GRAPHENE BATTERIES- SOLUTION TO ENERGY STORAGE

Kshitij Motke [1], Rajeshri Yallappa Mayanaikar [2]

[1] *Student, Computer Department, Dr D Y Patil School of Engineering Pune, Maharashtra, India*

[2] *Student, Computer Department, Dr D Y Patil School of Engineering & Technology Pune, Maharashtra, India*

ABSTRACT

Batteries are an integral part of any electronic gadgets and in the modern era, we are surrounded by numerous gadgets However advancement in technologies leads to high power consumption resulting in limitation in battery technology. Commonly used in lithium-ion batteries are toxic and have issues of sustainability, including resource depletion and the introduction of environmental and human health hazards. Moreover, lithium-ion batteries overheat, have a short life span, flammable and underperform extreme temperatures. The solution to these problems is Graphene batteries. Graphene initially known as graphite commonly "stuff pencils are made out of " Graphene is basically a 2D sheet of carbon atoms bonded together in a honeycomb lattice pattern exactly one atom thick. Graphene is highly conducive, incredibly lighter than steel but x200 stronger at the same time, with its large surface area to mass ratio graphene batteries holds great potential for applications in the energy industry. Batteries, with a higher charge capacity, faster rate of charge, and greater temperature tolerance, coupled with an accompanying method of production could revolutionize not only personal electronics but also electric vehicles.

Keywords: *Graphene, Batteries, Energy Storage, and Graphene Batteries.*

1. INTRODUCTION

Rapid innovation over the past several decades has led to an increase in the generation of electrically-powered gadgets. These gadgets have deeply impacted our lives and as such, have become integral parts of our society. Most of these gadgets' devices rely on portable sources of power in which energy is stored for future use the most common of which is the battery. The smartphone, for example, can only function as a portable communication and entertainment device because it is built with an internal power supply. Many of these devices are as weighty as a car (especially hybrid & all-electric cars) to as miniature as earbuds, smartwatches, laptops, and tablets. If any of these devices were constructed without batteries, they would require constant access to the power grid, and thus would be limited in their range of movement and use. Because so many devices rely on batteries, the capabilities of our technology are dependent upon the quality and capability of the batteries. The current, most widely-used battery is lithium-ion (Li-ion) batteries. Environmental factors, including climate change and finite fossil fuel supplies, have turned to the development of electric and hybrid vehicles to reduce emissions and fossil fuel dependence. Lithium-ion batteries have become the main power storage system for these vehicles but are still unable to match the performance of a vehicle driven by internal combustion engines.

Similar issues are faced in other sectors that rely on powerful batteries to function properly, one of the most prominent being the personal electronics industry. As personal electronic devices have become faster and more functional, they too have begun to reach a point where current lithium-ion batteries can no longer support them at peak efficiency. This is demonstrated prominently in smartphones. As they become more advanced, they begin to ask more of their power supplies. The battery life thus becomes a major concern, with each generation of phones typically offering a slightly better battery than the last to address this issue. However, this usually comes with the downside of a slightly bigger battery and thus a bulkier phone. In addition to the limited capabilities of lithium-ion batteries, there are other factors that demonstrate the need for new battery designs.

1.1 Traditional Batteries

Batteries commonly employ lithium and Zinc. Batteries are available but they generally have a shorter lifespan due to their high charge density. Batteries consist of two electrodes anode and cathode however the lithium-ion can flow in both the direction depending upon the battery is charging or discharging. Both anode and cathode have a rigid structure with defined holes, which allows for the absorption of lithium ions into the holes when the current is applied. When the current is cut off, the ions desorb into the electrolyte solution. Absorption of the lithium ions can occur on both the anode and cathode. When a battery is in use, the ions move to the cathode. When charging, the current is reversed and the ion absorbs into the anode. Moreover, the biggest issue in these batteries is heating. When a device is charging, heat is generated based on the resistivity of the conductor. Generated heat increases the resistivity of lithium. Since the lithium is hotter, the resistivity is higher, which means the device charges even more heat. All of this heat creates a positive feedback loop that can spiral out of control and cause the battery to literally burst into flames. As you can imagine, this isn't ideal, so to prevent it from catching on fire, batteries will regulate the speed of charging, but this results in battery charging speeds to slowly crawl.

