Energy Harvesting for Nanosystems

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Abstract

In this article, an introduction is presented about the energy harvesting technologies that have potential for powering nanosystems. Our discussion mainly focuses on the approaches other than the well-known solar cell and thermoelectrics. We mainly introduce the piezoelectric nanogenerators developed using aligned ZnO nanowire arrays. This is a potential technology for converting mechanical movement energy (such as body movement, muscle stretching, blood pressure), vibration energy (such as acoustic /ultrasonic wave), and hydraulic energy (such as flow of body fluid, blood flow, contraction of blood vessel, dynamic fluid in nature) into electric energy for self-powered nanosystems.

Keywords:Energy harvesting , nanosystem , Nanogenerator

1.Introduction

Exploring renewable, sustainable and green energy resources is the most critical challenge to sustainable development of human civilization [1,2]. At the large scale, besides the well known energy resources that power the world today, such as petroleum, coal, hydraulic, natural gas and nuclear, active research and development are being taken in exploring alternative energy resources such as solar, geothermal, biomass, nuclear, wind, and hydrogen. At a much smaller scale, energy and technologies are desperately needed for independent and continuous operations of implantable biosensors, ultrasensitive chemical and biomolecular sensors, nanorobotics, microelectromechanical systems, remote and mobile environmental sensors, homeland security and even portable personal electronics. A nanorobot, for example, is proposed to be a smart machine that may be able to sense and adapt to the environment, manipulate objects, taking actions, and perform complex functions, but a key challenge is to find a power source that can drive the nanorobot without adding much weight. An implanted wireless biosensor, for example, requires a power source, which may be provided directly or indirectly by charging of a battery. It is highly desired for wireless devices and even required for implanted biomedical devices to be self-powered without using battery. Therefore, it is desperate to develop nanotechnology that harvests energy from the environment for selfpowering these nanodevices. This is a key step towards self-powered nanosystems [3]. A key advantage of nanodevices and nanosystems is that they usually operate at a very low power in the range from nW to µW. As a result, the energy harvested from the environment may be sufficient to power the system .

sensor built used a single SnO2 nanobelt for detecting dimethyl methylphosphonate (DMMP), a nerve agent stimulant, at 50 ppb level [4]. The sensor operates at 1.5 V and the electrical current is in the range of 2- 3 nA, which means the power needed to operate this nanosensor is 5 nW excluding the heating unit. Scientists have developed various approaches for scavenging energy for mobile and wireless microelectronics using thermoelectrics, mechanical vibration, and piezoelectric (PZ) vibration [5,6]. Photovoltaic is one of the most well-established energy scavenging technology, which converts solar energy into electricity with the use of a photonelectron excitation process in semiconductor materials. A human body provides numerous potential power sources - mechanical energy, vibration energy, chemical energy (glucose), and hydraulic energy. If a small fraction of such energy could be converted into electricity, the energy may be suffi cient to power small devices for biomedical devices [7]. We now review a few approaches that have been developed for energy harvesting at small scales.

2. Microbial fuel cells

Micro-organisms can be used to transform bioconvertible substrates directly into electricity, in which the bacterium acts as an anode and the electrons flow from the cathode through a resistor [8]. The catalytic actions of micro-organisms have been used to produce electrical output from the different carbohydrates and complex substrates. The implantable direct glucose fuel cell can produce power output in the range of 50 µW, sufficient to supply a cardiac pacemaker. Animal trials of direct glucose fuel cells have shown durability of 150 days. Both glucose and oxygen are present in the cell and tissue of all eukaryotic organisms, including human beings. Therefore, it is possible to tap into the body's own resources, including the metabolic properties of our cells, to generate enough energy to power an array of clinical devices, including drug delivery systems, diagnostic tools, and human augmentation devices.

3. Adenosine tri-phosphate energy converter

Enzymes are proposed as an alternative to powering future nanomechanical devices. Possible nanoscale biological motor enzymes that could be used are kinesin [9], RNA polymerase [10], myosin [11], and adenosine tri-phosphate (ATP) syntase [12,13]. The motors are fueled by ATP molecule, which consists of adenine, ribose, and three phosphate groups that are linked by covalent bonds. As the first phosphate group is removed, which is signaled by a coenzyme, a large amount of energy is released with the form of a reaction product called adenosine diphosphate (ADP). If a further amount of energy is desirable, the second phosphate group is released to create adenosine monophosphate (AMP) . The energy created is made available to be used for chemosynthesis, locomotion (including muscle contraction in animals), and the active transport of ions and molecules across cell membranes. ATP is refueled by the rephosphorylation of ADP and AMP using the chemical energy generated from the oxidation of food. This concept leads to ATP serving as rechargeable batteries inside the human body.

