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GRAPHENE BATTERIES- A REVOLUTIONARY BREAKTHROUGH IN SMARTPHONES MARKET

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Abstract: Briefly, graphene is a composition of carbon atoms tightly bound in a hexagonal or honeycomb-like structure. What makes graphene so unique is that this structure is just one atomic layer thick, essentially making a graphene sheet two dimensional. This 2D structure produces very interesting properties, including excellent electrical and thermal conductivity, high flexibility, high strength, and low weight. What we're particularly interested in is the electrical and heat conductivity, which is actually superior to copper — the most conductive metal element.

Graphene batteries would allow smartphones to be thinner or offer more battery capacity while keeping their current proportions. There are also interesting implications for fast device-to-device charging. With batteries able to support very high currents and blazing fast recharge and discharge times, gadgets could charge each other up at super-fast speeds.

Although graphene battery technology remains some years away, it's a tantalizing prospect for future smartphones, gadgets, electric vehicles, and much more.

I. INTRODUCTION

Graphene is a 2D material made from carbon atoms that are arranged in a hexagonal pattern (a honeycomb crystal lattice). It is the basic building block of graphite, used in pencil tips, batteries and many other industrial applications. Graphene is considered a "wonder material" since it has many remarkable properties: It is the thinnest material in the world (just one carbon atom thick), and also one of the strongest - much stronger than both diamond and steel of the same thickness. Graphene is also flexible and transparent, has an extraordinarily large surface area, and is an extremely stretchable crystal. Graphene is one of the best conductors of electricity ever found and is also an excellent thermal conductor. In addition, it has fascinating optical properties.

Graphene battery technology has a similar structure to traditional batteries in that they have 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. The change primarily lies in the cathode, but carbon allotropes can be utilized in the anode as well. The cathode in a traditional battery is purely composed of solid-state materials, where as in a graphene battery the cathode is a composite-a hybrid material consisting of a solid-state metallic material and graphene. The amount of graphene in the composite can vary, depending upon the intended application. The amount of graphene incorporated into the electrode generally depends upon the performance requirements and is based upon the existing efficiencies and/or weaknesses of the solid-state precursor material.

Some properties of graphene battery include:

- Higher Capacity
- Faster Charging
- Light Weight
- High Temperature Range
- Flexibility

Smartphones are unquestionably one of the most useful devices of the 21st century but they continue to have one critical flaw – battery life. We've all been there – you forgot to charge your smartphone and you have 10% battery life left to see you through the day. You think of ways to charge it, perhaps stopping off at a local coffee shop to hook up to a power adapter, switching the phone off to make an important call later, or maybe you've even purchased a portable power pack to charge it on the go.

The trouble is, few if any manufacturers seem to have cottoned on to just how much each of us uses our smartphone. They, and sadly many consumers as well, have been obsessed with size and weight but they forget that smartphones are no longer just things we use lightly for an hour a day. The former might seem like an odd issue to raise but imagine if you could charge your smartphones to 80 or 90% in less than five minutes? Hook it up while you're having breakfast and by the time, you're ready to leave for school or work, it's nearly fully charged.

This would drastically improve the situation but as is stands, even connecting your smartphone to a mains socket as opposed to your laptop's USB port, it's still likely to take a at least an hour to fully charge a smartphone from flat. With graphene batteries, this might not be such a pipe dream.

II. GRAPHENE VS LITHIUM-ION

Just like lithium-ion (Li-ion) batteries, graphene cells use two conductive plates coated in a porous material and immersed in an electrolyte solution. But while their internal make-up is quite similar, the two batteries offer different

characteristics.
Graphene offers higher electrical conductivity than lithium-ion batteries. This allows for faster-charging cells that are able to deliver very high currents as well. This is particularly useful for car batteries, for example, or fast device-to-device charging. High heat conductance also means that batteries run cooler, prolonging their lifespan even in cramped cases like a smartphone. 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.
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.
You don't have to have one or the other though. Li-ion batteries can use graphene to enhance cathode conductor performance. These are known as graphene-metal oxide hybrids. Hybrid batteries result in lower weight, faster charge times, greater storage capacity, and a longer lifespan than today's batteries. The first consumer-grade graphene batteries are likely to be hybrids.
Future smartphones packing graphene power cells would exhibit the benefits outlined above. Handsets would charge even faster (check out the results when we tested a graphene powerbank in the video at the top of this article), battery life would easily last a day or two, if not longer, and devices could be thinner and lighter.
The move to graphene could offer 60% or more capacity compared to the same sized lithium-ion battery. Combined with better heat dissipation, cooler batteries will extend device lifespans too. You won't need to pay for expensive battery replacements after a couple of years to keep your old devices performing in top condition.

