Plethora of Battery breakthroughs to power future consumer electronics, smart homes, electric vehicles and Military Missions

Rechargeable lithium-ion batteries have been workhorse of the consumer electronics market including portable electronics, implantable devices, power tools, and hybrid/full electric vehicles (EVs) due to their ability to store large amounts of energy per unit weight and per unit volume, low self-discharge rate, long cycle life. They are also relatively maintenance-free and contain fewer toxic chemicals than other batteries.

Recently South Korean giant Samsung called for complete re haul of its latest flagship device- Galaxy Note 7 after consumers around the globe reported their handsets exploding and causing damages. Samsung in a statement said that it expects further $3 billion in lost income from to its move to scrap the fire-prone Galaxy Note 7 phone, raising the financial impact of the crisis to the equivalent of about half of its profit last year in the mobile division. One of the main causes of catching fire appears to continuous increase in energy density of Lithium-ion battery units driven by increased user requirements including full HD, large processing requirements of multi-core CPUs and increasing desire to produce sleeker design.

Because of these safety issues Researchers have developed many promising new battery chemistries to replace Lithium-ion. The increasing cost and limited resources of lithium may restrict their further application and hence demands urgent development of the low-cost batteries based on new energy storage chemistries.

The increasing demands to power electric vehicles, smart homes, smart phones, and even smart wearables are creating demand for advanced and high-performance, energy storage devices to satisfy the needs of modern society.

Batteries are also critical for military missions since mission success and soldiers' lives often depend directly on a military battery's performance. The expected improvements in energy density may enable advances in directed energy weapons, increase the loiter time of unmanned vehicles, lead to more effective sensors, and reduce the size and weight of manportable
systems.

Improving current Lithium-ion Batteries

Lithium-ion battery (LIB) consists of a graphite electrode (anode), an electrolyte (usually a lithium salt), and a metal oxide electrode (usually an oxide containing lithium). Lithium-ion batteries have large energy density of 372 mAh/g, hundreds of cycle of durability, and are routinely packed into mobile phones, laptops and electric cars. According to Frost & Sullivan, a leading growth-consulting firm, the global market of rechargeable lithium-ion batteries is projected to be worth US$23.4 billion in 2016

Toyota after observing the behavior of lithium ions in an electrolyte when a battery charges and discharges, have found the reason why a battery ages.Toyota's battery-boffins expect to use the new observation method to develop batteries that hold a better charge, and lead a longer life. Once the breakthrough is commercialized, which could take "two to three years," a new lithium ion battery could improve the battery-powered range of an electric vehicle by 15%, Dr. Hisao Yamashige of Toyota's advanced R&D and engineering division told a small group of reporters this morning at the company's Tokyo HQ.

For widespread adoption of electric cars, their range needs to be increased which require dramatic improvement in battery energy density and cycle durability as well as decreasing their cost. These next generation of batteries that are able to fully charge more quickly, and produce 30%-40% more electricity than today's lithium-ion batteries, could help transform the electric car market, allow the storage of solar electricity at the household scale and power the medical implantable devices.

Emerging New Battery Chemistries

We're on the verge of a power revolution with plethora of battery discoveries coming into commercial domain soon. Tech companies and car manufacturers are pumping money into battery development. Some of the promising batteries are Lithium-air breathing and Aluminum Air batteries, Gold nanowire batteries, titanium dioxide anode battery, Silicon and Germanium Nanowire, Solid state and Graphene batteries.

However there is need to develop efficient manufacturing processes, enhance durability and safety and reduce the costs before consumers start using these non-traditional batteries. Research firm IDTechEx estimates that advanced and post-lithium-ion battery technologies will achieve a market value of $14bn in 2026, comprising about 10 per cent of the entire battery market.

Batteries are of two types, the primary batteries that are single use batteries, once they are discharged, they must be discarded. Rechargeable batteries are generally referred to as secondary batteries.

