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High Power Organic Solar Cells from Efficient Utilization of Near-Infrared Solar Energy

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Tremendous Demand

The Global demand for energy is continually expanding. According to the U.S. Department of Energy's International Energy Outlook 2005, demand will nearly double by 2025 requiring an additional 11,743 billion kilowatt-hours of capacity. As outlined in President George W. Bush's 2006 State of the Union Speech, renewable energy technologies, and solar energy must play a major role in meeting this demand. Not surprisingly, renewable energy sources have experienced rapid growth in recent years as costs have improved and sensitivity to our reliance on fossil fuels has grown. Global solar cell production has grown 25% annually for the last 20 year reaching sales of $9 billion in 2005, a $3 billion dollar increase over 2004. This accelerating growth has resulted in a worldwide shortage of semiconductor silicon driving solar cell prices higher.

Solar cells generate power by converting photons from the sun into electricity through a mechanism called "the photovoltaic effect". The photovoltaic effect was first observed in 1839 in an electrochemical cell and by 1876 the first solid-state device was developed. Despite this early initial discovery, the Photovoltaic ("PV") industry as we know it today began in 1953 when scientists, at the Bell Telephone Laboratories in Murray Hill, New Jersey, successfully developed a solid-state silicon solar cell that converted 5% of the energy delivered from the sun to produce 5 milliwatts of electrical power. By 1956, silicon cells cost approximately $300 per watt of electricity produced, an enormous $30 per kilowatt-hour. Today, these so-called 1st Generation Solar cells have dropped in cost to approximately $3.50 per watt, or 35-50¢ per kilowatt-hour. This cost is still is too high as U.S. residential consumers pay on average about 8.5¢ per kilowatt-hour for their electricity.

Cost and Power Conversion Efficiency

For the PV industry to achieve a cost level that is competitive with traditional forms of electricity production, overall manufacturing and system costs must be reduced while power output improved, or held steady and lifetime maintained.

Power conversion efficiency (PCE) is a standard industry metric for solar cell performance. PCE measures the ratio of the electrical power produced by a solar cell per unit area in watts, divided by the watts of incident light under certain specified conditions called "Standard Test Conditions" or "STC".

STC represents a set of conditions under which cells or modules can be evaluated and compared. STC conditions include:

1. Irradiance intensity of 1000 Watts per sq. meter
2. AM1.5 solar reference spectrum, and
3. Cell/module temperature during measurement of 25 degrees C°.

$$\text{PCE} = \frac{\text{Solar Cell Power Output/m}^2\text{ (watts)}}{\text{1,000 watts/m}^2\text{ AM 1.5 Solar Spectrum Light}}$$

PCE, under STC conditions is thus a percentage representing the amount of optical power converted to electrical power. It is important to note that even though a solar cell's PCE < 100%, efficiency losses for solar cells do not contribute to either the capital or operating costs of a solar system as sunshine is ubiquitous and free. Traditional electricity generation methods can have conversion losses >60% and in these cases the energy lost contributes to higher operating expense as the cost of fuel is significant and real.

The Solar Spectrum and Power

To achieve high power output, solar devices must take advantage of as much of the solar spectrum as possible as the photons absorbed by a solar cell directly impacts the power output.

The solar spectrum includes invisible ultraviolet (UV) light, the visible spectrum of colors - violet, indigo, blue, green, yellow, orange and red -- and the invisible infrared or IR spectrum. Solar radiation includes wavelengths as short as 300 nanometers (nm) and as long as 4,045 nm or ~4 microns. The amount of incoming photons across the UV, visible and IR spectrums is about 3%, 45% and 52%, respectively.

A material's ability to efficiently absorb solar light across a broad range of wavelengths directly impacts the PCE potential of the same solar cell. The PCE performance of silicon is as a result of a nearly optimal bandgap (at 1.1eV) for absorbing solar light. Silicon devices efficiently absorb and convert solar energy up to about 1,050 nm, covering approximately 75% of the total photon flux from the sun. The visible-light spectrum covers a range of 390 nm (violet) to ~750 nm (red). Near-infrared begins at about 750 nm and extends to 1,400 nm, or 1.4 microns. Approximately 85% of the total photon flux from the sun is between 300 nm and 1,400 nm.

The best performing 1st Generation crystalline silicon cells have reached a PCE of 24.7% under STC. 2nd Generation thin-film silicon devices have reached 12.7% and 3rd Generation nanocrystalline inorganic/polymer hybrids are at about 1.8-2.7%. 4th Generation organic devices have reached approximately 5%. 4th Generation technologies have the potential to combine both high power output with an ultra-low cost of manufacture.

