series-interconnected modules instead of cells, both from series resistance and from inactive device area. In an optimized, conventional thin-film module design, these kinds of losses correspond to about 1% unit of efficiency. With a more advanced design using metal grids for interconnection, interconnect losses can be made nearly negligible [210]. Another kind of difference between modules and record cells is associated with the freedom to use higher process temperatures for cells that are not sensitive to deformed glass. These results are not necessarily relevant to module fabrication but indicate the potential of the materials.

In a product the initial efficiency is of little interest if it deteriorates after some time in operation. Cu(InGa)Se_2 modules fabricated by ARCO Solar and later Siemens Solar have shown stable performance in field tests over more than 12 years [3], as shown in Figure 13.24. On the other hand, severe degradation has been observed after exposure of cells to 85% relative humidity at 85°C for 1000 h [211], the so-called damp heat test, which is one of the certification tests in the IEC 61 646 protocol. While this test is rather severe and may not be relevant to thin-film modules, it shows the need for encapsulation techniques that minimize the exposure of the thin-film materials to moisture.

The outdoor module performance demonstrated in Figure 13.24 shows that Cu(InGa)Se_2 PV modules have the stability and performance to compete in any power application, be it stand-alone or grid-connected. Thin-film modules have a great advantage over silicon-wafer PV for consumer applications in which the power needed often is relatively small. The large substrate plates, which have a power of 40 W_P or more, can easily be cut into smaller pieces, to essentially any power specification. This is much less costly than making small crystalline-silicon modules in which each cell has to be cut into pieces before assembling the modules. Additionally, the patterning structure of the interconnects can be designed to fit a large variety of shape and voltage requirements. Aesthetically, the solid black appearance of Cu(InGa)Se_2 modules may be preferred to the nonuniform bluish appearance of the silicon-wafer modules in some building-integrated applications.

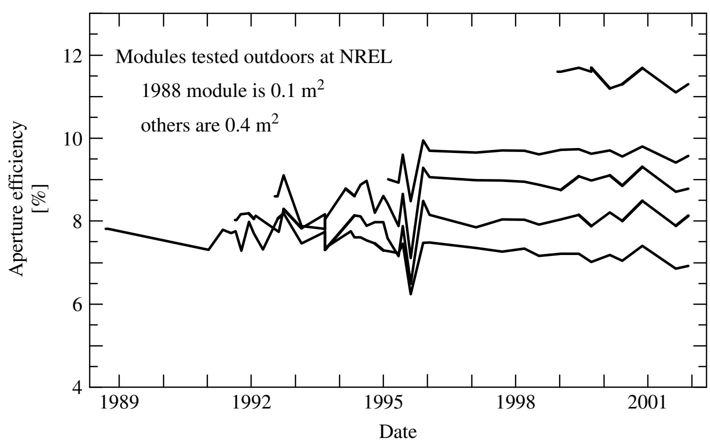

Figure 13.24 Examples of outdoor testing results at NREL of Cu(InGa)Se_2 modules showing stability over 12 years. Fluctuations in years 1992–1996 are due to changes in testing conditions. (Data courtesy of Shell Solar Industries)