Diverse Nanotechnology Applications for Electric Vehicles

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Abstract. The research on nanomaterials has been attracting more attention in recent years. At the same time, with the advancement of human development and social industrialization, traditional energy sources such as oil, natural gas, and coal, which are closely related to human beings, are decreasing day by day, and the resulting environmental pollution is becoming more and more serious, which threatens the sustainable development of human beings. The world is transforming from traditional cars to electric vehicles to realize a sustainable development strategy and protect the natural environment and resources. This article can be divided into three parts, focusing on nanomaterials' applications in electric automobiles. Firstly, the materials used on the car frame, such as aluminium alloys and steel, are introduced and compared. Then, the superhydrophobic coatings with fascinating self-cleaning and corrosion-resistant performance on these substrates are discussed. In the end, the latest discoveries of new battery materials are listed, and some potential research areas in the future and perspectives on these technologies are given out.

Keywords: Nanotechnology, electric vehicles, super hydrophobicity, coating, battery.

1. Introduction

As an emerging technology with the most market application potential, nanotechnology's potential commercial value and scientific value are very important and can even change the world as early as the 1980s and 1990s; some countries, such as the United Kingdom, Germany, Japan, the United States and China, began to support the research and development of nanotechnology [1]. In particular, the United States released the national nano plan implemented by trans federal departments in 2000. Nanotechnology has gradually penetrated the fields of physics, chemistry, new materials, information technology, biotechnology, medicine, national defense, environment, energy, agriculture, and food, and has made significant progress in many fields. Some nanotechnology has been put into the market [1].

In China, many scientific research institutions and universities have organized forces to carry out nanotechnology research and have made certain research achievements. The emergence of increased nanotechnology has made impossible things appear, such as powder atomic layer coating technology, which is the real embodiment of new domestic nanotechnology and can already be mass-produced. In short, nanotechnology is becoming the focus of the world's scientific and technological community to understand better the application of nanotechnology in some fields, especially in electric vehicles. So now there are some aspects of high-frequency discussion: vehicle frames, superhydrophobic coatings, and battery batteries for electric vehicles. Carbon fiber frames are making their way into everyday life, as the nanomaterial reduces weight and saves fuel. The superhydrophobic coating can prevent the vehicle from being contaminated by dirty water in the process of driving and avoid the cost of washing the car. Nano cellular battery has stronger performance than the traditional material battery, which is a powerful supplement to traditional fossil fuels and has good mitigation of environmental and energy problems, providing a basis for realizing the "double carbon" goal as soon as possible. Therefore, more and more people are studying nanotechnology, expecting to solve a series of problems that are difficult to solve now.

2. Hydrophobic coatings

2.1. Fundamentals

After the first observation of lotus leaves in which their leaves never get wet, people started to consider how to transfer such a natural phenomenon to the event of modern technology. A superhydrophobic coating is believed to protect the original surface from corrosion and dust. It has been used in many fields, including the marine and medical industries, while this report focuses on the application of electric vehicles [2]. The world is being transformed from fossil fuels to renewable energy, and the number of electric automobiles skyrocketed in recent years. A superhydrophobic coating can keep the attractive appearance of the vehicles and protect their internal equipment. In Tesla Model S, for example, the propulsion components are moved on the chassis to improve efficiency. They face a severe environment in such a position, and the protective coating role becomes more important [3].

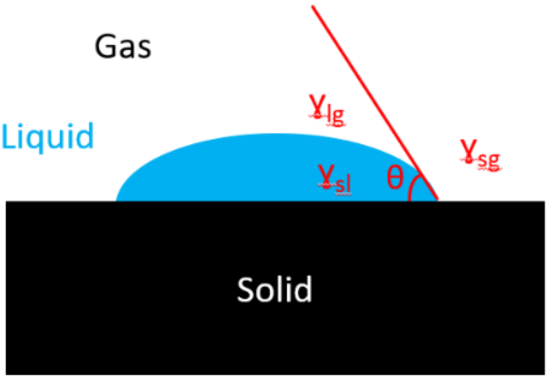

Figure 1. Scheme of a water drop.

