

In contrast to p/n homojunction development, CdTe heterojunction solar cells have been widely investigated since 1960, proceeding along two paths, according to CdTe conductivity type. For n -type CdTe single crystals and polycrystalline films, extensive work was carried out on heterojunctions with p -type Cu_2Te . In the early 1960s, n -type CdTe/ p -type Cu_2Te devices having a structure analogous to the CdS/ Cu_2S solar cell [10] were fabricated, by surface reaction of n -type single crystals or polycrystalline films in acidic aqueous solutions containing Cu salts for topotaxial conversion of CdTe to p -type Cu_2Te [11–15]. By the early 1970s, the best thin-film CdTe/ Cu_2Te cells achieved cell efficiencies $>7\%$, with $V_{\text{OC}} = 550$ mV, $J_{\text{SC}} \sim 16$ mA/cm² (60 mW/cm² irradiance), and $FF = 50\%$, as reported by Justi *et al.* [16]. Interestingly, these cells utilized an underlying 5- μm -thick n -type CdS layer to improve adhesion and electrical contact of the 20- μm -thick CdTe film on molybdenum substrates. Difficulty in controlling the Cu_2Te formation process, poor device stability in CdTe/ Cu_2Te cells, and lack of a transparent p -type conductor ultimately shifted research emphasis to heterojunction structures employing p -type CdTe. Other work with n -type CdTe utilized Schottky barrier devices, formed by heating Pt or Au grids in contact with n -type CdTe single crystals [16] or electrodeposited CdTe thin films, with efficiencies approaching 9% [17].

For solar cells with single-crystal p -type CdTe, heterojunctions using stable oxides, such as $\text{In}_2\text{O}_3:\text{Sn}$ (ITO), ZnO, SnO_2 , and CdS have been more widely investigated. In these devices, the short wavelength spectral response is influenced primarily by the transmission of the heteropartner and low-resistance contact, collectively referred to as the window layer. Solar cells based on p -type CdTe single crystals with electron-beam-evaporated indium–tin oxide (ITO) window layers with efficiencies = 10.5% were developed by the Stanford group, 1977, with $V_{\text{OC}} = 810$ mV, $J_{\text{SC}} = 20$ mA/cm², and $FF = 65\%$ [18]. In 1987, cells made by the reactive deposition of indium oxide, In_2O_3 , on p -type CdTe single crystals yielded total area efficiencies = 13.4%, with $V_{\text{OC}} = 892$ mV, $J_{\text{SC}} = 20.1$ mA/cm², and $FF = 74.5\%$ [19]. In this device, the CdTe crystal had a carrier concentration of $6 \times 10^{15}/\text{cm}^3$ and the CdTe (111) face was etched in bromine methanol prior to loading into vacuum for In_2O_3 deposition. The V_{OC} of this cell remains the highest ever reported for a CdTe device. Solar cells with ZnO window layers on p -type CdTe single crystals yielded poorer junction behavior, with efficiency $<9\%$ and $V_{\text{OC}} = 540$ mV [20].

Cells made by evaporating n -type CdS films onto single-crystal p -type CdTe were first prepared by Muller *et al.* in the mid-1960s [21, 22], yielding conversion efficiencies less than 5%. In 1977, Mitchell *et al.* reported a conversion efficiency = 7.9% with $V_{\text{OC}} = 630$ mV for a cell with 1- μm -thick CdS and an ITO transparent electrode [23]. The highest efficiency for a cell fabricated with thin-film CdS on p -type CdTe single crystal was reported by Yamaguchi *et al.* in 1977. Their cell utilized 0.5- μm -thick CdS deposited by chemical vapor deposition onto the (111) face of phosphorous-doped CdTe single crystals and gave 11.7% efficiency with $V_{\text{OC}} = 670$ mV [24].

Thin-film CdTe/CdS heterojunction solar cells have been fabricated in two different configurations, referred to as *substrate* and *superstrate*. In both configurations, light enters the cell through the transparent conducting oxide (TCO) and CdS films. However, in the superstrate cell, the TCO, CdS, and CdTe layers are sequentially deposited onto a glass superstrate, which also serves as the mechanical support for the cell, and light must pass through the supporting glass before reaching the CdS/CdTe junction. In the substrate configuration, the CdTe film is typically deposited first onto a suitable