

Nanotechnology in the Field of Electric Vehicles

Longhao Sun *

Mechanical Engineering, University of Leeds, Leeds, United Kingdom

* Corresponding author: mn20ls@leeds.ac.uk

Abstract. In this era of advocating environmental protection and low-carbon economy, electric vehicles (EVs) are now being promoted all over the world, and the world's leading traditional car brands are focusing their strategic approach on developing EVs. However, EVs do have many drawbacks such as paradox of battery performance and range. Batteries equipped in EVs nowadays usually have a low capacity, and heavy and large battery pack is not only expensive to manufacture but also reduces the range. Enhancing the performance of the battery pack and reducing the weight of the EVs has become a crucial problem. This article reveals that the application of nanotechnology has accelerated the development of EVs by improving the battery performance, enhancing the mechanical strength and reducing the weight of the car bodies. Specifically, nanomaterials such as nano LiFePO_4 , nano $\text{Li}_2\text{MnSiO}_4$ and carbon nanotubes can be applied to the electrodes to have a larger capacity, higher specific power, and longer cycle life, thus increasing performance and driving range. Besides, to achieve further reduction in body weight and increase body strength, lightweight nanocomposites such as carbon fibre reinforced composite can also be applied to structural application of an EV. The use of this nanocomposite significantly reduces the overall weight of the vehicle, increases the rigidity of the bodywork and improves the performance and safety of the vehicle. In the future, seeking for electric vehicles with longer driving ranges, more efficient batteries with better performance and higher long-term safety will be of academic and commercial significance.

Keywords: Nanomaterial, electric vehicles, lithium battery, nanocomposites.

1. Introduction

1.1. Electric Vehicles

The automotive industry has been persistent in its search for a replacement for the internal combustion engine. This is because the internal combustion engine is not only environmentally damaging to the planet but also a threat to human health.

According to IPCC data from 2007, 26% of the world's energy is used for transportation, and 23% of greenhouse gas emissions are energy related. Road traffic constitutes 74% of the world transportation sector [1]. Family cars with internal combustion engines account for a large proportion of greenhouse gas emissions. First, cars dominate the traffic in the majority of countries. Second, car sales are growing at the highest rates in the world. Third, alternative renewable energy source technologies such as electricity for the drivetrain are available, unlike for heavy load vehicles. Only small trucks could run electricity within a short range, and low efficiency, most of large transport cargo vehicles can only run on diesel fuel, which can be converted to a mixture of 80% methane (either fossil or biogenic) in the future to be greener. The popularization of electric vehicles will be an essential means of mitigating global warming and reducing carbon emissions.

Battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs) and hybrid electric vehicles (HEVs) are the three most common types of electric vehicles. BEVs are fully powered by electricity and are more efficient compared to hybrid and plug-in hybrid electric vehicles (PHEVs). Conventional HEVs and PHEVs are both regarded as hybrid electric vehicles [2].

1.2. Lithium-Ion Battery of Electric Vehicles

Lithium-ion is a newcomer in the battery technology. Conventional nickel-cadmium batteries, lead-acid batteries and nickel-metal hydride batteries are relatively mature technologies in their own right, but there are major problems with their use as power batteries in cars. Today, an increasing

number of automakers are choosing to use lithium batteries as batteries to power new electric vehicles. In comparison to other common batteries, lithium-ion batteries (LIBs) have many advantages [3]. claims that Li-ion batteries have high energy density of 165 WH/kg (3 times of hydrogen nickel battery), high working voltage (3 times higher than NiCd batteries), small size; light weight, long service life and environmental friendliness and are therefore used in a wide range of applications in electric vehicles. However, due to the large capacity and large number of series and parallel connections of lithium-ion batteries for vehicles, together with issues such as safety, durability, batch-to-batch variations and cost, the widespread use of lithium-ion batteries in vehicles has been limited [4]. The main components of a lithium battery are the cathode material, the anode material, the diaphragm, the electrolyte, etc. The cathode material occupies more than 40% of the total cost of LIB, and the properties of cathode material directly affect the performance of lithium battery, so the lithium cathode material occupies the central position in the lithium battery.