The self-cleaning and superhydrophobic characteristic is mainly determined by the contact angle θ (Figure 1) [4]. Due to the thermodynamic equilibrium, the sum of the surface tension γ_{lg} and γ_{sl} in the horizontal direction should equal γ_{sg}, as shown in Equation 1:

$$\gamma_{lg} \cos\theta + \gamma_{sl} = \gamma_{sg} \tag{1}$$

Where γ_{lg}, γ_{sl}, and γ_{sg} are the interfacial tension of liquid-gas, solid-liquid and solid-gas interfaces. Equation 1 can then be rearranged to Equation 2 easily:

$$\cos\theta = k_w = \frac{\gamma_{sg} - \gamma_{s_l}}{\gamma_{l_g}} \tag{2}$$

Where k_w is the wetting coefficient. Under constant temperature and pressure, surface tension is the same as the specific surface free energy. Therefore, the contact angle needs to be high to achieve ideal hydrophobicity.

The materials used for the frame and chassis must be considered when it comes to the coating of electric vehicles. Normally, composites and alloys are popularly used [5]. The overall materials selection depends heavily on the experimental and analytical data and maintenance properties. The report concentrates on the materials for electric vehicles: aluminum alloys and steel in Tesla Model 3 (Figure 2) [6]. By contrast, although magnesium has better performance, it cannot be used universally on general vehicle panels owing to the limited number of slip systems of hexagonal close-packed (HCP) crystal structures [7]. In addition to metals, those large areas of windows made of silica should also be designed to be anti-fogging and transparent [8].

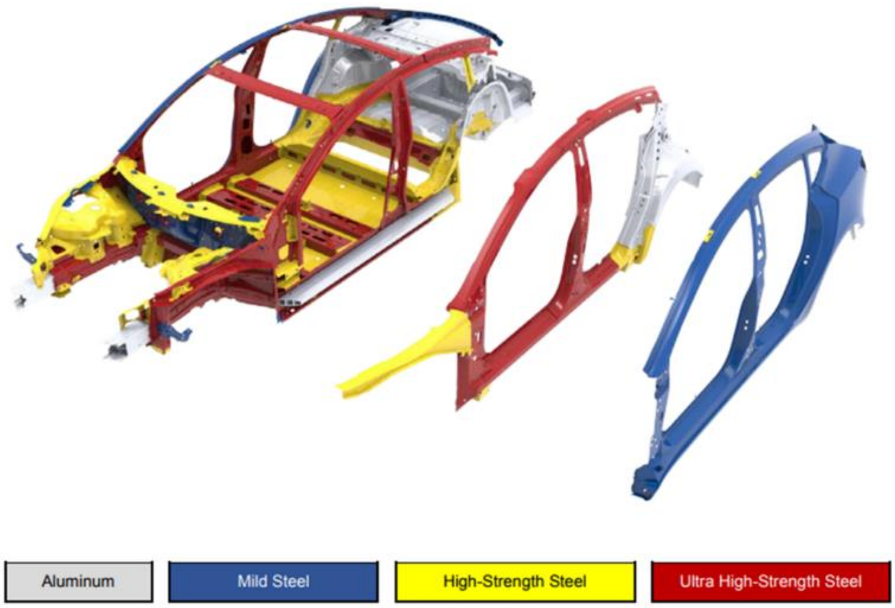

Figure 2. The Model 3 body from a front quarter exploded view [6].

2.2. Steel

Nowadays, scientists are trying to reproduce the superhydrophobic properties in nature and optimize them to obtain new materials. Rasitha et al. reported an electrodeposition method to fabricate a stable superhydrophobic coating on 9Cr-1Mo steel [9]. A two-electrode system was used to investigate the effects of applied voltage with a modified steel cathode. As shown in Figure 3, a cauliflower-like morphology was observed, and such structures can be observed in all superhydrophobic surfaces. The product fabricated at 40 V for 1o min has been proven to have an outstanding self-cleaning property due to the highest water contact angle (162.8 ± 2.4°). The slowest corrosion rate of 4.63×10^{-7} mm/y has only been found for the 40-V sample. Li et al. discovered a spray-coating procedure to create a green superhydrophobic composite [10]. Again, a high water contact angle (158.3 ± 1.7°) can be achieved if the mass ratio of nano-ZnO/PDMS is set to 1.5. In Figure 3c, the two materials combine to induce roughness and non-wetting properties on steel. The surface remained superhydrophobic (155.3 ± 2.9°) even after a 400 cm sandpaper abrasion distance. Zinc oxide nanoparticles can also be used with fluorinated polysiloxane (FPDHS) with a weight ratio of 13:7 to synthesize superhydrophobic coatings on steel substrates [11]. In Figure 3d, CH_3 and CH_2 functional groups were modified onto ZnO particles, turning them from hydrophilic to hydrophobic. With a contact angle of 166°, the coating not only displays self-cleaning properties but also resists corrosion significantly. Zheng et al. found that scaling the surface roughness into nano regions can achieve super hydrophobicity and develop durability against environmental disturbances [12, 13]. The heat treatment witnessed high thermal stability at 300 °C for 1 h, allowing electric cars to stay under the sun for a long time. As shown in Figure 3e, the air film between the sample surface, the corrosive medium, and the agglomerated silica nanoparticles can effectively avoid outside elements penetrating the sample.