Zinc Air

Zinc-air batteries have long-been thought of as a safer, cheaper and more sustainable replacement to lithium-ion. The heavy metal is one of the world's most abundant and more environmentally friendly to extract than lithium, but since zinc-air batteries were first produced in the 1930s they have only been single use, powering devices like hearing aids.

However a team from the University of Sydney's faculty of Engineering and IT have developed a new way to recharge the batteries using a three step method. Lead researcher Professor Yuan Chen says they found a way to control the composition, size and crystallinity of iron and cobalt, creating bifunctional oxygen electrocatalysts – in other words – react to increase and decrease the amount of oxygen needed to recharge the battery.

Their capacity to store five times more energy than current models makes the batteries suited for powering electric cars and other long lasting devices. Professor Chen said despite the excitement over the find, the technology will take time to perfect, with issues including a limited 120 recharge cycle compared to lithium-ion's 400-1200 range, and a slow energy delivery speed.

China develops Zn and Mg Batteries Powered Low-Speed Electric Vehicles

Under the guidance of CAS academician CHEN Liquan, Qingdao Industrial Energy Storage Research Institute(QIESRI) form Qingdao Institute of Bioenergy and Bioprocess Technology (QIBEBT), Chinese Academy of Sciences, discovered that highly concentrated aqueous electrolytes can optimize the Zn stripping/deposition processes and creatively proposed a smart cooling-recovery function by using a thermoreversible hydrogel as the functional electrolyte, which can repair the interfacial failure during cycling (Angew. Chem. Int. Ed., 2017, 56, 7871; Electrochem. Commun., 2016, 69, 6; ACS Appl. Mater. Interfaces, 2015, 7, 26396).

Based on preliminary progress in basic research and the technological development, QIESRI had broken through the technical bottlenecks of Zn batteries in the pilot-scale research and successfully developed new types of Zn batteries with high safety, energy density up to 40 Wh/kg, cycling life up to 500 times and cost less than 0.7 □/Wh, which are promising for the applications in the LSEVs, large-scale energy storage and flexible electronic devices.

In addition, QIESRI made the first attempt to design and synthesize boron-centered-anion-based Mg-ion electrolytes characterized by high ionic conductivity, non-nucleophilicity, and wide electrochemical window. The formation energy and phase transformation of the discharged intermediates are extensively investigated to understand the Mg-ion storage mechanism (Adv. Energy Mater., 2017, 1602055; Small, 2017, 1702277; Electrochem. Commun., 2017, 83, 72; J. Mater. Chem. A, 2016, 4, 2277). These scientific advances provide potential benefits and new research directions for future low-cost secondary Mg batteries.

These prospective researches on the rechargeable Zn and Mg batteries are highly in compliance with the lead-free trend in the LSEVs and corresponding low-cost applications. It would make important technical contribution for the green development of industry in China, accordingto cas.

Lithium-air breathing batteries

Many companies and researchers are experimenting with new lithium-air batteries that are smaller, lighter, and more energy-efficient than their forebears. Scientists from the Massachusetts Institute of Technology, the Argonne National Laboratory, and Peking University in China revealed a promising new version of lithium-air batteries. Their new device, the scientists said, can serve as a drop-in replacement for lithium-ion, while storing over five times more energy as today's batteries.

According to the scientists, the new design uses solid oxygen electrodes to overcome many of lithium-air's drawbacks. This new battery loses much less energy in the form of heat than earlier versions. The result is that it lasts longer and is more energy-efficient, making it a better option for electric cars and renewable energy storage.

"This means faster charging for cars, as heat removal from the battery pack is less of a safety concern, as well as energy efficiency benefits," said Ju Li, an MIT professor of nuclear science and engineering and author of the research.

Until now, lithium-air batteries inhaled outside air—driving a chemical reaction with the battery's lithium—while electric current flows out. This oxygen is released to the atmosphere during the charging cycle. The chemical reaction produces other molecules, known as lithium peroxide, that slowly clog the battery electrodes.

That raises several problems. According to Li, the solid particles formed by the reaction cause the battery to degrade faster than lithium-ion batteries, which are completely sealed from outside air. When the battery degrades, it stores less energy.

