Improve Carrier Generation and Collection with a Nanotube Photovoltaic Configuration

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Abstract - By using an anodic aluminum oxide membrane, we were able to manufacture semiconductor nanotubes with tunable geometric features on a transparent substrate. Three-dimensional nanotube solar cells are produced with semiconductor absorbers loaded not only in the nanotubes' inner core but also in the innertube space between the nanotubes, thereby eliminating the need for a membrane. Carriers are created and separated in the nanotube solar cells in three different locations: the nanotube core, the intertube space between nanotubes along the radial direction, and above the nanotubes along the axial direction. To prove the efficacy of this strategy, nanotube CdS-CdTe solar cells were produced in early tests. There is a robust and broad-spectrum response of quantum efficiency in nanotube CdS-CdTe solar cells, showing increased light absorption and carrier production and collection. Despite not having an antireflection coating, the cells showed a high-power conversion efficiency of 10.7% under 1Sun illumination and a broad-spectrum response of quantum efficiency (short current density of 25.5 mA/cm2; open circuit voltage of 750 mV; luminous intensity of 750 nm). Materials and electro-optical characterizations showed that the junction and interface behavior of these 3D nanotube solar cells was well characterized.

Keywords - Cadmium Sulfide Nanotube, Three-Dimensional Nanotube Solar Cells, Membrane-Assisted Patterning, Carrier Generation and Collection.

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INTRODUCTION

Thin films of organic semiconductors, such polymers and small-molecule compounds, are used to create organic photovoltaic devices (OPVs), with typical thicknesses on the order of 100 nm. Polymer-based OPVs are appealing for covering vast areas cheaply and flexible plastic surfaces because they may be manufactured using a coating method such as spin coating or inkjet printing. There is a lot of work being done in both business and academics to improve OPVs and increase their power conversion efficiency since they are a viable low-cost alternative to traditional solar cells constructed of crystalline silicon. The photovoltaic effect is researched in physics, photochemistry, and electrochemistry, and it is used in photovoltaics (PV) to convert light into energy in semiconducting materials. Commercial applications of the photovoltaic effect include power production and the creation of photosensors. Modules made up of solar cells are used in a photovoltaic system to generate electricity. Solar photovoltaic systems may be installed on the ground, on a roof, on a wall, or even on water. A solar tracker may be used to move the mount in the sky to follow the sun.

Because it produces far less carbon dioxide than fossil fuels, photovoltaic technology contributes to climate change mitigation efforts. Solar photovoltaic (PV) has distinct benefits as an energy source, including zero pollution and zero greenhouse gas emissions once installed, the ability to scale to meet increasing power demands, and abundant supplies of both silicon and other materials needed to make PV systems in the Earth's crust. Competition for land usage has also been cited as a key restriction.[1] PV has a variety of unique drawbacks, such as fluctuating power production that must be balanced, and employing it as a primary source necessitates expensive energy storage devices or worldwide distribution through high-voltage direct current power lines. While the pollutants and greenhouse gas emissions from production and installation are minimal compared to those from fossil fuels, they nonetheless exist.

As a result of escalating energy consumption and worries about their influence on the environment, researchers and innovators have turned their attention to cost-effective photovoltaics. Nanoscale device and material breakthroughs have just established a new benchmark for increasing solar panels' efficiency and decreasing their cost. Nanoscale three-dimensional structures may be useful for solar cells. Nanowires, nanorods, and nanoparticles have been used into polymer- and silicon-based solar cells to reduce the number of semiconductor components needed, improve optical control, and provide novel conversion efficiency strategies. widespread use.

Compared to planar solar cells, photovoltaics based on CdS nanopillars and CdS nanowires exhibit power conversion efficiency < 10%. Power The efficiency of conversion depends on a number of elements, one of which is how well light is absorbed, created, and collected. To do this, we designed and built a three-dimensional nanotube. a solar cell to create single-walled carbon nanotubes, one first molds a semiconductor material (semiconductor-1 or S-1) into the desired shape, and then deposits a second semiconductor material (semiconductor-2 or S-2) on the inside of the nanotubes in a way that causes it to wrap around the outside. S-2 may be built up endlessly on top of S-1. To manufacture nanotubes with inexpensively adjustable geometric properties, we devised a technique that employs anodic aluminum oxide (AAO) membranes.

