(see Chapter 16 for more detailed discussion). A triple-junction cell for which the *pin* component cells are current-matched under the standard AM1.5 global spectrum may show poor performance under a different light source, for example, a tungsten lamp. The triple-cell J_{SC} is usually close to the J_{SC} of the limiting component cell except when there is a large mismatch and the limiting cell has a very low fill factor. The V_{OC} of the triple cell is the sum of the V_{OC} of the component cells (and reduced by any photovoltages at the tunnel junctions). It should be noted here that the bottom component cell in a triple-stack generates only about one-third of the photocurrent that it would under full sunlight; therefore, its V_{OC} is slightly smaller (usually by ∼20 mV) than when it is exposed to the full sunlight. The middle cell will have about half the current that it would under the full sunlight. The fill factor of the triple cell depends sensitively on the fill factor of the limiting component cell and on the current mismatch among the component cells. A large mismatch leads to a higher triple-cell *FF*, while on the other hand it also leads to a lower triple-cell current.

12.5.3.4 Quantum efficiency measurements in multijunction cells

In measuring the *QE* of a triple-junction solar cell, appropriate light bias and electrical bias need to be applied during the *QE* measurements ([170, 171] or Chapter 16). A direct *QE* measurement without these optical and electrical biases, just as one measures a single-junction cell, would yield a "Λ"-shaped curve, because a current can flow through the cell only if all of the component cells are illuminated simultaneously. When the *QE* of a specific component cell needs to be measured, say the middle cell, a DC bias light is illuminated on the cell through a filter that transmits only blue light and red light so that the top and bottom cells are illuminated. Under this condition, the middle cell current is limiting when the light through the monochromator is absorbed by the cell. Therefore, the current through the sample is that of the middle cell, that is, the AC photo current at the monochromatic light that is absorbed in the middle cell. This AC photocurrent is modulated by an optical chopper, and therefore can be easily detected using a lock-in amplifier.

The other two component cells can be measured in the same way except that different optical filters for the bias light need to be used. When the cells are measured without externally applied electrical voltage bias, the component cell being measured is actually under reverse bias, equal to the sum of the V_{OC} of the other two component cells. In this case, the *QE* curve would indicate the *QE* of the cell under reverse bias condition, which mostly is close to the *QE* under short-circuit condition when the component cell *FF* is high. To measure the *QE* under short-circuit current condition, electrical voltage needs to be externally applied to cancel out the voltage generated by the other component cells under the optical bias light. Figure 12.26 shows the *QE* curves of a triple-junction solar cell measured using this method [158]. The short-circuit current of component cells can be calculated by integrating the *QE* values with the AM1.5 light spectrum. The outer profile in Figure 12.26 is obtained by adding the three component cell *QE* curves. Comparing the *QE* curves in Figure 12.26 and Figure 12.24, the middle cell *QE* is roughly the same as the difference between curves (b) and (a), while the bottom cell *QE* is roughly the same as the difference between curves (e) and (b). The outer profile is roughly the same as curve (e) in Figure 12.24.