The first high-efficiency GaInP/GaAs dual-junction solar cells were fabricated using an optically thin GaAs TJIC. The best tunnel junctions were doped with C and Se. Hence, they were reasonably stable under the thermal conditions required to grow the top cell and were capable of operating at more than 1000 suns, that is, $J_p > 14$ A/cm^2. They were also less than 30 nm thick and obscured less than 3% of the light destined for the lower cell. With optically thick, unannealed devices, peak tunneling currents were greater than 300 A/cm^2 with excess current densities close to zero [8].

9.6.6.1 AlGaAs/GaInP TJIC

Despite the higher band gap and its concomitant penalty, the p^{++}-AlGaAs/n^{++}-GaInP heterojunction tunnel diode proposed by Jung and coworkers is the preferred TJIC for one-sun operations and may be suitable for concentration [111]. It takes advantage of the innate propensity for AlGaAs to incorporate C and for GaInP to incorporate Se, so that high values of N^* are easily achieved. Hence, peak tunneling currents as high as 80 A/cm^2 were reported. The devices are also thermally stable; J_p is reduced to about 70 A/cm^2 for 30-min anneal at 650°C and to about 30 A/cm^2 for a 30-min anneal at 750°C. This TJIC is more optically transparent than a thin GaAs TJIC and therefore should yield a higher tandem-cell photocurrent.

9.6.7 Chemical Etchants

The processing of epitaxial products into finished devices is beyond the scope of this chapter. Most of the processes used by the industry are proprietary, and there are numerous laboratory processes, such as evaporation of metals and optical coatings, that are suitable for research. One very useful area that is common to both industrial and laboratory processes is the use of selective and nonselective etchants for the various materials used in GaInP/GaAs multijunction solar cells. A list of these etchants is given below (etch rates are at room temperature). Note that solutions containing H_2O_2 typically exhibit an etch rate that depends on the age of the solution [112].

- Mixtures of ammonia, hydrogen peroxide, and water etch GaAs, but do not etch GaInP and AlInP. A common formulation is 2 parts NH_4OH, 1 part 30% H_2O_2, and 10 parts H_2O (2:1:10). Also, a solution of H_3PO_4, H_2O_2, and H_2O combined in a ratio of 3:4:1 etches GaAs and not GaInP.
- Concentrated HCl rapidly etches GaInP, but the surface is easily passivated by dilute HCl and HCl vapor. HCl does not etch GaAs.
- Dilute HCl:H_2O etches AlInP [113].
- Au metallization is impervious to both 2:1:10 and concentrated HCl.
- A 1:20 solution of HCl and CH_3COOH (acetic acid) etches GaInP at a rate of 70 nm/min and GaAs at a rate of <5 μm/min [112].
- $5H_2SO_4$: $1H_2O_2$:$1H_2O$ at room temperature etches GaInP at a rate of about 25 nm/min. It etches GaAs much more rapidly (>1 μm/min).
- Mixtures of HCl:H_3PO_4:H_2O etch GaInP [114]. For high HCl compositions, the etch rate is ~ 1 μm/min.