11 A Little History of Solar Cells

We will start our discussion on PV technology with a brief summary of the *history of solar energy*. Already in the seventh century BCE, humans used magnifying glasses to concentrate sunlight and hence to make fire. Later, the ancient Greeks and Romans used concentrating mirrors for the same purpose.

In the 18th century the Swiss physicist Horace-Bénédict de Saussure build heat traps, which are a kind of miniature green houses. He constructed hot boxes, consisting of a glass box, within another bigger glass box, with a total number of up to five boxes. When exposed to direct solar irradiation, the temperature in the innermost box could rise up to values of 108°C; warm enough to boil water and cook food. These boxes can be considered as the World's first solar collectors.

In 1839, the French physicist Alexandre-Edmond Becquerel, discovered the photovoltaic effect at an age of only 19 years. He observed this effect in an electrolytic cell, which was made out of two platinum electrodes, placed in an *electrolyte*. An electrolyte is an electrically conducting solution; Becquerel used silver chloride dissolved in an acidic solution. Becquerel observed that the current of the cell was enhanced when his setup was irradiated with sunlight. A photograph is shown in Fig. 11.1.

In the 1860s and 1870s, the French inventor Augustin Mouchot developed solar powered steam engines using the World's first *parabolic trough* solar collector, that we will discuss in Chapter 22. Mouchot's motivation was his believe that the coal resources were limited. At that time, coal was *the* energy source for driving steam engines. However, as coal became cheaper, the French government decided that solar energy was too expensive and stopped funding Mouchet's research.

In 1876, the British natural philosopher William Grylls Adams together with his student Richard Evans Day demonstrated the photovoltaic effect in a junction based on platinum and the semiconductor selenium, however with a very poor performance. Seven years later, the American inventor Charles Fritts managed to make a PV-device based on a gold-

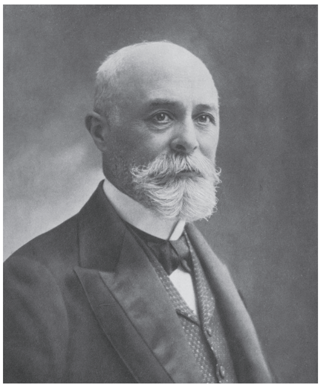

Figure 11.1: Alexandre-Edmond Becquerel [41]

Figure 11.2: Daryl M. Chapin, Calvin S. Fuller, and Gerald L. Pearson, the developers of the first modern solar cell [42].

selenium junction. The energy conversion efficiency of that device was 1%.

In 1887, the German physicist Heinrich Hertz discovered the photoelectric effect, already briefly mentioned in Chapter 3. In this effect, electrons are emitted from a material that has absorbed light with a wavelength shorter than a material-dependent threshold frequency. In 1905 Albert Einstein published a paper in which he explained the photoelectric effect with assuming that light energy is being carried with quantised packages of energy [23], which we nowadays call *photons*.

In 1918 the Polish chemist Jan Czochralski invented a method to grow high-quality crystalline materials. This technique nowadays is very important for growing monocrystalline silicon used for high-quality silicon solar cells that we will study in detail in Chapter 12. The development of the c-Si technology started in the second half of the 20$^{\text{th}}$ century.

In 1953, the American chemist Dan Trivich was the first one to perform theoretical calculations on the solar cell performance for materials with different bandgaps.

The real development of solar cells as we know them today, started at the *Bell Laboratories* in the United states. In 1954, their scientists Daryl M. Chapin, Calvin S. Fuller, and

Gerald L. Pearson, made a silicon-based solar cell with an efficiency of about 6% [43]. Figure 11.2 shows them in their laboratory. In the same year, D. C. Reynolds *et al.* reported on the photovoltaic effect for cadmium sulfide (CdS), a II-VI semiconductor [44].

In the mid and late 1950s several companies and laboratories started to develop silicon-based solar cells in order to power satellites orbiting the Earth. Among these were RCA Corporation, Hoffman Electronics Corporation but also the Unites States Army Signal Corps. In these days, research on PV technology was mainly driven by supplying space applications with energy. For example, the American satellite *Vanguard 1*, which was launched by the U.S. Navy in 1958, was powered by solar cells from Hoffman Electronics. It was the fourth artificial Earth satellite and the first one to be powered with solar cells. It was operating until 1964 and still is orbiting Earth. In 1962 Bell Telephone Laboratories launched the first solar powered telecommunications satellite and in 1966 NASA launched the first Orbiting Astronomical Observatory, which was powered by a 1 kW photovoltaic solar array.

