Solar Electron Source and Thermionic Solar Cell

P. Yaghoobi, M. Vahdani Moghaddam, A. Nojeh
Department of Electrical and Computer Engineering
University of British Columbia, Vancouver, BC V6T 1Z4, Canada
anojeh@ece.ubc.ca

Today's solar electricity generation is largely photovoltaic, although thermophotovoltaic devices are also receiving increasing attention. Thermal approaches such as using concentrated sunlight to boil water for a turbine are also pursued. In photovoltaics, electron-hole generation through photon absorption across a semiconductor's band gap is used. Thermionic electron emission from a hot cathode into vacuum and collection by an anode is a promising alternative with several potential benefits.[1] A thermionic converter could utilize a much broader range of the solar spectrum than dictated by a band gap. Thermionic converters could also deliver higher power per unit mass or volume than photovoltaic ones, and are inherently more robust against radiation damage. Yet, the literature on thermionic solar converters is very limited. The few existing prototypes typically use elaborate heating systems involving large, complex focusing and heat reception mechanisms, such as those available in NASA's specialized test facilities.[2] Still, many of the tests are performed using electric heating. The reason is that it is extremely difficult, if not impossible, to directly heat a conventional cathode to emission temperatures using sunlight; while a piece of paper can easily be burnt by focusing sunlight with a simple lens, bulk conductors dissipate heat effectively and do not heat up easily.

We have shown that the situation can be drastically different in a macroscopic-sized array of carbon nanotubes: through a so-called Heat Trap effect, a spot on the surface of the array can become thermally insulating under focused laser irradiation, while remaining electrically conductive, thus heating to thermionic emission temperatures with a low-power laser beam.[3] Here, we report the surprising result that such an effect can also be achieved with sunlight, despite its major differences with laser radiation. We focused sunlight using a simple off-the-shelf lens (50 mm in diameter) onto a ~ 1-mm-diameter spot on the sidewall of a carbon nanotube array (Figure 1) placed in front of a copper anode in a small, portable vacuum chamber. Under a large collection voltage, the solar electron source delivered an emission current as high as 1 mA. When a retarding voltage was applied, significant current was still measured, showing power generation (Figure 2). When simply connected to a load resistor, this thermionic solar cell produced several tens of millivolts. A fundamental advantage of this device, where the cathode is directly heated with sunlight, is that the exponential dependence of the thermionic current on temperature opens up the door to increasing the efficiency significantly by better focusing of the light.

---

[1] Y.-G. Deng and J. Liu, J. Renew. Sust. Energ. **1**, 052701 (2009)
[2] S. F. Adams, AIP Conf. Proc. **813**, 590 (2006)
[3] P. Yaghoobi, M. Vahdani Moghaddam and A. Nojeh, Solid State Commun. **151**, 1105 (2011)

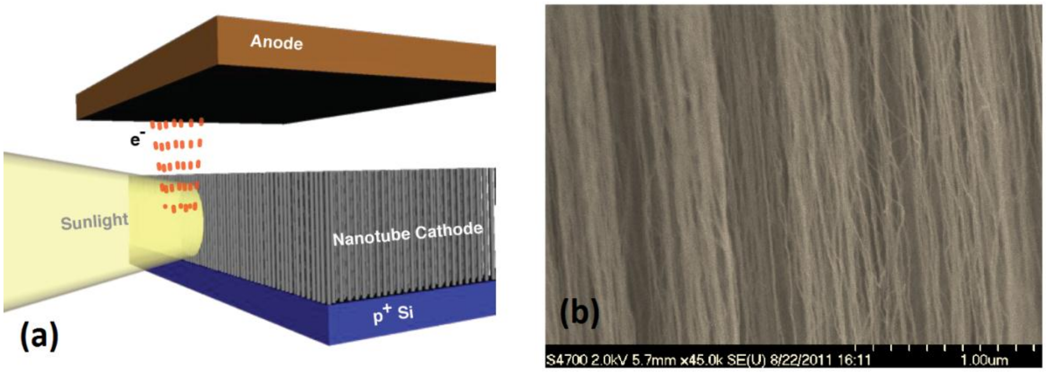

Figure 1: (a) A schematic (not to scale) of the solar cell. The array of aligned millimeter-long multiwalled carbon nanotubes, with lateral dimensions of approximately 5 millimeters, is grown on a silicon wafer. The nanotube “forest” cathode faces a copper anode approximately a millimeter away. The device is placed inside a small, portable vacuum chamber. A Keithley 6517A electrometer serves to apply a collection/retarding voltage and measure the emission current through vacuum feedthroughs connecting to the device. Sunlight, focused using a simple glass lens, heats a spot on the sidewall of the nanotube forest to thermionic emission temperatures through the Heat Trap effect. (b) Scanning electron micrograph of a nanotube forest, showing the alignment of the nanotubes.

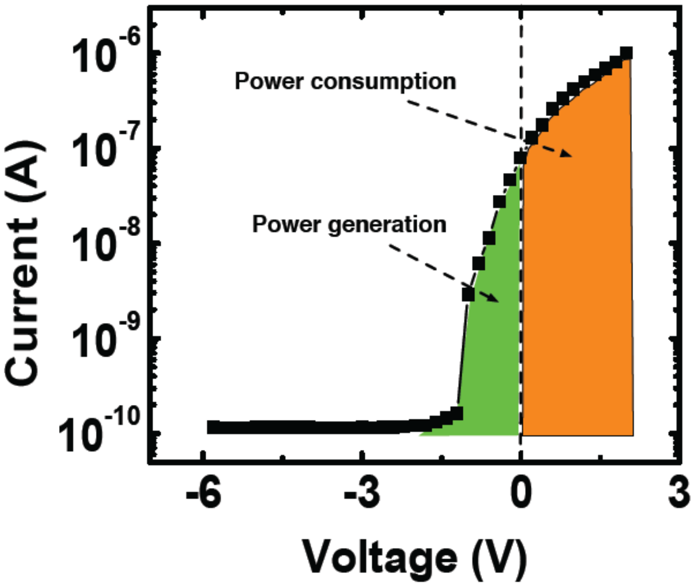

Figure 2: When the anode is positively biased, the electrons emitted from the hot cathode are collected and the device acts as a solar electron source. When the anode is negatively biased, it acts to block the emitted electrons from reaching the cathode. Those electrons with enough kinetic energy to overcome this retarding field still reach the anode and flow through the external circuit, delivering power to it. The device thus acts as a solar cell.