and the permanent support can be a rather inexpensive material. The temporary support can be a Si wafer, which is reusable for growing other Si films. A liftoff CLEFT (cleavage of lateral epitaxial films for transfer) technique was originally developed for Ge- and GaAs-based cells using zone-melting recrystallization [29–32]. This technique is very successful, but is not warranted for a low-cost device. (2) A thin film of Si is deposited on a permanent substrate and is then processed into a solar cell. To use conventional processes, such a substrate must withstand high-temperature processing. For example, several laboratories have investigated development of high-temperature glass, thermally matched to Si [33, 34]. Alternately, newer processing methods must be developed that are compatible with low-cost substrates.

The current techniques for TF-Si solar cell fabrication are diverse and use single-crystalline, large-grain multicrystalline, or fine-grain microcrystalline Si films. Although this distinction appears to be related to grain size, in reality, it separates the technologies related to the growth of the film itself. The single- and multicrystalline Si films require high temperature $>800^{\circ}$C, use of a Si substrate, some type of epitaxial growth, and/or separation from the substrate. The fine-grain films (μ-crystalline) are deposited on a low-cost substrate typically at $<600^{\circ}$C. Thus, the approaches currently used in thin-film Si solar cell fabrication can be categorized on the basis of processing temperature and substrates used for depositing the thin film. These approaches include using a single-crystalline wafer for deposition of a thin-Si layer, which is subsequently separated from it (or removing a thin layer from a single-crystal wafer and transferring it to another substrate), depositing thin films on a multicrystalline Si wafer, and using a non-Si substrate. Table 8.2 summarizes various substrate types, processing approaches, and the cell efficiencies obtained in the laboratory. Recently, a number of papers have reviewed approaches for TF-Si solar cells [35–37]. Here, we have selected some approaches for further discussion and to illustrate general requirements for design and processing of thin-film Si solar cells.

8.2.1 Single-crystal Films Using Single-crystal Si Substrates

This approach involves separating a single-crystal thin film from a single-crystal substrate. Three techniques are currently being followed. One approach consists of generating a porous-Si layer on a single-crystal substrate, which is then followed by epitaxial growth of a thin film. The thin film is then separated from the substrate by chemically etching the porous-Si interface. Figure 8.8 illustrates various process steps used for this approach [38, 39]. The best efficiency attained by such cells is about 12.5%. The parameters for the best cell (4 cm^2) are $V_{OC} = 623$ mV, $J_{SC} = 25.5$ mA/cm^2, and $FF = 79\%$.

The second approach that has been suggested is similar to the "smart cut" method used in the microelectronics field for wafer-bonding [40, 41]. It involves implanting a Si wafer with hydrogen and creating a defect interface below the surface, followed by a separation of the surface layer. This technique has been used successfully to separate thin (<1 μm) layers of Si, but may not be cost-effective for making the 10-μm-thick, separable layers needed for solar cells. For the hydrogen atoms to penetrate such a thick layer required for PV applications, requires a very high-energy implant. No single-junction cells have been made using this approach. Recently, however, this approach has been used for making stacked multijunction solar cells that use GaAs-based and Si-based devices.