Bacteriophage Power Generator

- Virus-based Piezoelectric Energy Generation

Commercial Analysis
May 20th 2013

LAWRENCE BERKELEY NATIONAL LABORATORY

Researchers: Dr. Seung-Wuk Lee
IB# 3128

Technology

Imagine a device, embedded in a shoe that converts the mechanical motion of walking into electricity to recharge a cell-phone battery. Or a pacemaker powered, literally, by the beating of a heart. In the future, thanks to scientists at Lawrence Berkeley National Laboratory (LBNL), such inventions may be powering our growing arsenal of electronic gadgets, as well as medical and military devices, eliminating the need for mountains of limited-use batteries.

> "The proposed approaches provide a sustainable, cost effective, non-toxic energy source, capable of powering electronics and microdevices."
>
> Joseph Akkara
> Biomaterials Program
> Div. Materials Research,
> National Science Foundation

LBNL's Bacteriophage Power Generator technology presented here provides a sustainable energy source capable of powering the networks of portable electronics and microdevices listed above. This invention converts environmental kinetic energy sources (e.g., body movement, blood flow, air flow, or mechanical vibration) into electrical energy via the piezoelectric properties of a biological material — a harmless virus that converts mechanical energy into electricity. The technology is unique in addressing the energy challenge of predominantly battery-driven devices. It provides a sustainable, cost-effective, nontoxic energy source capable of powering electronics and micro-devices.

> "There is a strong interest in the development of energy harvesters, devices that can convert environmental energy sources such as body movement, blood flow, air flow, and mechanical vibrations into electrical energy."
>
> Arun Majumdar
> Vice President, Energy
> Google Inc.

Because the energy-generating virus infects only bacteria, it is not harmful to humans and is biocompatible and nontoxic, unlike conventional piezoelectric materials such as lead, cadmium, and lithium. Such biocompatibility will revolutionize its application for biomedical devices, particularly those implanted in the human body.

This invention is also a breakthrough in the concept of nano-manufacturing, as it exploits the unique natural ability of a virus to synthesize materials that can self-assemble and self-replicate.

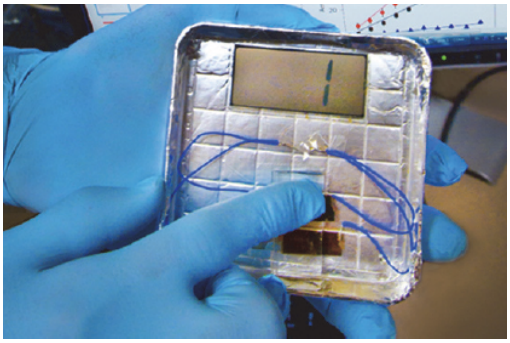

Figure 1 - Bacteriophage Power Generator. When the "virus film" is pressed with a finger, it generates enough electric energy to operate the LCD device, showing the number "1."

Applications

Recently, piezoelectric materials have attracted attention as one of the most promising candidates for energy-harvesting systems. Energy harvesting is a concept of scavenging energy from the environment in which the system is immersed. The electric potential difference induced by the separation of the space charge in piezoelectric materials that are externally vibrated can be converted and stored in the form of electric potential energy. It would be ideal for a wireless sensor system or a nanometer-scale device to have a self-generator rather than having its energy supplied by a source that has a finite lifetime (e.g., a battery).

Biocompatible, Sustainable, Environmentally Friendly, Nontoxic Energy Source

The Bacteriophage Power Generator's competitors are created using conventional piezoelectric materials: lead zirconate titanate (PZT), lithium niobate, gallium nitride, and barium titanate.
While devices that generate energy from everyday mechanical vibrations such as walking, typing, or airflow have been successfully generated with these materials, they are toxic, not biocompatible, and are created using environmentally harmful chemicals in energy-intensive conditions (i.e., high temperatures, high electric fields, and extreme pressures).

> "(This technology) is very suitable for biosensors and biomedical devices addressing the challenge on how to supply electric power to these devices."
>
> Dr. Ying-Lan Chang
> Director of Device Characterizating and Engineering
> GLO-USA, Inc.

Due to its biocompatibility, this invention has unique applications for biosensors and biomedical devices, particularly those to be embedded in the human body.

Other example applications include wearable electronics and wireless communications.

