ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3 , No.1, Pages : 353 – 356 (2014)

Special Issue of ICETETS 2014 - Held on 24-25 February, 2014 in Malla Reddy Institute of Engineering and Technology, Secunderabad– 14, AP, India

Revolutionising Medical Implants through micro generators

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Abstract*:* This paper describes about a new power source i.e., a micro generator for powering up the new generation medical implants like a cochlear implant or an artificial pace-maker. The human body is a platform for generation of various energy forms. A small portion of this energy is able to drive these power implanted medical devices. These microscopic power generators tap the body’s energy into a new form altogether.

Key words: figure of merit, nanogenerator, thermoelectric generator, zinc-oxide nanowire.

INTRODUCTION

A huge potency is being exhibited by the science of nanotechnology now-a-days. The emaciate energy which is generated by the body like pulse or vibrations, would be able to provide ample power to power up such petite gizmos. A range of nanowires arranged in the form of an array can help to captivate that energy and transfer it to the devices. These power stations are basically known as micro/nanogenerators.

This idea of transmitting the human waste energy into various usable forms was generated about a century ago through the transfer of human movement into mechanical energy. The homosapien’s body is a reservoir of power in various forms of energy like chemical, heat, mechanical and hydraulic energy. These forms can be utilized to power up the devices with a scale between nanowatts and microwatts.

THE USES AND SCOPE OF MICROGENERATORS

As it just implies, the application of nanogenerators to the field of medical instrumentation can be path-breaking and it may lead to a marvelous stretch-way towards the arena of medical electronics. The battery powered pace-makers may pose a major problem in terms of the reinstallation of battery in the case of their exhaustion. This procedure is costly and moreover leads to the invasion into the human body through surgery in order to get the battery replaced. So in order to avoid this, by the addition of a few sensors, the energy can be tapped and converted to electricity in the range of about tens of microwatts to a few mill watts. In other cases, the nanosensors are capable of monitoring a patient’s blood glucose level.

Activities	Total mechanical energy	Electrical energy available	Electrical energy per movement
Exhalation	1W	0.2W	1 joule
Walking	67W	11W	19 joules
Finger typing	7-20mW	1-3mW	230-400 micro joules
Inhalation	0.8W	0.15W	0.84 joule
Blood flow	0.9W	0.2W	0.16 joule
Upper limb	3W	0.5W	2.2 joules

On a mini-scale, minute movements of body such as a human pulse, random vibrations, temperature gradient and extraneous originated energies like ultrasonic waves and audible noises are being scrutinized under research in order to generate power. Employing these diminutive power specks, structures like strain sensors used in bridges, and environmental sensors for the detection of toxins can be run without the use of the replacement of batteries. They can also find their use in nanorobotics and microelectromechanical systems (MEMS).

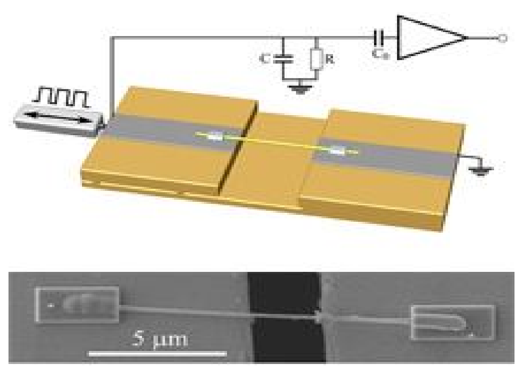

Fig 1:In this setup, the conversion of mechanical to electrical energy can take place using the barium-titan ate nanowires

DESIGN AND CONSTRUCTION

At first, a nanogenerator was designed based on the utilization of carbon nanotubes. But the carbon nanotubes were found to have uncontrollable electric properties. So based on the work that the metal oxides have better controlling electric properties, research with zinc oxide was started. It was found that when zinc oxide is grilled at 900-1200 degrees Celsius in the presence of argon gas, wool-like products with nanowires which is a hexagonal-column-like crystal grown on a solid substrate through a standard vapor-liquid-solid process (in a small furnace) is yielded.

