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Development of Nanotechnology-Piezoelectric Energy Generation

Issa Lukman Oluwadare[1], Lambe Adesina Mutalub[2], Olalekan Ogunbiyi[3]

[1]Kwara State Ministry of Power and Energy, Ilorin, Kwara State, Nigeria
[2,3]Electrical and Computer Engineering Kwara State University, Malete, Kwara State, Nigeria

ABSTRACT

Since an invention of piezoelectric nanogenerator in 2006 by Zhong Lin Wang a Chinese-American physicist, materials scientist and engineer specialized in nanotechnology. Nanotechnology has made it possible for devices to work without external power supply. This is a crucial step forward in the quest solving the world's energy problems and create a sustainable future. We are always pushing the boundaries of what's possible in energy generation and storage. The development of nanotechnology-piezoelectric energy generation is no exception. Nanotechnology has become a rapidly growing field in recent years, offering new and innovative solutions to a wide range of challenges facing humanity. One of the most promising applications of nanotechnology is the development of nanoscale piezoelectric energy generators which have the ability and capability to harvest energy from several sources and convert it to usable electricity. This technology is based on piezoelectric effect which produces quantity of electric-charge in response to mechanical stress. . By fabricating piezoelectric materials at the nanoscale, it is possible to create devices that are highly efficient and capable of converting even small amounts of mechanical energy into usable electricity. This article provides an overview of the current state of the art in nanotechnology-piezoelectric energy generation, including the materials and techniques used to create these devices, as well as their performance and potential applications. More so, the challenges facing the widespread adoption of nanoscale piezoelectric energy generators are also discussed, including issues related to cost, scalability, and durability. Despite these challenges, benefits of this technology are significant, and the continued development of nanotechnology-piezoelectric energy generation has the potential to revolutionize the way we think about energy generation and storage in the future.

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1. INTRODUCTION

It is with great excitement that I introduce you to the world of Nanotechnology-Piezoelectric Energy Generation. A discipline where the tiniest of atoms and the most brilliant of minds come together to solve biggest problem facing humanity - Energy. This journal is a testament to the limitless possibilities that can be achieved when science and innovation come hand in hand. It is a celebration of the boundless human potential and a reminder of what can be achieved when we put our minds to it.

Nanotechnology represents the understanding, engineering, and manipulation of materials at approximately 1 to 100 nanometers (Youtie, 2007). At this scale, materials have unique properties that have contributed significantly to the fields of electronics, the military, medicine, and consumer products. Nanotechnologies exist in many products that typical consumers might use quite frequently and without realizing it - from sunscreens and cosmetics to coatings on eyewear (Youtie, 2007).In more recent research developments, nanotechnologies have been implemented in medical systems with applications as drug delivery modules and biosensors. (Springer, 2004).

With innovation at so many scales, there is a need for new energy systems at each of those scales. Recently, the energy crisis has called for new, sustainable forms of energy that will continue to support rapid rates of innovation. Despite significant strides in the fields of larger-scale solar, geothermal, nuclear, wind, and hydrogen energy as alternative energy sources, we still face many uncertainties related to potential nanotechnologies. These devices typically require power sources within the milliwatt range to operate (Wang, 2011).

Piezoelectric materials (ZnO, PZT) present unique properties in their internal crystal array structures (Wang, 2008). Upon external disturbance, such as a vibration or mechanical wave, a voltage drop occurs because the internal atoms may not be symmetrically aligned (Springer, 2004). These unique characteristics, shared across all piezoelectric materials, allow for the generation of electricity through mechanical stress. Piezoelectric nanogenerators could convert mechanical energy into electrical energy for self-powered nano-systems through a variety of methods. Some potential applications for this energy source could include body/muscle movement, blood pressure, vibration energy (acoustic/ultrasonic waves), hydraulic energy, or dynamic fluids (Wang, 2008).

Nanotechnology, the manipulation and control of matter at the nanoscale, has revolutionized our understanding of materials and their properties. The development of nanotechnology had paved way for new and innovative technologies, including the generation of electricity from the motion of piezoelectric materials. We will explores the history and current state of piezoelectric energy generation and its role in the development of nanotechnology. This concept of piezoelectricity, the generation system of an electric charge in response to applied mechanical stress, was first discovered in 1880s. It wasn't until the development of nanotechnology that the potential of piezoelectric materials for energy generation became fully realized. The ability to control the properties of materials at the nanoscale allowed for the creation of highly efficient piezoelectric devices that can convert the motion of everyday objects into electricity.

This Article provides an in-depth examination of history of piezoelectric energy generation, from its early beginnings to its current state as a promising source of renewable energy. We also explore various materials and technologies used in the creation of piezoelectric devices and examine their potential for the future of energy generation purposes.