LITERATURE REVIEW

Nisar Ali et.al (2019) Homojunction solar cells have rekindled interest in a variety of materials due to their good lattice matching at the junction surfaces and minimal carrier recombination losses. This article provides an overview of the current state of the art in advanced homojunction solar cell design, fabrication, and materials, as well as the latest reported efficiencies. In this article, we trace the development of homojunction solar cells using a wide range of materials, from One-dimensional nanostructures include nanowires, nanorods, and nanotubes, whereas zero-dimensional nanostructures include nanodots and quantum dots. Homojunction solar cells, which include those built of CuInS2, InGaN, and other materials, are the principal focus of this research. While the focus is on InP, certain other thin film materials have been investigated for the same uses.

Leila Shabani et.al (2021) This research investigates the usage of active polymer solar cells (OPV) with a layer consisting of hexagonal plasmonic nanocrystals for light absorption. The relationship between the active layer shape and OPV solar cell performance is explored in a three-dimensional model. Therefore, the Lumirical is a 3D finite-difference time-domain approach used to study the field distribution and light absorption in the active layer as a function of wavelength. The incorporation of hexagonal lattice crystals, plasmonic nanoparticles, and a core-shell structure into the active layer of OPV solar cells has shown promising results. Studies have been undertaken on how the wavelength impacts the design, composition, dimensions, and active layer thickness of OPV solar cells. In order to increase optical absorption, an ultrathin active layer and a thinner shell were used. According to P3HT: PCBM, Ag plasmonic nanocrystals may Localized surface plasmon resonance (LSPR) was used to improve the optical absorbance of the active layer ester poly(3-hexylthiophene). Short circuit current was measured to be between 19.7 and 26.7 mA/cm2 for solar cells.

Glécia V. S. Luz et.al (2018) The purpose of this research was to create hybrid solar cells using the Grätzel method. ITO on PET substrate, a polymer using ITO as its foundation constituent. Four dyes, including Congo Red (CR), Bromocresol Green (BG), Acridine Orange (AO), and a Ruthenium Complex, were used to test ZnO nanoparticle (NP) films prepared using the Pechini process. When X-ray diffraction (XRD) was performed on ZnO NPs, peaks were seen that were indicative of the hexagonal wurtzite crystalline structure. This research also made use of ultraviolet-visible spectroscopy and transmission electron microscopy (TEM). The Rietveld analysis of the crystal yields a value of 115.23 28.16 nm. Thin sheets of ZnO and dye were deposited using spin-coating. The electrical properties of the finished films were analyzed using the Van der Pawn method. After assembly, an OSRAM 20W bulb was used to test the devices. Two kinds of transparent electrodes are available, PET/ITO/ZnO/AO and PET/ITO/ZnO/CR. The sheet resistance of the latter two materials was found to be lower. Voc values of 64 mV to CR and 73 mV to AO were found to be optimal. Thus, the results demonstrated fruitful interactions between the ZnO-Dye-Electrolyte layers.

Samy Almosni et.al (2017) Photovoltaic producing has rapidly evolved from a marginal energy option to a significant contributor to the ongoing energy revolution, making up 1.7% of worldwide electricity generation in only the last decade. Raw material and production process improvements have played a crucial role in this change. To deliver clean, abundant, and inexpensive power, photovoltaics will need to overcome a number of challenges. This article takes a retrospective look at that research direction, with an emphasis on the results obtained via the Next PV program of Japanese-French cooperation on prospective solar cell technology. The major focus of the partnership was on developing materials for printable solar cells, including colloidal quantum dots and inkjet-printed multijunction and thin solar cells with a high carrier concentration.

Khushboo Sharma et.al (2018) Thin-film solar cells, including dye-sensitized solar cells (DSSCs), have been explored by scientists for over two decades due to its low cost, simple preparation procedure, minimal toxicity, and low difficulty in manufacturing. There is much room for improvement in present DSSC materials due to their high price, limited availability, and poor durability. Current technological advancements have been made possible via the careful Dye-sensitized solar cells (DSSCs) can only reach efficiencies of up to 12%, whereas variants on thin-film solar cells and silicon solar cells have attained efficiencies of up to 20%. This article provides a high-level summary of DSSCs, discussing their design, operation, and major difficulties (low efficiency, restricted scalability, and low stability), as well as discussing possible efficient materials and briefly touching on commercialization.

