heavily from the safety procedures developed by the integrated circuit industry, use a variety of methods to improve the safety of workers. Toxic gases are diluted in hydrogen or silane to 1 to 20%. Gas cylinders are installed outside the building or in fireproof gas cabinets. Toxic gas monitors are installed throughout the plants. Automatic gas isolation and operation shutdowns are implemented. These, among other safety procedures, ensure safe operations in these plants.

The solar conversion efficiency of production modules is generally lower than the efficiency of the research and development (R&D) scale, small-area solar cells since production processes are more restrained by cost reductions. The differences in efficiency are mostly from the TCO performance, semiconductor material quality, deposition uniformity, encapsulation loss, bus bar shadow loss and electrical loss, and small shunts. Rech *et al*. provided a detailed analysis in the efficiency differences between R&D and manufacturing at Phototronics, Germany [191].

12.6.4 Module Performance

Two aspects of PV modules are generally evaluated: maximum solar conversion efficiency and environmental stability. Table 12.5 lists PV modules produced by selected organizations around the world; the table separately lists modules made in R&D type machines (area about 0.1 m^2) and large-area modules (area 0.4 m^2 or greater), mostly produced from production lines. Presently in 2002, large-area modules, with approximately 8% stable efficiency, are manufactured at United Solar and BP Solar and are commercially available in large quantities.

Photovoltaic modules are also evaluated through various environmental tests, as listed in UL, IEC, and IEEE standard testing procedures (see Chapter 16 for more on module testing). These tests generally include thermal cycles between −40 to 90°C; humidity freeze cycles between −40 to 85°C at 85% humidity; hail impact; wet hi-pot

Table 12.5 Stabilized efficiency of a-Si PV modules manufactured by various companies

Structure	Stable η [%]	Size [m^2]	Company	Reference
R&D modules				
a-Si/a-SiGe/a-SiGe	10.5	0.09	United Solar	[186]
a-Si/a-SiGe	9.1	0.08	BP Solar	[160]
a-Si/a-SiGe	9.5	0.12	Sanyo	[192]
Large-area modules				
a-Si/a-SiGe	9.3	0.52	Sanyo	[193]
a-Si/a-SiGe/a-SiGe	9.0	0.32	Fuji	[160]
a-Si/a-SiGe	8.1	0.36	BP Solar	
a-Si/a-SiGe/a-SiGe	7.9	0.45	United Solar	
a-Si/a-Si/a-SiGe	7.8	0.39	ECD	[185]
a-Si/poly-Si	10.0	0.37	Kaneka	[194]