III. DESIGN OF EXPERIMENTS- SYNTHESIZING GRAPHENE-BASED BATTERY ELECTRODE

Batteries are divided into two main types: primary and secondary. Primary batteries (disposable), are used once and rendered useless as the electrode materials in them irreversibly change during charging. Common examples are the zinc-carbon battery as well as the alkaline battery used in toys, flashlights and a multitude of portable devices. Secondary batteries (rechargeable), can be discharged and recharged multiple times as the original composition of the electrodes is able to regain functionality. Examples include lead-acid batteries used in vehicles and lithium-ion batteries used for portable electronics.

Batteries come in various shapes and sizes for countless different purposes. Different kinds of batteries display varied advantages and disadvantages. Nickel-Cadmium (NiCd) batteries are relatively low in energy density and are used where long life, high discharge rate and economical price are key. They can be found in video cameras and power tools, among other uses. NiCd batteries contain toxic metals and are environmentally unfriendly. Nickel-Metal hydride batteries have a higher energy density than NiCd ones, but also a shorter cycle-life. Applications include mobile phones and laptops. Lead-Acid batteries are heavy and play an important role in large power applications, where weight is not of the essence but economic price is. They are prevalent in uses like hospital equipment and emergency lighting.

Lithium-Ion (Li-ion) batteries are used where high-energy and minimal weight are important, but the technology is fragile and a protection circuit is required to assure safety. Applications include cell phones and various kinds of computers. Lithium Ion Polymer (Li-ion polymer) batteries are mostly found in mobile phones. They are lightweight and enjoy a slimmer form than that of Li-ion batteries. They are also usually safer and have longer lives. However, they seem to be less prevalent since Li-ion batteries are cheaper to manufacture and have higher energy density.
There are many methods available to convert graphene and metal-based inorganic compounds into usable graphene composites for electrodes. As this is an emerging field, new methods are frequently being developed and subsequently published. Some of the methods include chemical reduction, ex-situ hybridization, electroless deposition, in-situ crystallization, hydrothermal methods, sol-gel methods, thermal evaporation, electrochemical deposition, and in-situ self-assembly.
As with any method, there are multiple ways to synthesize the material itself. To cover each approach would be impractical, so here some specific ways to implement graphene into composite materials for use as electrodes in graphene battery R&D projects are discussed.
The values used are from published experiments and are used for ratio illustrative purposes only. The scale and amounts can be varied to better suit specific experiments.
The following is a DOE for graphene-lithium-sulphur batteries, a current leading technology.
"Synthesis of the Thermally Exfoliated Reduced Graphene.
Thermally exfoliated reduced graphene was obtained.
Preparation of Graphene-Sulphur Hybrids- The G/S hybrids were prepared by hydrothermal reduction assembly of GO with a sulphur-dissolving CS2 and alcohol solution. In brief, 50 mL of the GO aqueous dispersion and 15 mL of alcohol were mixed, and then 3 mL of CS2 containing 100, 150, and 200 mg of dissolved sulphur (tuning the sulphur content in the samples) was added to the GO dispersion. The mixture was stirred for 90 min and then sealed in an 80 mL Teflon-lined stainless-steel autoclave for a hydrothermal reaction at 180 C for 10 h. The black cylinder of the G/S hydrogel was washed by ethanol and distilled water, and the wet hydrogel was then freeze-dried to obtain the G/S hybrids.
Preparation of Graphene-Sulphur Hybrids (Powder)- G/S hybrids (powder) were prepared by mixing 90 mg of intercalation-exfoliated graphene and thermally exfoliated reduced graphene with 150 mg of sulphur under the same hydrothermal conditions as the G/S hybrids.