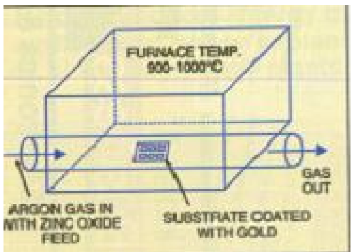

Fig 2: zinc oxide-wool like products with nanowires

Gold nanoparticles are deposited on a sapphire substrate so that the particles act as the catalyst, through which an argon gas flow carrier is flown through the furnace to heat the zinc oxide powder. This process is controlled by a mass-flow controller. (Fig 2)

The diffusion of zinc oxide into the catalyst particles and the growth of nanowires in the form of a hexagonal tube underneath the gold particles occur one by one. The dimensions are about 30 to 100 nanometers in diameter and 1to 3 microns in length with an average spacing of about 300nm.As shown in fig 2,by the process of bending to and fro, the piezoelectric zinc oxide nanowires acquire an voltage owing to the compressive and tensile strains on their sides. An atomic force microscope(AFM) is ascertained to have the property that when it bends a straight and vertical nanowire, establishment of strain takes place .The compressed surface is found to have shown negative strain and vice-versa for the stretched surface. The voltage for each contact position was found to be around 0-6.5mV(Fig 3).An electric field is created by the piezoelectric effect inside the volume of the nanowire , with the stretched and compressed sides of the wire showing positive and negative voltage.

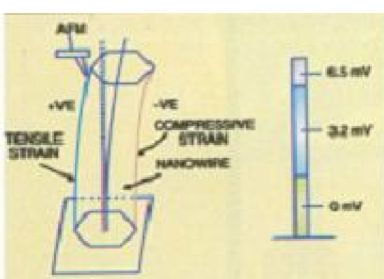

Fig 3: Piezoelectric effect of bent ZnO nanowire

In fig 4 a nanogenerator comprising an alignment of paralleled, perpendicular zinc-oxide nanowires is shown. The nanowires have the conventional properties described previously. Through these wires, continuous generation of electricity takes place which can be collected and delivered to a device.

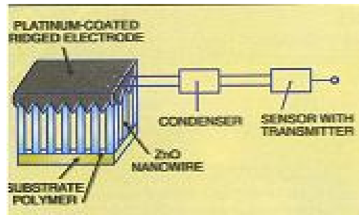

Fig 4: piezoelectric effect of bent ZnO wire

Semiconductor nanowires and the rectangular electrode which is conductive in nature, and having a ridged underside to move from side to side in answer to external stimuli like vibration, pulse, and acoustic waves, rectify the alternating current (AC) into direct current (DC).The output of this generator is stocked in a capacitor and shipped in a sporadic manner to a wireless sensor. The wireless sensor may measure body glucose levels or blood pressure. The rectangular electrode is coated with platinum in order to increase its conductivity and to make it act like a diode so that the current flows in only one direction. It is made with platinum coated silicon.

In order to derogate device failure, the factors like the packing technology are very important. Especially, the packing technology for assembling top electrode and the alignment of nanowires holds a significant role. It is important that the nanowires are manufactured with indistinguishable height and diameter. If the electrode presses on the nanowires too firmly, no current will generate. There should be enough bonding strength between the nanowires and optimization of wire spacing should be considered because it is crucial in increasing the discharge efficiency. The generation of electricity from the nanowires should be concurrent and continuous and the distribution after collection should be efficient.

Zinc oxide nanowires were hard and brittle initially owing to the ceramic and semi-conductor substrates. This made them impossible to be used for applications such as bio-sensors implanted in the body. After the discovery of many polymers which are bio-compatible and conductive, their application in using them as a substrate took pace. As the substrates now in use are very flexible, their surface profile is somewhat crinkled, leading to some missed contacts but they can be easily overpowered owing to the proper bonding strength and optimization of the wire spacing to increase the discharge efficiency. Attachment of the nanowires to the substrate can be increased by the addition of a thin layer of polymer onto the substrate in order to make sure that the roots of nanowires are partly implanted.

The average area of a nanogenerator is about 6 square millimeters. This area provides a voltage output of about 12mV and a current output of about 820mA.Inorder to increase the output voltage, the generators are often arranged in series whereas to increase the output current, they are connected in parallel. For instruments that work sporadically, these are the perfect ones because of their efficiency. An electric current is generated by the blood flow or a muscle twitch due to the compressions and the squeezes of the zinc-oxide nanowires. Comparatively, a large current is produced for a nanowire as thin as 40 nanometers in diameter.