4. Thermoelectric generator

Thermoelectric generator relies on the Seebeck Effect, which is about the electric potential observed flowing between two dissimilar metals that form a junction and are at different temperatures. The voltage produced is proportional to the temperature difference between the two ends. The proportionality constant is known as the Seebeck coeffi cient, and often referred to as the thermoelectric power or thermopower. This is the physical basis for a thermocouple, which is used often for temperature measurement. Seebeck coeffi cient of a material characterizes the magnitude of an induced thermoelectric voltage owing to a temperature difference present across the material. An applied temperature difference causes charged carriers in the material, whether they are electrons or holes, to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated. Mobile charged carriers migrating to the cold side leave behind their oppositely charged and immobile nuclei at the hot side thus giving rise to a thermoelectric voltage.

Thermoelectrics is one of the most exciting fields in nanotechnology [14]. One dimensional nanomaterials that have a small thermal conductivity but high electrical conductivity, such as Bi and BiTe, are very benefi cial for improving the thermal power. Thermoelectric generator usually has a large size because of the requirements of maintaining a higher temperature difference between the two ends of the device.

5. Vibration-based energy generation

Scientists have built vibration-based generators using three types of electromechanical transducers:

electromagnetic, electrostatic, and piezoelectric. The electromagnetic microgenerator utilizes a moving magnet or coil for inducting and alternating electric current in a close circuit.

Although some microgenerators have been fabricated at the scale of micro-electromechanical systems (MEMS), the technology tends to produce large structures ranging of 1- 75 cm^3, exploring vibration ranges from 50 Hz to 5 kHz that induce mechanical oscillations between one-half micrometer and over one millimeter, and producing power from tens of μW to over a kW. A typical piezoelectric vibration-based generator uses a double layered piezoelectric beam with a mass at the end . The principle of this design is based on piezoelectricity, which is the ability of certain crystals to generate a voltage in response to applied mechanical stress. When the gravitation attracts the beam to bend downward, the upper piezoelectric layer is under tensile strain and the lower layer is under compressive strain, resulting in a positive and negative voltage, respectively, across the beam. The mass oscillates back and forth; an alternating voltage would be output. This approach has been the basic principle for converting mechanical vibration energy into electricity for microsystems. This energy generator is reasonably large so that gravitation plays a major role for drive the oscillation of the mass.

This design has been one of the major microgenerators for mobile and wireless electronics.

6. Piezoelectric nanogenerators

If the size of the beam is in the nanometer scale, gravitation plays almost no role in driving the motion of the mass, so that the proposed generator would not work. For nanoscale energy source, innovations are needed for delivering nanoscale power source so that the nanodevices and nanosystems can work independently. We have explored innovative nanotechnologies for converting mechanical energy (such as body movement, muscle stretching), vibration energy (such as acoustic / ultrasonic wave), and hydraulic energy (such as body fluid and blood flow) into electric energy that will be used to power nanodevices without using battery [15]. Our study is based on aligned ZnO nanowires (NWs) grown on a conductive solid substrate . The measurements were performed by an atomic force microscope (AFM) using a Si tip coated with Pt film. In the AFM contact mode, a constant normal force of 5 nN was maintained between the tip and sample surface . The tip scanned over the top of the ZnO NW, and the tip's height was adjusted according to the surface morphology and local contacting force. In the corresponding voltage output image for each contact position, many sharp output peaks were observed .

7. Conclusion

In summary, this review presents the various approaches that have been demonstrated for harvesting energy from environment for low-power applications. For nanodevices and nanosystems, the most effective approach is probably the piezoelectric vibration-based generator. By using aligned nanowire arrays, a new nanogenerator has been demonstrated, which has the potential of converting mechanical movement energy (such as body movement, muscle stretching, blood pressure), vibration energy (such as acoustic/ultrasonic wave), and hydraulic energy (such as flow of body fluid, blood flow, contraction of blood vessel, dynamic fl uid in nature) into electric energy that may be sufficient for self-powering nanodevices and nanosystems. The technology could have important applications in wireless selfpowered nanodevices by harvesting energy from the environment. It also provides a method for indirectly charging of a battery.

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