We use these spectra to find out how much solar energy is absorbed by layers of varying thickness. The example used in the figure is an a-Si:H layer with a thickness $d = 500$ nm. Such a layer absorbs essentially all photons with energies greater than 1.9 eV (the energy at which $\alpha = 1/d$). We then look up how much solar irradiance lies above 1.9 eV. Assuming that the reflection of sunlight has been minimized, we find that about 420 W/m^2 is absorbed by the layer (the gray area labeled “absorbed”). Through such a layer 580 W/m^2 of energy is transmitted. These energies may be compared to the results for c-Si, for which a 500-nm-thick layer absorbs less than 200 W/m^2.

To absorb the same energy as the 500-nm a-Si:H layer, a c-Si layer needs to be much thicker. The implication is that much less material is required to make a solar cell from a-Si than from c-Si.[3] In the remainder of this section, we first describe how amorphous silicon solar cells are realized in practice, and we then briefly summarize some important aspects of their electrical characteristics.

12.1.2 Designs for Amorphous Silicon Solar Cells: A Guided Tour

Figure 12.1 illustrates the tremendous progress over the last 25 years in improving the efficiency of amorphous silicon–based solar cells. In this section we briefly introduce three basic ideas involved in contemporary, high-efficiency devices: (1) the *pin* photodiode structure, (2) the distinction between “substrate” and “superstrate” optical designs, and (3) multijunction photodiode structures. A good deal of this chapter is devoted to more detailed reviews of the implementation and importance of these concepts.

12.1.2.1 pin photodiodes

The fundamental photodiode inside an amorphous silicon–based solar cell has three layers deposited in either the p-i-n or the n-i-p sequence. The three layers are a very thin (typically 20 nm) p-type layer, a much thicker (typically a few hundred nanometer), undoped *intrinsic* (i) layer, and a very thin n-type layer. As illustrated in Figure 12.3, in this structure excess electrons are actually donated from the n-type layer to the p-type layer, leaving the layers positively and negatively charged (respectively), and creating a sizable “built-in” electric field (typically more than 10^4 V/cm).

Sunlight enters the photodiode as a stream of photons that pass through the p-type layer, which is a nearly transparent “window” layer. The solar photons are mostly absorbed in the much thicker intrinsic layer; each photon that is absorbed will generate one electron and one hole photocarrier [12, 13]. The photocarriers are swept away by the built-in electric field to the n-type and p-type layers, respectively – thus generating solar electricity!

The use of a *pin* structure for a-Si:H-based solar cells is something of a departure from solar cell designs for other materials, which are often based on simpler p-n structures.

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[3] The very different optical properties of c-Si and a-Si reflect the completely different nature of their electronic states. In solid-state physics textbooks, one learns about the “selection rules” that greatly reduce optical absorption in c-Si, which is an “indirect band gap” semiconductor. Such selections rules do not apply to a-Si. Additionally, the “band gap” of a-Si is considerably larger than that for c-Si.