Jawahar M. Bodulwar, 11:1
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

Recent Advances in Piezoelectric Devices: Special Reference to Sensing and Actuation Devices

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Abstract- For applications in flexible wearables, intelligent electronics, and human-computer interactive robotics, self-powered gadgets and microsensors are in high demand. Solutions for individualized medical treatment are provided by high-sensitivity, flexible, wearable, and breathable sensors that track signals from minute environmental changes. One of the most demanding sensors, piezoelectric sensors can be utilized in self-power energy harvesting sensors, home applications, and medical applications. Piezoelectric actuators are transducers that use the piezoelectric effect to turn electrical energy into mechanical displacement or stress, or the other way around. The current succinct review article explains the most recent advancements in sensors and actuators based on piezoelectric materials.

Keywords- Piezoelectric, Piezoelectricity, Sensors, Actuators.

I. INTRODUCTION

Numerus electrical devices working of the principle of piezoelectricity. When a voltage is applied across a piece of piezoelectric crystal, it mechanically bends and deforms. When the voltage is removed, it springs back at a natural resonant frequency. This kind of crystal used in a feedback circuit to yield oscillations at a specific frequency. These kinds of electrical oscillators are frequently constructed of crystalline quartz.

The piezoelectric transformer is an application from more recent times. The cold cathode fluorescent lamps that serve as the backlight for LCD displays have these components. In order to turn on, the lamps need about a thousand volts, and they use hundreds of volts when operating. These high voltages can be reached by magnetic and coil-based transformers, but piezoelectric transformers are substantially smaller and can be put on printed circuit boards. A conventional transformer has two coils and transforms AC electricity into magnetic energy before converting it back to AC electricity at a different voltage.

A piezoelectric transformer operates similarly, utilizing manifold energy conversion techniques. Such a gadget converts AC electricity to mechanical vibrations, which are subsequently converted back to AC power at a different voltage. These devices can produce high voltages with low currents because energy is conserved within them.

Every author uses a distinct set of assumptions, it is difficult to discuss the efficiency of energy conversion devices. Still, a commercial piezoelectric device's efficiency is low by any standard, frequently at or below 6%. Therefore, the piezoelectric devices are employed as sensors as a result of their low efficiency. However inefficient it may be, other technologies are still used for energy gathering. In train station, piezoelectric generators installed in the platforms used to provide electricity. Additionally, the energy from wind or fluid motion can be converted directly into electricity using piezoelectric devices. Piezoelectric technology has potential for use in medical fields. Quartz is non-toxic, robust, and piezoelectrically active crystal. It is also commonly available. Engineers have created implantable piezoelectric devices that can be used both inside and outside the body. There are some sensors that employ piezoelectric technology. Piezoelectric sensors also used to monitor the joints like the knees [1].

Additionally, ultrasound imaging is a widely used diagnostic method. The ultrasonic vibrations are produced and detected using piezoelectric devices. As a power source, additional biomedical piezoelectric devices are employed. Artificial hearts, pacemakers, and other devices depend on electricity, but the energy they can be supplied with depends frequently on battery technology. Piezoelectric generators can avoid the issue of having to change the batteries because they don't have any moving parts that could break down. Breathing is an example of a continuous physical activity. Walking is an example of a discontinuous physical activity. The mechanical energy for piezoelectric devices can come from either kind of physical action. Different biomedical equipment has a wide range of power requirements.

For instance, a pacemaker might only need a few microwatts while an artificial heart might need around 8 W. The energy from regular physical activity may be captured by piezoelectric devices and transformed into electrical energy to run the device. The 0.85 mW produced by a piezoelectric device in an artificial knee, and up to 8.4 mW produced by walking on a piezoelectric device in a shoe.

In addition to biological imaging systems, piezoelectric devices are employed in various kinds of imaging systems. Sonar systems were one of the earliest uses. The military actively developed sonar equipment to find boats and submarines during the time of World War One. Sonar technologies are used nowadays to locate fish and gauge the depth of water bodies. Sonar imaging is also used to inspect electrical circuits, find flaws in steel, and find fractures in welds. There are numerous other uses for piezoelectric technology. Some buttons and keyboards employ piezoelectric sensors. Accelerometers, which are used to measure pipe flow, are made with piezoelectric components. Piezoelectric components can be used to create buzzers, microphones, speakers, and other audio and ultrasonic equipment. Paints, culinary goods like peanut butter, and colors can all be emulsified using piezoelectric devices that produce ultrasonic impulses [2, 3].

