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Nanotechnology-Enabled Energy [R]evolution: Nanoscale Design of a Flexible Smart-Membrane for Harnessing Free Sources of Energy

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Abstract: ***Nanotechnology enhanced, thin-film solar cells constitute one of the most promising energy solutions in today's age. Along with the thin-film solar cells that harness free source of energy from the sun, thermoelectric devices play a significant role in addressing energy issues by making an efficient use of energy given out by humans as 'body heat'. The paper profiles smart integration of nano-structured components into a smart-grid termed as a 'smart-membrane' for availing free sources of energy. The membrane leverages the advantage of micro-supercapacitors that act as an energy storage unit interior to the membrane.***

Keywords: Thin-film Flexible Solar Cells, Flexible Micro-supercapacitors, Flexible Thermoelectric Generators (TEGs), Smart-membrane

1. Introduction

Harvesting renewable energy is increasingly viewed as critically important globally. Solar cells, or photovoltaics, convert solar energy into electricity. Theoretically all parts of the visible spectrum from near-infrared to ultraviolet can be harnessed. The backbone of solar energy at present rests on the silicon solar cell which accounts for about 80-85% of the energy market worldwide. In spite of being the mainstay in solar energy supply market, these cells have costlier inputs in terms of manufacturing expenses as well as the output efficiency. The expenditure incurred for per unit of power is many fold higher using silicon solar cells than the one derived from fossil fuel combustion [1].

Another challenge encountered while utilizing the solar energy to power electronic devices is that of integrating energy-storage units with electronic circuits at nanoscale level - which often limits the miniaturization of the entire system. Reason being, the necessary energy-storage components scale down poorly in size and they do not complement well to the planar geometries of most integrated fabrication processes.

In addition to solar energy, another free source of energy that can be pondered upon is the energy given away by humans in the form of body heat. The average human, at rest, produces around 100 - 120 watts of power, enough to power many of the electronics of our daily use, such as cell phone (about 1 watt), laptop (45 watts), etc. This equates to around 2000 kcal of food energy. Over periods of a few minutes (or a few hours in the case of trained athletes), we can comfortably sustain 300-400 watts — and in few other cases, a very short bursts of energy is given off, in activities such as sprinting - where some humans can output up to 2,000 watts.

The bulk of this energy is required for important tasks, voluntary as well as involuntary - such as pumping of heart and flexing of muscles, but a lot of it is wasted — primarily as heat, but also through other physical inefficiencies. Eighty percent of body power is given off as excess heat [11]. Almost all of this wasted energy could be captured and turned into electricity, which could then augment or completely replace our dependency on chemical batteries.

2. Nanostructured Layered Components

The 'smart-membrane' lays a stack of layered components. The layers include the following:

2.1 Thin-film Flexible Solar Cells

(a) Principle

Thin-film flexible solar cells are the new generation solar cells that accommodate multiple thin film layers of photo voltaic materials. The thin film solar cells (TFSC) are also termed as Thin Film Photo Voltaic cell (TFPV). The thicknesses of various thin film layers in a cell are in the measure of few nano-meters, in comparison to traditional P-N junction solar cells. Thin film is a more cost-effective solution in order to harvest solar energy than the age-old traditional solar cells. As a result much less material is required (as low as 1% compared with the wafers) which reduces the costs significantly [7].

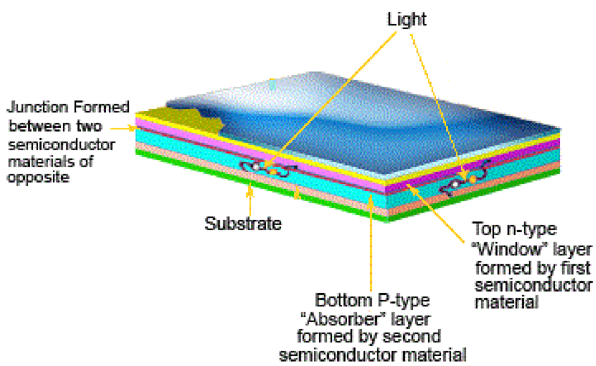

Figure 2.1(a): Structure of thin film solar cells [7]

(b) Operation

The elementary substance of a photovoltaic cell is semiconductors. The semiconductor doped with phosphorus develop an excess of free electrons (usually called N type material) and a semiconductor doped with boron, gallium or indium develop a vacancy (called holes) and these doped materials are known as P type materials. These n type and p type materials combine (join) to form a standard Photo voltaic cell. During the absence of light, a paltry number of atoms are excited and move across the junction. This causes a small voltage drop across the junction. In the presence of light, more atoms are excited and flow through the junction causing a larger current at the output [7]. The current at the output is stored in a micro-supercapacitor layer just below the solar cell layer and is used for several applications like charging electronic gadgets, appliances, etc.