The battery is also prone to losing energy in the form of heat. Its output is more than 1.2 volts lower than the voltage needed to charge it, causing it to lose 30% of the electricity as heat. Because of that, the battery can "actually burn if you charge it too fast," said Li. Overcharging can lead to structural damage or an explosive reaction known as thermal runaway.

The new design solves these problems by closing off the battery to outside oxygen. The same electrochemical reactions take place between lithium and oxygen during charging and discharging, but they take place without ever using oxygen gas. Instead, the oxygen stays inside the battery and switches between three solid chemical compounds: Li_2O, Li_2O_2, and LiO_2. This prevents the damaging particles from forming.

The new battery sharply cuts voltage loss, so only 8% of the electrical energy is lost as heat. It also inherently guards against overcharging: The device can shift between different lithium compounds if it is being overcharged to stop activity that might cause damage. The scientists overcharged the battery to 100 times its capacity for 15 days without any damage. They also found that through 120 charging cycles, the battery only lost 2% of its capacity.

The lithium-air battery can also do without components to pump air inside and out of the battery. Without these auxiliary parts, it can easily be adapted to existing devices or battery packs inside cars and power grid storage.

Aluminum Air battery

In January 2015, Japanese company Fuji Pigment Co. Ltd. announced it was developing a new type of battery called an aluminum-air battery. It simply needs to be filled with saltwater or fresh water to charge, and its theoretical specific energy level is 8,100 Wh/kg (watt hour/kilogram).

Compare it with commercial lithium-ion batteries, which have specific energy levels within 100-200 Wh/kg.It should last a hefty 14 days, according to its creators Fuji Pigment.

Aluminium-air batteries have a theoretical capacity more than 40 times greater than the lithium-ion cells. An aluminum-air battery generates electricity from the reaction of oxygen and aluminum, using water as an electrolyte. Furthermore, aluminum is abundant, commercially cheap and the most recycled metal in the world. As a result, aluminum-air batteries will be cheap.

A standard aluminium-air reaction consumes the aluminum anode, which must be physically replaced rather than electrically recharged. But Fuji Pigment claims that, by adding strategically placed layers of ceramic and carbon, it has managed to suppress corrosion and reaction by products, creating an aluminium-air battery that can be recharged multiple times by simply adding water.

Phinergy's has created aluminum-air battery breakthrough by using a silver-based catalyst that only allows oxygen from the ambient air into the positive cathode. The O2 then combines with the liquid electrolyte, releasing the latent electrical energy stored within the aluminium anode. The 'air cathode', acts like the breathable fabric, letting in O2 but no carbon dioxide, which would foul the chemical reaction.

Lighter, more compact, with greater energy output and conceivably less than half the price of lithium-ion batteries, aluminum-air technology might transform EV appeal. Renault is the front-runner to adopt this game-changing aluminium-air battery, which could yield a sevenfold boost in the electric Zoe's 130-mile range.

Gold nanowire batteries, the batteries that last a LIFETIME

A standard lithium-ion battery used in most smartphones is expected to have between 300 to 500 charge cycles in it before it starts to lose a sizeable chunk of capacity.The system designed by doctoral candidate Mya Le Thai can be cycled hundreds of thousands of times without wearing out, which could lead to a battery that never needs to be replaced.

Researchers replaced traditional lithium by gold nanowires which are thousands of times thinner than a human hair, have extremely high conductivity and surface area, making them ideal for the transfer and storage of electrons.

Nanowires, pose a great possibility for future batteries, but they become brittle after multiple charge cycles, resulting in tiny cracks that spread inside the battery. The team at UCI avoided that problem by coating gold nanowires in manganese dioxide, with a total thickness of just 300 nm. These were then encased in a gel called polymethyl-methacrylate (PMMA). The performance of these batteries declined only 5% after recharging over 200,000 times in three months. This could be ideal for future electric cars, spacecraft and phones that will never need new batteries

Ultrafast charging titanium dioxide anode battery

Researchers at Nangyang Technological University have developed a fast-charging titanium dioxide anode battery. The batteries can be recharged up to 70 per cent in only two minutes and also have a long lifespan of over 20 years, more than 10 times compared to existing lithium-ion batteries.