II. PIEZOELECTRIC BASED SENSING AND ACTUATION DEVICES

1. Piezoelectric based Sensing Devices

In their study, Kutis et al. look at the modelling and simulation of an AlGaN/GaN-based circular high electron mobility transistor used in a piezoelectric MEMS pressure sensor. For the MEMS piezoelectric pressure sensor to be correctly modelled, the influence of residual stress is crucial. The model uses the initial stress state of the membrane and residual stresses that were determined by micro-Raman spectroscopy. Considered are the circular and ring shapes of MEMS piezoelectric pressure sensors. The finite element method (FEM) code ANSYS is used to do the piezoelectric analysis of the MEMS sensor. A full 3D FEM model is used to validate the 2D simplified axisymmetric FEM model, which is very efficient in terms of computational time. Verified 2D Simplified Axisymmetric FEM Model investigates the impact of electrode position [4].Figure 1 depicts the pictorial representation of piezoelectric pressure sensor: a. circular design and b. ring design.

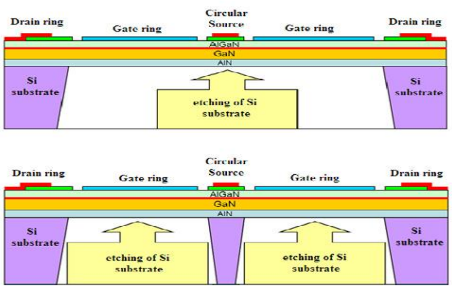

Figure 1. Pictorial representation of piezoelectric pressure sensor: a. circular design and b. ring design

The use of zinc oxide (ZnO) in pressure sensors that can be combined with microelectromechanical systems is described in this work. Due to its special characteristics as a semiconductor with a broad bandgap and piezoelectric effects, ZnO is one of the materials that has drawn a lot of interest. Low cost ZnO-based sensors are a result of ZnO easier crystal formation methods. Additionally, many ZnO sensing element-based pressure sensor designs have been investigated. Using COMSOL finite element approach, a thin circular ZnO sheet was modelled as a piezoelectric sensor. Variable pressure was applied to the thin film surface, and the displacement field and voltage at the membrane's centre were investigated using a boundary point probe. Pressure applied to the ZnO layer causes a linear change in the displacement field and voltage. The piezoelectric pressure sensor with strain sensors on the edge of the thin silicon plate is depicted in Figure 2 as having a thin silicon plate [5].

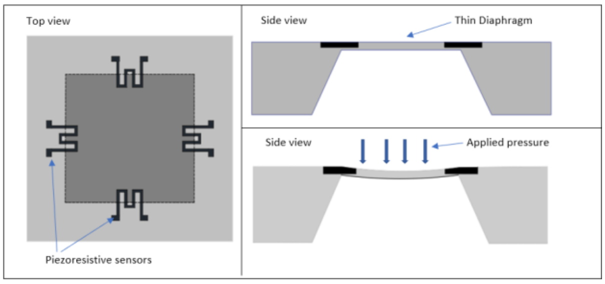

Figure 2. Piezoelectricity based pressure sensor having a thin silicon plate and strain sensors positioned on the edge of the thin silicon plate.

To solve the issue of the piezoelectric element's output charge reflecting as a composite of vectors in the three stress directions, the uniaxial piezoelectric sensor was created. It was investigated how well the uniaxial piezoelectric sensor performed under various load patterns and load rates.

To build a correlation between the embedded sensor and the external sensor, the elastic modulus of the sensor-which was embedded in concrete to monitor stress-was employed as an intermediary bridge. The mismatch between the medium of the sensor and the concrete was also addressed, and a correction factor for the charge transition strain was proposed.
A novel stress monitoring technique based on a uniaxial piezoelectric sensor was put forth in light of relevant circumstances, and it is capable of both confining stress monitoring in reinforced concrete columns and stress whole-process monitoring in concrete. The findings show that using the suggested method, the sensor's output charge curve significantly overlaps the stress waveform and exhibits good fitting linearity.

The sensor's working performance was consistent, and loading rate and load pattern had no effect on its sensitivity. Because it was embedded in concrete, the sensor can track how the concrete is changing. The sensor was implanted in concrete, and the correction factor for strain it measured was 1.07. The entire stress monitoring process might be implemented in concrete by taking advantage of the link between the charge generated by the embedded sensor and its external calibration sensitivity [6].