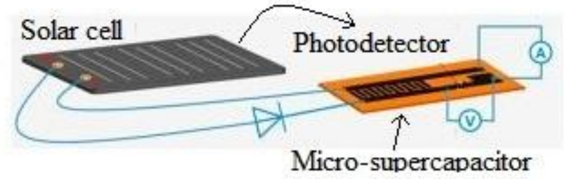

Figure 2.1(b): Lateral-view of a solar cell and a micro-supercpacitor as a unit [10] - reformed

2.2 Flexible Micro-supercapacitors

(a) Principle

Supercapacitors or ultracapacitors are the electrical storage devices, which have a high energy storage density simultaneously with a high power density. Supercapacitors have been desirable devices to use in microelectronics since they can store a great deal of energy for their nanoscaled size - they can be charged and discharged extremely quickly. In addition to this, the lifespan of supercapacitors is nearly limitless [2]. Micro-supercapacitors are flexible in structure and act as micro-batteries at the micro-scale degree.

(b) Operation

New structural design of the flexible micro-supercapacitors is developed en route the fabrication process. For any supercapacitor to be effective, two separated electrodes have to be positioned in a manner that maximizes the available surface area between them. This allows the supercapacitor to store a greater charge.

In the new design, the electrodes are placed side by side using an interdigitated pattern, akin to interwoven fingers. This aids in maximizing the accessible surface area available for each of the two electrodes while also reducing the path over which ions in the electrolyte would need to diffuse. As a result, the new supercapacitors have greater charge capacity and rate capability than their stacked counterparts [5].

It is also found that by placing more electrodes per unit area, the micro-supercapacitor's ability to store even more charge is boosted.

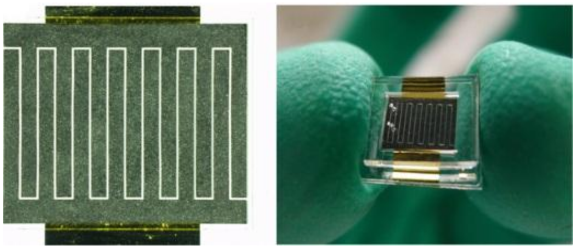

Figure 2.2: Micro-supercapacitors [8]

2.3 Flexible Thermoelectric Generators (TEGs)

(a) Principle

Thermoelectric generators (TEGs) generate electricity by making the use of temperature differential between a hot body and a cold body (i.e. human body and the ambient air in this case) – based on a proposition called the Seebeck effect [4]. The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. The energy generated through the process is termed as "Thermoelectric energy".

(b) Operation

A thermoelectric generator (TEG) can be used to harvest electrical energy from human body heat for powering wearable electronics, microelectronics, appliances, devices, etc. The new design contains a layer of thermally conductive material that rests on the skin and outspreads the heat. The conductive material has an overlay polymer layer that averts the captured heat from dissipating through to the outside air. This forces the body heat to pass through a centrally-located TEG that is approximately one cm^2. Heat that is not converted into electricity passes through the TEG into an outer layer of thermally conductive material, which rapidly dissipates the heat. The entire system is a flexible thin apparatus – of about 2 millimeters [6].

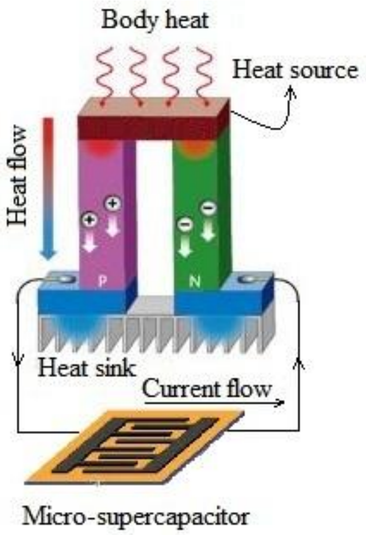

Figure 2.3(a): TEG mechanism – reformed [6]

(Note: When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. In the above diagram - when the pair is connected through an electrical circuit, direct current (DC) flows through that circuit. A thermoelectric circuit composed of

materials of different Seebeck coefficient (p-doped and n-doped semiconductors), is configured as a thermoelectric generator)

It is further noted that the upper arm is the most optimal location for body heat harvesting. While the skin temperature is higher around the wrist, the irregular contoured patterns of the wrist limit the surface area of contact between the TEG band structure and the skin.