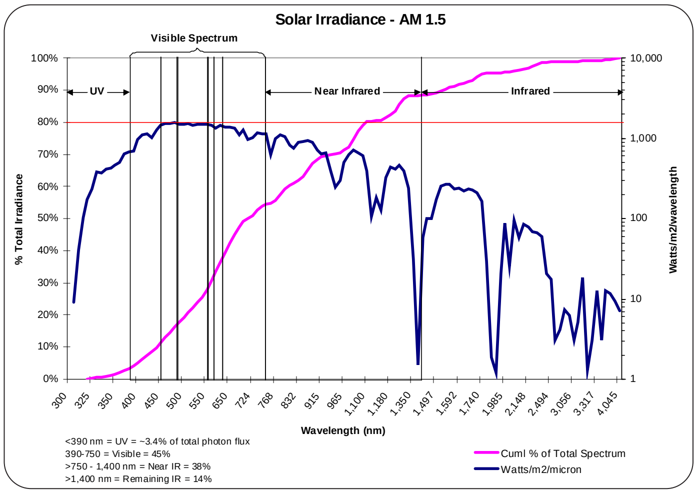

Figure 1: Solar irradiance and wavelength

It has long been understood that PCE performance could be improved by combining multiple materials with different absorption characteristics in a single device to create a broader spectral response than that of a device with a single material. Materials with different absorption characteristics can be stacked in tandem so that photons of different energies and wavelengths can be efficiently harvested to generate power and increase PCE. Each individual subcell is optimized to efficiently absorb and convert only a portion of the solar spectrum.

Using this approach has the potential to greatly improve overall device PCE. In practice for traditional inorganic semiconductors, tandem devices can be very cost-prohibitive to fabricate. Yet using this approach and exotic inorganic semiconductors has lead to PCE performance as high at 38%19. These stacked inorganic devices are extremely expensive to produce and are primarily used in niche space or military applications.

Organic Photovoltaics

Research being pursued by Global Photonic Energy Corporation (GPEC) through its sponsorship of Dr. Stephen R. Forrest at the University of Michigan, Ann Arbor, and Dr. Mark E. Thompson, at the University of Southern California (USC) is focused on developing high-power, ultra-low cost organic photovoltaic devices using organic semiconductor materials and nanostructures. This combination of high power and ultra-low cost using an organic semiconductor system is called "4th generation" solar cells.

There is significant global commercial interest in organic semiconductors due to their:

- Ability to be deposited at room temperature on a variety of very-low-cost substrate materials (plastic, glass and metal foils),
- Relative ease of processing,
- Materials are inherently flexible and readily available, and
- Ultra-low cost.

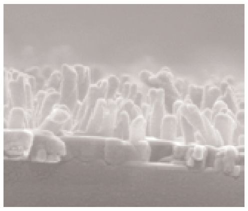

Figure 2: Nano-scale organic "fingers" created with low-temperature organic processing innovations.

In addition to these processing advantages, organic materials have several material properties of interest including:

- Very strong optical absorption per unit of thickness,
- Virtually infinite variety of molecules to choose from and/or design,
- Tunable absorption and electrical properties.

Organic materials can be applied to virtually any surface using a method akin to spray painting. Production methods of this sort are easily adaptable to continuous, "roll-to-roll" or batch manufacturing processes and hold the promise of dramatically reduced production costs. Organic materials also can be used in flexible applications. GPEC's proprietary OPV™ technologies can be used to create photovoltaic cells that are semitransparent and colors for window tinting in building-integrated applications.

Despite these advantages, characteristics of the absorption and excitation process in organic semiconductors require active layers to be thinner than the thickness necessary for complete absorption of incident solar illumination. Thus, the best performing organic solar cells absorb only a fraction of the visible portion of the solar spectrum converting only about 1/3 of the total available light.

Since half of solar radiation is in the infrared range (>~750 nm) future high-performance organic PV devices must efficiently capture and convert this radiation as well as improve on the harvesting of the visible portion of the spectrum.

Figure 3: 100 nm of transparent Organic PV material

New Materials

Recently GPEC's research partners at Princeton and USC announced the achievement of a new record in an organic solar cell that is responsive to light in the near-infrared (NIR) range of the solar spectrum. This device uses a novel architecture employing "Buckeyballs" (C60) and copper and tin phthalocyanines (CuPc and SnPc respectively).

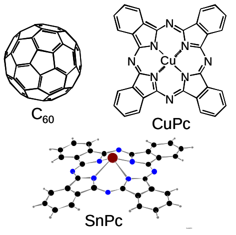

Figure 4: Organic PV materials

Beyond UV light, C60 is a good absorber for the shorter wavelengths, 450-550 nm. CuPc performs well from 560 nm to 750 nm and SnPc is a strong absorber for wavelengths from about 625 nm to 1,000 nm. NIR radiation which begins at about 750 nm is invisible to the human eye. See Figure 5 for absorption characteristics of C60, CuPc, SnPc and the overall device.

Innovative Architecture

In a typical high-performance organic PV architecture, the active organic layers (CuPc and C60) are sandwiched between a transparent conducting oxide layer (TCO) on one side and a blocking layer and metal electrode on the other. See Figure 6 for details.

In the typical bi-layer organic PV cell, the CuPc layer is only 10 nm thick and the C60 layer is about 40 nm thick, with a 10 nm blocking layer. Normally, researchers would have substituted the SnPc for the CuPc in this structure to improve long wavelength absorption as SnPc is a stronger absorber than CuPc over nearly its entire range.