SCANNING ELECTRONIC MICOSCOPE

The aforementioned AAO membrane-assisted electrodeposition may be used to generate CdS nanotubes and nanowires. Producing CdS nanotubes requires a combination of low CdCl2 concentration, low dc current density, and low deposition temperatures. When the deposition temperature is above 160 °C, the dc current density is over 7 mA/cm2, or both, CdS nanowires are generated instead of CdS nanotubes. 54 It's possible that this is how CdS nanotubes form. Sulfur atoms entered the AAO design via nanopores during a reduction process involving s-2 ions. Cd+2 was attracted to the nanopores by the electric field. When s-2 reacts with Cd+2 within nanopores, CdS crystals are created practically instantaneously.

When the concentration of CdCl2, the current density, and the temperature are all decreased, the nanopore walls of the AAO template become favorable locations for CdS nucleation and growth since this is where the Gibbs free energy is lowest. Due to the high Free energy of Gibbs towards the bottom of a nanopore, it is possible that insufficient energy will be provided by a low current density and temperature. As a result, CdS nuclei are prevented from forming at the nanopore's bottom. The AAO nanopores get lined with CdS crystals. As CdCl2 concentration is decreased, CdS precipitates out of solution at a slower pace. Therefore, CdS nanotubes are produced in a very short time frame. Due to the high voltage and current density, CdS nanowires were produced at the base of the nanopores, and CdS nucleated and grew quickly along the walls. The yellow color of CdS nanotubes is somewhat less intense than that of CdS nanowires. Scanning electron microscopy (SEM) was used to examine the AAO membrane and the CdS nanotubes.

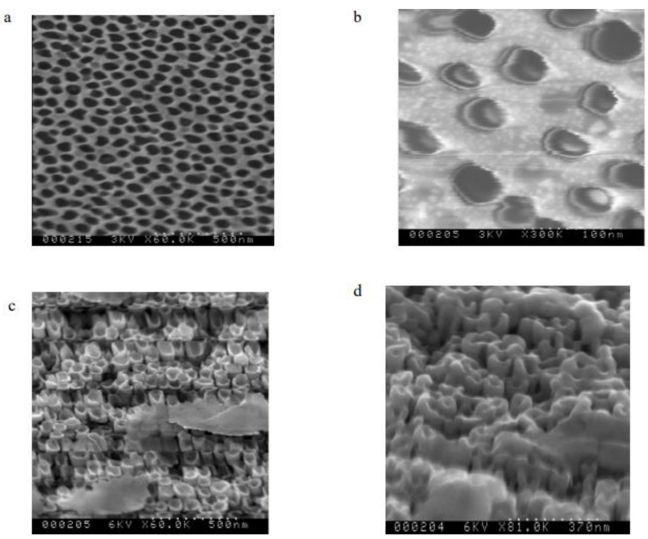


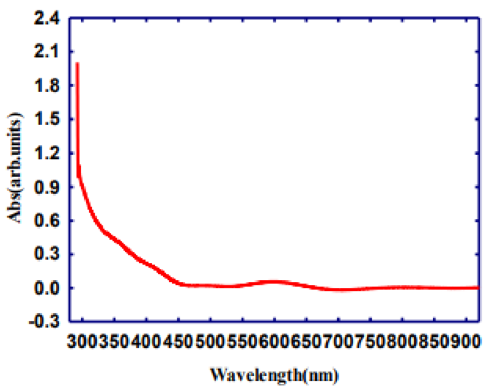
Figure 1: AAO membrane as seen in a top-down SEM image (a). Embedded CdS nanotubes in AAO membrane, shown from above using a scanning electron microscope (b). CdS nanotubes seen from the side (c). CdS nanotubes seen from the side (d).

CDS NANOTUBES' CAPACITY FOR ABSORPTION AND TRANSMISSION

The fundamental absorption and transmittance of CdS nanotubes might provide light on their intriguing features. transmission and absorption spectra of CdS nanotubes inside an atomically thin aluminum oxide (AAO) scaffold. Almost majority of the UV-visible spectroscopy of sunlight was employed to detect photons with energy beyond the wavelength range spanned by the band gap of the CdTe absorber, which is 300 nm to 900 nm. CdS nanotubes have almost zero absorption and good transmission from 450 to 900 nm. A little attenuation to 0.88 is caused by an absorption peak at 600 nm. There is a long absorption tail that extends from 450 nm to 296 nm because the transmittance of CdS nanotubes drops from 0.925 at 430 nm to 0.10 between 450 nm and 296 nm. These exceptional optical absorption and transmission properties are likely due to the form of CdS nanotubes and the opacity of the AAO membrane. To begin, more sunlight reaches the substrate thanks to the AAO membrane's almost negligible absorption. About 200 nm in length, CdS nanotubes are one thousand times shorter than the wavelength of the light being reflected.

