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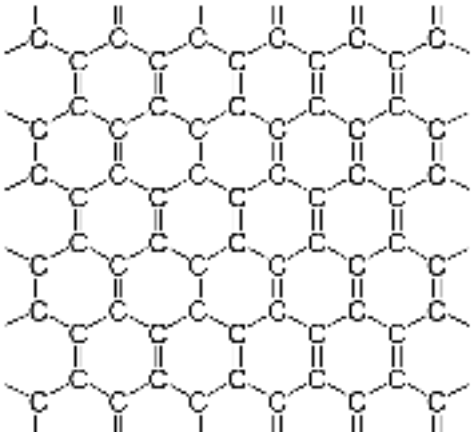
Shantanu Tyagi
SC 221 Engineered Materials Report

GRAPHENE: Super Carbon

The Wonder Material



Imagine a game-changing material that will revolutionize the way we currently produce materials and has almost unlimited applications. A hundred years ago, this material was plastic, and there were endless ways to utilize this invention. But the plastic industry got the boost it needed only because of the World War. The search for one material for everything has led us to the discovery of the wonder material of Graphene. Since the beginning of human civilizations, human ages have been defined by the material they harnessed. We had the Stone age, Bronze Age, Iron Age, and now the Silicon or Oil age. The near future is likely to be remembered as the Graphene Age. These materials are what civilizations are built from at its core. Space race might be the reason that'd give the Graphene industry the boost it needs, thus leading to more investments and better development of this technology. Graphene, because of its unique properties, has rightly earned this title, and these properties and how this material can change our lives are explained in the following sections using unique analogies. We start with the discovery of Graphene.

History and Discovery

Discovery of even a single molecule can make a lot of difference in human lives. Graphene's structure was first theorized by Philip Russel Wallace in 1947. However, it was only in 2004 that Graphene was isolated as a monolayer of Benzene rings by Andre Giem and Kostya Novoselov, two professors at the University of Manchester, thus awarding them the 2010 Nobel Prize in Physics. In simple terms, Graphene is just a single-layered Graphite - the same Graphite found in our pencils. Graphene was isolated by exfoliating Graphite. In a way, it can be considered as peeling off Graphene from Graphite. In fact, this method was used by Giem and Novoselov and is still used today. Actually, they were studying the electrical properties of Graphite and, just for fun, decided to make smaller layers of Graphite. They used regular tape and scribbled a circle with a pencil. Next, they folded the tape from the middle so that half of the Graphite stuck to the other side of the tape, thus reducing the circle's thickness. When repeated over and over, they got a very thin layer of Graphite, and the tape was dissolved, leaving behind a small quantity of Graphene. In an interview, Giem and Novoselov said that they did not want to hide what they had found from other labs as they believed that this technology would develop in a better way if every other lab would work on it together. Its properties were studied, and that gave it the name of the wonder material. This Scotch tape method was not new; in fact, it had been used to clean minerals before. It shows how simple things around us can. This groundbreaking discovery was actually accidental, and in the further sections, we will discuss if this technology is actually ahead of its time or not. The very first challenge we face is finding efficient manufacturing techniques that can yield industry-standard Graphene sheets.

Manufacturing

Carbon is the fourth most abundant element. So we are unlikely to run out of this immense source of possible Graphene anytime soon. Graphene is hard to isolate, synthesize, and expensive to manufacture. The adhesive tape method is still used in Labs, but much better methods have been found out. Exfoliation of Graphite Oxide while heating also forms some amount of Graphene flakes and carbon power. Graphite Oxide can be reduced using hydrazine with annealing in argon to give Graphene films. Electrochemical synthesis can also exfoliate Graphite to give Graphene. These were some simple top-down approaches to make Graphene. One bottom-up approach is hydrothermal self-assembly and is made using sugars like glucose or fructose. This method is more safe, friendly to the environment, and substrate-free. It can also be created by cutting open carbon nanotubes, which can happen under the action of Potassium permanganate or Sulphuric acid. Another commonly used bottom-up approach is Epitaxy, in which a crystal of the desired orientation is deposited on top of another crystalline structure as a substrate. Chemical Vapour Deposition uses a heated substrate and decomposition reactions with the reactants in vapor or gaseous form, passing over the substrate. Silicon Carbide can be heated to high temperatures under low pressures to form Graphene. It can also be done at room temperature and low pressure using Copper foil and Methane gas. The same process can also be done using Ni foil to overcome the limitations of using Cu. These form what is called epitaxial Graphene.

