Thin Film
Solar Cells

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Dedicated to

OUR PARENTS
who have been a source of inspiration to us
in our endeavor to explore
the frontiers of science and technology
in the service of mankind

Preface

"You, O Sun, are the eye of the world
You are the soul of all embodied beings
You are the source of all creatures
You are the discipline of all engaged in work"

— Translated from Mahabharata
3rd Century BC

Today, energy is the lifeline and status symbol of "civilized" societies. All nations have therefore embarked upon Research and Development programs of varying magnitudes to explore and effectively utilize renewable sources of energy. Albeit a low-grade energy with large temporal and spatial variations, solar energy is abundant, cheap, clean, and renewable, and thus presents a very attractive alternative source. The direct conversion of solar energy to electricity (photovoltaic effect) via devices called solar cells has already become an established frontier area of science and technology. Born out of necessity for remote area applications, the first commercially manufactured solar cells — single-crystal silicon and thin film CdS/Cu_2S — were available well over 20 years ago. Indeed, all space vehicles today are powered by silicon solar cells. But large-scale terrestrial applications of solar cells still await major breakthroughs in terms of discovering new and radical concepts in solar cell device structures, utilizing relatively more abundant, cheap, and even exotic materials, and inventing simpler and less energy intensive fabrication processes.

No doubt, this extraordinary challenge in R/D has led to a virtual explosion of activities in the field of photovoltaics in the last several years. Such new devices as barrier layer, inversion layer, cascade junction, tandem junction, spectrum splitting and shifting, and photoelectrochemical cells have emerged. Exotic materials of the type a-Si:H(F), a-SiC:H, Zn_3P_2, $CuInSe_2$, quaternaries and penternaries, and graded multicomponent semiconductors are very attractive options today. New materials technologies such as ribbon, LASS, TESS, RTR, spray pyrolysis, magnetron sputtering, ARE, chemical solution growth, and screen printing are much talked about. The theoretical understanding of the photovoltaic process has advanced considerably as a result of the development of more refined and realistic models of various types of junctions and the associated solid state physics, particularly that applicable to polycrystalline materials. Nevertheless, the R/D explosion has not yet reached its culmination.

A characteristic feature of good R/D activity is turbulent evolution of the field through critical published literature, seminars, conferences, reviews, and books. If scientific attention is a measure of the importance of a field, photovoltaics is among the top few frontiers today which continue to be hotly debated in conferences and in reviews all over the world. In the area of published literature, H. J. Hovel's book *Solar Cells* (1975) has served as a useful textbook for several years. A recent textbook, *Solar Cell Device Physics* by S. J. Fonash (1981), has brought the subject of the physics of junctions up to date. D. Pulfrey's book *Photovoltaic Power Generation* (1978) contains basic theory of junctions and emphasizes systems aspects of photovoltaic conversion. *Solar Energy Conversion: The Solar Cell* by Richard C. Neville (1978) provides good coverage of the related solid state physics, device design, and systems. An indispensable handbook for the systems engineer is provided by H. Rauschenbach in his book *Solar Cell Arrays* (1980). However, none of these books has addressed the problem from the *universally* accepted point of view that viable devices for terrestrial applications must necessarily be Thin Film Solar Cells. Such aspects as thin film materials; the associated preparation, measurement, and analysis techniques; and device technology are not discussed, or are treated perfunctorily at best in these books. The importance of these aspects and the fact that we in the Thin Film Laboratory have been engaged in very extensive R/D activities with thin film solar cells for over a decade have inspired us to undertake the job of writing a comprehensive book on the subject.

This book, consisting of 12 chapters, begins with a scientific, technological, and economic justification of "why thin film solar cells?" in Chapter 1. This is followed by a detailed description of the electron transport and optical processes in monocrystalline, polycrystalline, and amorphous semiconductors, and in metal films in Chapter 2. Different types of electronic junctions and the associated physics are presented in Chapter 3. Chapter 4 discusses measurement techniques for the analysis of junctions. A comprehensive review of the major deposition techniques of interest to the field of thin film solar cells forms Chapter 5. The significant physical properties of thin film materials for solar cell applications are discussed in Chapter 6. Chapters 7 through 10 are devoted to a description of the fabrication and critical discussion/analysis of the performance of solar cells based on copper sulfide, polycrystalline silicon, new and emerging materials, and amorphous silicon. An attractive alternative to an all solid state solar cell is a photoelectrochemical cell, which is the theme of Chapter 11. The last chapter deals with novel and futuristic concepts that have been proposed and experimented with for obtaining high-efficiency solar cells. Finally, six appendixes deal with the solar spectrum, antireflection coatings, grid design, solar cell arrays, concentrators, and degradation and encapsulation of solar cells. In all, the book is illustrated with over 200 figures and contains 42 tables of accumulated data.

In a rapidly changing field, strong and prejudiced views, errors, and omissions are inevitable. This book is no exception and we take full responsibility for it. We do, however, appeal to our readers to be critical and to communicate its shortcomings to us. As emphasized in Chapter 1, an unambiguous choice of a viable thin film solar cell material has yet to emerge. And, thus, some or even a substantial part of what is presented here as technology may become obsolete very soon. Indeed, we would be very disappointed if this did not happen!

Despite the rapidly evolving nature of the field, this book represents the first major attempt to expose graduate students and R/D scientists and engineers to a comprehensive treatment of many facets of materials, technologies, and solid state physics of thin film solar cell devices. We earnestly hope that this book, aside from serving as a text and research-cum-reference volume, will inspire the readers toward much awaited innovations in the field to make thin film solar cells viable enough to serve the energy-hungry societies of tomorrow.

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