This stands in stark contrast to the one-of-a-kind phenomena of long, thin silicon nanowire architectures scattering light. Increased light absorption occurs when the length of the nanotubes is bigger than the wavelength of the incident light. As a sponge, this section of nanotube shows enormous promise. CdTe nanotubes with a length of 200 nm were developed to improve light absorption, carrier generation, and carrier collecting in the absorber of CdS-CdTe solar cells. The CdTe absorber layer contains CdS nanotubes, which have a shape ideal for light absorption and carrier conversion but have peculiar light absorption behavior. CdS nanotube absorption spectra and AM 1.5D spectral simulations show how efficiently nanotube solar cells convert photon flux (P) to carriers.

a



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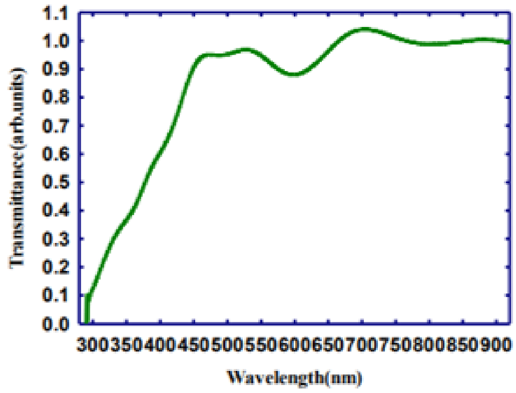
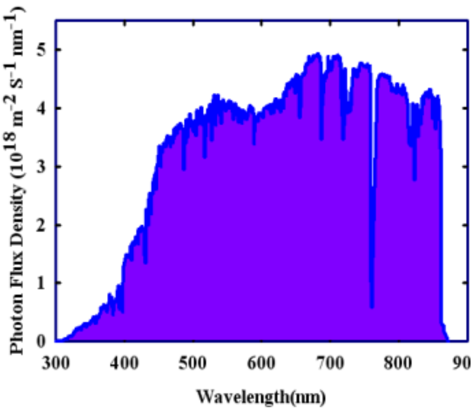
b



When exposed to the calculated photon flux P, solar cells fabricated from cadmium telluride produce a strong photocurrent. The spectral transmittance of CdS nanotubes and the absorbance coefficient of P nanotubes were used to describe the transit of photons through these materials. Modeling for nanotube growth allows for improved optical features, such as higher total photon absorption, that are unique to CdS nanotubes. CdS-CdTe solar cells are shown in Figure The photocurrent density is 29.18mA/cm2 and the electron-hole pair (EHP) generation rate is 18.23*1016/cm2/s. if the photon flux depicted in Figure is applied to solar cells composed of 3D nanotube CdS-CdTe.

c



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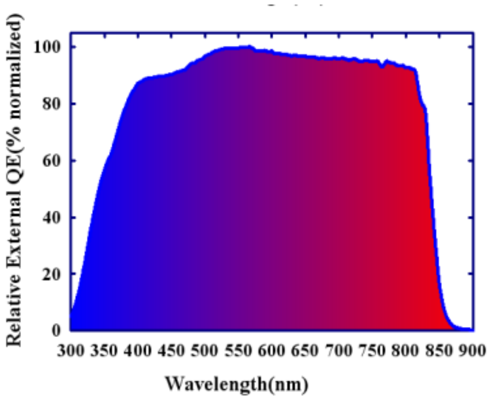


Figure 2: CdS nanotubes encased in an AAO membrane (a) absorption spectrum. Similar transmission using CdS nanotubes (b). (c) The theoretical amount of light entering a nanotube Solar cell made of cadmium telluride (CdSe). CdS-

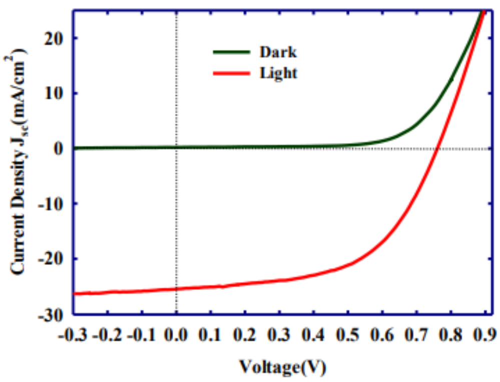
CdTe solar cells with a 3D nanostructured external quantum efficiency (d).

