1 Introduction

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1.1 INTRODUCTION

The environmental challenges to the world are now well known and publicised, and all but a small minority of scientists accept that a reduction on dependence on fossil fuels is essential for addressing the problems of the greenhouse effect and global warming. Everyone is aware of the limited nature of fossil-fuel resources, and the increasing cost and difficulty, as well as the environmental damage, of extracting the last remnants of oil, gas and other carbonaceous products from the earth's crust.

Photovoltaics, the conversion of sunlight into useful electrical energy, is accepted as an important part of any strategy to reduce this dependence on fossil fuels. All of us are now familiar with the appearance of solar cell modules on the roofs of houses, on public buildings, and more extensive solar generators. Recently, the world's PV capacity passed 100 GW, according to new market figures from the European Photovoltaic Industry Association (14 February 2013), which makes a substantial contribution to reducing the world's carbon emissions.

It is the aim of this book to discuss the latest developments in photovoltaic materials which are driving this technology forward, to extract the maximum amount of electrical power from the sun, at minimal cost both financially and environmentally.

1.2 THE SUN

The starting point of all this discussion is the sun itself. In his book 'Solar Electricity' (Wiley 1994), Tomas Markvart shows the various energy losses to the solar radiation that occur when it passes through the earth's atmosphere (Figure 1.1).

The atmosphere also affects the solar spectrum, as shown in Figure 1.2.

A concept that characterises the effect of a clear atmosphere on sunlight, is the 'air mass', equal to the relative length of the direct beam path through the atmosphere. The extraterrestrial spectrum, denoted by AM0 (air mass 0) is important for satellite applications of solar cells. At its zenith, the radiation from the sun corresponds to AM1, while AM1.5 is a typical solar spectrum on the earth's surface on a clear day that, with total irradiance of 1 kW/m^2, is used for the calibration of solar cells and modules. Also shown in Figure 1.2 are the principal absorption bands of the molecules in the air. AM1.5 is referred to frequently in a number of the chapters in this book, and readers should be aware of its meaning.

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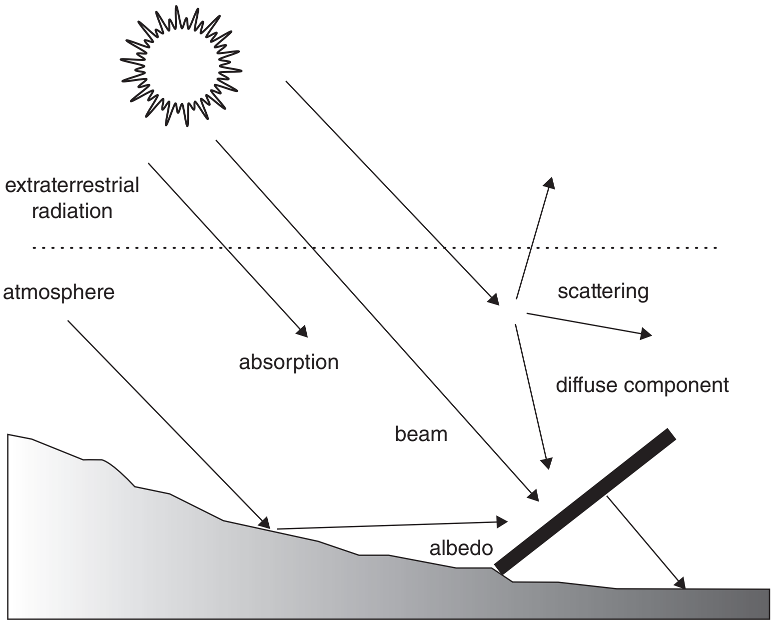

Figure 1.1 Solar radiation in the atmosphere. (Reproduced with permission from Markvart, 2000. Copyright © 2000, John Wiley & Sons, Ltd.)