Cathode materials of lithium-ion batteries must be capable of repeatedly (for charging) and rapidly (for high currents) accepting and releasing lithium ions. Lithium-ion battery cathode materials have a broad market and a very optimistic prospect. However, there are still certain technical bottlenecks for Li-ion battery cathode materials, especially their advantages of high electric capacity and strong safety performance have not yet been fully exploited. Majority of the materials utilized for cathode materials are ternary materials, LiMn_2O_4 , LiCoO_2 and LiFePO_4 . While the most common sources for anode materials are the negative electrode materials, artificial and natural graphite. Negative electrode materials include nitrides, PAS, tin alloys, tin oxides, nano-anode materials and other intermetallic compounds. Among those materials, anode materials are one of the four crucial components of lithium batteries, and they positively affect the capacity and cycling performance of the battery. In this day and age, one of the most glaring shortcomings in battery performance and battery durability stems from electrode design and materials. Conventional electrodes produce inefficient powers because they possess low conductivity and poor mechanical behaviour when charging and discharging. Using conventional electrodes can also cause early delamination and degradation, triggering safety concerns and durability issues.

1.3. Nanomaterials and Nanotechnology

Nanotechnology's definition is the understanding and the controlling of matter between 0.1 to 100 nanometres in size to exhibit unique physical and chemical properties. Such scientific phenomena make innovations possible. While humans continue to study and research nanomaterials throughout human history, they drastically accelerated the industrial revolution [5].

Engineered nanomaterials (ENMs) have uncommon attributes (e.g., optical, magnetic, electrical, etc) that have the potential to significantly influence electronics, medicine and other fields. Nanotechnology's application in medicine can provide precise cure on certain organs or cells. Especially in the realm of oncology, it can better the efficiency and accuracy of the treatment. When nanomaterials are added as additives to traditional building materials, as in the case of cement or textile fabrics and other materials to make them stronger, yet lighter or with other practical properties [6,7].

Because they are extremely small, they are highly applicable in the field of electronics, where nanotechnology can be used to make high-precision instruments and components such as chips or microprocessors. For instance, researchers from MIT in 2019 have built a modern microprocessor out of carbon nanotube transistors, which are widely perceived as a faster and more environmentally friendly alternative to their conventional silicon counterparts. Digital circuits based on carbon nanotube field effect transistors (CNFETs) offer the potential for significant energy savings [8].

Due to the special characteristics of nanomaterial, nanotechnology is now widely used in automotive industry. There are some latest developments of nanotechnology in the automotive industry, like nano-coatings and nano filters. There are also some innovative applications as well. For example, carbon black is used for tires, nanoparticles enhance the engine's performance and decrease

the fuel consumption. As nanotechnology can be applied to electrical engineering, nanomaterials and nanotechnology can also applied on electric vehicles.

2. The Nanomaterial Electrodes in EV Batteries

Developing high-electric power, high-electric energy density, is key point of next generation energy storage devices and it is critical to the success of electric and hybrid vehicles. Future energy storage technologies will depend upon innovative nanomaterials such as the development of electrode materials suitable of charging and discharging under high voltage and current situations. Nanomaterials can be applied to the design and fabrication of electrode materials. nanotechnology-based approaches have demonstrated many advantages in terms of increased efficiency, energy and power density, recyclability in life cycle and safety [9,10]. During the charging process, some of the lithium ions in the cathode are shed and passed through the electrolyte to the anode where they are embedded, while the positive releases electrons, electrode and go towards to the negative electrode in the path of external circuit, maintaining the conservation of the chemical reaction. Therefore, the selection of both cathode and anode materials is directly associated with charge transport processes, thus affecting the overall performance of LIBs.

2.1. Cathode Nanomaterials

The advantages of using LiFePO_4 as cathode materials of LIBs are to be able to have high energy density, high working voltage, decent safety performance, durable life cycle, short self-discharge rate and good resistance to high temperature. Also, attracted by LiFePO_4 's favourable electrochemical potential, low toxicity, low cost and abundance of Fe, scientists are keen to research its application to the cathode of electric car battery. In order to reduce the length of transport path of an electron to achieve higher coulombic efficiency, nanocoating LiFePO_4 with a medium have good conductivity, like carbon, conductive polymer or conductive metal phosphides have been tested as a solution [11,12].

Nanostructured LiMn_2O_4 is a material that can be applied to the positive electrode of electric vehicle batteries. Nanostructured $\text{Li}_2\text{MnSiO}_4$ cathodes can be modified by coating. For example, when coated with a carbon layer, the nanocomposite electrode materials gain a better electricity conductivity. The carbon layer can make the rapid electronic conduction have a continuous pathway. By reducing the composite cathode material internal resistance, reduced polarisation under high current densities and further improvements in high-rate capacity can be achieved. Another point is polarisation reduction. The specific surface area is increased as application of nanostructure materials, Further expansion of the interaction zone between electrode particles and electrolyte [12].

The length required for the lithium ions to diffuse from the surface of an individual particle into the bulk is defined as the lithium-ion diffusion length. To minimise the diffusion length of Li-ions, nanostructured LiMn_2O_4 materials are significant because of their intrinsically low lithium-ion diffusion rate. This is becoming accumulatively important at high current rates in battery packs. Applying nanostructured cathode reduction in polarisation at high current rates and before reaching the voltage cut-off, a higher capacity can be achieved from the cathode [12].

