Istanbul Technical University

Midterm Research Homework

Piezoelectric Materials

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MAL 201E

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11.06.2021

Throughout the years, mankind has designed and processed materials for their benefit. Since the materials are in different forms and have different physical and chemical properties, it was found appropriate to use different materials for different purposes instead of doing all the work with the same material. Although this process worked with trial-and-error-method at the beginning of humanity, the knowledge of the past has been transferred from generation to generation with the cumulative progress of science and has survived to the present day.

Energy is one of the most important concepts that make our life easier and more effective. The procurement of energy can be achieved in a variety of ways such as renewable energy sources. Whilst generating energy can be as simple as applying force to a material. The electrical energy produced in this way is called piezoelectric, and the materials that make this process possible are called piezoelectric materials. Piezoelectricity can be defined as "the ability of certain crystalline materials to develop an electric charge proportional to a mechanical stress". This phenomenon is also called pressure electricity due to its ability to produce electricity through pressure. Piezoelectric was discovered while a study of the effects of pressure on the crystals such as tourmaline and quartz by Pierre and Jacques Curie. The piezoelectric effect is frequently encountered in nature. The most well-known materials with the piezoelectric effect are known as quartz and silicon dioxide [1]. Considering that materials with this effect are frequently encountered and their benefits are many, it is inevitable that we use these materials frequently in our daily lives. It is possible to examine that the use of piezoelectricity in many items that we use in our daily life, makes our lives significantly easier. If an example needs to be given, piezoelectric is being used in intruder alarms, medical devices, PIN pads, fire alarms, microwave ovens, high temperature sensors, ultrasonic pet training collars and ultrasonic motors [2].

The piezoelectric effect of the substances is directly related to the chemical structure of the material. Thus, it is essential to understand how the piezoelectric effect occurs. The piezoelectric crystal placed between two metal plates is in a complete equilibrium at the

beginning and does not generate an electric current, but if a mechanical force is applied to this system, the charged atoms in the crystal cease to be in equilibrium. Therefore, negatively and positively charged atoms start to accumulate in different places which causes an imbalance between the two areas and ends up getting polarized. Piezoelectric materials belonging to the ferroelectric group of the materials, so the direction of their molecular structure is in the form of a dipole where local charge separation is observed. Dipole state, as mentioned, is a state that occurs when force is applied to the material. The outer metal plate collects positive and negative charges and generates the electric current that can be used in electrical circuits due to the magnetic field and accumulation of electrons. Mechanical force can be obtained by applying an electric current as well as electric current can be produced by applying mechanical force to piezoelectric materials. If the piezoelectric crystal is given with electric current, the reverse piezoelectric effect occurs. Thus, the crystal converts electrical energy into mechanical energy through sound waves [3-4].

The ability to store energy is extremely important in terms of energy transport and ease of use. Even a small amount of energy can make an enormous difference. Piezoelectric materials, thanks to their inimitable crystal structure, can convert the mechanical energy applied to them into electric current. Therefore, the material works as a complete harvester. Although the collected power is inadequate compared to energy needed by most electronic devices, this unique feature of piezoelectric materials is very essential in developing self-powered systems. Even though the capacitor and rechargeable nickel metal hydride batteries can be used to store this energy, it has been determined that the use of rechargeable batteries will be a more efficient way of storage as a result of the experiments and tests. The reason for this is that due to the low storage capacity of the capacitors, the pulsed output in the circuit limits the number of devices that can store energy. Thus, the optimal system to store energy that has been provided from mechanical force to the piezoelectric material is the one with rechargeable nickel metal hydride batteries. This has enabled many industrial applications and life-saving devices to be produced.

Furthermore, in recent years, studies on energy harvesting and storage have begun by combining piezoelectric and electrochemistry. This situation is of great importance in terms of achieving more sustainable energy harvest in the future. [5-6].

