Graphene the Pillar of Valleytronics-Review

Devayan Bhattacharya, Ajay Tibrewal, Suvradip Ghosh

Department of Electronics & Communication Engineering, Institute of Engineering & Management , Kolkata-700150, India

ABSTRACT: Graphene, which is an allotrope of carbon, has attracted the scientific community for its fundamental as well as its technological aspects. It has many promising applications which have revolutionized the semiconductor industry. It is the electronic charge which drives the semiconductor technology; however electrons have two additional degrees of freedom, spin and valley. Spin degrees of freedom has led to the well known subject of spintronics which has made tremendous progress in recent times. However, very limited progress has been made in the study of valley degrees of freedom of electrons, also known as valleytronics. Use of graphene in valleytronics, a revolutionary idea under intensive study, can truly make graphene overtake the markets of semiconductor materials. This paper focuses on those aspects of graphene which can prove to be a pillar of the much anticipated valleytronics field. The use of valley of an electron to increase the speed of the conventional computer by billion times has been discussed. Besides the gauge field (strain) in graphene which somewhat links valleytronics with straintronics is also bought under focus.

KEYWORDS: Graphene, Dirac Point, Pseudo-magnetic field, Valleytronics, quantum computing.

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1. INTRODUCTION

Regarded as the 'miracle material' graphene has been a noted substance since its discovery. Its potential being rarefied among material scientist, it is an acknowledged fact that it has superior properties. Graphene is the hardest material ever tested, conducts heat and electricity and is nearly transparent. It self-repairs on exposure to molecules containing carbon such as hydrocarbons. [1]

However graphene's band-gap properties have resulted in advent of a ground breaking new field valleytronics. As in classical electronics the charge of the electron is harnessed for computing, in valleytronics the valley number of an electron is used. It comes under the umbrella term quantum computing along with its contemporary spintronics which uses the spin orientation of an electron for storage. The paper reviews the several techniques of valley filtering which have been proposed in light of the properties of graphene.

1.1 GRAPHENE'S ENERGY SPECTRUM

Graphene is a two dimensional hexagonal array of atoms. Its energy spectrum is peculiar as it has two minimums or valleys, referred to as the K and the K' valley. These two degenerate energy levels, characterized by distinct wave-length and momentum, can be used to store bits. Electrons in graphene can exist in a superposition of these two degrees of freedoms. Graphene is a semiconductor with the band gap between the valance and conduction bands being zero. Thus they meet at the Dirac points. [2-3]

1.2 PSEUDO-MAGNETIC FIELD IN GRAPHENE

When an ideal planar sheet of graphene is subjected to deformation, in the same way as nanobubbles, electrons behave as they experienced an external force field. The effect of the force is that electrons in the K and K' experience forces in opposite directions. Thus the field acts as valley filter.

However these concepts are quite general and different deformations leads to forces of different trajectories on electrons. Researchers at CNG, under DTU nanotech are working to understand and control this pseudo-magnetic field. This strain induced field acts as a link between straintronics and valleytronics. The strain control of valley electrons is being regarded as better then substrate control.

1.3 GENERATION VALLEY CURRENTS

Interaction of graphene and hexagonal boron nitride (hBN) results in the flow of valley currents in graphene. Graphene devices deposited on a layer of hexagonal boron nitride have been seen to carry valley current. The hBN substrate is responsible in breaking the symmetry between the two sub-lattices of the honeycomb lattice, which opens an energy gap at the Dirac points. A valley polarized current is generated which is transverse to the applied electric field. The phenomenon is also known as valley Hall effect.

