Chapter 12
Carbon Nanotubes for Photovoltaics

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ABSTRACT
Recent developments show that the exceptional physical, optical, and electrical properties of Carbon Nanotubes (CNTs) have now caught the attention of the Photovoltaics (PV) industry. This chapter provides an updated and in-depth review of some of the most exciting and important developments in the application of CNTs in photovoltaics. The chapter begins with a discussion of the underlying properties of CNTs that make them promising for PV applications. A review of the literature on the application of CNTs in the photoactive layer of Silicon (Si)-based heterojunctions, as anchors for light harvesting materials in Dye Sensitized Solar Cells (DSSCs) and as components of other organic solar cells (OPVs), is then presented. Findings portend the promise of CNTs in bridging the gap between the two classes of solar cells currently in the market. Since the technology is in its early stages, it is generally limited by a general lack of understanding of CNTs and their adequate growth mechanisms.

INTRODUCTION
The PV effect in simple words refers to the creation of voltage and electric current by a diode upon exposure to light. In an ideal case, light (photons) absorbed by a photovoltaic material excite electrons into a higher state of energy, allowing them to act as charge carriers for electric current. However, the efficiency of this process is highly dependent on the material’s ability to successfully absorb photons in the light source’s spectrum, allow excitation of its electrons/holes and then safeguard the delivery of these electrons/holes to the electrodes before recombination occurs. In reality, ensuring the success of these processes is very difficult hence the relatively low efficiencies of most commercial solar cells today.

Over the years, Si has proven to be the leading material used in the PV industry with crystalline Si wafer based PV responsible for the majority of the world’s annual solar cell production (Müller, Ghosh, Sonnenschein, & Woditsch, 2006;
Laird, 2010). This is the case as the Si wafer based PV has long been a proven and robust PV technology. The cost of high efficiency Si wafer PV devices, limits this technology’s potential of performing well in the energy market; traditional mono crystalline Si PV and the most efficient multijunction PV (performing at about 40.7% under 240 sun illumination) can cost upwards of several dollars per installed watt (Kammen & Pacca, 2004; King et al., 2007; Camacho et al., 2007), with kWh cost several times higher than energy from traditional fossil fuel sources. In contrast, due to greatly reduced semiconductor material consumption and the ability to (i) fabricate the solar cells on inexpensive large-area foreign substrates and (ii) to monolithically series-connect the fabricated solar cells, thin-film PV has the potential of achieving module costs of well below $1.4 per W (Aberle, 2009). As thin film materials are typically polycrystalline or amorphous, they experience a high reduction in efficiency due to interface recombination and degradation under light illumination (Staebler-Wronsky effect) (Galloni, 1996), making them less efficient than their wafer based counterparts. Evidently, the present trend in the PV industry divides cells into two categories: cells which are affordable but of relatively low efficiency and cells which are of good efficiency but very costly. Figure 1 shows the efficiency and cost projection of these categories of cells. As it is expected that the PV market will continue to rise, it is of great interest to the PV industry to bridge the gap between these two categories of cells currently available and produce units which are not only of decent efficiency but also affordable enough to compete with other sources of secondary energy. Approaches in this line aims to decrease the cost to well below the $1/W level of the second-category PVs potentially to $0.20/W or better, by significantly increasing efficiencies but maintaining the economic and environmental cost advantages of thin-film deposition techniques (Conibeer, 2007). In order to establish a third category of PV devices, a lot of methods have been explored to bridge this and CNT unsurprisingly has been a well cited candidate in the field.

Figure 1. Efficiency and cost projections for first- (I), second- (II), and third category (III) PV technologies (wafer based, thin film and advanced technologies respectively) (Green, 2001)
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