

Chapter 15

Nanotechnology and Polymer Solar Cells

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ABSTRACT

In response to environmental concerns there is a drive towards developing renewable, and cleaner, energy technologies. Solar cells, which harvest energy directly from sunlight, may satisfy future energy requirements, but photovoltaic devices are currently too expensive to compete with existing fossil fuel based technologies. Polymer solar cells, on the other hand, are cheaper to produce than conventional inorganic solar cells and can be processed at relatively low temperatures. Furthermore, polymer solar cells can be fabricated on surfaces of arbitrary shape and flexibility, paving the way to a range of novel applications. Therefore, polymer solar cells are likely to play an important role in addressing, at least in some small part, man's future energy needs. Here, the physics of polymer photovoltaics are reviewed, with particular emphasis on the computational tools which can be used to investigate these systems. In particular, the authors discuss the application of nanotechnology in self-assembling complex nanoscale structures which can be tailored to optimize photovoltaic performance. The role of computer simulations, in correlating these intricate structures with their performance, can not only reveal interesting new insights into current devices, but also elucidate potentially new systems with more optimized nanostructures.

INTRODUCTION

More energy is incident upon the Earth in one hour than is consumed by the world's population in an entire year. Harvesting just a small fraction of this solar energy could provide the solution to our long-term energy needs. However, first it

is necessary for this solar energy to be captured, converted, and stored in a cost-effective fashion (Lewis, 2007). Solar cells are a promising method of both capturing this energy, and converting it directly into electrical energy. While this still leaves the need for energy storage, in order to provide electrical power during times of darkness, there are still many benefits to using solar cells. Firstly,

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solar cells could be used to complement other technologies which do not rely on sunlight. For example, times of low sunlight and darkness often coincide with instances of high winds and rainfall which could provide wind and hydroelectric power, respectively (Hinrichs, 2006). Secondly, our current fossil-fuel based methods of generating energy are having a devastating impact on our environment. Ice sheet disintegration, sea level rise, and other adverse consequences of global warming, have recently emphasized our need for developing inexpensive alternative energy sources (Kerr, 2007). Furthermore, due to the portable nature of solar technology, these devices will especially benefit isolated communities in the developing world, whose fragile existence is most likely to be affected by global warming. However, the need for solar cells which can generate electricity as inexpensively as fossil-fuel based technologies are required before this energy source can provide a practical long-term alternative.

Solar cells based on silicon are currently the dominant photovoltaic technology. Silicon solar cells are reliable and highly efficient at converting solar energy into electrical energy. Combined with the natural abundance of silicon, this has made silicon solar cells a popular choice since the first p-n junction devices were fabricated in the 1950's (Cummerow, 1954). However, the high cost of silicon, especially crystalline silicon which is the most effective material, has limited the societal impact of solar cell technology and led to an interest in alternative materials (Shaheen, 2005). Thin film inorganic materials, such as amorphous silicon, have also attracted interest but high processing temperatures can make all inorganic solar cells prohibitively expensive. That said, recent advances in solar concentration could decrease the amount of solar cell material required and decrease the costs of silicon photovoltaics, while providing novel features such as partially transparency devices with non-planar geometries (Currie, 2008). In terms of photovoltaic research,

however, there is still an impetus towards finding alternative materials and developing new devices.

In recent years, organic materials have emerged as a possible alternative to traditional inorganic semiconductor solar cells. Organic photovoltaic cells are typically produced from either small-molecular-weight films or polymer films. One of the main advantages of organic materials is their high optical absorption which results in solar cell thicknesses on the order of 100nm; a thousand times thinner than silicon-based solar cell and ten times thinner than inorganic thin film cells (Kietzke, 2007). The use of organic materials can also significantly reduce the costs of production through solution processing and continuous deposition techniques. In other words, less of these cheaper materials can be deposited at lower temperatures and over relatively large areas. The cost of producing organic solar cells, therefore, is significantly less than inorganic cells. However, organic solar cells are inefficient at converting solar energy into electrical energy, with power conversion efficiencies reported to be only as high as 6.8% (Chen, 2009). This means that while the cost of polymer solar cells is small, their inefficiencies limit the "cost per watt" of these devices. In order for polymer solar cells to be economically viable the cost per watt of energy would have to be reduced, requiring an increase in efficiencies without driving up costs.

The overall efficiency of polymer solar cells is influenced by four main processes; the absorption of a photon to create an exciton (a mobile but bound electron-hole pair), the dissociation of an exciton to form a hole and an electron, the potential recombination of these charges, and the collection of carriers at their respective electrodes (Shaheen, 2005). In polymer solar cells the absorption of a photon does not result in free charge carriers, as in inorganic devices, but rather the creation of a coulombically bound electron hole pair, or exciton. This exciton must then find an interface between two materials with different electron donating and electron accepting properties in

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