1.2 Lithium-ion Batteries

Like any other battery, a rechargeable lithium-ion battery is made of one or more power-generating compartments called cells. Each cell has essentially three components: a positive electrode anode(+ terminal), a negative electrode cathode (− terminal), and a chemical called an electrolyte in between them. The positive electrode is typically made from a chemical compound called lithium-cobalt oxide (LiCoO2) or, in newer batteries, from lithium iron phosphate (LiFePO4). The negative electrode is generally made from carbon (graphite) and the electrolyte varies from one type of battery to another.

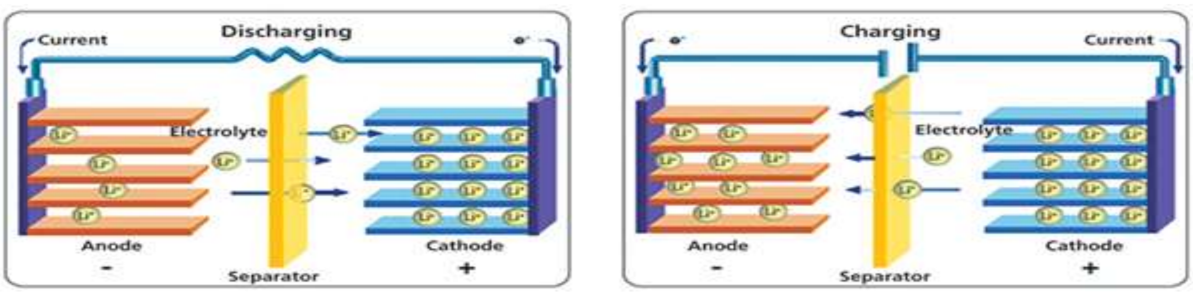


FIGURE 1.2.1 - **Structure of Lithium-ion Batteries**

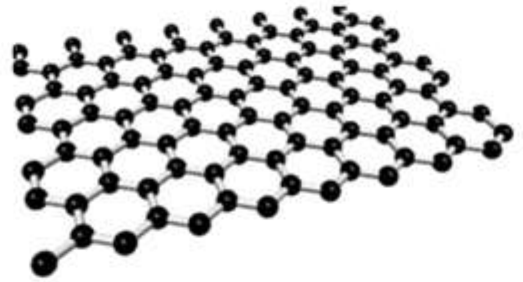
They work by transferring positively charged lithium ions (Li+) between the two electrodes of a battery. When charged, the ions are contained in the negative electrode(anode). On using, as the battery converts the chemical energy it has stored into electrical energy, the ions travel to the opposite electrode (the positive cathode), creating a current and thus transferring change and electricity. While charging, it's a reverse process, with electric energy being transferred to the chemical as the lithium ions travel back to the original electrode. Although the smartphone, for example, can only function as a portable communication and entertainment device because it is built with an internal power supply. Many other devices rely on batteries as well, including cars. As many devices are reliant upon batteries, the capabilities of our technology are dependent upon the quality and capability of batteries. However, this usually comes with the downside of a slightly bigger battery and thus a bulkier system. K.M. Abraham states that "Energy densities of Li-ion batteries, limited by the capacities of cathode materials, must increase by a factor of 2 or more to give all-electric automobiles a 300-mile driving range on a single charge".

1.2.1 Why not lithium batteries?

- The toxicity of the processes used to produce the raw materials that make them up is harmful to both the environment and human health.
- It's important to bear in mind what we're comparing them with. As a power source for automobiles, we really need to compare them not with other types of batteries but with gasoline.
- Lithium-ion batteries being rechargeable batteries still store only a fraction as much energy as ordinary gas in scientific words, they have a much lower energy density.

2. A POSSIBLE SOLUTION: GRAPHENE

As current batteries are not long-term solutions, we have begun to turn to alternatives. Since the weaknesses lie in the chemistry of the battery, new materials that could be used in composites to increase the efficiency of specific segments or in completely new battery designs have become a focus. One such material is graphene, due to a unique structure that increases its surface area and conductivity as well as other properties.