THE USE OF THERMOELECTRIC GENERATOR

The Seebeck effect was proposed by Thomas Seebeck in 1821.It states that an electromotive force is produced due to a temperature difference between junctions of two dissimilar metals. The Electromotive force depends only on material and temperature. This observation is found to be the fundamental thesis for thermoelectric power generation. Thermoelectricity is found to be the basic phenomenon where heat energy is directly converted into electricity. Its effect can be realized through the motion of electrons and holes. Intrinsic semiconductors have an electrical conductivity which is considerably lower than that of metals and it rises exponentially with temperature. An atom consists principally of nuclei and electrons. The inner electrons which are bound close to the nuclei do not interact with others. The outermost electrons are called valence electrons. The electron energy level fall into two bands, called the valence band and the conduction band. The valence band has lower energy and contributes to the bonding of the crystals whereas; the conduction band has higher energy and is empty. The valence band is completely filled up with electrons. The two bands are segregated by an energy gap. Based on this gap, the materials are classified as semiconductors, conductors and insulators. If the gap is preferably low, then it is called a conductor and if it is formidably high, it is considered, an insulator. In semiconductor the separation between conduction and valence bands is not quite large a jump to conduction band by a valence band electron is possible if it absorbs sufficient thermal energy, thus becoming a free charge carrier which creates mobile charge in both the bands.

Semiconductors are further divided into p-type conductors and n-type conductors. An n-type semiconductor is made by doping a suitable impurity that introduces excess electrons in the crystal structure. A p-type semiconductor is formed by doping an impurity which produces a deficiency of electrons called holes. The holes and electrons combinedly are termed as carriers. The Seebeck co-efficient is considerably large in semiconductors when compared to metals in the scale of about a few hundreds to thousand micro volts per degree Celsius. For thermoelectric application, a semi-conductor is ideal. However it should be a good electrical conductor since the process of electronic scattering is likely to generate high amounts of heat throughout the material and a poor thermal conductor since the difference between the hot and cold sides should be maintained in order to prevent a large heat backflow. In metals, electric current and most of the heat is carried by electrons and holes. Heat is normally transferred from hot to cold regions through the vibrations of atoms about the normal positions of the lattice. The most important mechanism in semiconductors is the lattice thermal conductivity. The semiconductors have a small number of electrons or holes-about one per 10,000 atoms. Lattice conduction determines the performance limit of a thermoelectric material.

A thermoelectric generator unit basically comprises of two types of thermoelectric semiconductors. The efficiency increases through the use of a base material which is both p- and n-type doped, so that the system of materials can be used on either side of the junctions.

The efficiency of thermoelectric couple is defined by figure of merit ‘Z’.

$Z=S\times\alpha/\lambda$

where S is Seebeck co-efficient,’ α’ is electrical conductivity and ‘λ’ is thermal conductivity.

For optimization and maximization of the figure of merit , a semiconductor material is to be selected such that controlled doping is possible. The Seebeck coefficient is large when the density of electrons or holes is small. However it is to be observed that the electrical resistivity will raise to a value so high that it leads to the reduction of figure of merit. Seebeck coefficient reaches the value of about 200 micro volts per degree Celsius when Z reaches the maximum value implying that the density of electrons or holes becomes one per 10,000 atoms.

The most important variable in selecting an optical thermoelectric material is the lattice thermal conductivity which alters by a factor of 1000 between semiconductors. It is found that compound semiconductors like bismuth telluride and lead telluride are the useful materials for the thermoelectric generators owing to the low lattice thermal conductivity of materials made of heavy atoms like lead and bismuth.

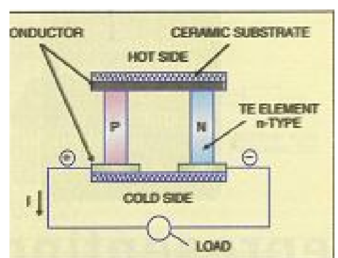

Fig 5: Basic unit of a thermoelectric generator

Disorderliness of the atomic arrangement in crystals is induced by many factors. This induction may lead to the reduction in thermal conductivity. For example ,if some of the atoms of bismuth and tellurium are replaced by that of antimony and selenium, a decrease of thermal conductivity by a factor of 10 takes place while the electrical property are retained. This probably would increase ‘Z’ by factor of more than 2. In order to optimize the power generation efficiency ‘Z’ and temperature differential between hot and cold sides should be as large as possible. The ideal commercial thermoelectric module, the average ‘Z’ is about 1.0.

