PERFORMANCE OF THE ENERGY HARvestING SYSTEM USING 3D PRINTED GRAPHene

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ABSTRACT

Material with high conductivity and less weight will have great potential to be used in the next generation of flexible electronics. Graphene is the material which is having these specific properties and is able to lead a pivotal role in the new generation of electronic devices manufacturing system. In this work, Direct Ink writing method as one of the three-dimensional (3D) printing technology has been used to print graphene material. The purpose of the work is to get good conductivity and harvesting the electrical energy and as well as to maintaining the mechanical properties. The direct ink writing method was used to print the graphene with PVA and the finite element method was applied for the printed model. Vibration-based energy harvesting has been designed and numerical modeling was formulated to attain the concentrated power efficiency and maximum output power.

Keywords: 3d printing electronics, piezoelectric material, graphene, direct ink writing (DIW) method, Vibration analysis, Energy harvesting

1. INTRODUCTION

In General, Graphene is an allotrope type of material and made in the form of 2D carbon atoms. The arrangement structure look like a honeycomb model. This model is available in hexagonal lattice and each and every atom forms vertex type with sp\textsuperscript{2} hybridization level [1, 3, 4, 6]. The structural broad range of graphene is their dramatic chemical, physical, mechanical, electrical, and electronic properties [2, 5] essential for comprehensive characterization of graphene material for implementation in various applications. The strong connection between the carbon to carbon atoms is very much high. Due to this strong connection, the thermal and chemical stability of the graphene also getting extremely high. The length between the nearest carbon atoms are 0.142nm only. The distance between the plane is 0.335nm. Graphene have a planar density is about 0.77 mg/m\textsuperscript{2} only that’s why it’s called a super light material, moreover due to this formation, advantages of being super thin and ultralight [6]. Three $\sigma$ bonds from the lattice formed a stable hexagonal structure and each lattice is having a strong connection[7, 8, 9, 10]. Its extremely high mechanical strength with high charge carrier mobility for excellent conductivity and moreover it’s having good intrinsic flexibility this will make good quality of graphene for so many applications. Carbon-based systems always have different types of structures in unlimited numbers and each structure has a wide variety of physical properties [11, 12]. These physical properties made its physical bonding more flexible and gives more varying structures. The carbon atom from each unit is formed in the form of hexagonal type ring. The unit structure area of the graphene is about 0.052 nm\textsuperscript{2}. Pair of carbon atoms from the hexagonal type ring were arranged in a vertex type model and mutually shared a space with three unit rings. [13,15,16].

3D Printing is essential for printing complex structures with a smaller number of tools and with more flexibility. It is also more beneficial cost-wise and production time-wise. In our process, multiple materials need to be added, and designated structure needs to be printed in microscale, so the 3D printing technique is more suitable for our process [14, 17].
This 3D printing technology has many classifications. Apart from all the methods, Direct Ink writing methods were deals with wide variety of functional materials available from the market to deliver the complex 3D structure. It is able to print the Ink formation of slurry. Through this printing method required to control the following parameters such as layer thickness, Speed, Infill rate, fill pattern, temperature, rheological structures. While making the 3D structure spanning feature, continuous solids and high aspect ratio also be constructed. [18, 19].

Plotting a 3D CAD design model is depends on the printing parameters which can able to delivering the high viscous material into a required structure through a pressed syringe shown in Fig. 1(e). All the three axis, head point can move and maintain the dynamic variations. Materials placed on the bed in the respective position to form the structure from the layer by layer. When the two reactive components have using mixing nozzles or induced UV light or by heat, curing reaction have been occurred [20, 21]. Most of the times, plotting a final positions completed by using the curing reaction. Here both the deposition speed and viscosity of the material have connected with each other to make the quality of the final output printed parts and provide an expected 3D printed CAD model[22, 23, 24, 25].

The main advantage of using this technique is flexibility of the material. Initially, any form (solution, past and hydrogel) of materials can be loaded into the printer, printing parameters have made the all other changes from materials into printing a required complex structure.

2. MODEL PREPARATION

After the PVA solution preparation has been done, then prepare the Graphene slurry for 3d printing. As per the procedure from the previous studies, this process has started with 80% and 20% combinations [Fig 1 and 2]. 80% of the PVA solution (16 gram) and 20% of the Graphene(4 gram) to be filled in the beaker and it will be trituration by nearly 15 to 20 mins then the final slurry will be ready for 3d printing and the final printed model also shown in Figure 3.[29, 30]

Graphene is a good conductor having a great conducting capability, making more free of airflow easily than other materials such as metal, etc.,

Charge carriers and free movement of electrons with low mass made graphene has the highest carrier mobility than all type of semiconductors.

\[
\mu = \frac{(q_e \Gamma)}{m^*}
\]

Where \(q_e\) is the charge carrier, \(\Gamma\) is the average scattering time and \(m^*\) is the effective mass.