According to these findings, the optical features of CdS nanobute arrays may be modified at the nanoscale to improve the photon current density. Independent testing of PV Measurements Inc.'s nanotube CdS-CdTe solar cell on intrinsic SnO2/ITO/soda-lime glass yielded the findings shown in Figure Assuming minimal transmittance loss from the substrate and full responsiveness from the device, the predicted photocurrent density is 28.05 mA/cm2. The EQE spectral response is integrated to arrive at this value. Peaking at 565 nm, close to the energy band gap of the CdTe absorber layer, the energy-to-light efficiency (EQE) of 56 steadily increases to 825 nm. The EQE response provides a reliable photocurrent density, which validates the calculated photon flux. Nanotube solar cells are gaining popularity because of their high EQE response over a broad spectral range, and because their structural arrangement may be useful for photocarrier generation and collection. The aforementioned equipment is produced on a Substrate of SnO2/ITO/soda-lime glass, which is both inexpensive and opaque. Therefore, the nanotube solar cells become more sensitive to the electromagnetic spectrum when a more transparent substrate is utilized.

NANOTUBE-BASED CDSE/CDTE SOLAR CELLS' PHOTOVOLTAIC EFFICIENCY

The photovoltaic efficiency of nanotube CdS-CdTe solar cells was determined by measuring their performance in the dark of a solar simulator while exposed to 1Sun's worth of light. defining features of Nanotube solar cells operate best in low-light conditions, as seen by a plot of dark current against voltage (J-V). Assuming a fill factor of 55.9, an open circuit voltage of 750 mV, and a short current density (Jsc) of 25.5 mA/cm2, we may infer that the high efficiency of CdS-CdTe nanotube solar cells is 10.7.