Properties

How can something so thin(0.345nm) be so strong? More than 100 times stronger than steel and at the same time be such a good conductor of electricity and heat. Its structure is 2D with three sigma bonds in the plane and one pi bond out of the plane. These sp2 orbitals are very tightly packed and give it its stability. Unlike any other material, Graphene as a large percentage of atom at its edges due to its sheet structure, giving it some unique chemical properties. It also has a zero bandgap and can be made into a superconductor. Electrons move in an almost massless way through Graphene. Its structure is usually defined as an "atomic chickenwire".

Here are are a few wondrous fantasy analogies of this wonder material:

Batman's new Batsuit: Our beloved superhero fights crime in Gotham City wearing his valuable Batsuit, which is a heavy high tech utility kevlar suit and glides across the night sky wearing it. It is high time that Lucius Fox, the tech genius at Wayne Enterprise, makes Bruce Wayne a suit out of Graphene. This new suit will be lightweight, bulletproof, more stronger than Kevlar, and harder than diamond. It can be embedded with circuits so as to still allow Batman to use his high tech utilities and, at the same time making it easier for Batman to glide across the sky and fight criminals because the suit is also made of up a more breathable material now. Moreover, the emergency shock wave that the suit could generate sounds more realistic now since it will be able to harness energy now. Graphene ink can be used to make circuits that are washable, foldable, and flexible. This ink can easily be embedded in polyester fabrics. One bonus feature is that these inks can also be used to detect fire and trigger alarms. Graphene can also be used to filter gases, which would have been very useful for Batman while fighting Scarecrow.

Superman's indestructible suit: Superman has always worn his Kryptonian skinsuit and flew at supersonic speeds wearing it. His suit, just like him, indestructible. Maybe it has been made from Graphene all this while. Graphene sheets also have the self-healing ability when pure carbon atoms are bombarded with it. Moreover, such clothes will be inherently bacteriostatic, which means bacteria vacant grow on the sweat that is absorbed by the fabric as well as lowering the humidity next to the body. It was also found out that Graphene is least stable when it is rounded up in cylinders.

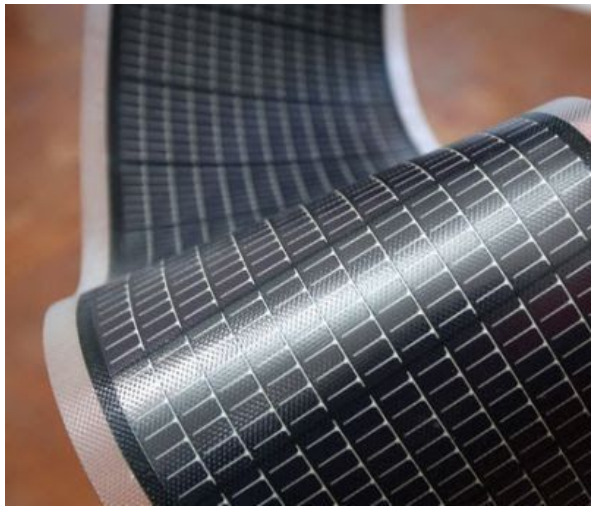
Spiderman's new web: We all know that spider webs are three times stronger than steel, and it is, in fact, possible for Spiderman to stop a moving train. One interesting thing about Graphene is that it can be combined with other substances, thus increasing their strength and durability. Even small amounts of Graphene mixed with other materials can significantly increase its tensile strength. Research shows that some spiders were fed with Graphene water their entire lives, and as a result, the spider web they produced also consisted of some amount of Graphene. This Graphene silk is found to be even stronger than the regular web, and it is very hydrophobic and theoretically might even allow Spiderman to stop a landing airplane now.