Furthermore, in this piece of writing, we will delve into the science behind piezoelectric energy generation, including principles, mechanisms and development that make its functions possible and realizable. We will also explore the various applications of piezoelectric materials, from small-scale devices for personal energy generation to large-scale systems for powering entire communities and industries.

Whether you are a scientist, engineer, or simply someone interested in the development of nanotechnology-piezoelectric and its potential for energy generation and usage, this journal is sure to provide you a wealth of information and insights. So, let begin our journey into the fascinating world of piezoelectric energy generation and the role it plays in the development of nanotechnology.

2. MATERIAL AND METHOD

There are numerous styles of designing Nanotechnology-piezoelectric energy generation but all these methodologies require the uses of piezoelectric material for energy generation. The following approach was adopted so as to achieve the central idea of this work. These are requirement definition and infrastructural modelling.

2.1. Description of Major Circuit Component

2.1.1. Piezoelectric Disc

Piezoelectricity is a fascinating concept in materials science that has revolutionized the world of electronics. It refers to the ability of certain materials to generate an electric charge in response to mechanical stress or strain. One of the most common applications of piezoelectricity is in the production of piezoelectric discs, which are widely used in a variety of devices such as sensors, actuators, and transducers.

Figure 1: Piezoelectric Disc

Piezoelectric discs are made from special materials such as quartz, lead zirconate titanate (PZT), and certain ceramics. These materials have a unique property that when they are subjected to mechanical stress or strain, they generate an electric charge. This is because the atoms in the material are arranged in a way that creates a dipole moment, which means that they have a positive charge on one end and a negative charge on the other. To make a piezoelectric disc, a thin slice of the piezoelectric material is first cut and shaped into a circular disc. The disc is then coated with metal electrodes on both sides, which are connected to wires. When a mechanical force is applied to the disc, it causes the material to compress or expand, which generates an electric charge that can be detected by the electrodes. (Bhalla, 2000).

One of the most interesting things about piezoelectric discs is that they can also work in reverse. That is, if an electric charge is applied to the electrodes, it causes the material to expand or contract, which creates a mechanical force. This property is used in devices such as actuators, which convert electrical energy into mechanical motion. (Uchino, 2011).

Piezoelectric discs have many practical applications. They are used in devices such as ultrasound machines, inkjet printers, and vibration sensors. They are also used in musical instruments such as electric guitars, where they are used to generate a sound wave by converting the mechanical vibrations of the strings into an electrical signal. In summary, piezoelectric disc generation is the process of creating a circular disc made of piezoelectric material, which can generate an electric charge in response to mechanical stress or strain. These discs have many practical applications and are widely used in modern electronics.

2.1.2. Diodes

A diode is an electronic element that allows the flow of current in a direction. Its resistivity at one end is lower and higher at the other end. Semiconductor substance with a pn junction connected to two electrical pins/legs (terminal) is a crystalline composition which is the generally applied kind of a semiconductor presently. A pn junction crystallized either silicon or germanium demitasse and is known as rectifier diodes. These diodes are made up of semiconductor substance and applied in rectification procedure. These groups of diode allow the current to flow in forward bias and block the inflow of current in reversed bias. Semiconductor diodes were the first semiconductor electronic devices. The ideal diode law states that (Lingam, 2008).

$I = Io\ (e^{\frac{qV}{kT}} - 1)$ (Sood, Kaur, and Lenka, 2013).

Where

I = the net current flowing through the diode

I_0 = "dark saturation current", the diode leakage current density in the absence of light

V = applied voltage across the terminals of the diode

q = absolute value of electron charge

k = Boltzmann's constant

T = absolute temperature (K)

Diodes are further classified based on their functions. These classes include, Light emitting diodes, power diode and Zener diodes (Lingam, 2008).

Power Diode: A kind of diode generally used in power inventories circuits is known as a power diode. Just like normal diode, a power diode has two-terminals and allows the inflow of current in one direction. A power diode varies in structure from a standard diode to allow this advanced current level. For the purpose of this project, four [power diode were used.

Figure 2: Power diode

Light Emitting Diode: A light-emitting diode (LED) is a kind of diode that emits glow when current passes through its terminals. When current passes through the pins/legs (terminal) of this diode, it generates light. In different terms, light is generated when a sufficient quantum of encouraging current passes through the LED. In multiple diodes, this glow emitted is not seeable as their frequency situations that don't allow visibility. LEDs are accessible in multiple colors such as tricolor LEDs that can radiate three colors at a time. The color of the light is dependable on the energy interval of the semiconductor applied.