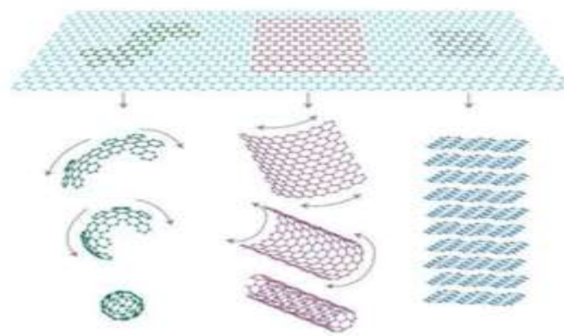


FIGURE 2(A) - **Graphene's 2D Hexagonal lattice** FIGURE 2(B) - **Graphene in various shapes and forms**

Graphene, in addition to displaying desirable characteristics, also seems to solve the issues with sustainability. Graphene's unique, featuring a structure that has contributed to many desirable characteristics. As a direct result of these properties, graphene holds great potential in energy storage. It is its structure and the properties that result from this structure that has led many researchers to attempt to incorporate graphene into numerous electrical and energy systems, of which batteries are one of the most prominent applications. Graphene is an allotrope or one of the various physical forms of carbon, along with other materials like diamond, coal, and graphite. Precisely, it is a two-dimensional sheet of carbon atoms, arranged in a honeycomb-lattice of hexagonal structure. This characteristic structure arises from the sp2 hybridization of its carbon atoms, which creates a trigonal planar geometry where each carbon atom is bonded to three others as in Figures: 2(A) & 2(B). Its two-dimensional structure, combined with its geometry and resultant hexagonal pattern has lent itself to structural flexibility, as well as numerous other desirable mechanical and electrical qualities.

Graphene powerful stability is because of the tightly packed carbon atoms and a sp^2 orbital hybridization – a combination of orbitals s, p_x and p_y that constitute the σ-bond. Finally, graphene is safer. While lithium-ion batteries have a very good safety record, there have been a few major incidents involving faulty products. Overheating, overcharging, and puncturing can cause runaway chemical imbalances in li-ion batteries that result in fire. Graphene is much more stable, flexible, and stronger, and is more resilient to such issues. Graphene-based batteries are quickly becoming more favorable than their graphite predecessors. Graphene batteries are an emerging technology that allows for increased electrode density, faster cycle times, as well as possessing the ability to hold the charge longer thus improving the battery's lifespan. Graphite batteries are well-established and come in many forms. Similar to graphite, there are now various types of functional graphene derivative electrodes and researchers are discovering multiple benefits when compared to pure graphite electrodes. Graphene itself can be manufactured in an environmentally friendly way that doesn't involve hazardous chemicals and extreme energy usage. Also, this new form of a carbon-polymer sheet is flexible, non-toxic and mechanically strong, in addition to being non-flammable. As graphene is known to be a zero-bandgap semiconductor, I understand its behavior to be somewhat like metal as the bandgap is zero and somewhat like a semiconductor as the name signifies.

2.1 Graphene Batteries

The main motive of this is Graphene Batteries can reduce the environmental impact of battery use. Graphene battery technology has a similar structure as that of traditional batteries consisting of two electrodes and an electrolyte solution to facilitate ion transfer. The main difference between solid-state batteries and graphene-based batteries is in the composition of one or both electrodes. Graphene batteries are also lighter and slimmer than today's lithium-ion cells. This means smaller, thinner devices or larger capacities without requiring extra room. Not only that, but graphene allows for much higher capacities. Lithium-ion stores up to 180Wh of energy per kilogram while graphene can store up to 1,000Wh per kilogram.

