1. Introduction

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This volume reviews key aspects of the materials science of solar energy conversion. The objective is an identification of problem areas in which a greater engagement of the solid-state physicist will improve existing technologies.

The involvement of the materials scientist may soon be of decisive importance. Solar energy conversion will contribute to future energy needs to the extent that existing devices can be improved in performance and lowered in cost. On the engineering level, most current approaches have been tried and perfected over the past 50 years without there being much hope for further improvement. However, a novel aspect has entered during the last two to three decades with the rapid development of the physics of solids which through their optoelectronic properties play a key role in major conversion schemes. Consequently, the greater involvement of modern solid-state physics will increase the chances to move solar technology beyond the barrier of economic marginality that now hinders its progress.

The necessary effort must start with the identification of problem areas in which the contribution of the solid-state physicist could be essential. The optical properties of solids ranks high on the list. Before the solar photon can interact with the material of the converter in a technologically useful manner, it must first penetrate through the surface and be absorbed. Small reflection and large absorption over the solar emission band is therefore a common requirement for materials used in most conversion schemes.

For photothermal conversion this is not sufficient, however. As the absorber converts the intercepted solar radiation into heat, the loss by thermal reradiation must be reduced. Surfaces of the proper spectral selectivity therefore provide optimum conversion efficiency. Chapter 2 deals with such spectrally selective surfaces and their impact on the efficiency of photothermal solar energy conversion. Considering the energy balance at the surface of the converter, the key role of the spectrally selective profile of the optical properties of this surface is established. A survey of the physical processes leading to spectral selectivity places the actual realization of converter surfaces in the frame of solid-state physics. A review of the most prominent methods for making selective blacks emphasizes the empirical character of the present state of the technology, and challenges the solid-state physicist to contribute to the necessary deeper understanding.

Chapter 3, by A. J. Sievers, deals with the interesting possibility of providing spectral selectivity through the optical properties of composite materials, made up from metallic and insulating components. The optical properties of these composite materials are reviewed first, considering effects of surface texture, roughness, and surface plasmons. Considering mainly the tandem action of an absorber overlaid onto a reflective backing, the limits of such a configuration for the attainable figure of merit are investigated. The optical properties of the composite absorber are described, using the Maxwell–Garnett theory. Particulate coatings of transition metal or copper substrates appear to be promising, and a technique is suggested that makes use of surface plasmon effects. In a final section, the state of the art of high-temperature selective coatings is reviewed, supporting the conclusion that current approaches are still a long way from the physical limits established in the article.

H. Gerischer's Chap. 4, "Solar Photoelectrolysis with Semiconductor Electrodes", is interdisciplinary between electrochemistry and solid-state physics. The great promise of converting solar radiation into energy which can be stored using the semiconductor-electrolyte interface presents a strong appeal to the solid-state physicist to learn the language and concepts of the electrochemist, and vice versa. The realization of the promise in practical terms will come from materials science, and in particular from semiconductor physics. It is therefore important that the author of this chapter succeeds in presenting the electrochemical situation in the terms used by the semiconductor physicist, beginning with the principles of photoelectrolysis, the electron transfer reactions, and the driving force of photoelectrolysis. Great emphasis is placed on the susceptibility of semiconductors to decomposition, the most serious problem for their application in photochemical cells. After describing function and efficiency in regenerative cells, including cells used for water photoelectrolysis, the conversion efficiency in relation to material properties is discussed, and guidelines for the selection of optimal materials are developed in analogy to solid-state photovoltaic conversion schemes. In the tenor of nearly all authors in this volume, Gerischer concludes that present photoelectrochemical cells fall short of the theoretically estimated performance, and that a great deal more materials research will have to be performed to approach the calculated values.

With the next Chap. 5 by K. Graff and H. Fischer, the text enters an area of great concern to the solid-state physicist. The carrier lifetime and its impact on the performance of photovoltaic solar cells is a central problem, in particular to the economically attractive thin-film approach. It is in this area that solid-state physics can provide solutions most effectively. For crystalline silicon the demand for a diffusion length of the photo-generated carriers to be equal to the penetration depth of the solar radiation is particularly difficult to fulfill. The authors describe the state of our knowledge concerning the dependence of carrier lifetime upon the type of silicon crystal used, process-induced variations of this parameter, and present technological limitations.

Once solar-cell fabrication reaches the required cost level of a few dollars per watt, the price of the material and its processing will dominate. Integrated circuitly opened a new area in electronics because the density of the components could be vastly increased. Since the density of the solar flux for a given power requirement determines the area of interception, the thickness of the active material is left as the only adjustable parameter for a reduction in cost. Ideally, the thickness of the active layer should equal the penetration depth of the solar radiation and the diffusion length of the photo-pairs. To realize this in an economical thin-film method that tolerates the polycrystalline material is the central challenge.

Chapter 6 by M. Savelli and his colleagues discusses state of the art, problems and promises for the Cu_2S/CdS solar cell, one of the most attractive realizations of the thin-film approach. Conversion efficiency, stability in operation and yield of fabrication depend strongly on the parameters of preparation. Further progress will depend on studies of the electronic consequences of the interface, and the structural and compositional characterization of the material on either side of it.

A large part of the promise – and at the same time the cause of most of the problems – of the Cu_2S/CdS cell rests with its heterojunction character. Chapter 7 by A. L. Fahrenbruch and J. Aranovich reviews in depth heterojunction phenomena and interfacial defects in photovoltaic converters. The requirement for a high absorption constant and a direct band gap in materials for thin-film cells in particular suggest the heterojunction as a possible solution. This configuration provides attractive features such as the window effect, an active region far from surface recombination, and others. The authors describe the problems to be solved before the advantages can be utilized. The carrier transport is dominated by the complex phenomena near or at the metallurgical interface, involving recombination and tunneling through interfacial states. The picture is further complicated by the presence of band-profile discontinuities which may be further distorted through the presence of electrical charges in the interfacial states. This chapter gives the solid-state perspective, with strong reference to the performance of solar cells based on heterojunctions. The article culminates in the conclusion that only further coordinated research in surface, solid-state and device physics will enable the educated manipulation of the interfacial properties of heterojunction devices that can bring about substantial improvements in solar converter technology.

All the chapters in this volume end on the same note. Their assessment of the current technology uncovers a disturbing discrepancy between the promise, as given by theoretical estimates for the performance, and the technology realized in existing devices. The size of the gap can be reduced by a greater engagement of the materials scientist. To attract his interest, an effort must be made to identify the key problem areas in which contributions from the solid-state physicist, the electrochemist, the metallurgist may bring about novel solutions. Without a claim to completeness or comprehensiveness, this volume has attempted this identification in areas of key importance for solar technology. The goal of this book will be fulfilled if it serves to stimulate further research in the solid-state aspects of solar energy conversion.