Figure 3: LED

Zener Diode: This is the most applicable kind of diode as it can give a steady source voltage. Zener diode is operated in rear bias and disintegrates down on the appearance of a specific voltage. However, a stable voltage is achieved when the current passing through the resistor is repressed. This diode is extensively used in power inventories to supply a reference voltage.

Figure 4: Zener diode

2.1.3. Capacitor

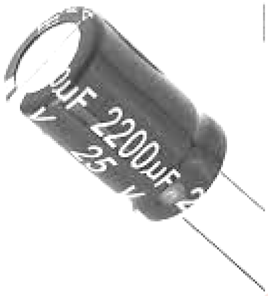

Figure 5: Capacitor

An electrical/electronic element that stores energy for a little period of time is known as capacitor. The forms of applied capacitors differ extensively; majority of the capacitor made up of no less than two conductors separated by an insulator (dielectric) when there is voltage detection around the positive charge on one side of the plate and a negative charge on the other side of the plate. In electrical networks, capacitors are used extensively. An absolute capacitor is depicted by stable capacitance C, measured in farads:

$C = \frac{Q}{V}$ (Lingam, 2008).

Where
C = Capacitance
V = Voltage
Q = Electric Charge

In practical application of these devices, incremental changes defines the capacitance (Bird,2003).

$C = \frac{dQ}{dV}$ (Neverova and Semanov, 1981).

The maximum energy stored in a capacitor can be represented by:

$E = \frac{1}{2} CV^2 = \frac{1}{2}\frac{\varepsilon A}{d}$ (Bird, 2003)

Where:
E = energy stored in the capacitor
d = diameter between the dielectric plates
A = area of the dielectric plates

The equation for capacitor charging can be expressed as the time constant at which it charge

$T = R * C$ (Gurevich, 2016)

Where:
R = Resistance
C = Capacitance

The capacitor discharge is the function of time during the discharge period

$Vc = Vs * e^{\frac{-t}{RC}}$ (Prayash, 2018)

Where:
Vc = voltage across the capacitor
RC = Time constant
Vs = Supply voltage and t = Time

2.2. Methodology

The development of nanotechnology-piezoelectric energy generation involves the use of nanoscale materials to create devices that can convert mechanical energy into electrical energy. This process is based on the piezoelectric effect, which refers to the ability of certain materials to generate an electrical charge in response to mechanical stress. To create this device, Piezoelectric Disc,2600mAh - 3.7v rechargeable Battery of 45mmx10mm, Battery case and Power bank charging Module will be employed. These materials are carefully selected based on their specific properties, such as their ability to withstand stress, their electrical conductivity, and their stability.

Once the materials are chosen, a variety of fabrication techniques are used to create the device. These techniques include photolithography, electron beam lithography, and atomic layer deposition. These processes allow for precise control over the size and shape of the nanoscale structures, which is essential for creating device that can generates consistent and reliable amounts of electrical energy. Once the devices are fabricated, they are tested and optimized to ensure they are generating as much electrical energy as possible. This involves measuring their output under a variety of conditions, such as different levels of mechanical stress. Through this process, one can identify any weaknesses in the devices and make improvements to increase their efficiency. Overall, the development of nanotechnology-piezoelectric energy generation involves a complex and interdisciplinary approach, combining materials science, nanotechnology, and electrical engineering. It is a rapidly evolving field that has the potential to revolutionize the way we generate and use energy.

