over either GaInAsP (1 eV)/GaInAs (0.75 eV) or GaSb [142, 143]. The difficulties in implementing these stacks are associated with making the upper cell very transparent to the sub–band gap light (use of a transparent GaAs substrate, nonconventional approach for the back contact, and a good AR coating on the back, as well as the front, of the upper cell) and with finding a way to mount both cells with simultaneous heat sinking and electrical isolation, a much greater problem at 500 to 1000X than at 10 to 50X. An advantage of this approach is the decoupling of the photocurrents of the two pieces (assuming that four-terminal measurements are made), allowing for greater flexibility in the choice of materials and higher efficiency when the spectrum is changed [99].

The efficiency of a solar cell depends on the operating conditions, complicating the prediction of outdoor performance of solar cells. This is especially complicated for series-connected, multijunction solar cells under variable spectra. The losses expected for two-terminal operation of three- and four-junction cells, compared with six- or eight-terminal operation of the same cells are significant, but may not be much more than the loss that a silicon cell experiences by operating at elevated temperature [29]. For two-terminal operation, the mechanical stack may most easily be accomplished by bonding the two semiconductor materials directly. Because wafer bonding is now routinely used for integrating many devices, techniques are available, and the wafer bond avoids the need to use a transparent substrate, avoids reflection losses, and removes the difficulty of heat sinking and electrically isolating the stacked cells. If a method for reusing the substrate can be made economical, wafer bonding also has the potential to reduce the substrate cost.

There are many more approaches to making a multijunction cell than can be discussed in this chapter. All approaches are variations on the structures shown in Figure 9.4. Wafer bonding of III-V multijunction cells to silicon would provide a lighter substrate (an advantage for space cells) and could reduce the cost if the original substrate could be reused. A method for making a GaAs-Si bond with ohmic character between a GaAs cell and a silicon wafer has been reported [144]. Wafer bonding has not yet been developed for high-yield manufacturing of solar cells, but large-area wafer bonding is a possibility given that eight-inch wafer-bonded silicon-on-insulator substrates are commercially available. The cost of these wafers is currently high (comparable to the cost of four-inch Ge wafers), but may be reduced in the future.

9.8.3 Growth on Other Substrates

A silicon-III-V stack may also be made by growing III-V epitaxial layers directly on silicon. Growth of GaAs on Si has always been problematic because of the large lattice mismatch between the two materials. However, growth of a lattice-matched III-V alloy on silicon might be more similar to the growth of GaAs on Ge. Tu and coworkers have reported the growth of AlGaNP alloys with lattice constants similar to silicon, but having band gaps in the range of 1.4 to 1.95 eV [145]. The use of Si as the 1-eV material in a multijunction higher-efficiency stack is compromised by the poor red *QE* of most Si cells, but the lower cost and weight of the silicon substrate might make it attractive even if higher efficiencies are not achieved.

High efficiencies have been achieved with two-junction (InP/GaInAs) structures on InP [18]. A three- or four-junction structure based on InP could, potentially, achieve