Preface

The world's primary energy sources are currently fossil fuels in the form of oil, coal, and natural gas. With rapidly growing global energy consumption, and for the first time in a century, the world faces serious energy, environmental, and economic crises as a result of depleted stocks of fossil fuels, pollution, climate change, etc. Development of sustainable and clean energy sources has taken on increased urgency. Solar energy is one of the most abundant energy sources on the planet, but despite its great promise, the cost and efficiency of current photovoltaic cells present great challenges to implement solar energy on a large scale. After over 30 years of slow development, the contribution of solar energy, including photovoltaic electricity, to global energy consumption is still marginal [1].

So far, one of the major challenges for widespread deployment of solar cells is the high cost of solar cells compared with fossil fuels. Further substantial improvements in current photovoltaic technologies are needed in terms of cost and efficiency. To this end, research efforts have divided mainly into two directions: exploring new cost-effective photovoltaic materials and development of new high efficiency device architectures. In the last decades, new classes of photovoltaic materials have been investigated, including amorphous silicon (a-Si), organic polymers, and CIGS [$CuIn_xGa_{1-x}Se(S)_2$], with the aim of cost-effective solar electricity generation. As a new technology becomes mature, material cost puts an ultimate limit on the effort to bring down the price-per-watt for power generation [2].

Development of new photovoltaic cells with substantially increased power conversion efficiency is critical to convert solar energy from a promising clean renewable energy to a competitive primary energy source. Nanostructured materials developed during the last 20 years are promising for fulfilling this task. Solar cells based on nanomaterials, including multiple exciton generation solar cells [3, 4], intermediate band solar cells [5, 6], and hot electron extraction solar cells [7, 8], have shown rapid improvement. While there are a number of books covering nanostructured solar cells, very few cover the recently fast-developing quantum dot solar cells. It is therefore the goal of this book to present a comprehensive overview of the current status of quantum dot solar cells and related technologies.

The main body of the book is comprised of contributions that focus on photovoltaic cells based on quantum dot materials. Various novel solar cell materials and structures are covered in different chapters. Specifically, Chaps. 1–4 offer a comprehensive perspective on hybrid colloidal quantum dot solar cells. Chapter 1 reviews recent advances in colloidal quantum dot sensitized quantum dot solar cells. Chapter 2 presents two unique hierarchically nanostructured quantum dot sensitized solar cells with improved light harvesting and charge collection. A unique hybrid solar cell structure with colloidal quantum dots deposited on traditional solar cells to boost efficiency is introduced in Chap. 3. Due to the equal importance of electricity generation and light generation, Chap. 3 also reports on improved light emission diode efficiency with colloidal quantum dots. In Chap. 4, photoinduced charge transfer in hybrid nanosystems with colloidal quantum dots is explored.

Chapters 5–7 introduce studies of quantum dot-based intermediate band solar cells. Chapters 5 and 6 are theoretical contributions which model electronic structure and optical properties and address the optimization of material selection for quantum dots by the finite element method, respectively. Chapter 7 presents a study on quaternary quantum dot solar cells and shows that two-photon absorption through the sub-bandgap indicates intermediate band formation.

Unlike quantum dot sensitized quantum dot solar cells and quantum dot intermediate band solar cells which aim for wide spectral absorption, hot electron solar cells and multiple exciton generation solar cells convert the excess carrier energies into electricity. Chapter 8 presents new models of operating principles of quantum dot hot-carrier solar cells using detailed balance of particle and energy fluxes and a search for the requisites of high conversion efficiency. Chapter 9 reviews recent progress in multiple exciton generation in quantum dots and solar cells benefiting from multiple exciton generation. Chapter 10 deals with multiple exciton generation dynamics in quantum dots using an improved transient grating technique.

Chapter 11 presents a comprehensive review of progress in low-cost graphene quantum dot solar cells. In Chap. 12, the synthesis of graphene and graphene quantum dots is introduced. Chapter 12 also addresses the application of graphene and quantum dots to photovoltaic devices.

While the above chapters focus on photovoltaic materials and devices based on quantum dots, the last two chapters cover a novel characterization technique and device architecture, respectively. Chapter 13 is devoted to a detailed analysis of an ultrafast photovoltammetry technique. This technique can be used to investigate surface charge carrier dynamics at the nanometer scale, such as in quantum dot solar cells. The authors of Chap. 14 discuss enhanced solar cell performance through light trapping and optical confinement from photonic and plasmonic structures. This issue is particularly important for quantum dot solar cells, which generally consists of optically thin active regions.

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Chengdu, China, People's Republic Jiang Wu
Chengdu, China, People's Republic Zhiming M. Wang

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