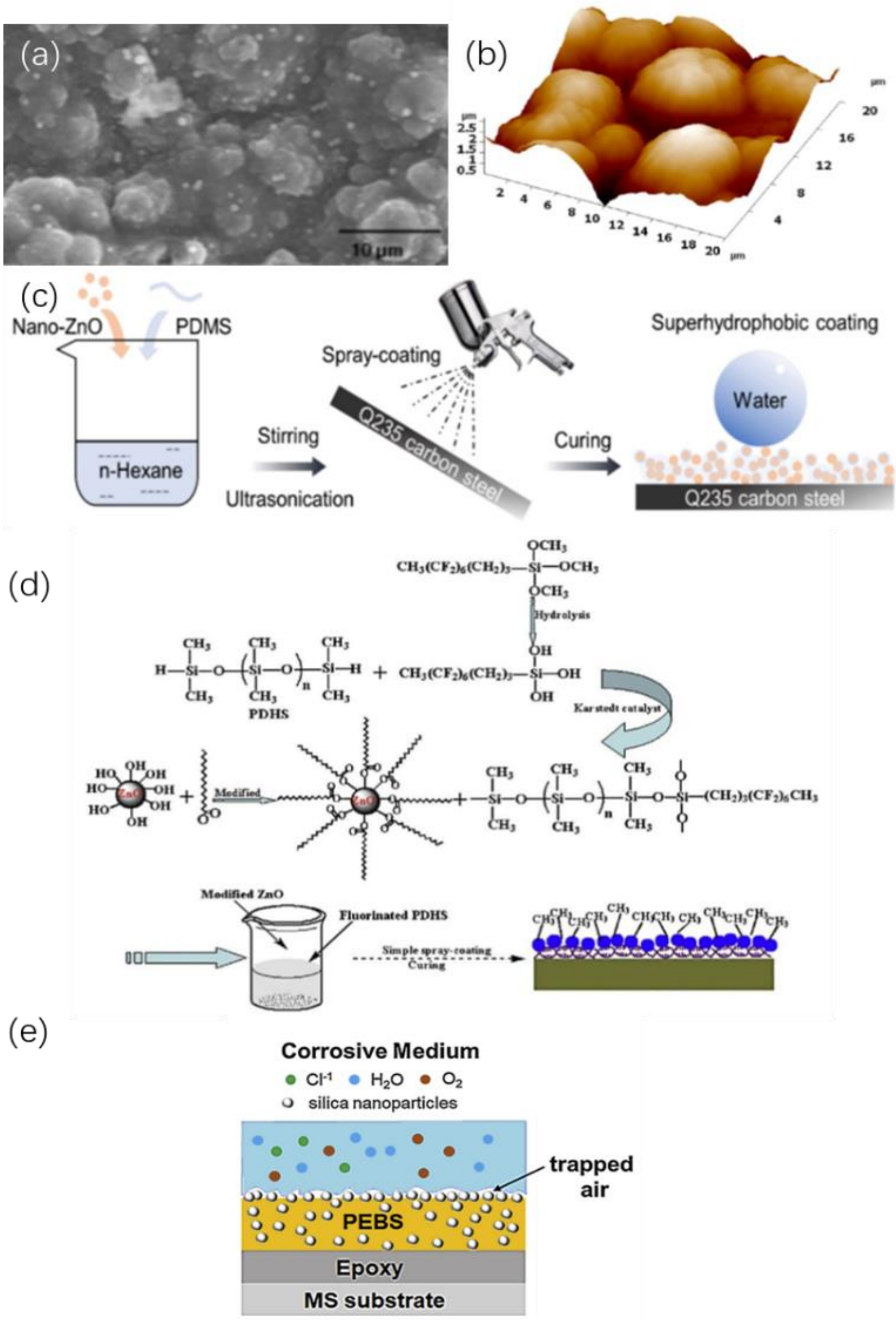

Figure 3. (a) A SEM image. (b) A 3D AFM image of the 9Cr-1Mo steel sample. They were applied at 40 V. (c) Schematic diagram of the construction process. (d) Schematic diagram of f FPDHS/ZnO superhydrophobic coating. (e) The working principle of the PEBS coated on mild steel [9-13].

2.3. Aluminum alloys

Aluminum alloys and their protection have generated great interest recently [14, 15]. The process was mainly done by the self-assembly deposition, which covered the aluminum alloy surface with TMES-modified SiO_2 nanoparticles. The resultant water contact angle was measured to be ~155°, and the corrosion inhibition efficiency of the coating was still larger than 99.5% after being immersed for 5 days. The long alkyl functional groups were grafted onto the aluminum alloy surface by STA to achieve superhydrophobic. With the boiling water treatment's porous and rough structure, the high contact angle of 155° ensures excellent corrosion resistance. An ultraviolet laser followed by chemical treatment can also be used to synthesize superhydrophobic coatings on aluminum alloy [16].

The hydrophobic surfaces were formed when the scanning was 30 μm, and the water contact angle was 156.27° (Figure 4a). The Cassie-to-Wenzel transition happened when the gap between the critical pressure and the dominant driving force became negative. The dispersive energy spectrum (EDS) in Figure 4b confirmed that the resultant surface was less polar and hydrophobic due to the new functional groups. Through high-speed electrical discharge machining, Qiu et al. produced superhydrophobic surfaces on aluminum alloys with a contact angle of 151.5° [17]. In Figure 4c, the lower solid-liquid contact area created space for air, which restrained the contact of the substrate with the salt. Barthwal et al. synthesized a superhydrophobic coating on micro-/nanostructured (MN-) aluminum surfaces via a chemical etching and an anodization method, and a vapor deposition method was used to modify the coating with PDMS to achieve anti-icing (Figure. 4d) [18]. The experiment revealed the durability of such coating at -10°C and high humidity (80%). Ice and frost propagation was slowed by the jumping of condensed water droplets and the rough nanostructure surface. It is noticeable that all the above fabrications are relatively simple, cost-effective, and efficient, which are important factors for large-scale production.