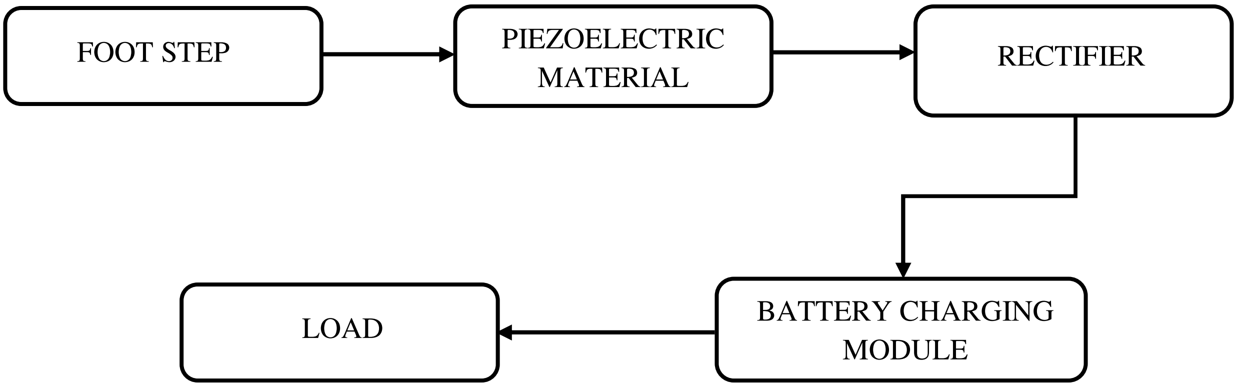

Figure 6: Block Diagram of footsteps energy generation

2.2.1. Piezoelectric Material

Piezoelectric materials exhibit the unique property known as the piezoelectric effect. When these materials are subjected to a compressive or tensile stress, an electric field is generated across the material, creating a voltage gradient and a subsequent current flow. This effect stems from the asymmetric nature of their unit cell when a stress is applied. The unit cell contains a small positively charges particle in the center. When a stress is applied this particle becomes shifted in one direction which creates a charge distribution, and subsequent electric field. These materials come in several different forms. The most common is crystals, but they are also found as plastics and ceramics.

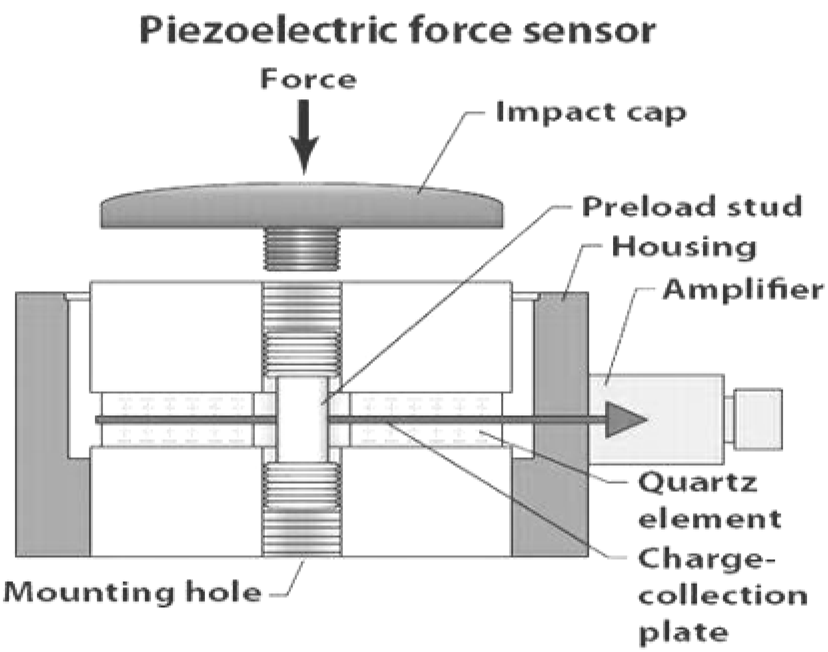

Figure 7: Piezoelectric detailed diagram

The piezoelectric effect is a phenomenon where certain materials generate an electric charge in response to mechanical stress or pressure. This effect is widely used in various applications, such as pressure sensors, microphones, and actuators.

Here is a pictorial explanation of the piezoelectric effect:

- When an external force or pressure is applied to a piezoelectric material, it causes a deformation in the material's crystal structure.
- As a result of this deformation, some of the electric charges in the material become separated, creating a separation of positive and negative charges along the crystal's surface.
- This separation of charges generates an electric potential across the material, which can be measured with an external circuit.
- When the external force or pressure is released, the material returns to its original shape, and the electric charges and potential disappear.
- Conversely, if an electric potential is applied to the material, it will cause a deformation in the crystal structure, resulting in a change in shape or mechanical motion.

Here is a simple illustration of the piezoelectric effect in action:

