The optimum substrate doping depends on the cell structure and dominant recombination mechanism. Though intrinsic substrates present the advantage of highest Auger-limiting lifetimes, higher doping is favored when SRH recombination is present, since recombination is proportional to the excess density that decreases, for a given voltage, as doping increases [29]. This is balanced with a reduction of the lifetime itself.

A high doping also helps in minimizing the series resistance losses associated to the transport of carriers to the back face in thick cells with the majority carrier contact at the back.

Doping levels in the 10^{16} cm^{-3} range are found in the substrate of industrial cells. Very high efficiencies have been obtained with both low (1 Ω·cm for PERL cells) and high substrate resistivities, as in the point-contact cells [33].

7.3.2.3 Thickness

From the point of view of electrical performance, the choice of the optimum substrate thickness also depends on the structure and the quality of the materials and involves several considerations. In cells with diffusion lengths longer than the thickness, the most important issue is surface recombination: if S at the back is higher than D/L for the minority carriers in the substrate (around 250 $cm \cdot s^{-1}$ for the best cells), thinning the cell increases recombination at a given voltage, and vice versa. Thinner cells always absorb less light as well, which is attenuated by light-trapping techniques. Passivated emitter and rear locally diffused (PERL) cells were reported to improve when going from 280- to 400-μm thickness because of a (relatively) high rear surface recombination and nonideal light-trapping [49].

The losses associated with the transport of carriers extracted at the nonilluminated face decrease with thinning: in conventional structure cells; this leads to decreased series resistance. In back-contacted cells, both types of carriers benefit from thinning and the trade-off in absorption leads to lower w values, around 150 to 200 μm.

The diffusion length of industrial cells (around 100 μm) is generally lower than thickness. These cells are rather insensitive to thinning because they collect only the generation near the contact and are not affected by rear surface recombination. The driving criteria are cost and fabricability. A thickness in the 200- to 300-μm range is usually employed but there is a clear trend toward thinner wafers for saving expensive silicon material [47], and advanced wafering techniques and procedures to process very thin, large-area substrates without breaking are being developed: light-trapping and back recombination will become increasingly important.

7.3.3 The Front Surface

7.3.3.1 Metallization techniques

Metal grids are used at the front face to collect the distributedly photogenerated carriers. The compromise between transparency and series resistance requires metallization technologies able to produce very narrow but thick and highly conductive metal lines with