Figure 2 shows bilayer graphene between two layers of hBN substrate. This property of graphene to produce valley currents is the most essential feature of valleytronics because, if it is to be implemented at all, then an electronic interface is a must. Researchers are relying the most on valley FETs made by graphene. [4,5]

Corresponding Author:* ***devayanbhattacharya222000@gmail.com*
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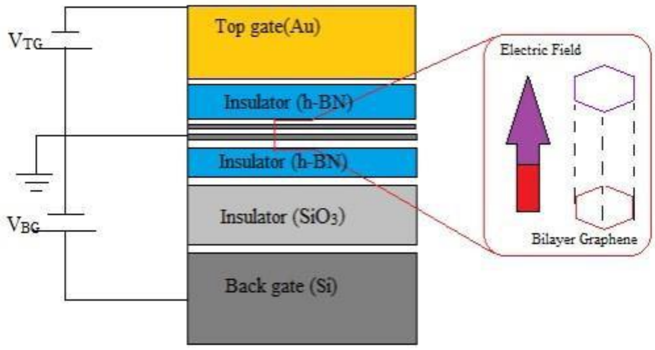
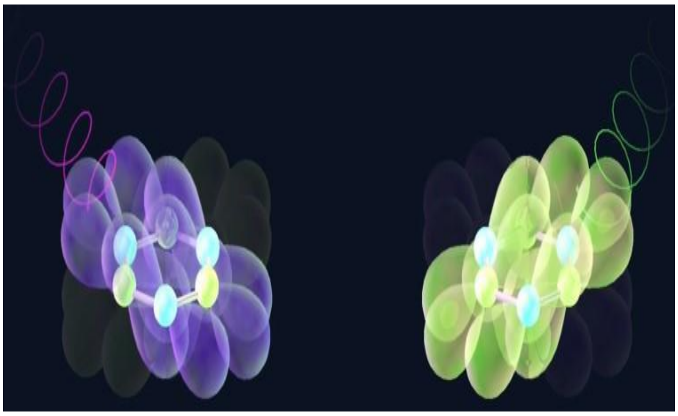


Figure 2: Bilayer Graphene Sandwiched between hBN layers



1.4 LIGHT BASED VALLEYTRONICS

Light wave valleytronics uses intense light waves in moments of electron to process logic. It starts with a two dimensional semiconductor, i.e. a single fragmented material which has a unique conduction properties. In this type of semiconducting material electron favors one of two specific momentum. [6,7]
These two specific momentum are often referred to as valley. It takes a lot of energy for an electron to enter from one valley to another. To get the unexcited electron to either valley, energy must be introduced by a circularly polarized light. A pulse of circularly polarized light in clockwise direction excites the electron in one valley and a pulse of circulating polarized light in anticlockwise direction excites the electron in another valley.

The resulting valley state is easily observed because the spin of the light emitted by an electron depends on which valley they are in. The electron will stay excited in either valley for a few femtosecond. [8-10]
In order to build a conventional computer there needs to be a way to represent a bits of information in two possible values 0 or 1, in these case valley 1 or 2 but that bit must also be able to switch between 0 or 1 to perform operation. This is done by using high energy linearly polarized light which helps the electron to change the momentum and hop the electron from one valley to another. This opens the door to incredibly fast valleytronic logic. [11-13]

If these system is used to build a conventional computer than it would be billion of times faster than the computer we use today. These quantum state can also exists in the quantum superposition with one another meaning that both the electrons are in the same state at the same time, midst between 0 and 1. [15,16] This would make it possible to build a quantum computer at room temperature

2. CONCLUSION

The complicated problems of the future sciences would be beyond the scope of classical electronics to handle. Quantum computing algorithms have already been designed to tackle the overload of equations of the modern sciences. Therefore intensive studies are being carried out to realize the ideas of valleytronics and spintronics. So in turn graphene regarded as the 'miracle material' is now also being seen as the future material for computation.
However no valley based device in graphene has been realized yet. Valleytronics concerning graphene or other two dimensional materials is not a near future. Quantum computing is still a far reach thought for modern science. Moreover if valleytronics devices are to be made for general public to use, then the price of graphene emerges as another major barrier. The

properties of graphene no matter how favourable for valley splitting and for generation of valley current, are yet to be utilized for computing applications.

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