2.2. Anode Nanomaterials

Carbon nanomaterials has more advantages than conventional materials when it comes to attribute to energy conversation process and energy storage performance, because carbon nanomaterials have a special size-/surface dependent, such as optical, morphological, electrical, and mechanical properties These properties facilitate the fabrication of electrodes for electric vehicle batteries

According to Zhang's research in 2014, CNTs and CNT composites can be applied as the anode materials of Li ion battery. As the graphite structure of carbon nanotube makes the CNTS an great alternative as the electrode material, CNTs have a typical multi-layered hollow structure, being coaxial circular tubes consisting mainly twelve layers of carbon atoms arranged in a hexagonal pattern

[13]. Carbon nanotubes have a large specific surface area, so they can combine much higher concentrations of lithium. CNT-based electrode can enhance the performance of lithium ions battery in battery capacity, energy density, and lifetime, as well as being clean. Due to its high durability, the ultra-fast carbon electrodes are applicable in EV battery pack. In addition, in order to improve the performance of CNT electrode and make the most of the structural advantages of the CNT so as for the enormous specific surface area and the support as a framework, the material with high specific capacity such as metallic oxide and Si can be applied to composite with CNTs.

Typical activated carbon electrodes currently on the market are made from a mixture of powders, additives and binders, which makes it easy for charged ions to become embedded in the electrode, resulting in low efficiency, loss of capacity and reduced battery life. The French battery development company Nawa Technologies has designed an ingenious electrode structure made of CNTs [14]. They have designed a vertically aligned carbon nanotube, similar to a hairbrush structure, with 100 billion straight, highly conductive nanotubes sticking out per square centimetre. The nanotubes are similar to a straight highway, allowing lithium ions to be embedded in the electrodes faster and more efficiently, just like a car on a motorway. In addition, thanks to the ultra-lightweight nanotube support and the lesser use of exotic binders and additive materials, the battery becomes lighter and more compact, with a tripling of energy density for the same amount of space. Vertical carbon nanotube electrodes allow more lithium ions to be embedded in the electrodes, reducing lithium leaching due to repeated charging or fast charging, significantly reducing battery capacity degradation, and increasing battery life by up to five times [13,15].

Nano titanium dioxide (TiO_2) such as TiO_2 nanowires, is a kind of nanostructured materials which can also be applied on the lithium battery as negative electrode. Nanostructured TiO_2 has many advantages to be a good performance anode, due to its great strength of its structure, high voltage discharge, great recyclability, environmental friendliness, high level of safety and minimal cost, thus ameliorating the safety level and enhanced performance of battery [16].

3. The Application of Lightweight Nanocomposites in Structural Application of Electric Vehicles

The development and application of high-performance strength lightweight materials, and the associated new concepts for product design and rapid assembly of structures, are essential elements in the rapidly advancing structures and vehicles for both the aerospace industries and the automotive industries [17]. According to Bhatt's research, carbon fibre composites have the following characteristics: light weight, good strength, high stiffness, high vibration resistance and high corrosion resistance [18]. In the case of carbon fibre composites applied to the body of the vehicle, the total mass is reduced by at least fifty percent compared to traditional steel structures. Although engineering composite plastics can reduce weight by up to 20%, their mechanical and physical properties, such as strength, fracture and impact properties, shear modulus and elasticity, are drastically less superior than most of metal alloy materials. In order to improve the characteristics of engineering plastics to make them more suitable as automotive bodies, taking nano-sized fillers in order to enhance the strength of polymers, as known as nanomaterial is considered as a feasible solution. With corporation with nano-sized fillers, the physical properties of composite plastic will be improved. The cost of using carbon fibre composite parts is also huge compared to steel, which costs roughly five times more than steel [18]. Another point is that carbon fibre composite components are not easy to repair in the event of a collision compared to traditional alloy materials. Therefore, carbon fibre material is not commonly used in ordinary traditional family cars, but once the cost is further reduced, carbon fibre nanocomposites can reduce a large part of the weight of electric vehicles, which will enhance the driving safety and driving performance of electric vehicles [18].

According to BMW (2020), because carbon fibre reinforced thermoplastics offer a very high strength to weight ratio, carbon fibre reinforced thermoplastics (CFRTP) are commonly used in automotive industry [19].

