# Dec-2019 ISSUE- IV, VOLUME-VIII

Published Quarterly issue
With ISSN 2394-8426 International Impact Factor 6.222
Peer Reviewed Journal

Published On Date 31.12.2019

Issue Online Available At : http://gurukuljournal.com/

Organized &
Published By

**Chief Editor,**
Gurukul International Multidisciplinary Research Journal
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Website : http://gurukuljournal.com/

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**Gurukul International Multidisciplinary Research Journal (GIMRJ)***with*
**International Impact Factor 6.222**
**Peer Reviewed Journal**

**ISSN No. 2394-8426**
**Dec-2019**
**Issue–IV, Volume–VIII**

# Piezoelectricity in Graphene: Recent Advancements

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## Abstract

The present brief review article explores the recent developments in piezoelectricity in graphene. Basically, the pure graphene is non-piezoelectric material. But the its surface decoration metal oxide nanoparticles make it appropriate for the potential piezoelectric applications. In this article, the straintronics, piezoelectricity in graphene and anomalous piezoelectricity in graphene like concepts and their origins are discussed.

**Keywords:** Piezoelectricity; Graphene, Metal Oxide

## Introduction

In 2004, scientists extracted graphene for the first time using the Scotch tape method using a piece of glue. Carbon atoms are organised in a single layer of graphene in a honeycomb-like hexagonal arrangement. It has a chicken wire appearance. Graphene is a miraculous substance. It is a hundred times better electrical conductor than silicon. It is more durable than a diamond. It is also so thin—just one atom thick—that it resembles a two-dimensional substance. Graphene has received the greatest research over the past ten years, especially in the field of nanotechnology, due to its intriguing physics. The scientists that initially isolated it received the Nobel Prize in 2010. Graphene is several things, yet it is not piezoelectric. The ability of some materials to generate an electric charge when bent, compressed, or twisted is known as piezoelectricity. The fact that piezoelectricity is reversible may be more significant. Piezoelectric materials alter form when an electric field is applied, providing an astounding amount of technical control. Numerous gadgets, including watches, radios, ultrasound machines, and propane grill push-button starters, employ piezoelectrics, but each of these applications calls for quite substantial, three-dimensional amounts of piezoelectric materials. Two Stanford materials engineers have now revealed how they incorporated piezoelectrics into graphene in a study that was just published in the journal ACS Nano, bringing for the first time such exquisite physical control to the nanoscale [1]. The single-layered graphene sheet is seen in Figure 1.

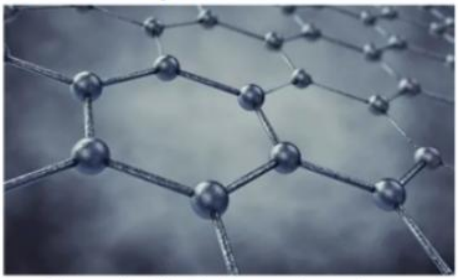

Figure 1. Single layered graphene.

### Straintronics

The electrical field applied directly relates to the physical deformations we are able to produce. This is a completely fresh approach to nanoscale electrical control. Because of the way the electrical field deforms the carbon lattice, causing it to change shape in predictable ways, this phenomena gives the idea of straintronics a new dimension. For uses ranging from touchscreens to nanoscale transistors, piezoelectric graphene may offer an unmatched level of electrical, optical, or mechanical control. The engineers evaluated the piezoelectric effect while simulating the deposition of atoms on one side of a graphene lattice, a procedure known as doping, using a sophisticated modelling tool running on high-performance supercomputers. They created models of graphene doped with lithium, hydrogen, potassium, and fluorine in addition to mixtures of those elements on each side of the lattice. The key to the technique is to just dope one side of the graphene or to dope both sides with different atoms, breaking the graphene's perfect physical symmetry, which would otherwise nullify the piezoelectric effect. First, it is assumed that the piezoelectric effect would exist, albeit in a minor capacity. However, the levels of piezoelectricity in such graphene are equivalent to those in conventional three-dimensional materials [2]. The many modes to generate the straintronics effect are shown in Figure 2.

