NANOPRODUCTS

Hybrid Solar Cells Based on Carbon Nanotubes and Nanoporous Silicon

IGOR A. LEVITSKY

DESPITE INTENSIVE RESEARCH and substantial investments over the past decade, existing organic/hybrid photovoltaics (PVs) are still unable to overcome the 7% conversion efficiency barrier.

Our innovative solar cells of third generation are based on photonic band gap structures using the exceptional optical properties of nanoporous silicon (Si) infiltrated with single-walled carbon nanotubes (SWNTs). The novel nanocomposite concept should provide the highest light entrapping, charge separation, and high charge mobility, which could demonstrate superior PV properties exceeding 10% conversion efficiency with respect to other organic/hybrid PV materials. It is established that 10% conversion is critical for commercialization of organic/hybrid solar cells.

The proposed technology combines the unique PV property of carbon nanotube–Si composites (novel material) with light entrapping inside a one-dimensional (1-D) photonic crystal (novel approach) fabricated from porous Si (PSi).

SWNTs are very attractive for solar cell applications because of its ability to absorb light in the near-IR (NIR) spectral range (800–1,800 nm), which is not possible for most organic compounds (we were the first to report conductivity of SWNT film under continuous wave illumination in the NIR–Vis spectral range [1]). In addition, the high carrier mobility of individual SWNTs (>100,000 $cm^2/V \cdot s$) provides fast diffusion and photocarrier collection at the external electrode.

Our innovative solar cells of third generation are based on photonic band gap structures using the exceptional optical properties of nanoporous Si infiltrated with SWNTs.

Recently, we discovered that SWNTs work as an active photosensing material at n-type Si junctions [2]. Thus, both SWNTs and Si contribute to photocarrier generation. A high interfacial area between entrapped SWNTs and PSi should result in efficient photocarriers separation and collection at external electrodes (Figure 1). In addition, PSi carrier mobility (up to approximately 1 $cm^2/V \cdot s$) is higher than amorphous Si, and therefore, PSi is more suitable for PV applications than other amorphous/colloidal semiconducting materials. Also, PSi-based solar cells can be fabricated as thin, flexible, and lightweight films. Finally, 1-D photonic crystals can be easily prepared by electrochemical etching of Si under varied current density (Figure 1). The proper design of the photonic band gap structure enables localization of solar light, which minimizes reflection and scattering losses.

The major advantages of our solar cells over other organic/composite/hybrid third-generation PVs are as follows:

- high carrier mobility of SWNTs, and their absorption in the NIR spectral range
- large interfacial area (specific surface area 200–800 m^2/cm^3) between entrapped SWNT and PSi enabling efficient photocarrier generation
- capability for the proper design of 1-D photonic nanoporous crystals to minimize optical losses
- thin film feature

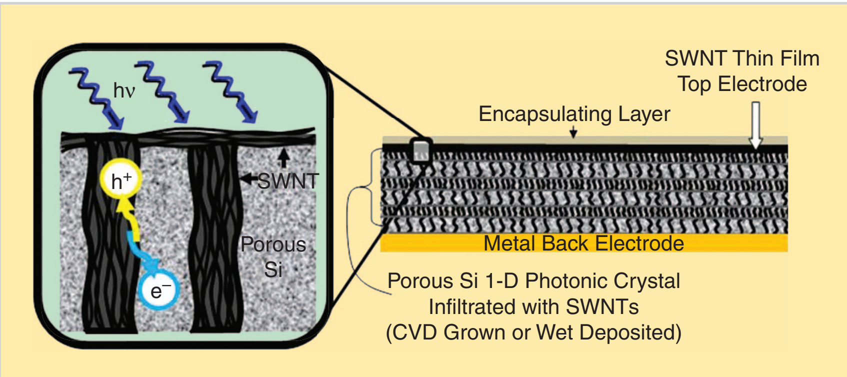

FIGURE 1 Cross-sectional view of a solar cell based on 1-D photonic crystal prepared by electrochemical etching of Si and infiltrated with SWNTs.

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◆ cost-effective fabrication method (wet etching and deposition).

A combination of light localization and harvesting with efficient charge separation and charge collection due to the continuous porous semiconductor and SWNT medium should provide a novel nanocomposite material with advanced photosensing properties.