Harry Potter's invisibility cloak: As children, we were fascinated by Harry Potter's invisibility cloak. Experiments on the small scale show that gold lenses, when covered with graphene layers, can bend light waves in such a way that it can be theoretically possible to make this cloak of invisibility. However, unlike what is written in the books, it cannot protect one against wizard spells yet. Talking about a similar property, Graphene is also a very transparent material and can replace glasses and, at the same time, be unbreakable. It would also give up to 10K resolution and way better refresh rates.

Here are a few reasons why I would like Mr. Elon Musk to invest in Graphene technology and how it could benefit him in his current ventures:

1. **Tesla:** Graphene could easily replace the currently used carbon fiber and aluminum, making the vehicle lightweight, stronger, and fuel-efficient. It can make the parts rust-free and water repellent. Graphene is also being used to make more efficient rechargeable batteries that last longer. These batteries would charge in very little time and would last longer than traditional batteries used in electric cars. They would also have a higher dynamic temperature range, more capacity, and would deliver much more current. Samsung has already made Graphene-based batteries, which is a hybrid Li-ion battery. Another alternative is Graphene supercapacitors that can completely eliminate the use of traditional batteries. They would also not suffer wear and tear.

2. **SpaceX:** Graphene can be used to make rocket bodies like discussed, just like the bodies of cars. Moreover, the rocket's propellers or ion thrusters accelerate ions using electricity, thus creating the thrust needed. They use the Xenon element, which is costly to produce at an industrial scale and one space mission can consume almost 10% of the total production. Scientists are now trying to make Graphene filters that could capture the Xe present in the atmosphere and thus increasing the production rate. This is an essential step because space exploration projects might lead to more investments in Graphene technology. It is most suitable for analog systems like satellites, sensors, and imaging devices.



3. **SolarCity:** Graphene-based products contribute to much lesser carbon emission than other products. Graphene can be the new material to make solar panels. These will be flexible and can be put on any surface. SolarCity provides smart solutions for rooftop solar panels, but now it is possible for an entire structure to act as a giant solar panel since the Graphene ones can easily be deployed anywhere. Being more efficient and immune to wear and tear, they can be a better sustainable energy source. Who knows, one day even the roads might become a solar panel. Solar panels are an expensive investment. However, Graphene ones are expected to be much cheaper. Talking about clean energy, Graphene can also help us in solving one of the other major environmental problems we face today, the unavailability of clean drinking water. More than a billion people across the globe face this problem. The industrial method to purify the drinking water in reverse osmosis, which again is

very expensive. Graphene membrane can be made into a selective filter, just like the other form of carbon, activated charcoal. Graphene's small pores can block the impurities while letting the water pass through. Another application is making aerogels, which are the least dense solids. They are highly porous and can soak up oil spills by absorbing 1000 times their own weight.

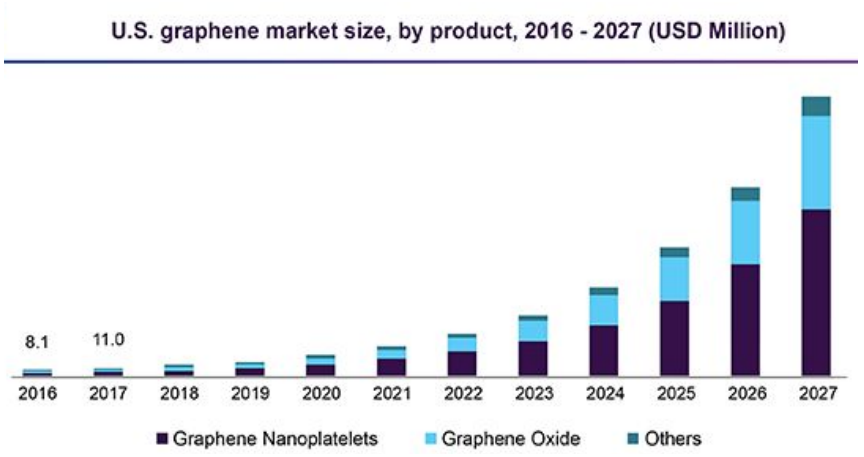
Future and Expectations

Most of the uses of Graphene are being held back because the current technology is not developed enough so as to allow us to possibly use Graphene the way we want to. Nevertheless, breakthroughs are being made and thousands of patents have already been claimed. The quality of synthetic Graphene will keep on improving in the coming years. We were made promises like a moon elevator that would take the man to the moon. We would get clean energy, optical computing, unbreakable mobile screens, nuclear waste disposal, improved military equipment, brain-computer interfaces, bionics and implants, prosthetics, and what not. It has been a decade, and this dream still seems far away. What is stopping us from getting there will be discussed in the following section.