Preparation of Graphene-Sulphurmix -The G/Smix was prepared by mixing- 50 mL of the GO aqueous dispersion, 15 mL of alcohol, and 150 mg of sulphur under the same conditions but without CS2.

Electrochemical Measurements. The G/S hybrid was cut, compressed, and shaped into a circular pellet with a diameter of 12 and directly used as a cathode. The mass loading of a G/S electrode was about 2 mg cm^2. The G S59 or G S60 hybrid (powder) cathode was prepared by mixing 90 wt % G S59 or G S60 hybrid (powder) with 10 wt % polyvinylidene fluoride dissolved in N-methyl-2-pyrrolidone as a binder to form a slurry, which was then coated on an aluminium foil and dried under vacuum at 70 C for 12 h. The foil was pressed between twin rollers, shaped into a circular pellet with a diameter of 12 mm, and used as a cathode. The electrolyte was 1.0 M lithium bis-trifluoromethanesulfonylimide in 1,3-dioxolane and 1,2-di-methoxyethane (1:1 by volume) with 0.5 wt % LiNO3 additive. A 2025 type stainless steel coin cell was used to assemble a test cell. A lithium metal foil was used as the anode, and a G/S slice as the cathode. A LAND galvanostatic charge discharge instrument was used to perform the measurements. The coin-type cell was assembled in an Ar-filled glovebox (MBraun Unilab). The current density set for cell tests was referred to the mass of sulphur in the cathode and varied from 0.3 to 4.5 A g^{-1}. The charge discharge voltage range was 1.5 2.8 V. The CV was measured using a VSP- 300 multichannel potentiostat/galvanostat (Bio-Logic, France) workstation in the voltage range 1.5 2.8 V (vs Liþ/Li) at a scan rate of 0.1 mV s^{-1}. The G S63 hybrid electrode was discharged to the end of the second plateau and disassembled, dried in the glovebox, and followed by transferring to the vacuum chamber of XPS for structure characterization."

Three more types of graphene electrode DOEs are discussed in the following sections.

A pure graphene-based electrode is created by dispersing graphene oxide powder (100 mg) in distilled water (30 mL) and sonicating for 30 minutes. The resulting suspension is heated on a hot plate until it reaches 100 °C and 3 mL of hydrazine hydrate is then added.

The suspension is kept at 98 °C for 24 hours to reduce the graphene oxide to rGO. The reduced graphene oxide can be collected by filtration to leave a black powder. The filtered powder is then washed several times with distilled water in order to reduce the excess hydrazine.

The graphene powder is re-dispersed into water by sonication and the resulting solution is then centrifuged at 4000 rpm for 3 minutes to remove the larger particles. Graphene is collected by vacuum filtration and dried in a vacuum. This step can be left out if rGO is used.

To create the electrode, graphene is dispersed in ethanol until a concentration of 0.2 $mgmL^{-1}$ is achieved. The resulting suspension is filtered by vacuum filtration and then collected on the microporous filter paper. The filtered graphene is cut into 1 x 2 cm^2 (1 mg weight) for subsequent use. It is attached to a cell with an electrolyte buffer in order to examine the graphene electrode.

The second method explains the preparation of a cobalt-graphene hybrid electrode for use as an electrode in lithium-ion batteries. To prepare the electrode, graphene oxide (0.1 g) is added to cobalt acetate (350 mg) and deionized water (400 mL). NH4OH (3800 µL) and hydrazine (250 µL) are added to the solution and the mixture is stirred for 4 hours at 100 °C.

The resulting solution is filtered out once the reaction is complete. The solution is then re-crystallized by heating the product for 6 hours at 200 °C.

This last method involves creating a tin-graphene nanoribbon composite electrode for use in lithium-ion batteries. To create the electrode, graphene nanoribbon (GNR) (75 mg), SnCl2.H2O (1.33g, 5.89 mmol), 2-pyrrolidinone (65 mL) and a magnetic stirrer bar are added to a dried round-bottom flask.