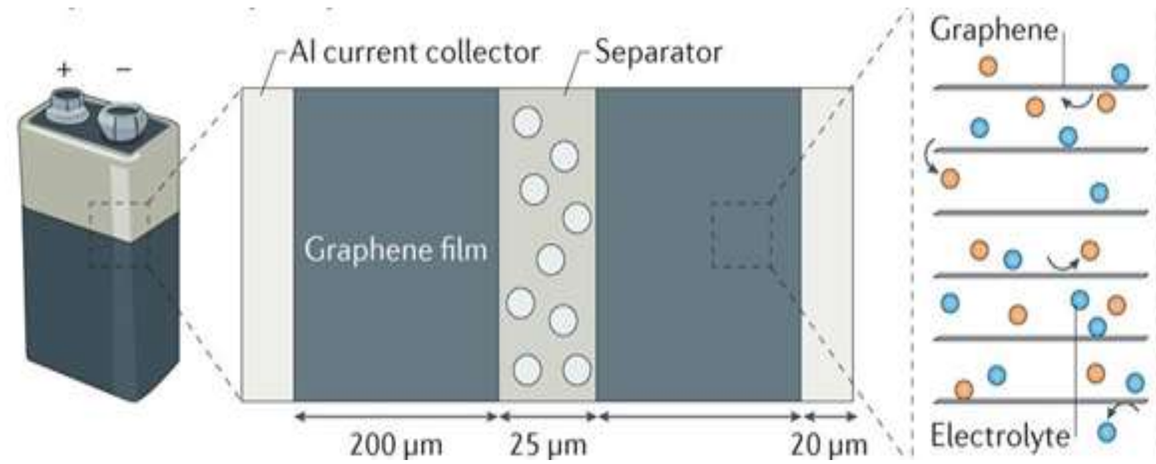


FIGURE 2.1- **Structure of Graphene Battery**

2.2 Working of Graphene Battery

Samsung’s graphene ball working. Samsung's version of graphene batteries comes in a form of little balls, a 3D structure synthesized from silicon dioxide.

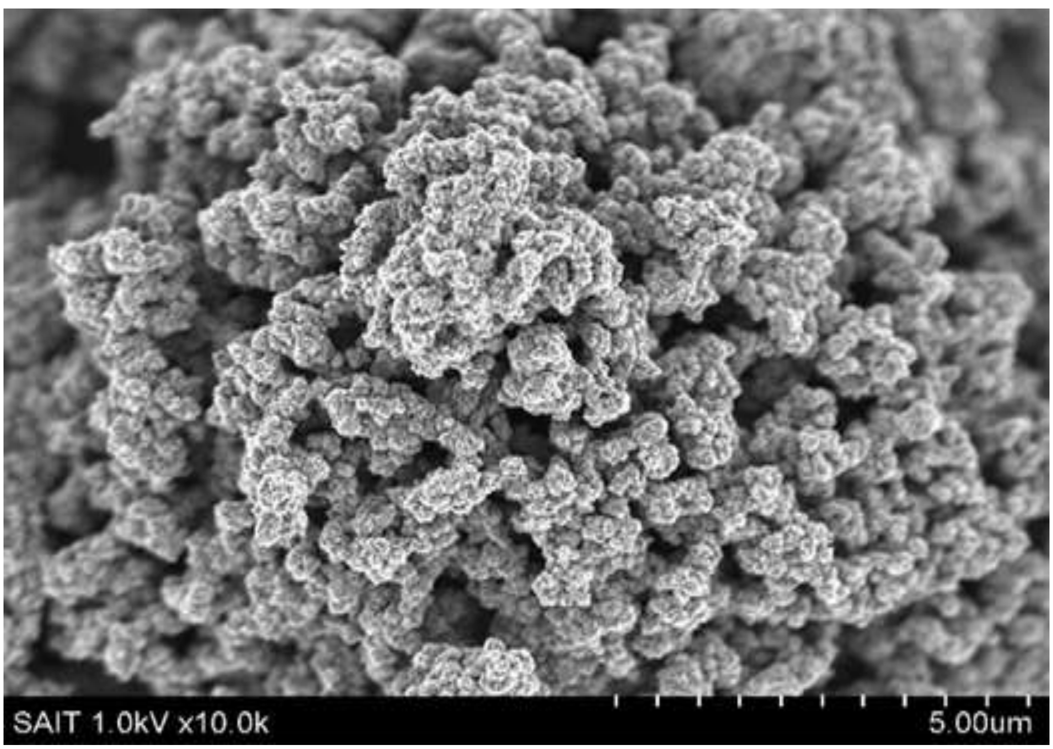


FIGURE 2.2 (A)

