is used. For an R&D type deposition system with a 200-cm^2 electrode area and for the deposition of a-Si at the rate of 1 Å/s, a few sccm (cubic centimeters per minute at atmospheric pressure) of SiH_4 flow is typical. As one may easily calculate, for such a chamber with an electrode diameter of 16 cm and an electrode gap of 2.54 cm, 1 sccm of SiH_4 (or 0.005 sccm/cm^2 for this chamber) for a 1-Å/s deposition rate corresponds to a gas utilization of 11%. For the deposition of high-quality, stable a-Si material, a hydrogen dilution at appropriate level is usually used, as will be discussed in Section 12.3.6.

Another important aspect of the growth of high-quality a-Si films is the reduction of contaminants, such as oxygen, carbon, nitrogen, or metal elements. Fortunately, because of the flexibility of the bonding network in an amorphous solid, the tolerance level for contaminants in a-Si is much higher than that of its crystalline counterpart. For example, for one of the cells (with a 1.84-eV intrinsic layer) whose optoelectronic behavior is shown in Figure 12.23, a secondary ion mass spectroscopy (SIMS) measurement [78] reveals that the intrinsic layer has concentrations of O, C, and N around 1.3×10^{19}, 2.2×10^{18}, and $1.7 \times 10^{17}/cm^3$. Despite these contamination levels, this cell has a very good efficiency; the contamination levels indicated are typical for a-Si-based i-layers. However, when the amount of contaminants are higher than these in the i-layers, the device performance, particularly the fill factor, will suffer as a result of the reduced diffusion length of photogenerated carriers.

To understand and monitor the film growth in a PECVD process, various spectroscopic tools, including optical emission spectroscopy [79], optical absorption spectroscopy [80], and residual gas analyzer [81] have often been used to measure the plasma and the concentration of various species inside the reactor. It is believed that the SiH_3 radical is mostly responsible for the growth of high-quality a-Si film [82]. Such spectroscopic tools could be useful in studying and monitoring the active species and contaminants during growth, especially for process control in manufacturing.

RF glow discharge systems may be designed with different geometries based on specific needs and deposition requirements. While in R&D process the substrates and electrode are usually placed horizontally, in manufacturing processes the substrates are often installed vertically for high throughput production.

12.3.3 Glow Discharge Deposition at Different Frequencies

The standard RF frequency for glow discharge deposition is $f = 13.56$ MHz, which is a frequency allotted for industrial processes by federal and international authorities. A much larger frequency range has been explored, including DC ($f = 0$), low frequency ($f \sim$ kHz), very high frequency (VHF) ($f \sim 20-150$ MHz), and microwave frequency (MW) ($f = 2.45$ GHz). DC glow discharges were used in the early days of amorphous silicon at RCA Laboratories, and they are presently used in manufacturing at BP Solar, Inc. [63, 64]. AC glow discharge, including RF, VHF, and MW PECVD, are more widely used because of the relative ease in maintaining the plasma and because of more efficient ionization. VHF and MW deposition have been intensively studied because of the higher deposition rate both for amorphous and, recently, for microcrystalline and polycrystalline silicon films. In the following, we discuss the use of VHF and MW PECVD for a-Si deposition.