The solution is sonicated for 20 minutes and then refluxed for 1 hour. The vessel is cooled down to room temperature and sonicated overnight in an open-air environment. The mixture is quenched with acetone and water three times, and filtered over a PTFE membrane (0.45 µm). The resulting product is dried in a vacuum (60 °C) for 24 hours and annealed in a quartz furnace (500 °C, Ar atmosphere) for 2 hours. The theoretical yield is 380 mg.

IV. ADOPTION OF TECHNOLOGY

- Samsung is looking to develop a smartphone with a graphene battery
- It could be on at least one Samsung smartphone by 2021
- Most smartphones today have lithium-ion batteries

According to the new market research report "Graphene Battery Market by Type (Lithium-Ion Graphene Battery, Lithium-Sulphur Graphene Battery, Graphene Supercapacitor), End-Use Industry (Consumer Electronics, Automotive, Industrial, Power), Region - Global Forecast to 2030", the global Graphene Battery Market size is projected to grow from USD 168 million in 2024 to USD 609 million by 2030, at a CAGR of 23.9% from 2024 to 2030. The market growth is driven by the advantages of graphene that is used as a battery material in graphene batteries and increasing demand for these batteries in consumer electronics and automotive industries.

By type, the lithium-ion graphene battery segment is estimated to account for the largest share of the graphene battery industry in 2021. Graphene lithium-ion batteries are consumed by end-use industries such as consumer electronics, automotive, industrial, power and others due as they are light, durable and suitable for high capacity energy storage, as well as shortens the charging times. The lithium-ion graphene battery segment is forecasted to have the highest growth rate owing to the increasing demand for lithium-ion batteries compared to other batteries due to its various applications in the consumer electronics and automotive industries.

The Asia Pacific region is expected to account for the largest share of the market in 2021. China, Japan, and South Korea are key countries contributing to the increased demand for graphene batteries in this region. In China, Japan and South Korea along with electric vehicles, graphene batteries are used in consumer electronics. Europe is estimated to have the second-largest share of the global graphene battery market in 2021.

Samsung SDI (South Korea), Huawei Technologies Co., Ltd.

(China), Log 9 Materials Scientific Private Limited (India), Cabot Corporation (US), Grabat Graphenano Energy (Spain), Nanotech Energy (US), Nanotek Instruments, Inc. (US), XG Sciences, Inc. (US), ZEN Graphene Solutions Ltd. (Canada), Graphene NanoChem (Malaysia), Global Graphene Group (US), Vorbeck Materials Corp. (US), Graphenea Group (Spain), Hybrid Kinetic Group Ltd. (Hong Kong) and Targray Group (Canada) are some of the leading players operating in the Graphene Battery Market.

According to SamMobile, Samsung is done with the development of graphene batteries and the company might likely introduce smartphones with new battery technology next year.

While rumours speculate Samsung Galaxy S10 to likely carry new graphene batteries, SamMobile cites that there is no such indication that the new battery technology will be introduced in the company's next flagship smartphone. To recall, Samsung in November last year received a patent for a graphene-based solution. The company patented this new battery technology in the US and South Korea. Samsung back then stated that its Advanced Institute of Technology could synthesize its 'patented' graphene ball.

Smartphone batteries aren't something that we think a lot about beyond the capacity, since that usually gives you an indication of how long the smartphone will last on a full charge. Most smartphones today have lithium-ion batteries, which while capable, are now falling short on capabilities as smartphones are getting more powerful. The solution could be in the smartphone industry adopting graphene batteries, which could be coming to at least one Samsung smartphone by 2021, according to tipster Evan Blass.

Graphene batteries on smartphones using Samsung's graphene ball technology have been tipped for some time now, but a new tweet by Evan Blass suggests that it's still some time away. Blass' source suggests that Samsung hopes to have at least one smartphone with a graphene battery by 2021. For the time being, capacities still need to be raised while simultaneously lowering costs, according to the tweet.

The technology is still expensive to develop, but has potential for smartphone batteries for a couple of key reasons. For one, graphene batteries will allow for more capacity in a smaller size, allowing for slim smartphones with compact batteries that can power the phone for longer. Additionally, graphene batteries can be charged much faster, with Blass stating that a full charge could happen in under 30 minutes.

