9.6.4.2 Optical properties

The optical parameters of GaAs are tabulated in the work of Aspnes and coworkers [94] and a model for the optical dielectric function of GaAs (and $Al_xGa_{1-x}As$) has been proposed [95].

9.6.4.3 Window layers and back-surface fields

$Ga_xIn_{1-x}P$ and $Al_xIn_{1-x}P$ should both make excellent window layers and back-surface field layers for GaAs solar cells [96, 97]. Both have Type 1 band alignment with GaAs, with reasonably adequate conduction- and valence-band offsets [86, 98]. Ideally, $Al_xIn_{1-x}P$ would make a better window layer than $Ga_xIn_{1-x}P$ because of its larger band gap energy. However, because of its sensitivity to oxygen contamination, $Al_xIn_{1-x}P$ will probably never produce as good an interface with GaAs as does $Ga_xIn_{1-x}P$. (This is the main problem with the AlGaAs/GaAs interface used widely for single-junction GaAs solar cells [19].) The undoped $Ga_xIn_{1-x}P$/GaAs interface has one of the lowest interface recombination velocities (S < 1.5 cm/s) of any heterostructure ever measured, including the SiO_2/Si interface [96]. In addition, it is difficult to dope $Al_xIn_{1-x}P$ p-type at a level of $p > 1 \times 10^{18}/cm^3$. For these reasons, $Ga_xIn_{1-x}P$ is usually the preferred window layer and BSF layer for GaAs solar cells in GaInP/GaAs tandem-cell structures.

9.6.5 Ge Cells

9.6.5.1 Optical properties of Ge

The optical and electronic properties of Ge are well documented (see Reference [37]). Germanium has a lattice constant close to that of GaAs and has a diamond structure. It is also mechanically stronger than GaAs and, hence, has long been viewed as an excellent substitute for GaAs substrates. With a band gap of 0.67 eV, it is current matched to a thin GaAs top cell [7] and is also a good bottom-cell candidate in a four-junction stack [99]. However, in both these cases, it has several properties that put it at a disadvantage:

- The V_{OC} is limited by its indirect band gap to about 300 mV and is relatively more sensitive to temperature [100].
- It is relatively expensive, hence, it cannot be viewed as a one-sun solar cell material (with the exception of its use in space).
- Germanium is an n-type dopant in GaAs and GaInP. In GaInP, it also exhibits amphoteric behavior with a compensation ratio $N_a/N_d = 0.4$ [101] and has been associated with a deep acceptor state [102].
- Gallium, As, In, and P are all shallow dopants in Ge. Hence, the control of the junction-formation process becomes complicated when it is combined with the III-V heteroepitaxy process (*vide infra*).

9.6.5.2 Junction formation

Diffusion of a Group V or a Group III dopant into a Ge substrate is the most common junction-formation process for Ge subcells. Indeed, because of the proximity of III-V