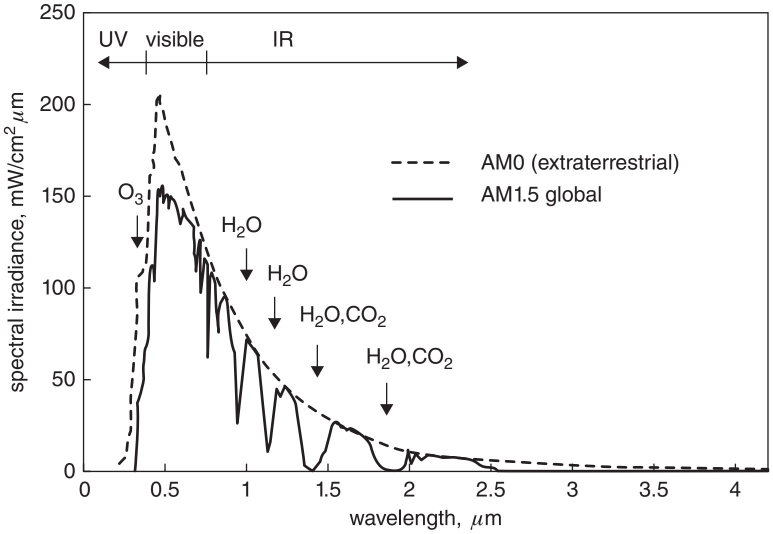

Figure 1.2 The solar spectrum. (Reproduced with permission from Markvart, 2000. Copyright © 2000, John Wiley & Sons, Ltd.)

1.3 BOOK OUTLINE

The book starts with a clear exposition of the fundamental physical limits to photovoltaic conversion, by Jean-Francois Guillemoles. This covers the thermodynamic limits, the limitations of classical devices, and develops this theme for more advanced devices. The identification of device parameters used in other chapters can also be found in this chapter.

Material parameters, of course, also require a thorough understanding of characterisation tools, and the second chapter, by Daniel Bellet and Edith Bellet-Amalric, outlines the main material characterisation techniques of special interest in solar cell science. X-ray analysis, electron microscopy, ion-beam techniques and spectroscopy characterisation methods are discussed, including Raman, X-ray photoelectron and UV/Visible spectroscopy, which are rarely detailed in such a materials book.

The next chapter, by Martin A Green, concentrates on developments in crystalline silicon solar cells. Despite the fact that silicon is an indirect-bandgap semiconductor, and therefore is a much less efficient absorber of above-bandgap light than direct-gap semiconductors (such as GaAs), silicon is still the overwhelming choice for solar cell manufacture. As the second most abundant element in the earth's crust, with a well-established technology, the chapter explores recent developments that have produced low-cost devices with efficiencies approaching the maximum physically possible.

Amorphous and microcrystalline silicon solar cells, are next reviewed by Ruud E I Schropp. These thin-film technologies are finding many exploitable applications with their lower usage of absorber materials and use of foreign substrates.

Turning next to direct-bandgap semiconductors, Nicholas J Ekins-Daukes outlines recent developments in III-V solar cells. III-Vs give the highest efficiencies of any solar cell materials. But despite their large absorption coefficients for above-bandgap light, the materials are relatively expensive, and often difficult and rare to extract from the earth's crust. Their place in the technology is assessed, together with recent advances.

Chalcogenide thin-film solar cells are next reviewed by Miriam Paire, Sebastian Delbois, Julien Vidal, Nagar Naghavi and Jean-Francois Guillemoles. Cu(In Ga)Se_2 or CIGS cells have made impressive progress in recent years with the highest efficiencies for thin-film cells, while Cu_2ZnSn $(S,Se)_4$ or CZTS or kesterite uses less-rare elements than CIGS, and so has significant potential for large-scale production.

The field of organic photovoltaics (OPV) has become of great interest since the efficiency achieved rapidly increased from around 1% in 1999, to more than 10% in 2012 (Green 2013). The chapter by Claudia Hoth, Andrea Seemann, Roland Steim, Tayebeh Amin, Hamed Azimi and Christoph Brabec reviews this novel technology, concentrating on the state-of-the-art in realising a photovoltaic product.

Lastly, one of us (Gavin Conibeer) looks to the future, by outlining third-generation strategies that aim to provide high conversion efficiency of photon energy at low manufacturing cost. Approaches covered include multiple energy level cells (such as tandem cells and multiple exciton generation), modification of the solar spectrum (such as by down- and upconversion), and thermal approaches (such as thermophotovoltaics and hot-carrier cells). The emphasis in all these approaches is on efficiency, spectral robustness, and low-cost processes using abundant nontoxic materials. The book ends with some concluding remarks by the editors, looking to the future in this rapidly developing field.

Finally, no book in this very extensive field can claim to be complete. To explore the field further, readers are recommended to consult 'Thin Film Solar Cells' by Jef Poortmans and Vladimir Arkipov (Wiley 2006), a companion volume in this Wiley Series on Materials for Electronic and Optoelectronic Applications, which includes such areas as dye-sensitised solar cells (DSSCs), in the chapter by Michael Gratzel. We hope that this book, with its emphasis on technological materials, will be of use to all who are interested in this field.

REFERENCES

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Green, M.A., Emery, K, Hishikawa, Y., Warta, W., and Dunlop, E.D., Solar cell efficiency tables (version 41), Progress in Photovoltaics: *Research and Applications*, 21 (2013) p. 1–11.