The titanium dioxide nanotubes were used as a gel that transfers electrons more efficiently than today’s graphite anodes, hence speeding up the charging process. It also delays deterioration, thereby multiplying the battery’s lifespan by six to seven times. The titanium dioxide batteries are not just great for smartphones, but for electric cars as well.

Another plus point for this new breed of batteries is the abundance of titanium dioxide in nature. It is a naturally occurring oxide found mainly in ilmenite and rutile ores, and many miners are dedicated to producing these minerals. One such promising mining company is White Mountain Titanium Corporation (OTCQB: WMTM), which operates its Cerro Blanco titanium project at Chile’s Atacama region. It is expected to produce as much as 112 million high-grade rutile tons, which can be used for the development of titanium dioxide anodes that could upgrade the lithium-ion batteries and finally help them keep up with the fast-changing times.

Manufacturing this new nanotube gel is very easy. Titanium dioxide and sodium hydroxide are mixed together and stirred under a certain temperature so battery manufacturers will find it easy to integrate the new gel into their current production processes.

Silicon Anodes

Silicon and Germanium are two candidates that can replace the traditional graphite anode to increase the energy density and cycle durability of lithium-ion batteries. Even though Silicon has the highest known theoretical specific capacity of any material (~3600 mAh/g), it has limited use as an anode in lithium ion batteries due to the mechanical instability caused by the large volume expansion that occurs upon Li insertion. Like silicon, germanium too doesn’t handle charging very well, it expands during charging and disintegrate after a small number of cycles.

A KAIST research team led by Professors Jang Wook Choi and Ali Coskun reported a molecular pulley binder for high-capacity silicon anodes of lithium ion batteries in Science in July 2017. The KAIST team integrated molecular pulleys, called polyrotaxanes, into a battery electrode binder, a polymer included in battery electrodes to attach the electrodes onto metallic substrates.

In a polyrotaxane, rings are threaded into a polymer backbone and can freely move along the backbone. The free moving of the rings in polyrotaxanes can follow the volume changes of the silicon particles. The rings' sliding motion can efficiently hold Si particles without disintegration during their continuous volume change.

It is remarkable that even pulverized silicon particles can remain coalesced because of the high elasticity of the polyrotaxane binder. The functionality of the new binders is in sharp contrast with existing binders (usually simple linear polymers) with limited elasticity, since existing binders are not capable of holding pulverized particles firmly. Previous binders allowed pulverized particles to scatter, and the silicon electrode thus degrades and loses its capacity.

Silicon and Germanium Nanowire

Researchers have turned to using silicon nanowire and germanium nanowire anodes due to their advantages like efficient electron transport and larger surface area that further increases the battery's power density, allowing for fast charging and current delivery.

Researchers at the University of California, Riverside (UCR) have developed a silicon anode for lithium-ion batteries that outperforms current materials and gets around previous issues. A research team led by professors Mihri and Cengiz Ozkan now developed an electrode consisting of sponge-like silicon nanofibers having several structural advancements at the nanometer scale that help with the minimization of undesired large volume expansion as observed in other standard Si materials,”

Research at University of California, Los Angeles, has shown that growing a SiO_2 layer on silicon nanowires (SiNW) can improve cycle life to 400 cycles at a capacity of 2400 mAh/g. Canonical announced on July 22, 2013, that its Ubuntu Edge smartphone would contain a silicon-anode lithium-ion battery. Amprius currently makes silicon nanowires in a small-scale batch process using chemical vapor deposition (CVD), a process borrowed from the semiconductor industry.

A research team at the University of Limerick, Ireland, restructured germanium using nanowires to create a porous material that remains stable during charging. The anodes were claimed to retain capacities of 900 mAh/g after 1100 cycles, even at discharge rates of 20–100C.

This performance was attributed to a restructuring of the nanowires that occurs within the first 100 cycles to form a mechanically robust, continuously porous network.