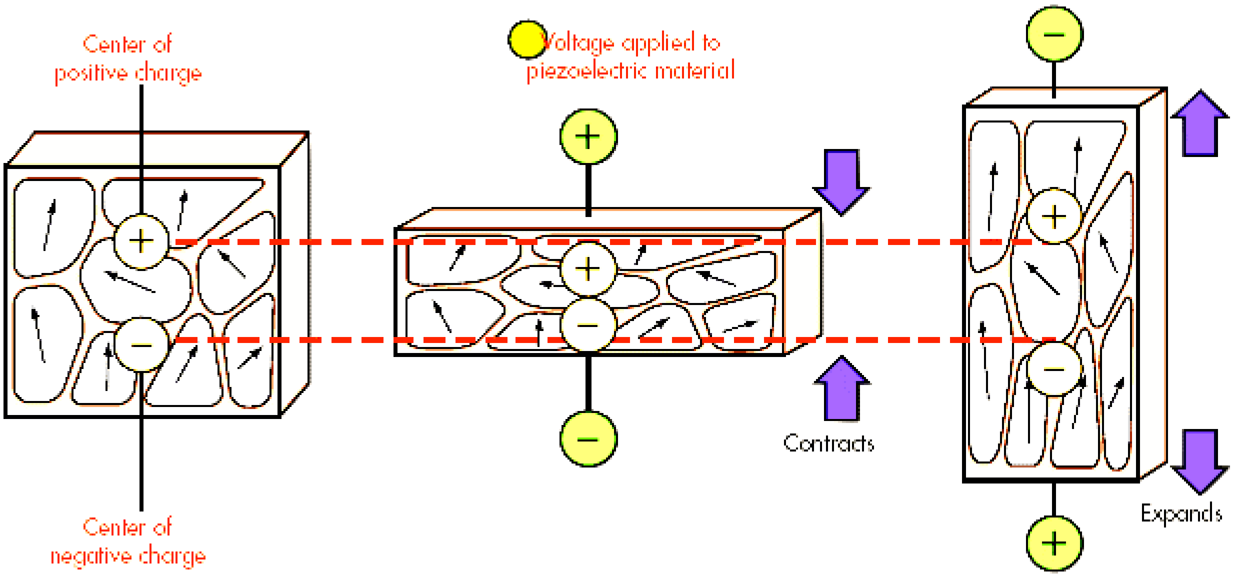

Figure 8: Pictorial explanation on piezoelectric effect.

In the above illustration, a force is applied to a piezoelectric crystal, causing it to deform and generate an electric potential across its surface. This potential can be measured with an external circuit, which could be used to monitor changes in pressure, strain, or vibration. Conversely, applying an electric potential to the crystal would cause it to deform and produce a mechanical motion, which could be used in applications such as actuators or motors.

2.2.2. Rectifier

A bridge rectifier is made up of four diodes which makes a full wave rectifier that converts AC input generated from Piezoelectric Disc to DC output. Bridge rectifiers are considerably used in power inventories that give the demanded DC voltage for electronic factors. D1, D2, D3 & D4 are used for designing the bridge rectifier. These diodes are connected in a way such that AC is converted to DC efficiently. The AC output (two terminals) of the Piezoelectric Disc were connected to D1-D2 and D3-D4 respectively called terminal A and B and the Output DC voltage terminals were obtained from D1-D4 and D2-D3 terminals called terminal C and D respectively. During the positive cycle, two diodes like D1 and D3 will conduct electricity and during the negative cycle, two diodes like D2 and D4 will conduct electricity.

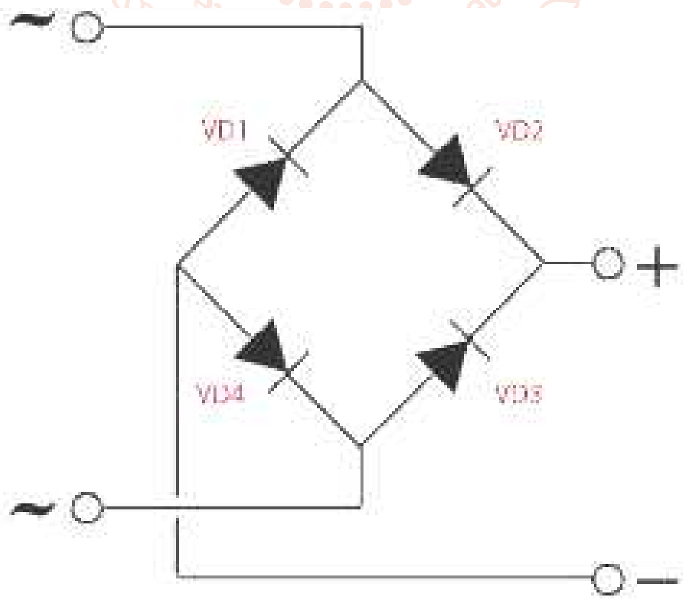

Figure 9: Bridge Rectifier

2.2.3. Battery charging module

A battery charging module is a device that is used to charge rechargeable batteries. It typically includes a charging circuit, which controls the charging process to prevent overcharging or undercharging of the battery. This module is made for charging rechargeable lithium batteries using the constant-current/constant-voltage (CC/CV) charging method.

The charging module consists of a power input port, usually a USB port or a DC jack, and a set of charging pins or wires that are connected to the battery. It also includes a charge controller, which regulates the charging process and ensures that the battery is charged at the correct voltage and current. The charge controller typically has a built-in voltage regulator to maintain a constant voltage during the charging process. It also monitors the battery's charge level and adjusts the charging current accordingly to prevent overcharging, which can cause the battery to overheat or even explode.

This module also include additional features such as battery protection circuits, power output ports, and LED indicators to indicate the charging status.

Battery charging modules are useful tools for ensuring that rechargeable batteries are charged safely and efficiently. They can be used in a wide range of applications, from charging the batteries in portable electronic devices to charging large batteries in electric vehicles.