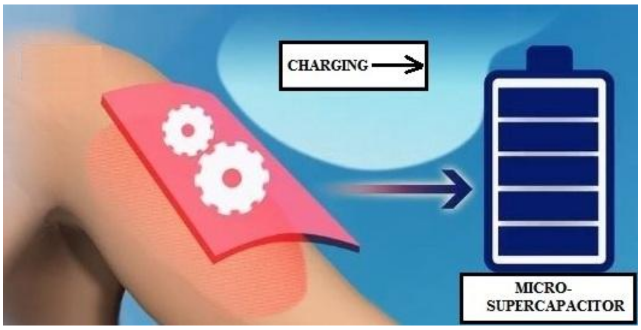

Figure 2.3 (b): TEG operation – remodeled [9]

(Note: Once the membrane is placed on skin surface, the TEG device senses temperature difference and initiates its service of charging the micro-supercapacitor)

3. "Smart-Membrane": A smart integration of layered components

Smart integration of energy into electricity grids is of paramount importance [3]. The smart-membrane is a leaflet like skin that embodies the layered components stacked over one another. The outer layer of the membrane holds the thin flexible solar cell for its operation when exposed to sunlight. The thin film captures photons and excites atoms as they flow through the junction and cause a significant current at the output.

Under the solar cell, micro-supercapacitor is placed to store the energy generated by the thin solar film. Micro-supercapacitors are precisely used as storage devices, as it can be charged and discharged within no-time.

The lower layer of the membrane consists of TEG hardware. This is designed to aid in capturing heat given out by a human body. When the membrane is placed over the body surface, the temperature difference between the outer skin and the environment around develops a current in the TEG device. This very energy is picked up and stored in the micro-supercapacitor for future use.

The assembly and fabrication of the layered components in the electronic "smart membrane" can be visualized as in the figure below:

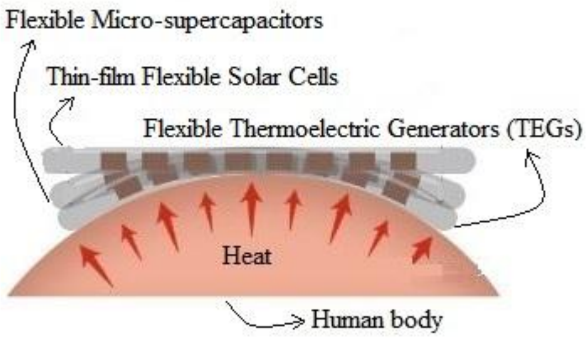

Figure 3(a): Three-Layered Smart-Membrane – reformed [6]

(Note: The above diagram depicts the nanoscale design of a membrane placed over human body - three nanostructured layers are shown as separate flaps for better perception)

The smart-membrane is termed as 'smart' for its fundamental property of switching between the two energy capturing units based on sensors employed in the membrane. The membrane intelligently switches between a solar cell and the TEG structure based on the sensing capability of the membrane. It senses the incidence of photons on the solar cells during daylight and smartly switches over to operate the solar cell for storing charge onto micro-supercapacitor. Accordingly during cloudy weather or in cold countries like Norway, Finland, etc. where sunlight isn't at its peak intensity for enough length of time; the membrane is placed on the skin surface. As soon as the membrane is placed on the skin, the TEG device senses the temperature difference between the skin and colder air around. This triggers the operation of a TEG to capture the body heat and store the energy for later applications.

The membrane has an advantage of capturing and storing energy from both the sources of energy (i.e. solar or body) parallely.