In 2014, researchers at Missouri University of Science and Technology developed a simple way to produce nanowires of germanium from an aqueous solution. They modified the electrochemical liquid-liquid-solid process (ec-LLS), an electrodeposition process designed by a group of researchers at the University of Michigan, in order to grow nanowires of germanium using liquid metal electrodes at room temperature. Their one-step approach could lead to a simpler, less expensive way to grow germanium nanowires.

Supercapacitors based Battery will let phones charge in seconds and last for a week

A new type of battery that lasts for days with only a few seconds' charge has been created by researchers at the University of Central Florida. The high-powered battery is packed with supercapacitors that can store a large amount of energy. It looks like a thin piece of flexible metal that is about the size of a finger nail and could be used in phones, electric vehicles and wearables, according to the researchers.

"If they were to replace the batteries with these supercapacitors, you could charge your mobile phone in a few seconds and you wouldn't need to charge it again for over a week," said Professor Nitin Choudhary, one of the researchers behind the new technology.

To date supercapacitors weren't used to make batteries as they'd have to be much larger than those currently available. But the Florida researchers have overcome this hurdle by making their supercapacitors with tiny wires that are a nanometre thick. Coated with a high energy shell, the core of the wires is highly conductive to allow for superfast charging.

"For small electronic devices, our materials are surpassing the conventional ones worldwide in terms of energy density, power density and cyclic stability," said Prof Choudhary. Cyclic stability refers to the number of times a battery can be fully charged and drained before it starts to degrade.

Solid state batteries

In solid-state batteries the liquid electrolytes normally used in conventional lithium-ion batteries are replaced with solid ones, which make it possible to replace conventional electrodes with lithium metal ones that hold far more energy. Doing away with the liquid electrolyte, which is flammable, can also improve the safety of batteries, which leads to cost and size savings, particularly in electric vehicles, by reducing the need for complex cooling systems.

The result is a battery that can operate at super capacitor levels to completely charge or discharge in just seven minutes – making it ideal for cars. Since its solid state that also means it’s far more stable and safer than current batteries. The solid-state unit should also be able to work in as low as minus 30 degrees Celsius and up to one hundred.

Researchers at Toyota and Tokyo Institute of Technology said they had developed solid-state batteries with more than three times the storage capacity of lithium-ion state batteries. Hitachi Zosen of Japan says it plans to commercialize the technology by 2020, but acknowledges it has yet to work out the manufacturing process.

Dyson, has invested $15 million in Sakti3, a Michigan-based developer of solid-state battery technology. Sakti 3 has successfully demonstrated a battery that produces 1,000 watt-hours of energy per liter of battery volume, which in practice could more than double the driving range of a current Tesla. Pathion Michael Liddle projects that solid-state battery technology will be market-ready within two years.

The real question is whether they can produce that affordably and at scale; Pathion’s CEO Michael Liddle says “Many startups and researchers can produce a better cathode, anode, or electrolyte, but all three must work together perfectly to make a battery. The capital to bring the pieces together, and bring production of new batteries to scale, has been scarce.”

Graphene car batteries

Fisker has betrothed his new electric automobile will have a range surpassing 400 miles — that would be huge, deliberation the longest operation now belongs to a high-end chronicle of the Model S, that gets 315 miles on a singular charge. Rather than operative with required lithium-ion batteries, Fisker is turning to graphene supercapacitors. Graphene is a thinnest element on Earth and strongest material famous to man.

Graphene batteries are the future. “Graphene shows a higher electron mobility, meaning that electrons can move faster through it. This will, e.g. charge a battery much faster,” Lucia Gauchia, an assistant professor of energy storage system at Michigan Technological University, told Business Insider. “Graphene is also lighter and it can present a higher active surface, so that more charge can be stored.

“The reason we are not using it yet, even though the material is not a new one, is that there is no mass production for it yet that can show reasonable cost and scalability,” Gauchia explained.