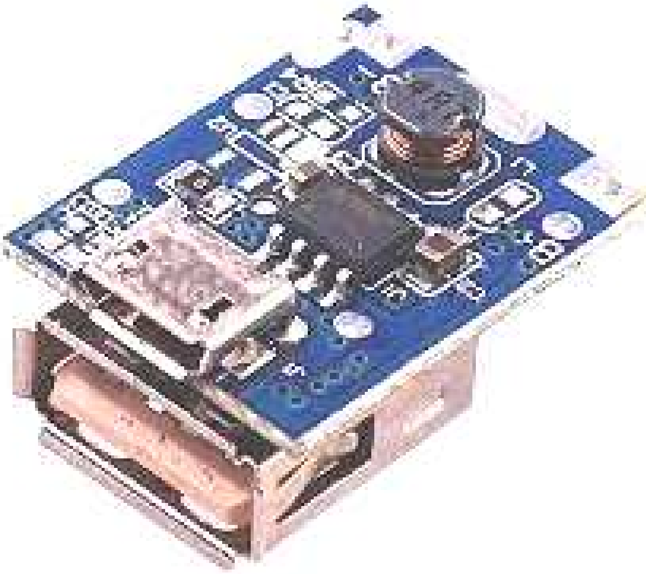

Figure 10: Battery charging module

The battery used for the above module is a lithium rechargeable battery of 2600mAh - 13.7v. 3.7V 2600mAh is an high capacity, High energy density and lower weight than other rechargeable batteries Manufactured under ISO9001-2000 to assure quality Battery tested based on International Electro technical Commission (IEC) standard to ensure high capacity and quality.

Figure 11: 3.7v, 2600mAh Battery and its case

2.3. Implementation of the Sub circuits Connections

A conceptual design of the project is designed to know how the circuit will look like and how each component used will function to the best of their capacity. The design gives an overview of the roles of the major block, how they are integrated, and the information flow arrangement. After the design has been made, the construction of the circuit begins; the piezoelectric material used is established on the circuit design with other component connection and flexibility. The other component such as the Rectifier module, Battery charging module and the load which is a mobile phone were used for the construction of the project.

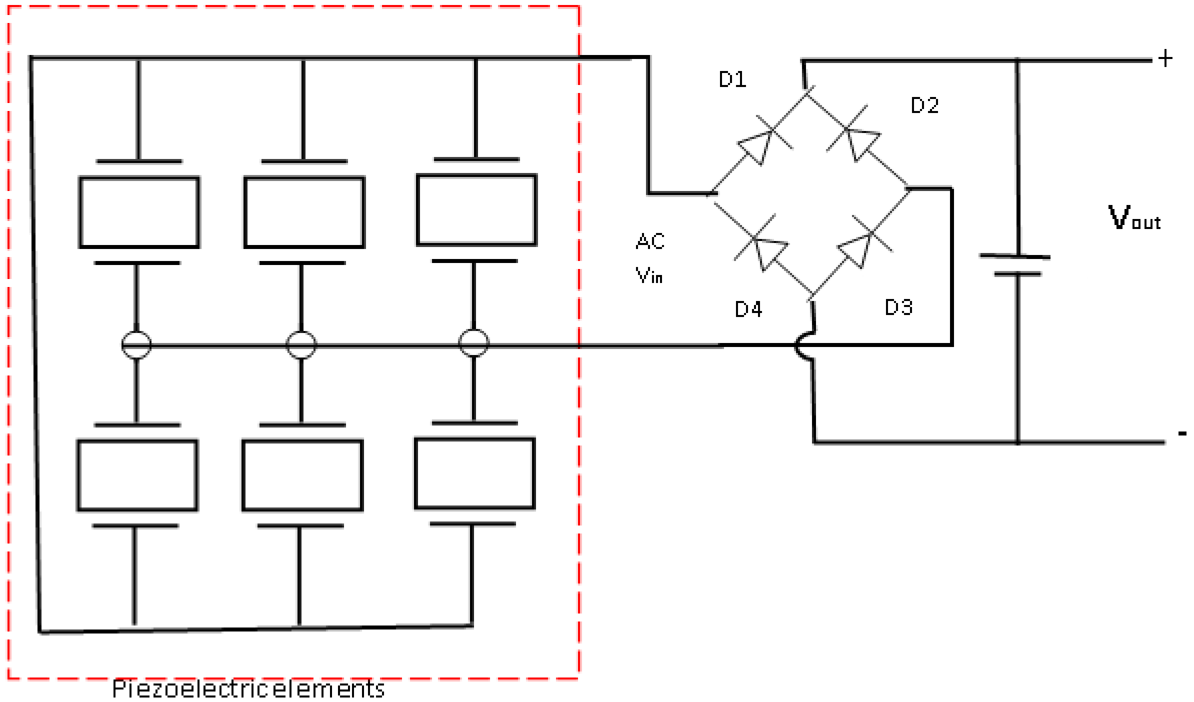

Figure 12: circuit Diagram of the project

In nanotechnology, piezoelectric energy generation can be achieved through the use of various subcomponents, which are connected in a specific circuit. The following is an overview of the circuit connection of all subcomponents in the development of nanotechnology-piezoelectric energy generation:

Piezoelectric Material: The piezoelectric material is the heart of the piezoelectric energy generation circuit. It is made up of a crystal lattice structure, which produces a voltage potential difference when mechanical stress is applied to it. This material is connected in series with the rest of the circuit, and it is the component that generates the electrical energy.

Transducer: The transducer is a component that converts the mechanical stress applied to the piezoelectric material into electrical energy. It is connected in series with the piezoelectric material, and it helps to amplify the voltage potential difference produced by the piezoelectric material. Shoe is serves as transducer in the project.

Power Conditioning Circuit: It consists of a rectifier and filter, which work together to convert the raw AC voltage generated by the piezoelectric material into a stable DC voltage that can be used to power other electronic devices.

Energy Storage Unit: The energy storage unit is a component that stores the electrical energy produced by the piezoelectric material and the transducer. It is usually a battery or a capacitor that is connected in parallel with the power conditioning circuit. The energy storage unit helps to ensure that the electrical energy generated by the piezoelectric material is not wasted, and can be used at a later time.

Load: The load is the component that consumes the electrical energy produced by the piezoelectric material and the transducer. It is connected in parallel with the energy storage unit, and it can be any electronic device that requires electrical power.

In summary, the subcomponents in the development of nanotechnology-piezoelectric energy generation are connected in a series and parallel circuit, where the piezoelectric material is the component that generates the electrical energy. The transducer amplifies the voltage potential difference produced by the piezoelectric material, while the power conditioning circuit converts the raw AC voltage into a stable DC voltage. The energy storage unit stores the electrical energy, and the load consumes it.

Algorithm code for the development of nanotechnology-piezoelectric energy generation:

- Initialize the system.
- Define the requirements for piezoelectric energy generation, including the type of piezoelectric materials, transducers, and other components required.
- Design the circuit based on the identified requirements, including the placement of the components, the type of connections between them, and the specifications for each component.

- Build the circuit using the designed circuit diagram, by soldering the components together and connecting the wires.
- Test the circuit for functionality, by measuring the voltage generated by the piezoelectric material and the transducer, and comparing it to the expected values.
- Add an energy storage unit to the circuit, to store the electrical energy generated by the piezoelectric material.
- Connect the load to the circuit, to consume the electrical energy generated by the piezoelectric material.
- Perform final testing of the complete system, under different conditions to confirm its performance
- If the system meets the required performance specifications, then the development of the nanotechnology-piezoelectric energy generation system is complete.
- If the system does not meet the required performance specifications, then identify the issues and modify the design accordingly, before retesting the system.

This algorithm code can be implemented using any programming language, with the appropriate functions and variables defined to carry out each step above.