A new super thermoelectric material invention was developed through the Nanotechnology and its quantum – scale synthesis. This material has the property that gives higher ‘Z’ by suppressing the thermal conductivity as well as by confining electrons to two – dimensional quantum wells. A recent research on this particular subject led to the discovery of super thermoelectric materials with a 'Z' of about 2.4 for a nanoscale structure constructed through alternating layers of two thermoelectric materials that both improve the Seebeck coefficient and suppress thermal conductivity at normal temperature with a conversion efficiency nearing 20 per cent.

The basic thermoelectric generator consists of two types of high performance thermoelectric materials such as Bismuth telluride or Silicon telluride, a p-type and an n-type semiconductor respectively. Both the elements of one end are connected together with a metal of high conductivity which enables electrons to flow from n-type to p-type leg and also uniform hot-side temperature. To prevent short circuit or leakage of electricity, the thermoelectric is electrically separated from hot and cold fluids by a preferable insulator. On cold side two metallic electrodes are connected to the legs, thus forming positive and negative power terminals.

Owing to the temperature differential, electron-hole pairs are created at the hot ends and the heat is absorbed whereas the cold end rejects the heat and the pairs recombine. The Seebeck voltage potential is created between the hot and cold junctions thus leading to an appearance of net voltage across the bottom of the thermoelectric legs. To extract power, an extraneous load can be connected to the thermoelectric materials.

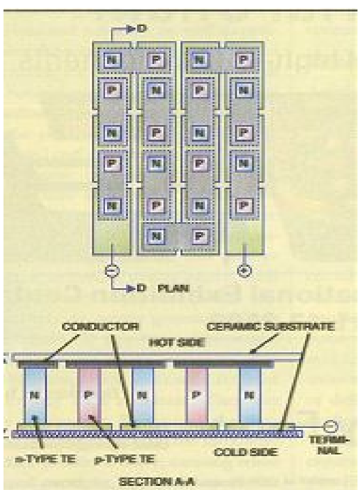

Fig 6: Thermoelectric module for power generation

The component of human body temperature difference can also be used for the generation of electricity. For example, a large amount of heat is lost by the body at the rate of about 100 watts just when we are sitting or listening to music. So the temperature difference between body and air, can be used to make electrons flow, thereby generating electricity. Even though this technique has been in use in the industry since long, to tap a large amount of waste heat' it is not easy to reproduce the same in human body. This is because the tiny voltages generated due to the temperature differences cannot be stepped up to useful levels resulting in a low power output.

Recent researchers have made a tremendous advance in this particular field by constructing a thermoelectric generator about one square centimeter and which can generate about 150 microwatts with a temperature difference of just 0.9 degrees Celsius, which is easy to find across the human body. They are barely visible because of their thinness. To step up the low voltages from this material to the sort of level required for running pace makers and others, a snag has occurred. Losses during conversion slash 150 micro watts scavenged to 70 micro watts which is still enough to power a pacemaker. It is possible to make such a small device by connecting thousands of nanothermogenerators in series to boost the power output (Fig 6).

The latest invention is the implantable micro generator which is capable of producing power for an implanted electronics pacemaker. This is widely used in today's medical applications. This pacemaker is responsible for triggering the heartbeat of patients suffering from tachycardia. To eliminate the need of repeated operations for replacing the batteries, a tiny isotope can be used whose life span is about 10 years.

MICROGENERATOR THROUGH BODY MOVEMENT

An in-body micro generator which was developed recently is powered up through body or limb movements. It works by tapping the inertia of a movable mass either to force the charged plates of a charged capacitor together or to move a conducting coil through a magnetic field. The dimensions are about 20mm×6mm with a power generating capability of about 150 microwatts. This easily runs a pacemaker or a biosensor. This is possible because the body movement is capable of inducing an electric current when the body movement moves in a magnetic field.

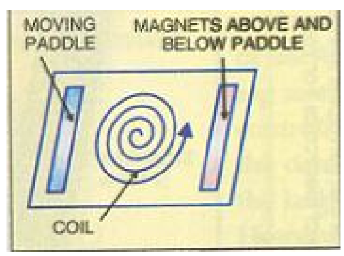

Fig 7: An in-body micro generator

CONCLUSION

This generation is viable in near future in a large scale and at this juncture, though under research stage, is bound to have a vast potential. There are various body movements through which the energy can be harnessed. For example, just by sitting, hundreds of watts of power is produced of which just a menial amount of it could be used up to power up the implanted devices.

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