This year, we reported a study of a solar cell based on SWNT/n-type Si heterojunction with conversion efficiency of approximately 2% [2]. Figure 2(a) and (b) depicts the SEM images of SWNT–Si heterojunction, the related *I–V* characteristics is shown in Figure 2(d), and the accompanying proposed band structure is shown in Figure 2(c). It should be noted that the solar cell in this study is not optimized; therefore, there is substantial potential for the following performance improvements: 1) SWNT doping to increase nanotube conductivity, 2) selection of an optimal film thicknesses to provide a balance between Si and SWNT absorption, 3) multistep centrifugation to refine further the network morphology, 4) the use of PSi to reduce the reflection from Si surface, or 5) increasing n-Si doping. In addition, the simple and scalable SWNT wet deposition offers to create a variety of p–n junction with other n-type substrates other than crystalline Si, e.g., any crystalline thin film amorphous/nanoporous semiconductors.

The cost-effective processing, lightweight, flexibility, and robustness are important to consumer/industrial needs for clean energy technology approach. We believe that the proposed innovative solar cells could find their niche in the market of electronic and communication equipment, airborne applications, offshore platforms, and emergency power systems. According to the March 2009 report by Clean Edge Inc. (a leading research and consulting firm in the area of clean technologies), solar PVs will grow from a US$29.6 billion industry in 2008 to US$80.6 billion by 2018.

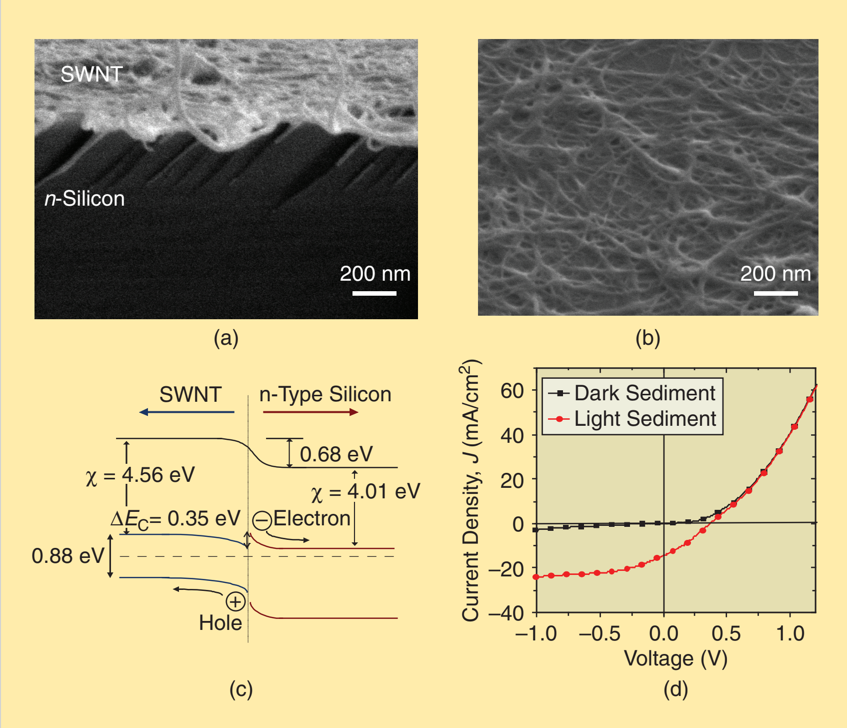

FIGURE 2 (a) Cross-sectional SEM images of SWNT on Si; (b) top-view SEM image of SWNT deposited on Si; (c) schematic energy band diagram of SWNT–n-type Si heterojunction based on Anderson model; (d) current–voltage (*I–V*) plot of SWNT–Si heterojunction solar cell under dark and light illumination [2].

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The Social Funds' sustainability investment news contends that solar energy is expected to maintain its status as the world's fastest-growing energy technology. It is hard to overestimate the benefits of the emergence of novel nanocomposite solar cells on the current multibillion dollar market.

ABOUT THE AUTHOR

Igor A. Levitsky (ilevitsky@emitechinc.com) earned his Ph.D. degree from the Institute for Low Temperature Physics, Ukraine, in 1991. He has been the principal scientist at Emitech, Inc., in Fall River, Massachusetts, since 2002 and is adjunct assistant professor in the Department of Chemistry, the University of Rhode Island.

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