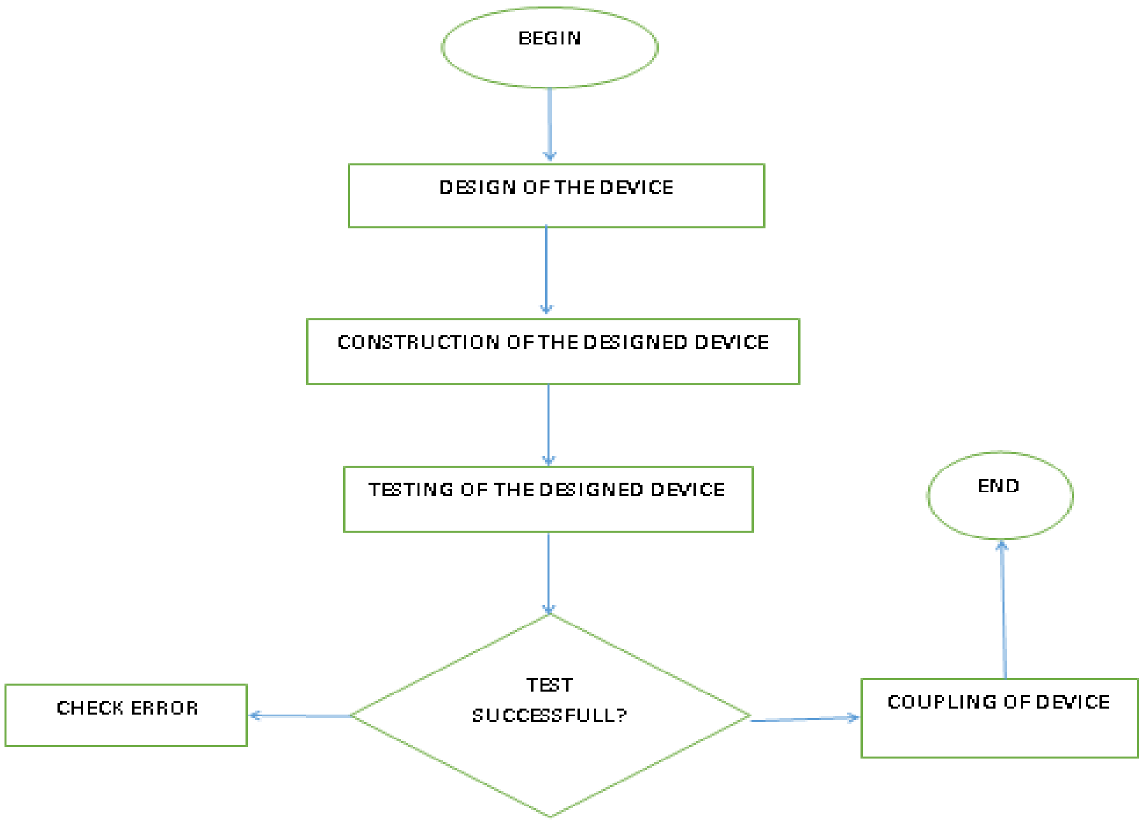

Figure 13: Flow Diagram of Nanotechnology-Piezoelectric Energy Generation

The flowchart for the development of nanotechnology-piezoelectric energy generation involves identifying the requirements, designing and building the circuit, testing the circuit, adding an energy storage unit, connecting the load, and performing final testing.

3. IMPLEMENTATION AND TESTING

Testing and integration is done to make sure that the design is performing duly as anticipated there by allowing one or truly aimed users for which the design was targeted for, treasure its performance and inversely approaches exploited in the design and integration of several modules of the construction. All the components/modules were connected together, and a device was created. All component and section performed as defined in the design. Tests such as component test, rectifier test, battery charging module test and battery test were carried out. Component like Piezoelectric disc, capacitor, LED, and diode used in the project are tested. The performance of the piezoelectric nanogenerators (PENG) device was evaluated by measuring the output voltage and current under different mechanical loading conditions. The results showed that the device was capable of generating an output voltage of up to 5V and an output current of up to 2 mA when subjected to mechanical deformation. The result of the testing is provided in Table 1.

Table 1: RESULTS OF TESTED COMPONENTS USED

S/N	Components	Test performed	Status
1.	Piezoelectric disc	AC test	Okay
2.	Diode	Continuity test and voltage drop test	Okay
3.	Capacitor	Charging and Discharging test	Okay
4.	Battery	Initial test	Okay
5.	LED		Okay

All components are tested OK.

Figure 14: implementation Stages

4. RESULT AND DISCUSSION

4.1. Result

The development of nanotechnology-based piezoelectric energy generation has shown promising results in generating electrical energy from mechanical pressure or vibrations. With the integration of nanotechnology, the energy output and efficiency of piezoelectric materials have significantly improved, making them a potential component for future energy generation.

Figure 15: Test Stages

4.2. Discussion

The use of nanotechnology in piezoelectric energy generation has allowed for the creation of more efficient and flexible devices that can convert mechanical energy into electrical energy. The integration of piezoelectric generators has also allowed for the creation of smaller and more portable devices.

One of the major advantages of nanotechnology-based piezoelectric energy generation is its potential for use in various applications such as wearable electronics, self-powered sensors, and biomedical implants. With the advancement of nanotechnology, piezoelectric generators can be designed to be more sensitive and durable, making them suitable for use in harsh environments.

However, there are still some challenges that need to be addressed in the development of nanotechnology-based piezoelectric energy generation. The efficiency of energy conversion is still relatively low, and the cost of producing these devices is currently high. Additionally, there is a need for more research to be conducted on the long-term durability and reliability of these devices.

5. CONCLUSION

An average living being on planet earth survival depends on energy as it is one of the most treasured resources on earth. The purpose of this project was to put in place a system that can solve the energy problem and provide a better self-energy generation without external source(s). The development of nanotechnology-based piezoelectric energy generation has shown significant promise in generating electrical energy from mechanical pressure or vibrations. While there are still some challenges that need to be addressed, the integration of nanotechnology has allowed for the creation of more efficient and flexible devices that can be used in various applications.

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