charges that affect the number of carriers at the surface, and because the capture probability for electrons and holes is different [27]. N-type or intrinsic surfaces are usually better than p-type ones. Stability under UV exposure is another fundamental concern.

In the second approach, the excess carrier density at the interface is decreased relative to the bulk. This effect has already been commented upon with respect to contacts and results in a reduced effective SRV at the bulk edge of the corresponding space charge region. It can be produced by charges in the surface layer, by the electrostatics associated to a MOS structure [28] or by doping.

The surface layer can be accumulated or inverted, or, correspondingly, doped with the same or the opposite type of the substrate. Its recombination activity is better described by a constant saturation current density, J_0, whose minimization follows the same rules as mentioned for the contacts if S at the surface is high. On the contrary, if S is low when compared to D/L for minority carriers (with D the diffusion constant and L the diffusion length in the substrate) in the surface layer, it is better for it to be thin or "transparent" to minority-carrier flow ($w < L$). The optimum doping level is a compromise between reduction of the excess carriers, and heavy doping effects and the increase of the SRV with doping. Moderate doping levels are favored in this case. Under passivated surfaces, J_0 values around 10^{-14} A·cm^{-2} are achievable, with phosphorus-doped substrates giving better results than boron-doped ones [16, 17].

In conclusion, recombination at a noncontacted surface can be made much smaller than at a metallized one, and this has a deep influence in the evolution of Si solar cell design.

7.3 CRYSTALLINE SILICON SOLAR CELLS

7.3.1 Cell Structure

Several studies have been carried out to find the limiting efficiency and the optimum structure of a-Si solar cell [29–31]. All avoidable losses are assumed to be suppressed:

1. no reflection losses and maximum absorption as achieved by ideal light-trapping techniques,
2. minimum recombination: SRH and surface recombination are assumed avoidable and only Auger recombination remains,
3. the contacts are ideal: neither shading nor series resistance losses,
4. no transport losses in the substrate: the carrier profiles in the substrate are flat so that recombination is the minimum possible for a given voltage.

The optimum cell should use intrinsic material, to minimize Auger recombination and free-carrier absorption, and should be around 80-μm thick, the result of the trade-off between absorption and recombination. It could attain nearly 29% efficiency at one sun AM1.5 Global, 25°C [30].

This ideal case does not tell us where to put the contacts. To realize Condition 4 mentioned above, the contacts should be located at the illuminated or the front face, closest to photogeneration (Figure 7.1a). Because of metal shading losses this threatens