT/e)\ \ln(10) = 60$ mV for an ideal $n = 1$ junction at 300 K. For a series-connected multijunction device, each junction will contribute this amount to the net increase in V_{OC} with concentration. This increase in V_{OC} gives a significant boost to cell efficiency with concentration, a boost that is relatively greater for low band gap junctions. For instance, a two-junction GaInP/GaAs cell with a one-sun V_{OC} of 2.4 V will go to $V_{OC} = 2.76$ V at 1000 suns for an increase of 15%, whereas a three-junction GaInP/GaAs/Ge cell with a one-sun V_{OC} of 2.6 V will go to $V_{OC} = 3.14$ V at 1000 suns for an increase of 21%. For a cell with negligible series resistance, the fill factor will also increase with concentration, although not in as numerically simple a fashion as does V_{OC}. The increase with concentration is proportionally much less than that for V_{OC}; the fill factor typically increases on the order of 1 to 2% as the concentration is raised from 1 to 1000 suns, for the ideal case of no series resistance.

It is interesting to note that while series-connected multijunction devices maintain their current matching with increasing light intensity (assuming that the spectrum does not change), the increase in junction voltage with concentration means that voltage-matched devices are voltage-matched only for a fixed concentration ratio.

9.5.9.3 Series resistance and metallization

In practice, of course, series resistance is unavoidable. The resulting J^2R power loss scales as the square of the current, and thus eventually becomes a dominant factor for the cell efficiency with increasing current. This series resistance will manifest itself as a loss in the fill factor (and, at very high currents or for very high resistance, in J_{SC} as well). Series-connected multijunction cells, which distribute the spectrum into several subcells and are thus inherently lower-current devices than single-junction cells, therefore have a great advantage in minimizing J^2R losses at high concentrations. For example, the GaInP/GaAs tandem operates at half the current of a single-junction GaAs cell, and thus suffers only one quarter the J^2R loss for a given resistance and concentration.

Even with this low-current advantage of multijunction cells, in adapting a cell from one sun to concentrator operation it may be well worth reducing series resistance. One of the most vital adaptations of a cell design for concentrator operation is the front-contact metallization. The series resistance of the cell depends on the density of front-contact grid fingers [30]; a grid design optimized for 1000 suns will have a much higher density of grid fingers than a one-sun grid. Grid-finger spacings of 200 μm or less are not unusual at 1000 suns. Naturally, decreasing the grid-finger spacing increases the device shadowing and so decreases the current; thus, concentrator grid design involves careful trade-offs of the shadowing versus the series resistance. Fortunately, with the sophisticated photolithography/evaporation/liftoff metallization processing used for high-efficiency devices, grid-finger widths on the order of 3 μm, with height/width aspect ratios of two or more, can be achieved. Such finger dimensions allow a very dense packing of high-conductivity grids, while maintaining a reasonably low shadow loss.

An additional approach to decreasing the series resistance is to raise the emitter conductivity in the top subcell (for monolithic two-terminal devices, there is no lateral