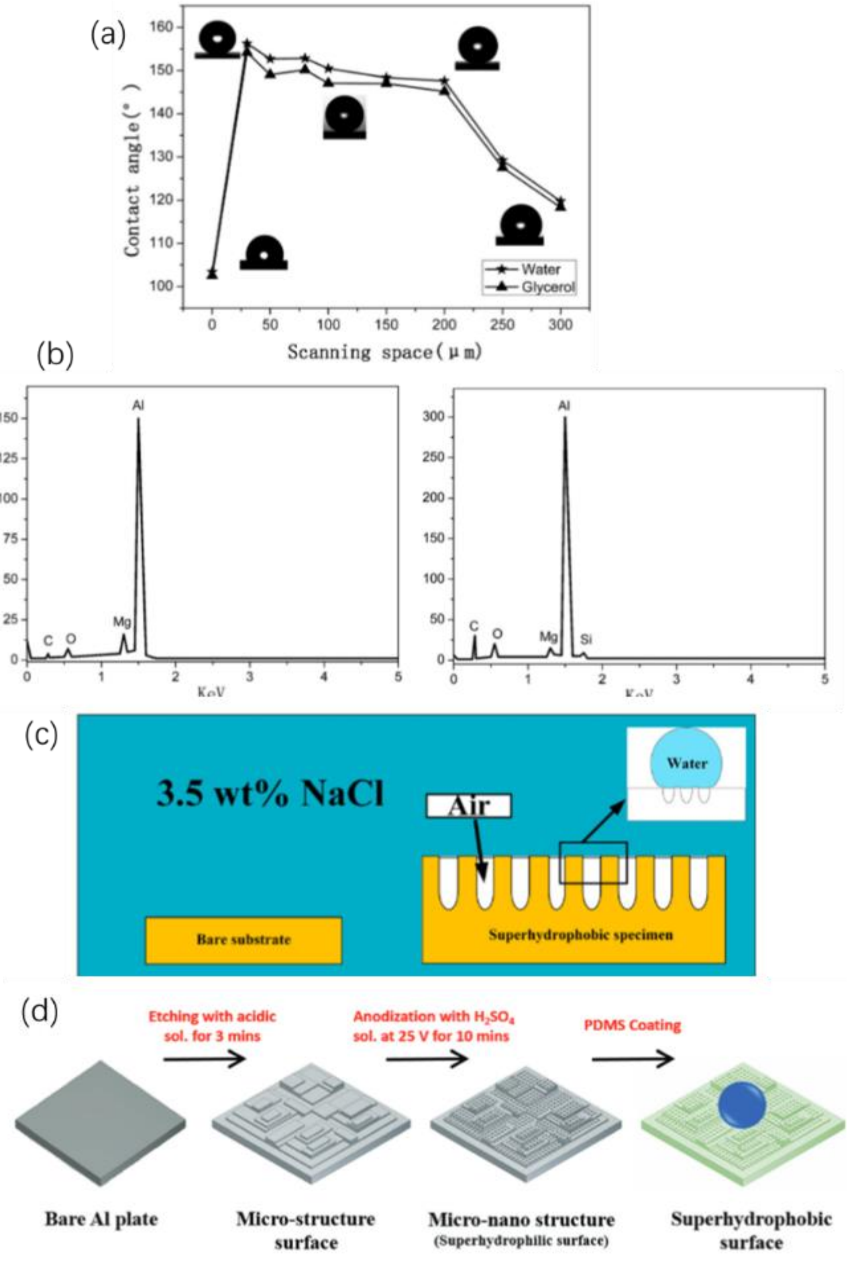

Figure 4. (a) Plot of contact angle varying with scanning space after chemical modification. (b) The EDS spectrum. (c) Corrosion models of the original substrate and superhydrophobic specimen. (d) Scheme of preparation [14-18].

2.4. Windshields

Compared to the coatings on the previous two substrates, the materials used for superhydrophobic surfaces on windshields must be transparent. With an alternative dip and spray deposition approach, Sutar et al. successfully prepared superhydrophobic PVC/SiO_2 coating [19]. Specifically, silica nanoparticles were sprayed three times on the glass substrate, which was covered by a layer of polyvinyl chloride. It has been found that the rough surface exhibited the highest water contact of 169 ± 2° only when 3 layers of the coating were applied, as shown in Figure 5a. Spray-method is also accessible on glass panels by organic Polydimethylsiloxane (PDMS) polymers and inorganic nano-support for the embedded silica nanoparticle to make the coating superhydrophobic (Figure 5b) [20]. The thickness of SNS was controlled by an OSP scraping ink bar, and the contact angle was measured to be 163°. In Figure 5c, Sriram et al. combined sol-gel of PMMA, SiO_2, with a dip-coating technique [21]. The transparency was believed to exceed 91%. In general, most hydrophobic glass coatings contain polymers that do not absorb the wavelength of any visible light, so the size of the introduced nanoparticles must range from 1 to 100 nm [22].