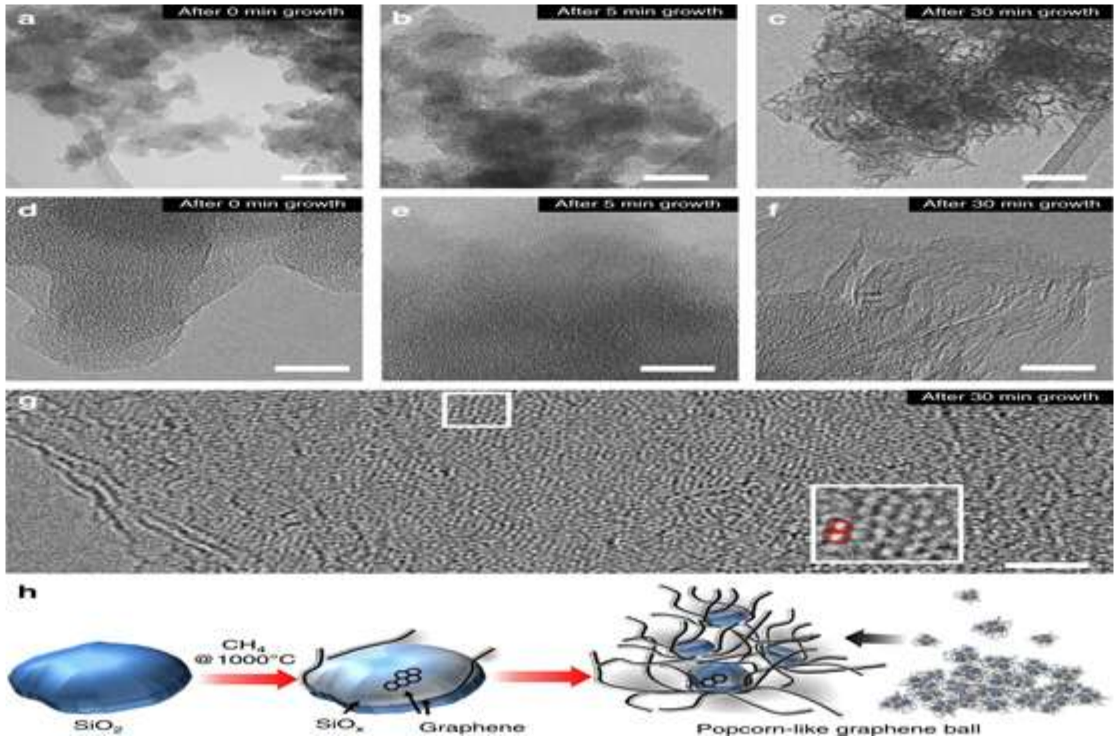


FIGURE 2.2 (B) - Magnified images of the growth of Graphene balls from Silicon dioxide

As the above image FIGURE, 2.2 (B) SHOWS Graphene growth from SiO2 nanoparticles. a–c TEM characterization a before CVD growth, b after 5 min growth, and c after 30 min growth (scale bars, 50 nm). d–f Their respective magnified images (scale bars, 10 nm). g Higher magnification image of graphene after 30 min growth and its atom-level view from the white box (inset) (scale bar, 2 nm). h Graphical illustration of popcorn-like graphene growth from SiO2 nanoparticles.

These graphene balls cover the anode and cathode materials that enable the charging of batteries 5x times faster. Applying a graphene composite layer which will help transfer the electricity dramatically reducing resistivity also at the same time the graphene composite layer uniformly spreads any generated heat across dissipating heat much quicker. These graphene balls, when established on the cathode of the battery, suppress the damaging reactions that occur with continued charging while also improving the current flow the new cells are said to retain 78.6% of the capacity after 500 charge cycles. This is about a pile of current batteries. But in case of rapid charging things differ, here FIGURE 2.2 (c) is the chart of the capacity of a regular battery versus a battery with graphene balls added over time.