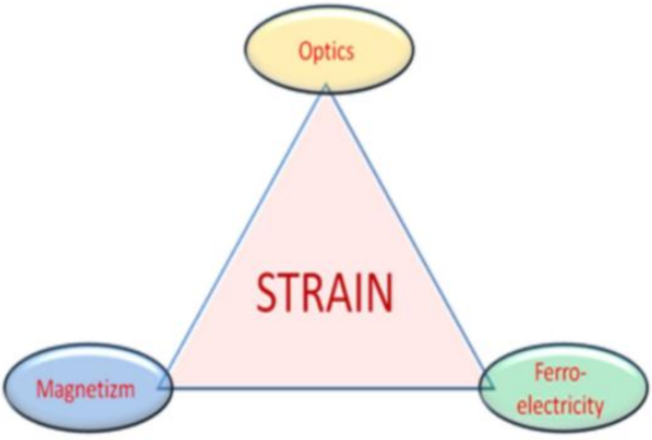

Figure 2. Various modes to achieve straintronics effect.

### Graphene and Piezoelectricity

Stretchable electronics, sensors, actuators, and other electronic components based on the direct and converse piezoelectric effects now have new avenues for development thanks to the recent finding of piezoelectricity in two-dimensional (2D) materials. One of the best choices for these uses is graphene, a 2D monoatomic substance with several special features. Numerous emerging characteristics, including excellent heat conductivity, great mechanical strength, and exceptionally high flexibility, are displayed by it. Despite the fact that pristine graphene lacks any piezoelectric activity due to its intrinsically centrosymmetric crystal structure, it is possible to induce piezoelectricity by adsorbing foreign atoms to disrupt inversion symmetry, creating particular in-plane defects, or non-uniformly deforming graphene layers so that strain gradients induce internal polarisation in a material. Modified graphene is projected to have a sufficiently high and similar piezoelectricity to that of traditional piezoelectric materials.

However, only theoretical hypotheses—which gave the anticipated values of piezoelectric coefficients—have so far been published. The semi-conducting or insulating condition of graphene is one of the prerequisites for any type of graphene to show piezoelectricity. It has been demonstrated that the designed strain in graphene causes the band gap to expand or tune, allowing graphene to transition from a semi-metal to a semi-conducting state. Theoretically, the apparent piezoelectric response will disappear if centrosymmetric graphene is exposed to a symmetrical strain field since net polarisation will stay zero. The non-zero net polarisation and subsequent apparent piezoelectricity of graphene need a non-symmetric strain field (or strain gradient).

The period of the substrate determines the anisotropic strain geometry of a graphene layer placed on top of a grid structure. The polarization-dependent Raman spectra supported this. Another result of the chemical interaction of the graphene with the SiO2 surface in the periodically modulated graphene on the grating was periodic localised doping. The band gap opening, the net dipole moment, and polarisation in the graphene layer can also be brought about by this interaction with the atoms of the substrate underneath [3]. The piezoelectricity of graphene is seen in Figure 3.

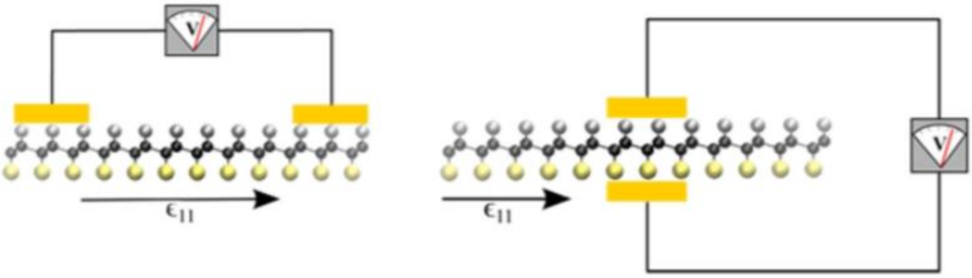

Figure 3. Piezoelectricity in Graphene.

**Anomalous Piezoelectricity in Graphene**

Numerous minerals and rocks that are not often thought of as being piezoelectric show transitory electric polarisation in response to abrupt changes in stress load. The normal, static piezoelectric response, in which electric charges manifest as a result of crystal lattice deformation, is distinct from this anomalous piezoelectric action. The abnormal piezoelectricity dynamically degrades over a period of a few seconds or tens of seconds. Different polarisation qualities are found in certain materials, though. It is necessary to postulate a number of complex electric charge creation and relaxation mechanisms in their number, with concurrence of two or three relaxation processes, in order to explain some elements of the polarisation signal rise and decay [4].

