rejected for commercialization due to fundamental and fatal stability problems related to electrochemical decomposition [71]. In contrast, a-Si has a minor stability problem that is not catastrophic and has not been a major barrier to further development and production as discussed in Chapter 12. No fundamental stability problem has been found with $Cu(InGa)Se_2$ and CdTe modules. Consequently, significant industrial and government-sponsored research and development resources have been directed worldwide at TFSC technology. This has led to steady progress in champion cell efficiencies as seen in Figure 1.8.

The main advantage of TFSC is that they will eventually have lower costs than c-Si-wafer PV technology when they are produced in sufficiently large volumes to offset the initial capital investment. The lower costs of TFSC derive from the following characteristics: they are typically 100 times thinner than Si wafers ($\sim$1–3 μm for all the semiconductor layers) deposited onto relatively low-cost substrates such as glass, metal foils, and plastics; they are deposited continuously over large areas at much lower temperature (200 to 500°C vs $\sim$1400°C for c-Si); they can tolerate higher impurities (thus needing less expensive purification of raw materials); and they are easily integrated into a monolithic interconnected module. For a reference, the semiconductors in typical TFSC are 10 times thinner than a human hair. TFSC are either polycrystalline with small $\sim$1 μm sized grains such as $Cu(InGa)Se_2$ or CdTe, or else amorphous like a-Si. This is a consequence of being deposited at temperatures too low to allow perfect crystalline bond formation. TFSCs typically consist of 5 to 10 different layers whose functions include reducing resistance, forming the *pn* junction, reducing reflection losses, and providing a robust layer for contacting and interconnection between cells. Some of the layers are only $\sim$20 atoms thick (10 nm), yet they may be a meter wide! This requires excellent process control. The manufacturing process is designed such that they are deposited sequentially on moving substrates as in a continuous process line. This minimizes handling and facilitates automation, including laser scribing, to isolate and interconnect individual cells on the module, called monolithic integration.

With all the advantages of TFSCs, why does c-Si or multi-Si still dominate 90% of the world market? This brings us to the disadvantages of TFSC: they have lower efficiencies (so far), and they have a much less-developed knowledge and technology base compared to c-Si. Consequently, under-capitalized companies have had to struggle to develop not only an understanding of the materials and devices but also the equipment and processing to manufacture them. The thin-film PV industry has had to develop the technologies all by itself with considerably less financial resources than the Si industry had. They were not able to adopt a mature technology like the Si PV community did from the Si electronics industry.

What are the strengths and remaining challenges for the TFSC industry? We will review the salient characteristics of the three leaders: a-Si, $Cu(InGa)Se_2$/CdS, and CdTe/CdS.

Amorphous Si (Chapter 12) is deposited from hydride gases such as SiH_4 using plasma to decompose the gas. This is called *plasma-enhanced CVD* (PECVD) and allows for large areas to be coated rather uniformly and with excellent control. However, the utilization of gases is only around 10 to 30%, meaning much of the source material is