There are already many well-known car manufacturers working on the development of nanocomposites for electric vehicle applications. The BMW i3 is the first electric vehicle with a primary part of its frame and body made of carbon fibre reinforced plastic (CFRP) is mass manufactured. Thanks to the use of carbon fibre nanocomposites in the frame of this electric car, the car weighs just 1195 kg. The lightweight frame allows this electric vehicle to be driven with much lower energy consumption, which increases the driving range [19].

In addition, the application of strong lightweight nanocomposites is expected to help optimise the body design and as a result reduce the drag coefficient due to an estimated 10% increase in aerodynamic improvements, which in turn will lead to a 20% reduction in rolling resistance of the tires and a 7.5% increase in the average efficiency of the powertrain [20].

4. Conclusion

Nanotechnology makes a great impact in improving performance of electric vehicle battery packs. LIBs are a reasonable and sensible choice for future electric vehicles due to their high energy density, high discharge power and long life cycle. Due to the unique chemical properties of nanomaterials, higher lithium storage capacity, shorter lithium-ion transport path and higher electron transfer rate can be achieved.

On the other hand, application of using nanocomposite in frame structure of EVs, by using carbon fiber reinforced plastic, the mass of the electric vehicles can be reduced significantly, and the driving range of the battery and enhance the dynamic performance of the vehicle. However, the application of nanotechnology and nanomaterials usually costs way more than the conventional materials due to their difficulty of mass production.

References

- [1] IPCC: Greenhouse gas emissions accelerate despite reduction efforts.
- [2] Thackeray, M.M., Wolverton, C. and Isaacs, E.D. (2012) "Electrical Energy Storage for transportation—approaching the limits of, and going beyond, lithium-ion batteries," *Energy & Environmental Science*, 5 (7), p. 7854.
- [3] Diouf, B. and Pode, R. (2015) "Potential of lithium-ion batteries in renewable energy," *Renewable Energy*, 76, pp. 375 – 380.
- [4] Lu, L. et al. (2013) "A review on the key issues for lithium-ion battery management in Electric Vehicles," *Journal of Power Sources*, 226, pp. 272 – 288.
- [5] National Nanotechnology Initiative (NNI). National Science and Technology Council. Committee on Technology, Subcommittee on Nanoscale Science, National Technology Initiative Strategic Plan, www.nano.gov (2011, accessed 25 August 2015).
- [6] M.C. Coelho, G. Torrão, N. Emami, J. Grácio, J. Nanoscience and Nanotechnology, 12 (2012), 1 – 10.
- [7] Nanomaterials (no date) National Institute of Environmental Health Sciences. U.S. Department of Health and Human Services.
- [8] Hills, G. et al. (2019) "Modern microprocessor built from complementary carbon nanotube transistors," *Nature*, 572 (7771), pp. 595 – 602.
- [9] Shafique, M. and Luo, X. (2019) "Nanotechnology in transportation vehicles: An overview of its applications, environmental, health and safety concerns," *Materials*, 12 (15), p. 2493.
- [10] Deshpande, V.S. and Talele, M.N. (2017) "Nanotechnology enabled hybrid power system suitable for batteries in Hybrid Electric Vehicle," 2017 Third International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB).

- [11] Jiang C, Hosono E, Zhou H. (2006) Nanomaterials for lithium-ion batteries, *Nano Today*. 2006, 1 (4): 28 - 33.
- [12] Lu, J. et al. (2016) “The role of nanotechnology in the development of battery materials for electric vehicles,” *Nature Nanotechnology*, 11 (12), pp. 1031 – 1038.
- [13] Zhang, J. et al. (2014) “High-capacity graphene oxide/graphite/carbon nanotube composites for use in lithium-ion battery anodes,” *Carbon*, 74, pp. 153 – 162.
- [14] Nawatechnologies - innovations based on nanostructured materials (2021) NAWA Technologies.
- [15] Xiong, Z., Yun, Y. and Jin, H.-J. (2013) “Applications of carbon nanotubes for lithium-ion battery.
- [16] El Halya, N. et al. (2022) “TiO₂ based nanomaterials and their application as anode for rechargeable lithium-ion batteries,” *Titanium Dioxide - Advances and Applications* [Preprint].
- [17] Bhatt P and Goe A 2017 Carbon Fibres: Production, properties and potential use *Material Science Research India* 14 52 - 7.
- [18] Gutowski, W. V. et al. (2017) “Lightweight nanocomposite materials,” *Lightweight and Sustainable Materials for Automotive Applications*, pp. 277 – 302.
- [19] Bmw (2022) Lightweight, stable, and high-tech – all there is to know about carbon fiber, all there is to know about carbon fiber in cars | BMW.com. BMW.
- [20] M.C. Coelho, G. Torráo, N. Emami, J. Grácio, J. *Nanoscience and Nanotechnology*, 12 (2012), 1 – 10.