Several companies worldwide are pursuing the commercial development of $Cu(InGa)Se_2$-based modules. The most advanced, having demonstrated excellent reproducibility in its module manufacturing using the two-stage selenization process for $Cu(InGa)(SeS)_2$ deposition [3], is Shell Solar Industries (SSI) in California, which was formerly ARCO Solar and then Siemens Solar. They are now in production with 5-, 10-, 20-, and 40-W modules that are commercially available. In Germany, Würth Solar is in pilot production using an in-line coevaporation process for $Cu(InGa)Se_2$ deposition and has also reported large area modules with >12% efficiency. In the USA, several companies are in preproduction or pilot production: Energy Photovoltaics, Inc. (EPV) is using its own in-line evaporation process, International Solar Electric Technology (ISET) is developing a particle-based precursor for selenization, and Global Solar Energy (GSE) is pursuing a process for roll-to-roll coevaporation onto a flexible substrate. In Japan, Showa Shell, using a two-stage selenization process, and Matsushita, using coevaporation for $Cu(InGa)Se_2$ deposition, are also in production development stages.

Despite the level of effort on developing manufacturing processes, there remains a large discrepancy in efficiency between the laboratory-scale solar cells and minimodules, and the best full-scale modules. In part, this is due to the necessity for developing completely new processes and equipment for the large-area, high-throughput deposition needed for manufacturing thin-film photovoltaics. This is compounded by the lack of a comprehensive scientific base for $Cu(InGa)Se_2$ materials and devices, due partly to the fact that it has not attracted a broader interest for other applications. This lack of a science base has been perhaps the biggest hindrance to the maturation of $Cu(InGa)Se_2$ solar cell technology as most of the progress has been empirical. Still, in many areas a deeper understanding has emerged in the recent years.

In this chapter we will review the current status and the understanding of thin-film $Cu(InGa)Se_2$ solar cells from a technology perspective. For deeper scientific discussion of some aspects, we refer to suitable references. In order of presentation, this review covers (Section 13.2) structural, optical, and electrical properties of $Cu(InGa)Se_2$ including a discussion of the influence of Na and O impurities; (Section 13.3) methods used to deposit $Cu(InGa)Se_2$ thin films, the most common of which can be divided into two general types, multisource coevaporation and two-stage processes of precursor deposition followed by Se annealing; (Section 13.4) junction and device formation, which typically is done with chemical bath CdS deposition and a ZnO conduction layer; (Section 13.5) device operation with emphasis on the optical, current-collection, and recombination-loss mechanisms; (Section 13.6) module-manufacturing issues, including process and performance issues and a discussion of environmental concerns; and finally, (Section 13.7) a discussion of the outlook for $CuInSe_2$-based solar cells and critical issues for the future. In places where aspects of $Cu(InGa)Se_2$ solar cells cannot be covered in full, reference will be made to other review works that serve to complement this chapter.

13.2 MATERIAL PROPERTIES

The understanding of $Cu(InGa)Se_2$ thin films, as used in photovoltaic (PV) devices, is primarily based on studies of its base material, pure $CuInSe_2$. Thorough reviews on $CuInSe_2$ can be found in References [23–25]. However, the material used for making solar cells is $Cu(InGa)Se_2$ containing significant amounts (of the order of 0.1%) of Na [26].