However, the cost of putting such a battery into a smartphone is still too high, and could take a while to come down to reasonable levels. When it does, graphene batteries could finally allow smartphones to achieve greater potential without relying on oversized and heavy lithium ion batteries. However, till then, we're going to have to keep struggling with poor battery life on our smartphones, and slow charging times.

V. DISADVANTAGES OF THIS TECHNOLOGY

- As mentioned above, the cost of using graphene batteries is very expensive. The downside is that a graphene battery would add about 30% extra cost to the battery component of a phone. But I'm sure most high-end consumers wouldn't mind. To be perfectly clear, even though the overall battery life increases in terms of the life cycle, the actual capacity has not increased that much. In the world of batteries, the last remaining hurdle is higher capacity per unit volume.
- In order to grow graphene, toxic chemicals are being used at high temperatures. Due to this it exhibits toxic qualities. Research has proven that graphene exhibits some toxic qualities. Scientists discovered that graphene features jagged edge s that can easily pierce cell membranes, allowing it to enter into the cell and disrupt normal functions.
- It is susceptive to oxidative atmosphere.
- Being a great conductor of electricity, although it doesn't have a band gap (can't be switched off). Scientists are working on rectifying this.

VI. OTHER APPLICATIONS OF GRAPHENE

A. BIOLOGICAL ENGINEERING

Bioengineering will certainly be a field in which graphene will become a vital part of in the future; though some obstacles need to be overcome before it can be used. Current estimations suggest that it will not be until 2030 when we will begin to see graphene widely used in biological applications as we still need to understand its biocompatibility (and it must undergo numerous safety, clinical and regulatory trials which, simply put, will take a very long time).

B. OPTICAL ELECTRONICS

One particular area in which we will soon begin to see graphene used on a commercial scale is that in optoelectronics; specifically, touchscreens, liquid crystal displays (LCD) and organic light emitting diodes (OLEDs). For a material to be able to be used in optoelectronic applications, it must be able to transmit more than 90% of light and also offer electrically conductive properties exceeding 1 x 106 Ω1m1 and therefore low electrical resistance. Graphene is an almost completely transparent material and is able to optically transmit up to 97.7% of light. It is also highly conductive, as we have previously mentioned and so it would work very well in optoelectronic applications such as LCD touchscreens for smartphones, tablet and desktop computers and televisions.

C. ENERGY STORAGE

One area of research that is being very highly studied is energy storage. While all areas of electronics have been advancing over a very fast rate over the last few decades (in reference to Moore's law which states that the number of transistors used in electronic circuitry will double every 2 years), the problem has always been storing the energy in batteries and capacitors when it is not being used. These energy storage solutions have been developing at a much slower rate. The problem is this: a battery can potentially hold a lot of energy, but it can take a long time to charge, a capacitor, on the other hand, can be charged very quickly, but can't hold that much energy (comparatively speaking). The solution is to develop energy storage components such as either a supercapacitor or a battery that is able to provide both of these positive characteristics without compromise

VII. CONCLUSION AND FUTURE WORK

On the basis of efficiency, graphene-based batteries are on par with conventional solid-state batteries. Due to continuous advancement in graphene-based batteries, it will not be long before they outperform their solid-state predecessors.

Moreover, the additional advantages associated with graphene being present in the electrodes can be useful, even if the efficiency is not as high. Graphene batteries are an ideal option for batteries that contains similar efficiency and because of this reason researchers are working hard to further advance this class of batteries

Graphene batteries have started to gain attention in the commercial marketplace and it will not be long before these batteries become the norm and phase-out solid-state batteries. To quote recent forecasts "the world graphene battery market is expected to reach $115 million by 2022, growing at a CAGR of 38.4% during the forecast period. The automotive industry is estimated to dominate the market throughout the analysis period. Geographically, Europe is expected to be the leading market in 2016, with a revenue contribution of around 38%."

With ever-increasing energy demands all across the world, developing improved energy storage devices with reduced negative environmental impacts related to consumer-based battery usage is a noble objective.

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