But Fisker told Business Insider that his battery division, Fisker Nanotech, is patenting a appurtenance that he claims can produce as many as 1,000 kilograms of graphene during a cost of usually 10 cents a gram.

“The plea with regulating graphene in a supercapacitor in the past has been that we don’t have a same firmness and ability to store as many energy,” Jack Kavanaugh, a conduct of Fisker Nanotech, said. “Well we have solved that emanate with record we are operative on.” Kavanaugh pronounced altering a structure of a graphene has allowed them to urge a supercapacitor’s appetite density, though didn’t elaborate serve since a record is “unique and proprietary.” He combined a obvious for a appurtenance is pending.

Graphenano company has developed a new battery, called Grabat, that could offer electric cars a driving range of up to 500 miles on a charge. The batteries can be charged to full in just a few minutes; it charges and discharges 33 times faster than lithium ion. The capacity of the 2.3V Grabat is huge with around 1000 Wh/kg which compares to lithium ion’s current 180 Wh/kg.

Military Requirements for Batteries

“Batteries enable radio communication among combat squad members and field headquarters. They provide the power to obtain accurate location data essential for maneuver and combat air support. Laser range finders and night-vision goggles are two more examples of battery-powered capabilities that give U.S. troops battlefield superiority,” says RAND.

“This variety in battery applications leads to variety in the types of batteries that the military acquires; a battery cell designed to periodically provide small amounts of power to a flashlight is built differently than a large, one-shot cell inside a missile, which may lie dormant for many years and then be expected to provide a large amount of power at a moment’s notice.”

For military purposes, however, battery cost is secondary to dependability. Therefore military is willing to pay somewhat higher prices to ensure that its batteries will be effective in combat situations and rugged environments. In addition to requirements for characteristics of battery performance, requirements are established for battery survivability in harsh conditions.

Because the rate at which chemicals within a battery react is dependent on temperature, reactions proceed more quickly as temperature increases. This means that, for military batteries, great care has to be taken to ensure that the power generated in a cold-weather environment is sufficient to meet a soldier’s needs.

Because a battery is an energy storage device, by definition a good battery contains large amounts of energy in a confined space. Safety, therefore, is a paramount concern, and it must be established that Soldier Portable batteries (SPBs) will fail gracefully, i.e., without damaging other components of an electrical system or posing a danger to operators. Graceful failure must hold in the face of many different types of possible abuse: Requirements cover the testing necessary to establish the battery’s response to explosive decompression, submersion, thermal and mechanical shock, sand and dust storms, and numerous other environmental hazards that a military battery might encounter during its service life.

Military Batteries

The advantages of Li-ion battery are reduced when used in high-temperature environments or is forced to generate large currents for extended periods of time.

Two nickel-based chemistries are also used in rechargeable batteries: nickel-metal-hydride (NiMH) and nickel-cadmium (NiCd). Both chemistries involve positive electrodes made of NiOOH (nickel oxyhydroxide) but differ in the materials used in their negative electrodes. NiMH has largely replaced NiCd because of its much greater specific energy and lower toxicity. NiMH batteries are competitive with Li-ion technology in some applications, and can match the lower end of the Li-ion battery spectrum in specific energy.

When compared to Li-ion technology in other respects, though, NiMH batteries have several disadvantages. For example, their high self-discharge rate keeps them from being stored for any length of time without needing to be recharged. Battery structures with lower self-discharge have been introduced, but generally have lower capacity than standard varieties.

Sulphur-based batteries

Lithium-sulphur is a closely watched technology that can also be used for military and aerospace applications. The batteries' energy density is at least twice that of current lithium-ion batteries.
Oxis Energy, an Oxfordshire-based company that has a patent for lithium-sulphur batteries, says it has achieved a theoretical energy density five times greater than lithium-ion. It is working with Seat, the Spanish car brand owned by Volkswagen. Nasa, the US space agency, has invested in lithium-sulphur batteries for exploration missions.

For the technology to move from experiment to commercial product it will need to achieve longer life cycles. Mr Gonzalez at IDTechEx adds that start-ups must be able to produce the same-quality batteries in large volumes.

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