It is known that each material has its own physical and chemical properties. Therefore, it is important to understand the fact that which materials will be used for the given application. The process of choosing the most suitable material can be sweltering since it varies depending on physical properties such as piezoelectric charge coefficient, electromechanical coupling factor and dielectric constant. All these properties have their importance for assorted piezoelectric application and have varied primacies. For instance, piezoelectric constant indicates the capability of a material to generate electrical signal when mechanical pressure is applied which is one of the key parameters in determining material for actuator and sensor applications. Likewise, the dielectric constant emphasizes materials' ability to store electrical energy and electromechanical coupling factor shows the conversion efficiency of material. Piezoelectric materials have many uses and can be used in combination with many kinds of materials to fulfill specific tasks in these applications. For instance, to generate charge at high voltages, the piezoelectric material must be at a level that can resist electrical and mechanical damage due to mechanical stress. Another application of piezoelectric materials is the control of frequency. In order for the piezoelectric material to adapt to this application, its material properties should not be constantly variable depending on time and temperature. The coupling coefficient of the piezoelectric material required for the application or the other material to be used as a compound should be high in order to minimize the losses of the substances depending on these parameters. To conclude, selection of materials for specific purpose should be made with consideration of material's physical, chemical properties and their response to diverse circumstances [7-8].

Furthermore, since the right piezoelectric material has been decided, talking about how these materials are used in which areas will enable them to see their real-life applications, so

their importance will be understood more. One of the usage areas of piezoelectric materials is ultrasonic motors which are a type of motor that takes its energy through ultrasonic vibration of a component. Usage of piezoelectric motors provides tremendous advantages over conventional electromagnetic motors which can be mentioned as having high holding torque preserved at no given power and ineffectiveness by the electromagnetic environment. Despite these advantages, some disadvantages can be mentioned. For instance, it can be given that it has a shorter lifespan, requires high voltages to operate and requires high frequency energy sources [9]. Moreover, another application of piezoelectric materials is high temperature sensors. If high temperature technologies are to be mentioned first, they are the technologies that have an important place in the automotive, aerospace and renewable industries. The main reasons why high-temperature piezoelectric materials are preferred in these areas are that they can detect parameters such as vibration, strain and temperature in harsh environments. In general, non-ferroelectric piezoelectric materials have low sensitivity, but extremely small mechanical and dielectric losses, high electrical resistances make these materials the most accurate choice for high temperature sensing applications thus making them a perfect candidate for high temperature sensors [10]. What is more, one of the industries that piezoelectric materials are used in the aerospace industry. Piezoelectric materials are mostly used as sensors in this industry. To briefly explain the operating logic of these sensors, an electrical potential arises because of mechanical power and this potential is detected by electrodes connected to the end of the crystals. According to Elahi et al., “their frequency ranges from 0.01 Hz to 1 MHz and the temperature variation from -270 °C to +650 °C”. Eventually, the last to be talked about the application of piezoelectric materials is in the healthcare industry. Piezoelectric sensors and actuators bring a new perspective to sought-after health-monitoring techniques. Embedded smart structure with piezoelectric system and actuator provides many advantages such as being simple in design, low cost but long service life [11-12].

All things considered above it can be said that the desire to use energy, which has an important place in our lives, has given rise to the need to produce this energy in different ways. Therefore, with the help of piezoelectric materials which are structurally crystal, electrical current energy can be produced by applying mechanical force to these substances. This fact has been implemented in many daily applications, making our lives much easier. The reason why these materials can produce electric current by applying mechanical power is that the positive and negative charges in the structure of the crystals go to separate poles, polarize the material and move electrons through the electric field. Although it is important to produce an electric current in this way, it is equally important to harvest the energy provided by this current. Energy harvesting from piezoelectric materials can be done with rechargeable batteries. At the same time, joint studies are carried out with the science of electrochemistry for these studies. There are physical and chemical properties that distinguish piezoelectric materials from each other. When choosing the materials we will use, taking these features into consideration ensures maximum efficiency from the application. Thus, the material selection process should be done with great care. Finally, piezoelectric materials are used as essential materials in various industries such as health, aerospace and consumer electronics. It is anticipated that piezoelectric materials, which are an inevitable material with their life-saving aspects in these areas, will increase the number of industries used in the future.

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