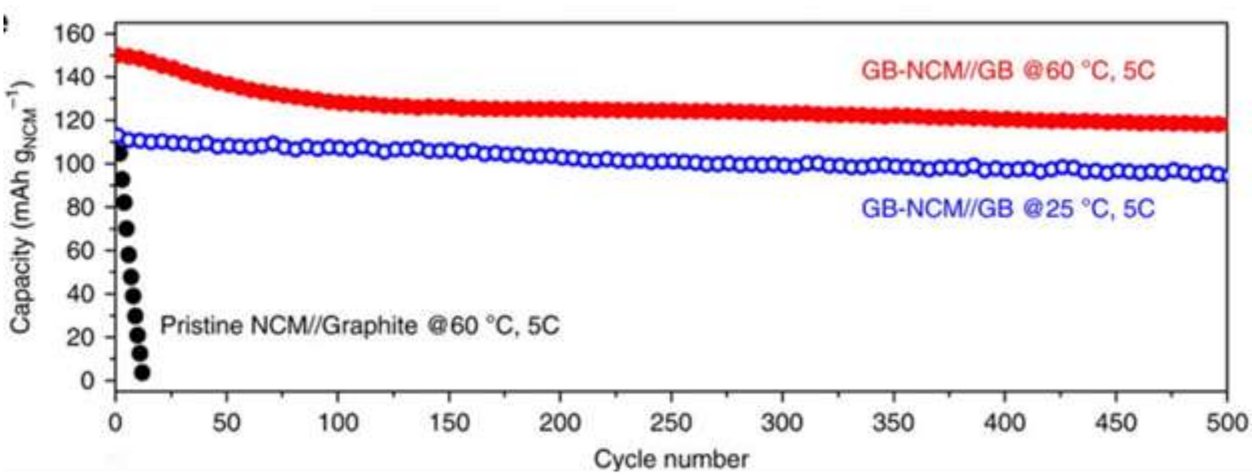


FIGURE 2.2 (C)

Notice the steep drop-off of the regular battery which is the black dotted line normal batteries in comparison just can't handle the current.

Samsung also states that these new batteries could have 45% higher capacities than when compared to the current state-of-the-art charging times will be 12 minutes instead of one hour. Individuals may think that this will be expensive but Samsung claims that this would be a cheap manufacturer because of a new method called chemical vapor deposition. Also, Samsung unveils new electric car batteries for up to 600 km (430 miles) of range just by 20 minutes of charge. As a leading business in the technology industry, Samsung's use of the battery could catalyze for other companies to follow suit in adopting and further developing graphene-based energy storage solutions.

3. PRODUCTION OF GRAPHENE

3.1.1 Scotch Tape Method

As we all know in 2004, Andre Geim and Konstantin Novoselov created graphene for the first time by a method called the "Scotch Tape method". In this process, the researcher is peeling tape with layers of graphite away from a larger piece until only a single layer remains - (that is graphene).

FIGURE 3.1.1 - Scotch Tape method

Although, they successfully created graphene to test the characteristics and properties. However, this method is not effective because it is strangely manual. As a result, researchers have been searching for more efficient methods to create this material.

3.1.2 Wedge-based Mechanical Exfoliation

Wedge-based mechanical exfoliation - is a method that involves the use of an ultra-sharp single-crystal diamond wedge to penetrate inside material and leave a thin layer of material. It was proposed to produce a few layers of graphene from a bulk highly ordered pyrolytic graphite (HOPG).