Economics

Lowest Estimated Manufacturing Cost
Manufacturing costs for this device are very low, as it leverages nature's unique ability to self-replicate and self-assemble. Millions of copies can be created in several hours through bacterial host cells. In addition, nature produces diverse, hierarchically organized materials at near-ambient temperatures using benign and abundantly available resources. For example, naturally existing DNA, cellulose, and collagen structures are known to be piezoelectric when they align in a proper structure. In contrast, fabricating inorganic counterparts and creating artificially aligned structures to make piezoelectric materials or devices from these materials, is energy-expensive and complicated.

Cost
The manufacturing cost for the Bacteriophage Power Generator is estimated to be between $0.02 (materials cost) and $.78 (materials and labor) for a device measuring 1 cm x 1 cm, depending on its application.

Market

In the United States alone in 2012, the consumption of batteries to power the new generation of energy-hungry electronic devices, such as consumer electronics (digital cameras, ebooks, pico projectors) and high-performance portable computing devices, was close to $20 billion. It is fair to assume that this market will grow at a rate comparable to or higher than the battery-pack power growth rate. Forecasts show that the worldwide battery power-pack market is expected to grow from 2.5 billion units in 2012 to 4.1 billion units in 2017. Driven by all five segments — computer, consumer, portable medical devices, military devices, and the large communications segment — it is projected to grow at a compounded annual growth rate (CAGR) of 10.2%.

Competitive landscape

A product comparison of the following three technologies is shown in Table 1 below:

1. Conventional PZT piezoelectric materials from Materials Systems, Inc., www.matsysinc.com
2. ZnO Nanowire piezoelectric materials, as described in the publication by the team at Georgia Tech, Wang, Z. L. & Song, J., "Piezoelectric nanogenerators based on zinc oxide nanowire arrays", Science 312, 242–246 (2006).
3. Organic piezoelectric (PVDF) materials, as described in the publication by the team at UC Berkeley, Chang, C., Tran, V. H., Wang, J., Fuh, Y-K. & Lin, "L. Direct-write piezoelectric polymeric nanogenerator with high energy conversion efficiency", Nano Lett. 10, 726–731 (2010).

Table 1- Matrix showing how the product's key features compare with existing products or technologies.

Feature	Conventional Piezoelectric Materials (MSI Inc.)	Nanowire-based from Prof. ZL Wang (GATech)	Organic materials from Prof. L Lin (UC Berkeley)	Berkeley Lab Bacteriophage Power Generator Device	Bacteriophage Power Generator Advantage
Material	PZT	Zinc oxide	PVDF (Polyvinyl difluoride)	Virus (protein and DNA)	Biomaterial: M13 bacteriophage
Toxicity of Materials	Toxic	Low	Low	Not toxic	Bacteriophage is nontoxic, biocompatible, and easily disposable. Opens up medical device applications.
Manufacturing Method	Ceramic growth process	Inorganic crystal growth and microfabrication	Organic synthesis and electrospinning	Fermentation and self-assembly of thin film	Bio-based manufacturing. The virus reproduces quickly through bacterial amplification.
Manufacturing Cost	Very high	High	Relatively low	Very low	Very cost effective. No need for environmentally harmful chemicals and energy- intensive conditions (e.g., high temperatures, high electric fields, extreme-pressures).
Scalability	Very limited	Limited	Scalable	Scalable	Very scalable: Solution-based self-assembly processing can be scale up into any size.
Power Generation (Watt)	~7.5mWatt	~40 nWatt	~0.06 nWatt	~2.4 nWatt	Today it is relatively low. Efforts to boost the power output by orders of magnitude have been achieved.
Piezoelectric Constant (D33)	330 pm/V	~20pm/V	33pm/V	7.8 pm/V	Relatively low compared with inorganic materials. However, we can enhance the piezoelectric constant through further genetic engineering.

Intellectual Property

Patent pending. The technology is available for licensing or collaborative research.

Licensing Strategy

As further development will be required, a joint development agreement with a manufacturer and exclusive license is likely the most attractive option for developing and commercializing the Bacteriophage technology.

Next Steps

Companies interested in licensing this technology may contact ttd@lbl.gov or call 510-486-6457.

For more info, the video below describes this invention and some of its potential applications. [http://abclocal.go.com/kgo/story?section=news/technology&id=8661729]