There are a bunch of opportunities to study the folds, wrinkles, and crumpling of Graphene sheets. This is termed as Graphene origami. This theory touched the surface of what is possible with this new and exciting material, and hopefully, new ways will open up as scientists and engineers continue to explore this unique material. Graphene will also serve as a parent for manufacturing other nanomaterials like carbon nanotubes, buckyballs, etc. It is also likely to enter the field of supercomputing. The speed of computers is limited by the gate length and the material the transistors are made up of. It is expected that Graphene can increase speed by 1000 times and consume much less power at the same time. Such speeds are needed in space programs and big data modeling. Display technology is trending these days as companies are trying to make better and better displays for televisions and mobiles. Expensive technologies like OLED and QDs can be improved. In contrast to typical Quantum Dots, Graphene QDs are photo-stable, biocompatible, have enhanced surface grafting, and inherit preferred and superior electrical, mechanical and thermal properties from Graphene. Nevertheless, Graphene began its journey as an exciting new material for fundamental physics and has now become the focus of efforts by scientists in a wide range of disciplines.

Market implications and Limitations

One of the immediate implications of Graphene entering the tech industry can be the extension of the famous Moore's law, which was thought to have reached its saturation point. This is because Graphene will now allow us to make smaller, faster, and more efficient computers and even supercomputers. Thanks to its perfect lattice structure, thus allowing electrons to move in one direction at such high speeds that we need to account for relativity effects now. Graphene is most likely to replace Silicon in the near future.



In 2014, there was a so-called Graphene hype. It was all over the media and was shown as a futuristic material that would soon change our lives. There is just this one problem we need to tackle first. Graphene is very difficult to produce at the industrial scale as one continuous sheet without crystal defects and misaligned lattices. The production is also very expensive and it lacks the investment it needs. The market has witnessed volatility in graphite prices over the historic period, owing to a rise in export taxes. However, one significant thing to note is that the fluctuations in graphite prices will not have any significant impact on the prices of

products since a single graphite mine can supply sufficiently enough quantity of raw material required for the production of Graphene. Maybe Graphene really is ahead of its time and market, and social acceptance of technology also plays a very important role in the development of that technology. A technology ahead of its time is most likely to fail. Developments in new production methods are still being found as I type this report. There are a few Graphene startups that are making Graphene-based clothing, graphene-based lighting, improved batteries, etc. This material also has a few limitations. Firstly it has 0 bandgap so it cannot be used as a switch. Switching action is not possible since it cannot be turned OFF. Then there are some researches that suggest Graphene is toxic for the cells at the nanoscale by piercing cell membranes. However, this is true only after specific concentrations. Graphene also reacts instantly with oxygen to form graphite oxide, which is the most common form of Graphene. Again, for Graphene to work all the wonders its capable of, it needs to be really perfect, which is very difficult to achieve. But, most importantly, it is very difficult to generate three-dimensional materials out of Graphene while still conserving its properties.

Conclusion

Nanotechnology has taught us that in order to think big, we need to consider even the smallest. The material of tomorrow has always been hidden in our pencil. This technology is highly likely to spread throughout our civilization and thus making way for more innovations. Today's age is driven by innovations in material science. Scientists are working hard day by day, to utilize this substance practically more and more, to change all these beautiful dreams into reality. It indeed holds great promises to become one of the primary materials of the times to come. Graphene truly has completely revolutionized the way we look at the potential limits of our abilities as scientists, engineers, and inventors.
Graphene is undoubtedly the future, and it is in our hands how quickly we want to get there.

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