awaited some understanding of how to improve optical losses through enhanced absorption and the recognition and mitigation of electronic losses because of carrier recombination at interfaces.

Initial theoretical analysis based on thermodynamic considerations [5] suggested that rough surfaces and an asymmetric cell structure would effectively enhance optical absorption in the cell. Surface texturing, which was initially introduced to reduce surface reflectance for broadband illumination, also resulted in an increase in the optical path of light transmitted into a Si wafer [6–10]. Following the initial success, texture etching became a standard process step for fabricating Si solar cells, both in the laboratory and commercially. Figure 8.3 shows calculated short-circuit current density (J_{SC}) values as a function of thickness for different texture structures including planar, standard chemical texture, pyramids, inverted pyramids, and perpendicular slats. The surface structures are illustrated in Figure 8.4. However, only the laboratory cells, fabricated on high-quality wafers and with high-reflectance back contacts, realized the advantage of light-trapping. Although commercial cells also use texturing, its usefulness was perhaps largely limited to lowering the surface reflectance, rather than enhancing light-trapping. This is because the typical commercial solar cells use an Al-alloyed back contact that develops a rough interface, which has very low reflectance and allows most of the light to be transmitted into the metal where it is absorbed. The light absorbed in the metal constitutes an optical loss.

Surface texture has been successfully produced by anisotropic chemical etching in solutions of KOH or NaOH. It is known that texturing involves exposition of (111) crystallographic planes, which yield pyramids on (100) wafers. However, good texturing requires tedious process steps of developing a chemical composition containing silicates [11]. It was fortunate that texture etching could be combined with saw-damage removal for a low cost process. Recently, other texturing techniques have been developed that include reactive-ion etching, mechanical scribing of grooves, and acid etching [12–14]. However, none of these methods are suitable for thin-film solar cells because they produce deep

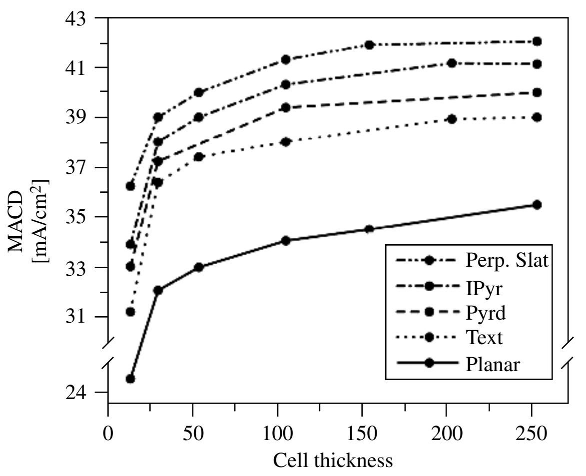

Figure 8.3 Calculated MACD for Si solar cells with different texture shapes: perpendicular slats, inverted pyramids, uniformly textured pyramids, chemically textured random pyramids and planar