array [33]. EPRI terminated funding in 1993. Since then, Amonix and SunPower have continued development using other sources of funds. Both companies have since demonstrated modules with efficiency around 20%, showing the potential of point-contact silicon cells [34, 35]. These companies will be discussed in more detail in Section 11.5.

11.3.8 Other Concentrator Programs

Most PV concentrator activity, until recent times, was centered in the United States, probably because of the large direct normal solar resource located in the desert southwest region of that county. Cloudier regions were less prone to see an advantage in concentrators. Nevertheless, there were significant activities in Spain and small activities scattered elsewhere. The Spanish group at the Polytechnic University of Madrid, headed by Professor A. Luque, developed since 1975 bifacial cells for static concentrators, in order to achieve more concentration in static concentrators of the CPC type in Figure 11.5. Three different cell approaches were investigated with the support of the Spanish funding Agency CAICYT: a vertical multijunction cell, similar to the one developed in the United States by Sater and Brandhorst [36], and two more original structures, one n^+pn^+ interdigitated in the back [37] and another one n^+pp^+ [38], were examined and the latter was retained as the most promising and commercialized by the start-up Isofotón, today the seventh world cells manufacturer.[12]

The retained cell structure was based on the long base lifetime found in lowly doped silicon. Lowly doped silicon was thought at the time to produce low voltages, but as the cell operated in high injection the pp^+ homopolar junction provided additional voltage to the existing level of voltage in ordinary cells [39].

A module of size similar to a flat module was built [40], as shown in Figure 11.15. The optics is a derivation of the Winston's CPC. The concentrator was filled with transparent oil that allowed the concentration to increase and provided convective cooling to the bifacial cells. A geometrical concentration over 4 for a static system that collected the sunbeam for the full year was achieved.

The potential of concentrators based on diffusive reflectors of the sunlight, that is, of surfaces painted on white (or just snowed) were used with bifacial cells. This gave rise to the so-called albedo-collecting modules that consisted of flat modules of bifacial cells that collected the diffusely reflected light of a white background on its rear face. In some optimal cases the extra output due to the albedo was over 50% [39] but in most cases it was limited to around 20 to 30%. Figure 11.16 shows an example of such albedo-collecting fields.

Stimulated by the Sandia program, several groups in Europe developed similar approaches. In particular, three modules were developed by the LAAS of Toulouse, France, the Spanish Group of the Polytechnic University of Madrid, and the Italian company Ansaldo. A later additional effort was made at the Fraunhofer Institute for Solar Energy, Frankfurt, Germany. Both of these groups are active in concentrator systems today. Their activities will be covered in Section 11.5. One noteworthy concept from the

[12] This company, founded in 1981, stopped the production of bifacial cells around 1986, to fabricate the more conventional monofacial cells that they found cheaper to manufacture.