2.2 Piezoelectric based Actuation Devices

It is a key component in the development of soft robotics, flexible and stretchy electronics, energy harvesters, sensors and actuators, and soft materials exhibiting electromechanical coupling. Since common dielectric elastomers are based on electrostriction and Maxwellian stress effects, they are essentially nonexistent and exhibit only unidirectional electromechanical interaction. Unfortunately, this piezoelectric effect, however large, is primarily limited to longitudinal electromechanical interactions, the so-called d33 piezoelectric coefficient. Transverse piezoelectric properties or the so-called d31 coefficient are less important.

This difference is significant as these soft electrets exhibit low electromechanical coupling under bending deformation. For this reason, traditionally designed soft electrets are completely inadequate for energy harvesting, actuation, and bending motion detection, which are essential for applications such as soft robotics. This paper provides a practical approach to design soft electrets with large transverse piezoelectric coefficients (d31) and flexoelectric coefficients. Finally, it has been shown that in properly constructed soft electrets, the structure can be distorted even in a uniform external electric field, indicating that electrets can be used as bending actuators. Figure 3 shows the poling direction [7].

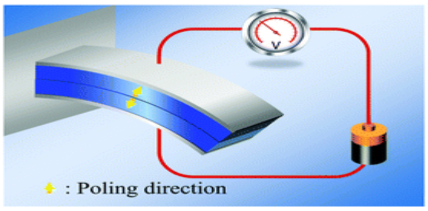

Figure 3. Poling direction.

In order to undertake chemical synthesis with solid products, Kuhn et al. describe a general, economical approach for creating a Teflon stack microreactor with an integrated piezoelectric actuator. Palladium-catalyzed C-N cross-coupling processes, which are known to block microchannels by producing insoluble salts as byproducts, are used to show the microreactors. Studies of the piezoelectric actuator's applied ultrasonic waveform show that 50 kHz and 30 W of load power are the ideal values. Under these operating circumstances, the newly created Teflon microreactor manages the generated insoluble particles and no blockage is noticed. High isolated yields (>95% yield) and full conversion are attained by the researched reactions in remarkably brief reaction durations [8].

Microfluidic fluorescence-activated cell sorting (FACS) devices have the ability to prevent cross-contamination, get rid of bio-aerosols, and reduce device footprints. These features could make them the foundation for the next-generation cell sorter. Here, we present a fast and reliable sorting method using an on-chip flow switching based FACS mechanism with piezoelectric actuation. To create the FACS system, a microfluidic chip with a bifurcate design and displacement amplified piezoelectric microvalves was created.

From a purity of 0.5% to more than 90%, rare fluorescent microparticles of various sizes have been greatly enhanced. For fluorescently labelled MCF-7 breast cancer cells from Jurkat cells, an enrichment of 150-fold from 0.6% to 91% has also been confirmed, although viability following sorting was preserved. The suggested FACS system provides a new option that can meet the requirements of sorting performance, target selectivity, device lifetime, and cost-effectiveness of implementation by taking advantage of its simple construction, cheap cost, quick reaction, and dependable flow control [9]. Figure 4 shows microfluidic fluorescence-activated cell sorting (FACS) device.

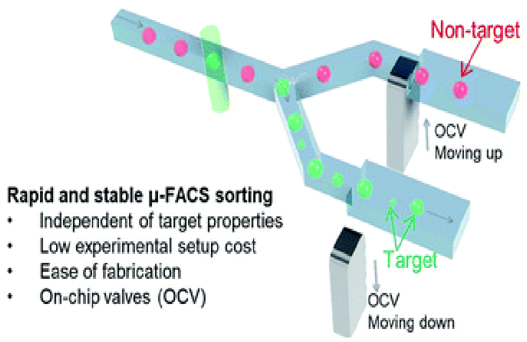

Figure 4. Microfluidic fluorescence-activated cell sorting (FACS) device.

III. CONCLUSIONS

The significance of piezoelectric actuators/sensors in the medical and other vital fields is introduced in this succinct overview study. This document summarizes a recent study that includes descriptions, results, and analysis of uses for piezoelectric materials. This page provides a brief overview of the topics of piezoelectric material research. Some inferences have been drawn from the current investigations:

1. Piezoelectric sensors are adaptable instruments for measuring a range of processes. In numerous sectors, they are employed for process control, quality assurance, and R&D.
2. Precision machining tools, lenses, mirrors, and other equipment can be accurately adjusted using the exact movement control provided by piezoelectric actuators. A piezo actuator can be utilized in a variety of applications that call for movement or force, including controlling hydraulic valves, serving as a small-volume pump or special-purpose motor, and more.

Acknowledgement

Authors are very much thankful to Principal, Amolakchand Mahavidyalaya, Yavatmal for providing necessary academic help.

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