a



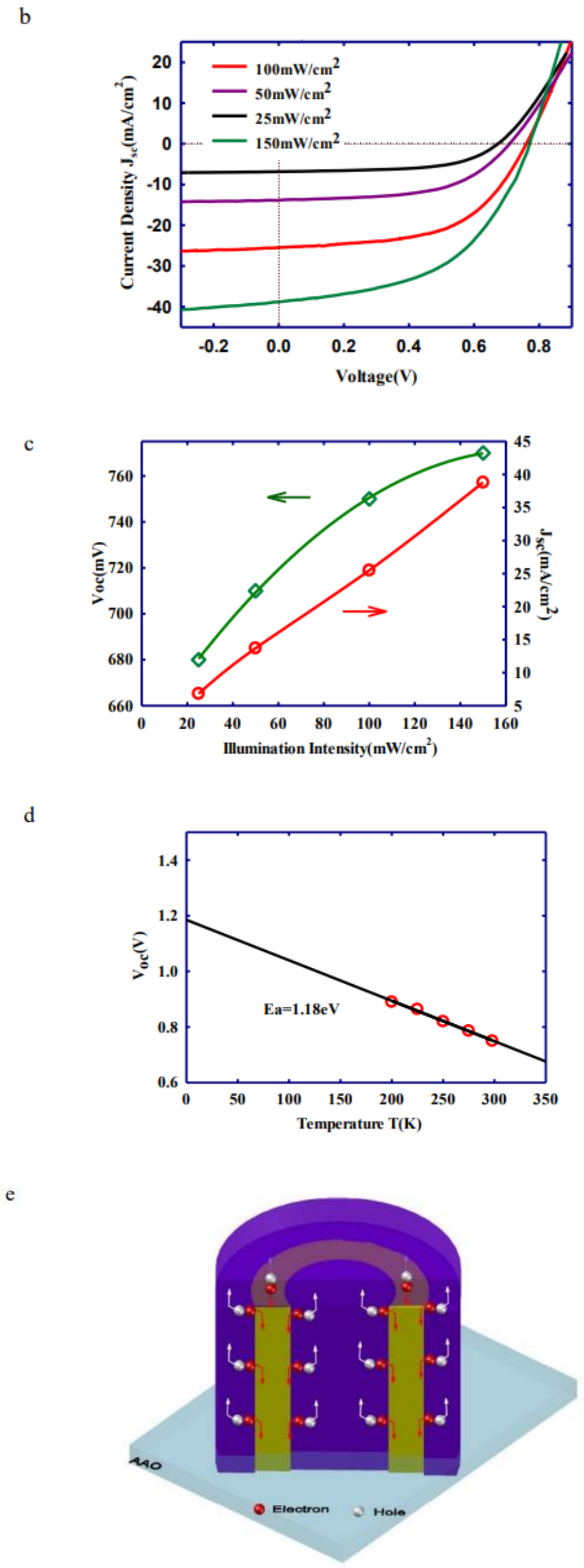


Figure 3: A dark (a) and an illuminated (1Sun) J-V curve for a nanotube A solar cell made of cadmium telluride (CdS-CdTe). Nanotube-based CdSe/CdTe solar cells' J-V curves vs light intensity. Nanotube CdS-CdTe solar cells and their open-circuit voltage (Voc) to short-circuit current (Jsc) and incident light intensity (d). Single-sun temperature versus voltage output a CdSe-CdTe (Voc) nanotube solar cell. (e) Carrier transport in CdS nanotubes; yellow indicates nanotubes, purple indicates absorber; radial transport occurs inside the nanotube and intertube space, whereas axial transport occurs above the nanotube.

Photovoltaic experiments have revealed that the efficiency of nanotube solar cells remains essentially stable over a wide range of light intensities. At half a Sun's brightness, efficiency soars to an astounding 10.9%. Increases in productivity of more than 10.7 percent are therefore feasible. Figure and illustrate and tabulate Jsc and Voc's respective light sensitivities. The rise in Jsc to 38.8 mA/cm2 and the jump in Voc from 675 mV to 770 mV in response to an increase in light intensity are both indicative of the predominance of photo-generated carriers.

Table 1: CdS-CdTe solar cells' photovoltaic efficiency made with 4 nanotubes changes with illumination level.

Sun Intensity	J_{sc}(mA/cm²)	V_{oc} (mV)	FF(%)	Efficiency (%)	Rs(Ω /cm²)	Shunt Resistance (Ω /cm²)
0.25SUN	6.81	675	57.6	10.6	7.75	935.7
0.5SUN	13.7	710	56	10.9	7.47	431.6
1SUN	25.5	750	55.9	10.7	4.92	228.6
1.5SUN	38.8	770	50.6	10.08	3.95	128.2

Substrate is built of SnO2/ITO/soda-lime glass, which has low transmittance but may naturally reduce photocurrent. Even without anti-reflective coating, the short-circuit current density of the 1 Sun's light is 25.5 mA/cm2 for nanotube solar cells. Successful A high Jsc requires light absorption, electron production, and electron collection. CdTe reaches out and touches the inner core and innertube space of the nanotubes as well as the air gap above them to form radial and axial contacts with the CdS nanotubes in the three-dimensional nanotube solar cell structure. Backlighting the AAO and CdS membranes lets light go through to the nanotubes behind it, where it is absorbed by the CdTe absorber and converted into electrons and holes.

CONCLUSION

Nanotube CdS-CdTe solar cells, in which the CdTe absorber is filled in the inner core space and the intertube space of the CdS nanotubes, have been produced and described for the first time. Carrier production and collection in the novel nanotube solar cell topologies explored here take place in three dimensions, spanning the inner core and intertube space in the radial direction, and the region above the nanotubes in the axial direction. Our results show that nanotube solar cells with a certain configuration may significantly improve carrier production and collection, as seen by a broad and robust quantum efficiency spectrum. Under 1Sun irradiation, the nanotube CdS-CdTe solar cells showed a power conversion efficiency of 10.7%, an open circuit voltage of 750mV, and a short current density of 25.5 mA/cm2. Nanotube CdS-CdTe solar cells have a well-defined diode junction, according to junction analysis. The PCE value may be greatly increased by different techniques. This nanotube solar cell structure will be widely used, particularly for solar cells 13 with absorbers that have short minority carrier lifetimes, since it improves the production and collection of carriers in three spatial dimensions.

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