Princeton researchers found that because of the low mobility of SnPc a simple substitution approach would not improve the cell's performance. To get around the mobility issue, researchers hypothesized that they could use a very thin layer to absorb NIR light without hindering mobility. As the SnPc layer was thinned, however, researchers found that electrical shorts began to form between the C60 material and the TCO layer as the SnPc layer was no longer continuous. It formed more of a "swiss-cheese" structure than a smooth continuous film.

The successful solution was created by utilizing CuPc as a "wetting" layer prior to the deposition of the very thin, SnPc layer. Despite the thinness of the SnPc, its stronger absorption characteristics allowed for the device to efficiently perform out into the near-infrared portion of the solar spectrum. The device achieved a peak external quantum efficiency of 35% and exceeded 10% out to 850 nm. (See Figure 5). The Company's researcher partners detail this latest achievement in the December 2, 2005 issue of Applied Physics Letters.

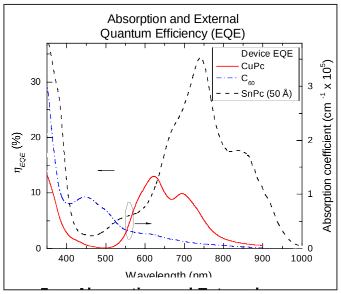

Figure 5: Absorption and External Quantum Efficiency

This achievement is the highest level of conversion performance yet achieved for an organic solar cell in the IR portion of the solar spectrum. Researchers also found that the NIR organic PV device could perform under concentrated light. PCE increased with illumination levels of 100 milliwatts per square meter on up to 1,000 milliwatts per square meter.

This latest device demonstrates that significant power can be harvested from the IR and near-IR portion of the solar spectrum", said Dr. Stephen R. Forrest. "In fact, this novel approach has the potential to double the power output of organic solar devices with power harvested from the near-IR and IR portion of the solar spectrum. With this approach we are well on our way to power levels exceeding 100 watts per square meter", Forrest concluded.

Future Challenges

One benefit of stacking solar cells in tandem is that the optically tuned sub-cells can utilize incremental portions of the solar spectrum. One of the remaining opportunities for a tandem device is that each sub-cell must generate the same amount of current to obtain the full benefits of stacking.

Like stacked batteries, the voltage of the overall stack of solar cells is the sum of the individual sub-cell voltages. The current of the overall device is the current of the lowest sub-cell. Thus if one sub-cell can generate 20mA of current at 0.5 volts and another 10mA at 0.8 volts then the overall device will generate ~10 mA at ~1.3 volts. The current mis-match effectively reduces the overall efficiency of the tandem device to less than the advantage provided by the increased voltage inherent in this architecture.

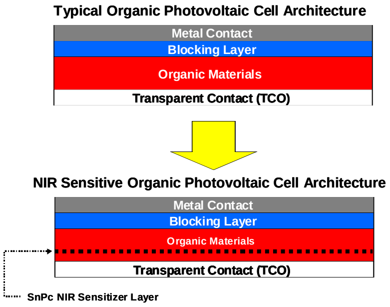

Figure 6: Typical and NIR Sensitive SnPc Architecture

Continued development of this NIR absorbing solar cell will focus on current matching so that it can be productively combined with the record setting hybrid planar-mixed molecular heterojunction work previously reported (See References #2, and #4).

Like all new and disruptive technologies, attaining commercial performance goals takes time. For organic photovoltaics incremental functionality and cost reductions are the driving force behind rapid developments. Improvements in power output, cost and lifetime for organic photovoltaic devices will be achieved by further improvements in materials, device architecture and processing improvements.

Exciting Times for Solar

As we finish this article, we are greatly encouraged by the U.S. Department of Energy's recent announcement of the details behind the Solar America Initiative. The U.S. is increasing its focus and effort in combining breakthrough thinking, technologies and funding together to enhance our national security and energy supply. Solar energy in the U.S. has a very bright future.

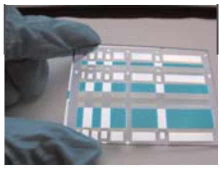

Figure 7:
GPEC OPV™ Technology

About Global Photonic Energy Corporation

Global Photonic Energy Corporation (GPEC) is the world leader in developing Organic Photovoltaic (OPV™) and Photo Fuel™ (Hydrogen) production technologies. GPEC is collaborating with world-class organizations to transform energy markets. GPEC has a long-standing research partnership with Princeton University and the University of Southern California.

GPEC was founded in 1994 by entrepreneur Sherwin I. Seligsohn. Mr. Seligsohn has been the Chairman of the Board and Chief Executive Officer of the Company since its inception. Mr. Seligsohn is also the founder, Chairman and Chief Executive Officer of Universal Display Corporation, a public company (NASDAQ: PANL), and American Biomimetics Corporation, a new materials sciences and technology venture group. Previously, Mr. Seligsohn founded and served as the Chairman of the Board and then Chairman Emeritus of InterDigital Communications Corporation (Formerly International Mobile Machines Corporation), a public company (NASDAQ: IDCC).

Global Photonic Energy Corporation is located at the Princeton Crossroads Corporate Center in Ewing, New Jersey, minutes away from its research partner at Princeton University. Contact them at: www.globalphotonic.com.

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