Table 10.6 Small area thin-film solar cell efficiency and specific power. AM0 and AM1.5 given when available. Results for a-Si devices in initial state before stabilization. AM0 results for a-Si triple junctions of a-Si/a-SiGe/a-SiGe [42] are higher than AM1.5 because they were optimized for AM0 spectrum, all other cells optimized for AM1.5. Substrate thickness estimated in some cases. Specific power calculated by authors with some assumptions. (n/a means not available)

Cell type	Cell + substrate thickness	AM1.5 efficiency [%]	AM0 efficiency [%]	Specific power [W/kg] @AM1.5	Reference for cell results
a-Si triple junction	Stainless steel, 128 μm	11.9	12.7	108	[39]
a-Si triple junction	Stainless steel, 7 μm	6.5	n/a	1080	[40]
a-Si triple junction	Kapton, 52 μm	∼12 (est.)	12.7	∼1200	[39]
a-Si double junction	Glass, ∼1.5 mm	11.7	n/a	31	[41]
$Cu(InGa)Se_2$	Glass, ∼1.5 mm	18.8	n/a	50	[42]
$Cu(InGa)Se_2$	Stainless steel 128 μm	17.4	n/a	156	[42]
$Cu(InGa)Se_2$	Polyimide 54 μm	12.1	n/a	1260	[43]
$Cu(InGa)S_2$	Stainless steel 128 μm	10.4	8.8	93	[44]
CdTe	Polyimide 10 μm	8.6	n/a	n/a	[45]
CdTe	Glass, ∼1.5 mm	15	n/a	40	[46]

efficiency is possible with a dual-junction device. NASA and NREL have both initiated dual-junction CIS-based thin-film device programs. The use of Ga to widen the bandgap of CIGS and thus improve the efficiency is well established [42]. The substitution of S for Se also appears to be attractive as a top cell material. In particular, AM0 cell efficiencies 8.8% have been measured for $CuIn_{0.7}Ga_{0.3}S_2$ (E_g 1.55 eV) thin-film devices on flexible stainless steel substrates [44]. Other wide bandgap top cell possibilities under investigation include adding CdZnTe absorbers as discussed at the end of Chapter 14 .

The majority of thin-film devices developed for terrestrial applications have been on heavy substrates such as glass. However, progress is being made in reducing substrate mass through the use of thin metal foils and lightweight flexible polyimide or plastic substrates [47]. The use of such plastic substrates as Upilex or Kapton puts a slight restriction on the processing temperatures. This of course can be obviated by the use of metal foil if one is willing to accept the mass penalty.

In addition to cost and weight savings for spacecraft, thin-film solar cells have potential for improved radiation resistance relative to single-crystal cells, possibly extending mission lifetimes. For example, after a dose of 10^{16} 1 MeV *electrons*/cm^2, the maximum power generated by a GaAs cell can decrease to less than half of its BOL value. By contrast, after a dose of 10^{13}/cm^2 10 MeV *protons* (which would degrade GaAs cell power performance to less than 50% of BOL), the power generated by CIS cells has been shown to retain more than 85% of its BOL value [48].

In addition to thin-film cell development, there is the problem of making thin-film arrays for space. The flexibility of a thin-film cell on a polymeric substrate is a great advantage when it comes to stowability and deployment; however, it must be rigidly