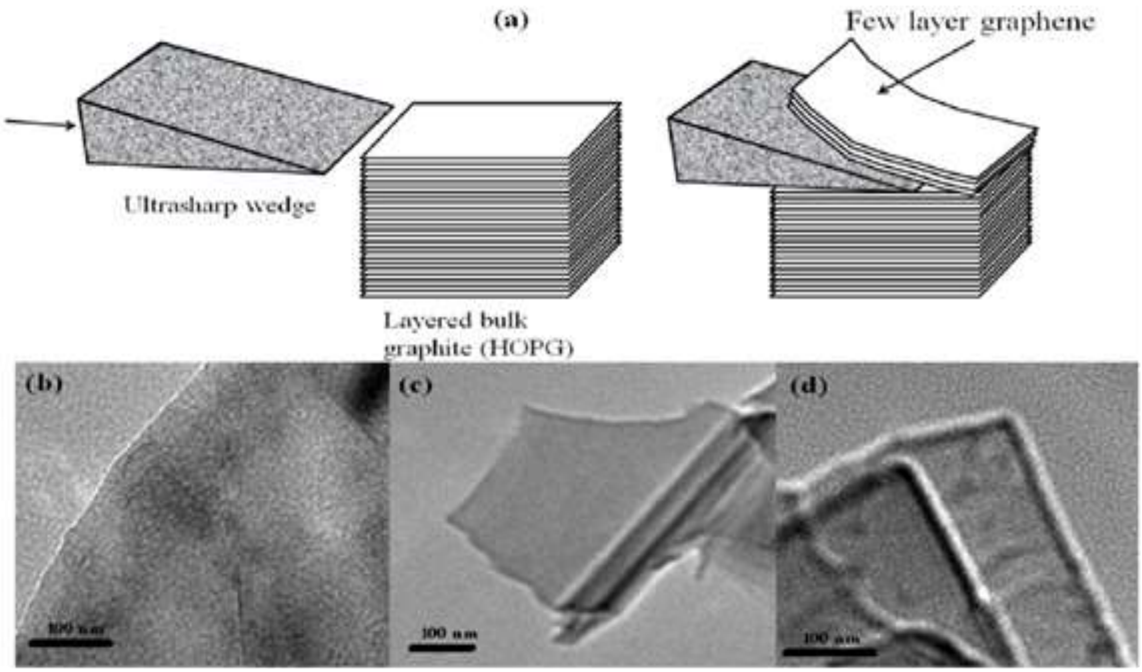


FIGURE 3.2 - Wedge-based mechanical exfoliation

3.1.3 Solvent Aided Method

Dispersing graphite in a proper liquid medium can produce graphene by sonication. Graphene is separated from graphite by centrifugation, producing graphene concentrations initially up to 0.01 mg/ml in N-methyl pyrrolidone (NMP) and later to 2.1 mg/ml in NMP. Using a suitable ionic liquid as the dispersing liquid medium produced concentrations of 5.33 mg/ml. Graphene concentration produced by this method is very low because nothing prevents the sheets from restacking due to van der Waals forces. The maximum concentrations achieved are the points at which the van der Waals forces overcome the interactive forces between the graphene sheets and the solvent molecules. Graphene is essentially a one-atom-thick graphite layer, made from elemental carbon. Now, physicists from Kansas State University may have found a way to mass-produce graphene cheaply, and all it takes are three easy steps and uses only three simple materials: hydrocarbon gas, oxygen, and a spark plug.

Process - filling a chamber with acetylene or ethylene gas and oxygen. Then, a container detonation is created within the chamber using a vehicle spark plug. The soot from the detonation is graphene and appears as an aerosol gel in the chamber. Sorensen stated, "Our process has many positive properties, from the economic feasibility, the possibility for large-scale production and the lack of nasty chemicals. The best property of all is that the energy required to make a gram of graphene through our process is much less than other processes because it only demands a single spark.

There are several ways to generate graphene, However, many of the current methods cannot generate the material at a large enough scale to allow it to become commercially prevalent or are simply too harmful to both human health and the environment to warrant their widespread use. But more theoretical methods, like those proposed by Kansas State University, will address these concerns and provide sustainable ways to efficiently produce the material. This will then allow for the widespread, and sustainable use of graphene.

3.2 Why Graphene Is Not in The Picture?

- As graphene is a single layer of graphite. Extremely difficult to manufacture in large quantities.
- Graphene is rapidly becoming commercialized and many of the applications which use graphene today are not public knowledge because the end-users do not wish to signal their competitors how they are using it to improve some of their products.