The development of atomically thin piezoelectric materials is anticipated to have a wide range of uses in the field of nanoelectromechanical systems, including flexible smart electronics, skins, switches, and various kinds of sensors, among others. The only material system that appears to fulfil this description at this time is boron nitride nanosheets. Recent studies imply that tungsten disulphide and molybdenum disulphide sheets, which are three atomic layers thicker, are likewise piezoelectric. Due to its unique characteristics and wide availability, graphene is undoubtedly the most well-known two-dimensional (2D) material and has a number of emerging uses.

Dejectedly, graphene is often conductive and non-piezoelectric by nature; the only exceptions are certain arrangements of graphene nanoribbons. However, apparent piezoelectricity may be achieved by combining symmetry, nanoscale size effects, and flexoelectricity, a feature of the material that results from the energy required to produce internal polarisations in the presence of strain gradients. Our quantum mechanical simulations, based on these ideas, predict that the addition of nanoscale triangular-shaped holes to edge-terminated graphene nanoribbons would result in the appearance of piezoelectric activity. We present the first experimental support for this claim in our paper.

Dielectric functionalized graphene nanoribbons are particularly challenging to create triangular holes at the nanometer scale. As a result, we choose for the electrically non-conducting graphene nitride nanosheets as an alternate 2D structure. The structure of carbon nitride in graphitic form naturally contains regularly spaced triangular nanopores. Because the carbon and nitrogen atoms at the pore edges of graphene nitride are totally saturable, they don't need to be passivated by any functional groups, which is a significant distinction from the nanopores in pure graphene. In contrast to porous graphene, graphene nitride may be produced from the bottom up more easily due to its structural stability. This article discusses the manufacturing process known as liquid-phase exfoliation.

This method may be used to create graphene nitride, which naturally has nanoscale pores between one and two nanometers in size. Commercially available graphene nitride, which is made from fundamental chemical building blocks, has already found use in technologies like gas filtration and catalytic improvement. However, this material's potential applications for piezoelectric devices have largely gone untapped [5]. We demonstrate that 2D graphene nitride is indeed piezoelectric with a corresponding coefficient significantly higher than that of -quartz, making it a promising candidate for nano- and micro-electromechanical applications. We do this using state-of-the-art piezoresponse force microscopy (PFM) and findings from ab initio calculations. The anomalous piezoelectricity of graphene is seen in Figure 4(a-c).

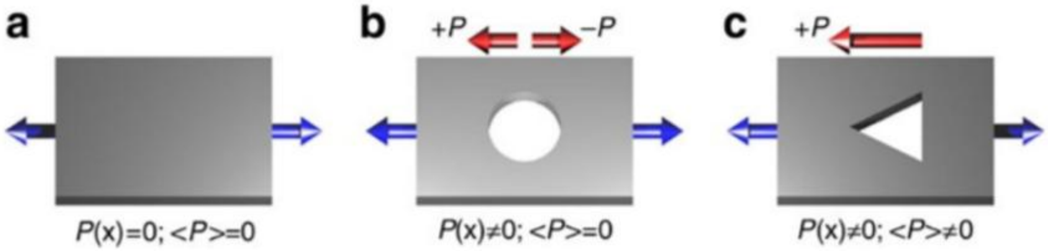

Figure 4. (a) A non-piezoelectric material with no pores exhibits no piezoelectric response; (b) with circular (centrosymmetric) pores, local polarization is non-zero while net polarization

remains zero, and overall there is no apparent piezoelectric response; (c) with triangular (non-centrosymmetric) pores, a non-zero local and net polarization exist and the material possesses an apparent piezoelectricity.

## Conclusions

In summary, it is determined that mechanical prebending or electric excitation may be used to realise the potential of graphene adorned with metal oxide nanoparticles as a piezoelectric nanogenerator. New technologies in the areas of electronics, photonics, energy harvesting, chemical sensing, and high frequency acoustics may be made possible by engineered piezoelectricity at the nanoscale. By breaking the inversion symmetry of graphene by adsorbing atoms onto its surface, researchers were able to produce levels of piezoelectricity that were on par with those of other 2D and 3D materials. This fundamentally new kind of piezoelectricity, in contrast to previous piezoelectric materials, is designed into a nonpiezoelectric material, made feasible by the 2D nanoscale structure of graphene.

## Acknowledgement

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

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