The electron mobility of graphene is calculated as approximately 200,000 cm2v-1s-1at low temperatures. For comparison, silicon displays electronic mobility of 1400 cm2v-1s-1 at 300 K, a factor 143 times smaller [4, 5, 9].
HYPER MESH has been considered as the software component which can able to do the meshing analysis. By using the several studies, SIZE CONTROL have the option to calculate the size of mesh. Finite element method (FME) used to calculate the deflection and stress analysis conducted on leaf spring analysis [33, 34]. To considering the various geometric analysis and dynamic loading conditions, stress analysis and vertical stiffness have been calculated on the particular stress concentration region and vertical loading region respectively. When these two parameters were considered on parabolic springs, the predicted results has been derived a shown in Figure 4 [37].

This meshing analysis technique was used in the process of evaluating the stress in the particular region. Once the stress has been evaluated, durability of the spring simulated and accelerated based on the fatigue life testing. [38, 39].

For forthcoming electronic device manufacturing systems, graphene has focused more because of this electron mobility on the device. Compare with other materials especially silicon [Si], graphene having more electron mobility because of the contact between the electron and phonon were decreased in the lower carrier scattering [Fig. 5]. When the electric field has increased, mobility has decreased [40].

![Fig 2. Preparation procedure for graphene solution](image)

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Fig 5. Mobility with Electric Field

3. ENERGY HARVESTING CIRCUIT

To make continues working with the battery-operated systems, Energy Harvesting (EH) from the atmosphere is an eye-catching way to utilize the energy properly. At the same time it’s mainly useful for long-standing purpose and currently this is the only alternate way for self-supporting electronics device manufacturing systems [41, 42, 43, 44]. To design the Energy harvesting circuits, the energy generation devices and interfacing circuits are essential elements to control the energy flow. Applying force to the piezoelectric system in any form like pressure or vibration will harvesting the energy. That force factors are the variables which can able to calculating the value of both mechanical and electrical in the system. Increase in the value from the systems were associated with the efficiency and the resonant power. These output parameters were varied with respect to the system circuits, analysis value and optimization parameters [45, 48, 49].

The below-mentioned methods are classified based on the circuit processed the energy extraction with the device. This methods are also dealing the how the materials are connected with the circuit for deriving the output equation.

1. Parallel Energy Harvesting circuit [PEHC]
2. Series Energy Harvesting circuit [SEHC]
3. Distinctive Energy storage circuit [DESC]
4. Distinctive Electric Charge circuit [DECC]

In Vibration based energy harvesting devices, Distinctive Energy storage circuit is the most frequently used interface circuit. It has been interface with battery or capacitor [46, 47, 51, 52]. But based on the comparison with the previous studies shows the TECE[Fig 6] circuit has good results when they are having weak
electromechanical coupling. Always electromechanical has showing the weak results due to that small indication in external load resistance and mechanical damping ($\alpha2=1$).

![Diagram](image)

**Fig 6. Distinctive Electric charge extraction Circuit**

For distinctive energy storage circuit mentioned in the above diagram, whenever the charge extraction phase occurring in the circuit, the electronic switch(S) is ready to close. Then, each phase directly electrical energy stored in the blocking capacitor (C0) with the variations in the Inductor (L). Mechanical vibration has occurred with the maximum and minimum displacement ($z$) with the extraction [50].

Step 1: External vibration force is considered to be moving on the frames
Step 2: System mass (m) moves concerning
Step 3: When the circuit is in an open condition, mechanical velocity is always related to voltage.
Step 4: To the voltage mean voltage and harvesting power depends on maximum displacement.
Step 5: The energy equilibrium has derived from the above two factors harvesting power and maximum displacement.
Step 6: Maximum input power derived from the mean resonance.
Step 7: Normalized dimensionless input resonance power consider like reference power, then harvested resonant power and overall circuit efficiency with respect to the resonance frequency also formulated.

$Y(x) = Y_v \sin(\omega x)$

$Z(x) = Z_v \sin(\omega x + \phi)$

The Induction

$\beta \cdot \dot{x} = C_0 \cdot v$

The integration gives

$V_{\text{mean}} = \frac{\beta}{C_0} \cdot X_{\text{mean}}$

$Power_{\text{harvest}} = \frac{\beta^2 x_{\text{mean}}^2}{2 \cdot r \cdot C_0^2}$

