Preface

Global warming and climate change are a result of excessive emission of green house gases in the recent decades. During the same period we have experienced a dramatic *increase in energy demand to support the global industry and a "modern life style"*. These events, combined with the astronomic increase of the *energy prices* since the beginning of the 21st century, make it obvious that the *global energy mix* needs to be changed in favor of *clean renewable energy sources*. At the same time we must improve the *energy efficiency* of all technologies.

Solar energy conversion, particularly *Photovoltaics* (PV) represents one of the most interesting and dynamically growing branches of the industry at the moment. Although today the cost of PV is still relatively high, it has dropped considerably in the past years and will continue to do so. A main driving force behind the development of solar energy is its enormous, practically unlimited potential. Unlike other renewable energy sources like wind or water, solar energy can be utilized everywhere on the globe. The cost of PV will have to continue to drop if the goal of economic viability is to be reached. Prices of PV modules and systems follow a well-determined learning curve. If present trends continue, it has been predicted that grid parity (cost of PV equal to grid electricity at the consumer's site) will be reached in about 10 years in favorable locations. An important aspect of the learning curve is that it includes not only scale effects of mass production but also technical advances and new concepts. It can be shown that for most applications *high efficiency* is a prerequisite *for lowering cost*. It is the purpose of this book to give a survey of the most important technologies for increasing efficiency and lowering cost of PV.

In the last five to six years the PV market has grown exponentially: not all over the world yet, but in some countries like Germany and Spain in the EU, and Japan in Asia. Japan and Germany may be considered as front-runners and engines of the newborn *PV Mega Industry*. The German *preferential feed-in tariff for solar electricity* and the new RES Law (*called EEG in German*) opened new market dimensions and made it possible that the German market outgrew a country like Japan, which was and is still the biggest PV producer worldwide. Germany reached this state in spite of the fact that it is not the sunniest part of Europe, due to the *joint efforts* *of politics, industry and academia*. About one-fourth of all PV modules produced worldwide till the end of 2007 are installed in the southern part of Germany (mainly in Bavaria and Baden-Wuerttemberg)! The exceptionally successful *EEG* law also influenced many other countries. In the last five years more than 30 countries copied and/or modified it. In this way, a *PV network* was formed. This network spawned a very active PV development in several countries of the EU like Italy, Portugal, Greece, and even new member-states like Bulgaria. PV is becoming accepted also in countries like USA, Australia and Russia, as well as well as in the newly developing economies like China, India and Turkey, which are on their way to sign the Kyoto Protocol and to support the targets for Clean Energy.

So far the PV Market is dominated by the so called *first-generation* PV, the production and installation of which recently reached the gigawatt scale. First-generation PV, which can be seen on many solar roofs today, is based mainly on mono- and poly-crystalline Si, and these wafers are not made of low cost material. This generation is characterized by relatively low efficiencies of the cells and modules, considerably below the theoretical limits and below results that have been obtained in the laboratory. In spite of this fact, the demand for PV is increasing exponentially so that several crises along the value chain of the PV industry have occurred: for example the shortage of solar grade poly Si feedstock since 2005, or the one for solar glass, appearing on the sky-line now. The crises of the Si feed stock are causing a deviation from the learning curve. The fast growth of the PV demand at one side, and the shortage of Si at the other have generated not only supply problems, but they also led to a change of perspectives and to a search for innovative solutions, based on new materials, cells and module-systems. These new solutions are based on reduced consumption of expensive semiconductor material using for example *thin film PV technology* (*second-generation PV*), or on improved efficiency of crystalline cells and systems, while making use of cost effective *concentrators for solar radiation* (*third-generation PV*).

The aim of this book is to present some important trends and achievements that are shaping the *High Efficient Low Cost Photovoltaic* (*HELCPV*) *Industry*.

Our intention here is not to deal with the basics of PV, which are covered elsewhere. We also don't focus in this book on thin-film PV. Our ambition is to present here the most important strategies and developments in the *transition period for the PV industry between* 2000 *and* 2007 on its way *to a gigawatt industry*, and to predict some of the tendencies of development of the near future, focusing on innovative *highly efficient wafer-based solar cell* and innovative *modules* and systems, making use of *concentrated sun radiation.*

The book consists of 13 chapters, written by 25 authors. In chapter 1 an attempt is made to put together in a chronologic manner the milestones of the PV since the discovery of the photovoltaic effect in 1839 and to focus the attention on the important steps to develop a powerful and sustainable PV industry. In Chap. 2 a comprehensive review of PV for space applications as a for-runner of the PV Industry and its impact on the terrestrial PV is demonstrated. Chapter 3 focuses on the development of the terrestrial PV from a niche market in the beginning of the

21st century to one of the most important mainstream markets for electricity at the moment.

Chapter 4 reviews state of the art poly Si technology based on the Siemens process, which remains the major technology also after the recent shortage for poly Si. In Chap. 5 the recent advances of the so called ribbon technology, which gives the unique chance to reduce the consumption of Poly Si during wafer manufacturing are described. In Chap. 6 an unambiguous answer to the question "Why high efficient, bifacial c-Si PV cells?" is given, and a novel high-efficient rear contact c-Si cell with bifacial sensitivity and elegant simple manufacturing steps is described. Chapter 7 reviews the commercially available power c-Si PV cells, like the Point-Contact Solar Cell of Sun Power, the HIT Solar Cells of Sanyo and the Buried-Contact Solar Cell manufactured by BP. This gives opportunity to the reader to compare the concepts available already on the market with the one presented and analysed in Chap. 6.

Chapter 8 reviews the development of III–V multi-junction PV cells with efficiency close to 40%, on relatively less expensive c-Ge substrates. The ability of such cells to operate under extreme conditions (more than 1,000 suns) is emphasized. Cost effective concentrator systems based on Fresnel mini-lenses arrays, prepared out of silicone, and sun truckers for such concentrator modules are described here. In Chap. 9 the economic perspectives of the III–V concentrator PV when manufactured on megawatt scale is discussed and compared to the first generation c-Si PV. It is argued why CPV should be considered as a promising candidate on the market, capable to compete with the c-Si PV particularly in the very sunny regions in the solar belt-countries.

In Chap. 10 the attention is focused on an alternative device concentrating the sun radiation, named Fluorescent Concentrator, which is less popular than the one based on Fresnel-optics, but which is unique in its ability to concentrate diffuse radiation in a sophisticated way. The basics and the more recent advances to develop further and to simplify this device are reviewed in this part. Chapter 11 deals with a concept of a novel hybrid Photovoltaic/Thermal concentrator. Chapter 12 points the attention then to some innovative PV installation concepts and future PV applications.

Chapter 13 reviews the recent advances in the field of Organic Solar Cells and deals with some design rules, helping to make the organic PV relatively high efficient. We believe that OPV will continue to develop similar to the OLEDs and will be able to supply the market with high efficient low cost PV in a very near future.

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