4 APPLICATION

4.1 Supercapacitors with AC line filtering.

Capacitors are essential components in almost all electronic devices. They are primarily used as electronic filters to smooth out the ripples from power supplies because they have a very fast response time. However, unlike transistors and other electronic components that are constantly shrinking over time, capacitors are still bulky and often limit the miniaturization of the entire system. Commercial-grade carbon-based supercapacitors charge and discharge in seconds, which is much faster than batteries but not quite fast enough to be used as electronic filters. It was reported that an EDL capacitor based on vertically oriented graphene sheets could be charged and discharged in less than a millisecond, which is similar to the performance of capacitors but with a capacitance per volume at least ten times higher. This ultrafast supercapacitor could replace the large electrolytic capacitors used in today's electronics and may someday help make electronic devices smaller and lighter. The key to achieving ultrafast charging and discharging is to vertically oriented graphene electrodes with external rather than internal surface area. This leads to a high-frequency response and eliminates the slow diffusion of ions, which has so far limited the speed of carbon-based supercapacitors.

4.2 Flexible, rollable and twistable energy-storage devices.

The market for flexible and printed electronics is rapidly growing, with products now ranging from flexible solar-cell arrays to flexible displays and wearable electronics. The rise of this technology is mainly due to rapid progress in the production of flexible electronic devices over large areas at a fraction of the cost of traditional semiconductor technology. In the field of energy storage, various devices, such as flexible supercapacitors and thin LIBs with variable sizes, shapes and mechanical properties, are being developed. Current batteries and supercapacitors come in several sizes and shapes but are all rigid therefore, bending them may cause cell damage and electrolyte leakage. In brief, this is because the current technology relies on particulate-like energy-storage materials, which lose their mechanical integrity upon bending. With its 2D one-atom-thick structure, graphene can adapt to mechanical stress by deforming in the direction normal to its surface. This inherent mechanical flexibility together with exceptional electrical properties and large surface area makes graphene attractive for flexible energy-storage devices.

4.3 Energy-storage devices for wearable electronics.

Portable electronics have revolutionized our everyday lives and have driven the development of other future electronic devices (for example, wearable electronics that can be incorporated into clothing and accessories, and worn comfortably on the body). These smartwatches, smart bands are expected to need to communicate with the user to give them access to information in real-time.

4.4 Fast charging batteries for Smartphone / Electric vehicles

The use of graphene allows faster electron and ion transport in the electrodes, which controls the speed over which the battery can be charged and discharged. For example, a fast-charging LIB was developed by loading nanoscale $Li_4Ti_5O_{12}$ anode and $LiFePO_4$ cathode materials on flexible graphene foam without the use of conducting additives or binders. The excellent electrical conductivity and the open pore structure of the hybrid electrodes allowed the battery to become fully charged in only the 18s. Pure graphene can also be used as the anode for LIBs with improved capacity, and ultrafast charge and discharge rate. Few-layered graphene may have an important role in the progress of other battery chemistries. For example, an aluminum-ion battery was recently reported that can be fully charged in under one minute because of the ultrafast ion intercalation into 3D graphene foams

5. CONCLUSION

With the enormous amount of technological advancements in the past few decades, we have reached a new era of more complex, impactful inventions. While researching this topic, we found that we still tend to use traditional batteries for our primary energy storage requirement. Our paper focuses on this problem and proposes a solution to this problem with a new material Graphene. It brightens, with its futuristic vision, the small light which was already illuminated with courtesy to other research papers in this field. Of course, we are still in the process of fully understanding the properties of graphene. However, research thus far demonstrates that the incorporation of graphene into batteries can provide an economically sustainable and environmentally-friendly solution to current lithium-ion batteries. While researchers have yet to determine the most effective way to utilize graphene in batteries, the great variety suggests flexibility of application as needed by the technology in question. In this way, graphene batteries can help drive much-needed innovation.

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BIOGRAPHIES

	Kshitij Motke [1] Pursuing Bachelor of Engineering in Computer Science at Dr .D .Y. Patil SOE, Pune, Maharashtra (3rd Year of course as of 2020) Interested in Research, Mathematics, logics, Programing, User experience, Designing, Automobile, open-source & Web Development
	Rajeshri Yallappa Mayanaikar [2] Pursuing BE (Computer Engineering) at Dr Dr.D Y Patil School of Engineering & Technology, Pune, Maharashtra (3rd Year of Course as of 2020) Interests are Artificial Intelligence, Data Science, Machine Learning, Neural Networks, Statistical Mathematics and Web Development.)