System Energy Equilibrium,

$P_{\text{input}} = \text{Mean resonant power at input region}$

$P_c = \text{Damping dissipation power at Mechanical region}$

$P_{\text{harvest}} = \text{Harvested resonant power}$
\[
\frac{1}{2} \ddot{m} a X_m = \frac{1}{2} \beta^2 X_m^2 \frac{\ddot{m}}{rC_0^2} + \frac{1}{2} c X_m^2 \ddot{\vartheta}^2
\]

\[
\frac{\ddot{m} a X_m}{2} = \frac{\beta^2 X_m^2}{2rC_0^2} + \frac{c X_m^2 \ddot{\vartheta}^2}{2}
\]

\[
= \frac{X_m^2}{2} \left[ \frac{\beta^2}{rC_0^2} + c \ddot{\vartheta}^2 \right]
\]

\[
Power_{i/p} = \frac{(ma)^2 \ddot{\vartheta}}{2[c\ddot{\vartheta} + \beta^2/r\vartheta C_0^2]}
\]

Normalized dimensionless

\[
\frac{Power_{i/p}}{(ma)^2/rC_0^2} = \frac{1}{2 \vartheta_n + \beta_n^2}
\]

\[
\eta = \frac{\beta_n^2}{\vartheta_n + \beta_n^2}
\]

4. RESULT & DISCUSSION

Fig. 7(a) represents the Harvested resonant power and Voltage as the output parameter versus the variable input acceleration from DESC Circuit. In this case, apart from the two measured parameters which are mentioned above all the parameters are meant to be constant [51].

The value of resistance which is mentioned in the input region is not a peak resistance value, so that the voltage in the output side is directly related to the input acceleration in a linear region and as well as produced the maximum power and voltage.

Fig. 7(b) illustrates harvested resonant power with the output voltage versus the mechanical damping of the piezoelectric harvester in a mechanical region with a base acceleration of 9.8 m/s² and the remaining parameters means to be constant values only [51].
Fig 7. (a) Harvested resonant power with input acceleration, (b) Voltage with input acceleration, (c) Mechanical damping with Harvested resonant power, (d) voltage with mechanical damping [base acceleration]

In a certain level of resistance, when mechanical damping growth has increased, both the level of voltage and resonant power decreased as well as the electrical circuit with the resonant piezoelectric harvester adds the more resistive value to the system in damping area which decreases the output voltage as well as the harvested power but inductance power does not lose due to simple load resister [Fig 7(c) and 7(d)].

Fig 8(a). Shows that both the harvested resonant power and output voltages versus the electrical load resistance under the acceleration of 9.8 m/s² and the remaining parameters means to be constant values only. In most commonly when voltage increases the resistance of the circuit also will increase [51]. But on the other side when specific load resistance optimized the harvested resonant power and it is mainly related to the piezoelectric material of the circuit and matching the electrical impedance [Fig 8(b)].

Fig 8. (a) Harvested resonant power with resistance [base acceleration], (b) Output voltage with resistance under the base acceleration.

Fig(9) Shows that both the harvested resonant power and output voltages versus the electrical load resistance under the acceleration of 9.8 m/s² and the remaining parameters means to be constant values only. When force factors increased as well as the resistance also reached a particular value the resonant power increases and that peak value decreased before it reached the region. In many cases, the amount of force factor would extent the maximum of harvested power and it will be decided by the size and property of the piezoelectric material. Once the harvested resonant power extents the extreme peak value due to the multiple parameters of the circuit such as value of the resonant frequency, mechanical damping region value, load resistance factor, and the blocking capacity of the graphene material enclosure in the circuit[51, 52].
In Distinctive Electric charge extraction circuit method Graphene is the lightweight and strongest material which is having a remarkable piezoelectric property and printed by using the Direct Ink writing method of 3D printed technology and the Energy harvesting was the prominent feature for the piezoelectric materials. This analysis also has been carried out by using the distinctive electric charge extraction circuit method. The energy harvesting efficiency and harvested resonant power are marked to be good based on the results drawn and these values are originated based on the factors which include mechanical damping, harvester resonant frequency, load resistance and force factor.

CONCLUSION

This paper presented the performance of the graphene material in energy harvesting system, which is printed by direct ink writing method. Energy harvesting system circuit has done with distinctive electric charge extraction circuit followed by vibration analysis. From that bringing the common strategy for overall optimization of the graphene material considering the electrical dynamics variations of vibration-based energy harvesting system and structural model system. A typical equivalent circuit for the modified energy harvester has developed and the corresponding distinctive impedance for achieving the determined output power as well as the concentrated output efficiency was driven theoretically and the different types of characteristics curves also have been analyzed. Numerical modeling was also developed for calculating the stress and strain analysis of the material. Based on the result analysis of the characteristics curve, the following major points to be noted,

a) The force factor and resistance of the circuit has derived from the predefined parameters of the circuit and the maximum power has achieved from the circuit is 5.3 mw with the base acceleration of 9.8 m/s².

b) Moreover to maintain the force factor are equal to the maximum average value and is likely to be one so that the maximum efficiency of the energy harvesting circuit has reached in good.

c) Maximum of output power and efficiency in the vibration-based energy harvesting circuit has been maintained between the electrical and mechanical system and it depends on the load resistance, resonant frequency, mechanical damping and force factor only.

REFERENCE