In 1968, the Italien scientist Giovanni Francia built the first concentrated solar power plant near Genoa, Italy. The plant was able to produce 1 MW with superheated steam at 100 bar and 500°C.

In 1970, the Soviet physicist Zhores Alferov developed solar cells based on a gallium arsenide heterojunction. This was the first solar cell based on III-V semiconductor materials that we will discuss in Section 13.2. In 1976, Dave E. Carlson and Chris R. Wronski developed the first thin-film photovoltaic devices based on amorphous silicon at RCA Laboratories. We will discuss this technology in Section 13.3. In 1978, the Japanese companies SHARP and Tokyo Electronic Application Laboratory brought the first solar powered calculators on the market.

Because of the 1970s oil crisis, which lead to sharply rising oil price, the public interest in photovoltaic technology for terrestrial application was increasing in the 1970s. In that time, PV technology moved from a niche technology for space application to a technology applicable for terrestrial applications. In the late 1970s and 1980s many companies started to develop PV modules and system for terrestrial applications. Solar cell still are very important for space applications as seen in Fig. 11.3, which shows a solar panel array on the International Space Station (ISS).

In 1980 the first thin film solar cells based on a copper-sulfide/cadmium-sulfide junction was demonstrated with a conversion efficiency above 10% at the University of Delaware. In 1985, crystalline silicon solar cells with efficiencies above 20% were demonstrated at the University of New South Wales in Australia.

From 1984 through 1991 the World's largest solar thermal energy generating facility in the world was built in the Mojave Desert in California. It consists of 9 plants with a combined capacity of 354 Megawatts.

In 1991 the first high efficiency Dye-sensitized solar cell was published by the École polytechnique fédérale de Lausanne in Switzerland by Michael Grätzel and coworkers. The Dye-sensitized solar cell is a kind of photo-electrochemical system, in which a semiconductor material based on molecular sensitizers, is placed between a photoanode and an electrolyte. We will introduce this technology in Section 13.6.

In 1994, the U.S. *National Renewable Energy Laboratory* in Golden, Colorado, demonstrated a concentrator solar cell based on III-V semiconductor materials. Their cell based on a indium-gallium-phosphide/gallium-arsenide tandem junction exceeded the 30% con-

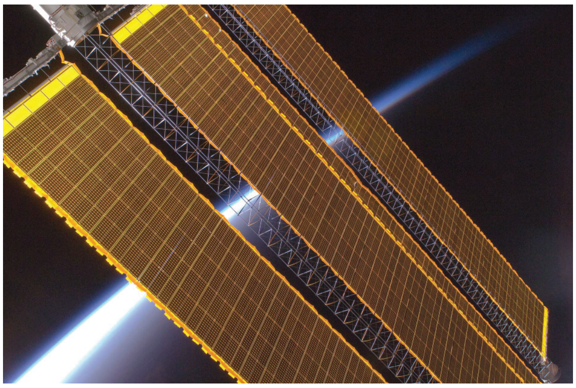

Figure 11.3: A solar panel array on the International Space Station (ISS) [45].

version limit.

In 1999, the total global installed photovoltaic power passed 1 GW_p. Starting from about 2000, environmental issues and economic issues started to become more and more important in the public discussion, which renewed the public interest in solar energy. Since 2000, the PV market therefore transformed from a regional market to a global market, as discussed in Chapter 2. Germany took the lead with a progressive feed-in tariff policy, leading to a large national solar market and industry [19].

Since about 2008, the Chinese government has been heavily investing in their PV industry. As a result, China has been the dominant PV module manufacturer for several years now. In 2012 the world-wide solar energy capacity surpassed the magic barrier of 100 GW_p [17]. Between 1999 and 2012, the installed PV capacity hence has grown with a factor 100. In other words, in the last 13 years, the average annual growth of the installed PV capacity was about 40%.