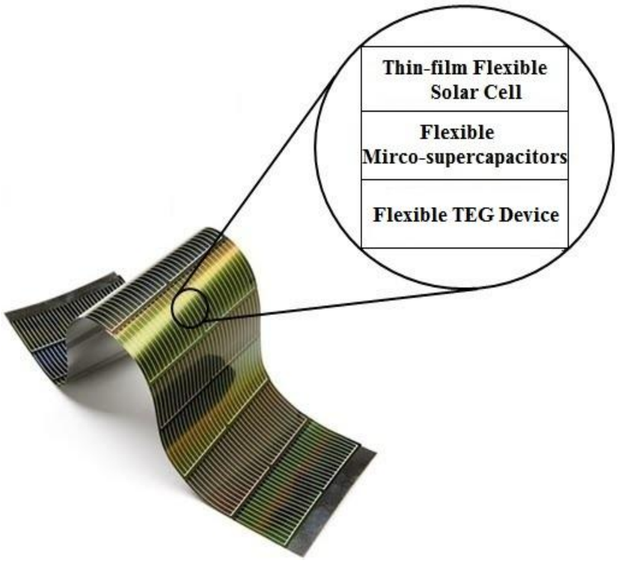

Figure 3(b): Arrangement of Stacked Components
(Source: Thin film solar cell - remodeled)

(Note: The flexible membrane is a thin sheet comprising layers of thin-film solar cells, micro-supercapacitors and

TEGs respectively. The membrane further incorporates sensors to sense the temperature gradient between a hot body and the cold ambient air thereby enabling the TEGs to function)

A USB connector is provided to the membrane for the purpose of conveying the captured electric energy to any electronic framework. For an electronic device to be charged the flexible membrane is placed over the device or near-by to the device and the USB connector is inserted into the charging slot of the corresponding device.

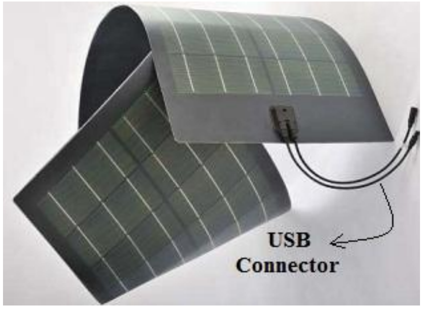

Figure 3(c): "Smart-Membrane" – Final Product
(Source: Flexible CIGS solar cells - remodeled)

(Note: The membrane can be provided with different types of USB connectors (micro or mini) – to ensure the universality of the membrane for charging plethora of devices having variety of charging slots)

4. Advantages

a) Free source of energy
b) Flexible
c) Multiple sources of energy can act as input.

5. Applications

a) Electronic powering circuits
b) Home light applications
c) Used in Solar fields
d) Electronic devices/gadgets: Smartphone, Laptops, Watch, etc.
e) Household appliances: Mixers, Washing machines, etc.

6. Conclusion

The paper embeds three technologies into a single electronic membrane. Technologies include: thin film flexible solar cell to capture solar energy, recently discovered flexible 'micro-supercapacitors' as an entity to store energy, and the flexible TEG device to harness body heat. The two free sources of energy (solar energy and human body heat) would assist in curbing the artificial energy needs posed by household electrical appliances, devices, etc. The paper paves a way for harnessing natural sources of energy as a new solution for growing 'sustainable energy' demands.

7. Acknowledgement

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References

[1] Ying Guo et al., "Nanotechnology-Enhanced Thin-Film Solar Cells: Analysis of Global Research Activities with Future Prospects", https://www.researchgate.net/publication/228708799, January 2009.
[2] Adrian Schneuwly et al., "Properties and applications of supercapacitors from the state-of-the-art to future trends", Proceeding PCIM 2000.
[3] Sir David King et al., "Energy Harnessing: New Solutions for Sustainability and Growing Demand", University of Cambridge, United Kingdom, October 2013.
[4] Melissa Hyland et al., "Wearable thermoelectric generators for human body heat harvesting" Journal: Applied Energy, Aug. 27 2016.
[5] Maher F. El-Kady et al., "How a Microscopic Supercapacitor Will Supercharge Mobile Electronics", http://spectrum.ieee.org/semiconductors/materials/how-a-microscopic-supercapacitor-will-supercharge-mobile-electronics, 28 Sep 2015.
[6] Professor Cho, http://tegway.co/, April 2014.
[7] Vysakh, http://www.circuitstoday.com/thin-film-solar-cell , June 6, 2011.
[8] Siwei Li et al., "Micro supercapacitors based on a 3D structure with symmetric graphene or activated carbon electrodes", Journal of Micromechanics and Microengineering, Volume 23, Number 11, 25 October 2013.
[9] MBC News Desk, tegway, January 30, 2015
[10] Jinguang Cai et al., "Laser direct writing of high-performance flexible all-solid-state carbon micro-supercapacitors for an on-chip self-powered photodetection system", 9 September 2016.
[11] Osman Can Ozcanli, "Turning Body Heat Into Electricity", 6/08/2010.

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