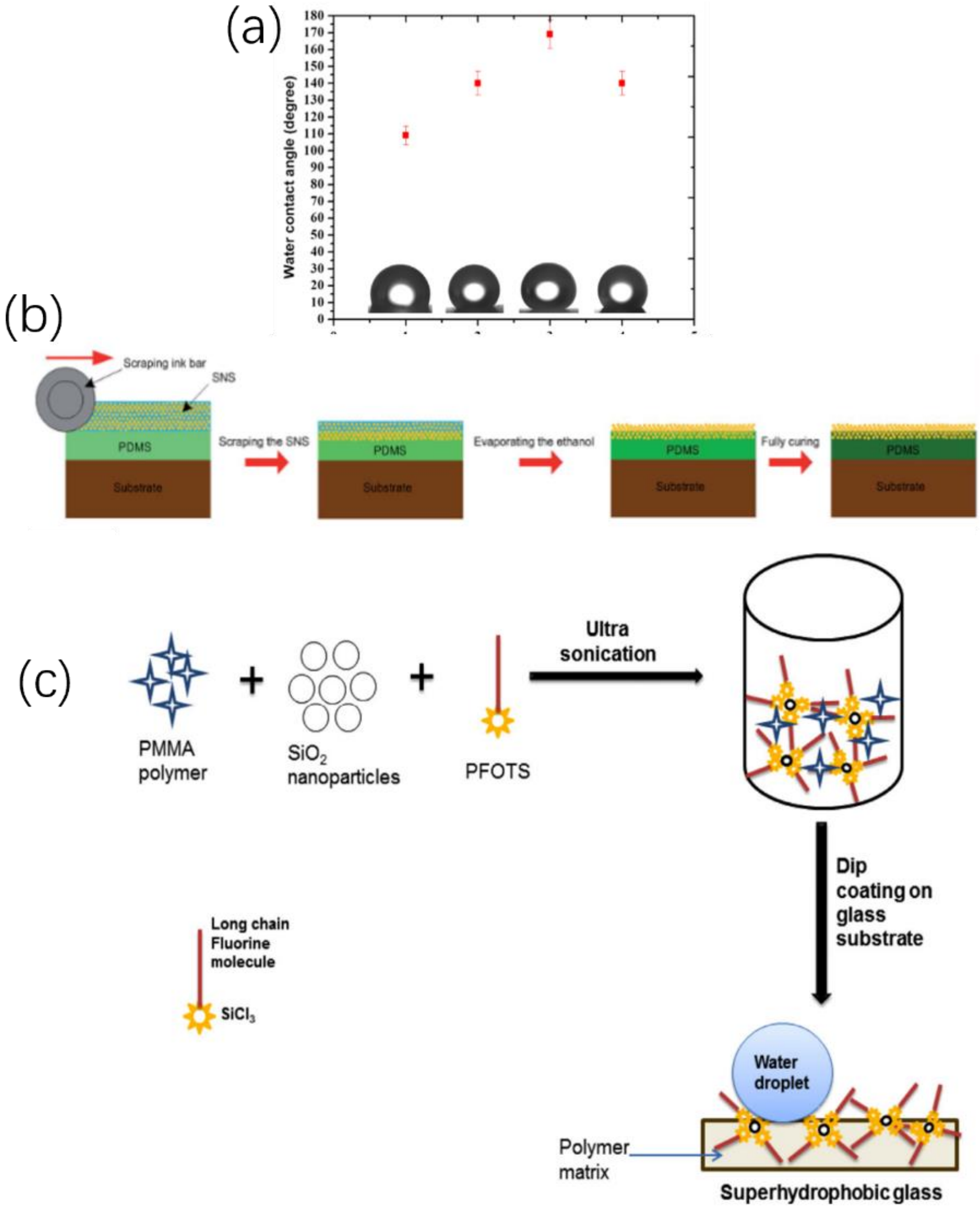

Figure 5. (a) The variation of water contact angle as a function of many SiO_2 particles and polyvinyl chloride. (b) Schematic of mechanism of PDMS coating. (c) Fabrication of PMMA, SiO_2, and PFOTS superhydrophobic coating on the glass [20-22].

3. Car frame material

3.1. Material frequently used in the frame of family cars

The aim of the car nowadays is to be lightweight. There are several benefits of lightweight. Reducing vehicle weight can reduce the running resistance and save the energy required for traction and braking. Reducing the pressure on the road surface reduces the wear of the wheels and the road surface. Increasing the vehicle speed. Three main materials are used in vehicle frames: metal, composite, and nanomaterials. In the new lightweight process, commonly used materials include various high-strength steel and aluminum alloys [23].

3.2. Properties of different materials

3.2.1. Aluminum alloy and steel in the car frame

The hot forming of steel is a complex process. It requires a complex heating procedure to make the material reach the ideal state, and then mold the material in this state and rapidly cool at the critical cooling rate to finally generate the desired microstructure. Complex parts with excellent strength performance can be produced through heating, heat preservation, molding, and rapid cooling [24].

Although steel is still the first choice for automobile manufacturing, aluminum can still be a potential material. The density of aluminum is only 1/3 of steel (Figure 6). High-strength aluminum alloy can meet the stiffness and torsional requirements of automobile components. At present, the application of aluminum alloy is mainly in the casting of engine parts and the transmission unit of transmission. The application of aluminum alloy is aa5754 alloy used in various sports cars.

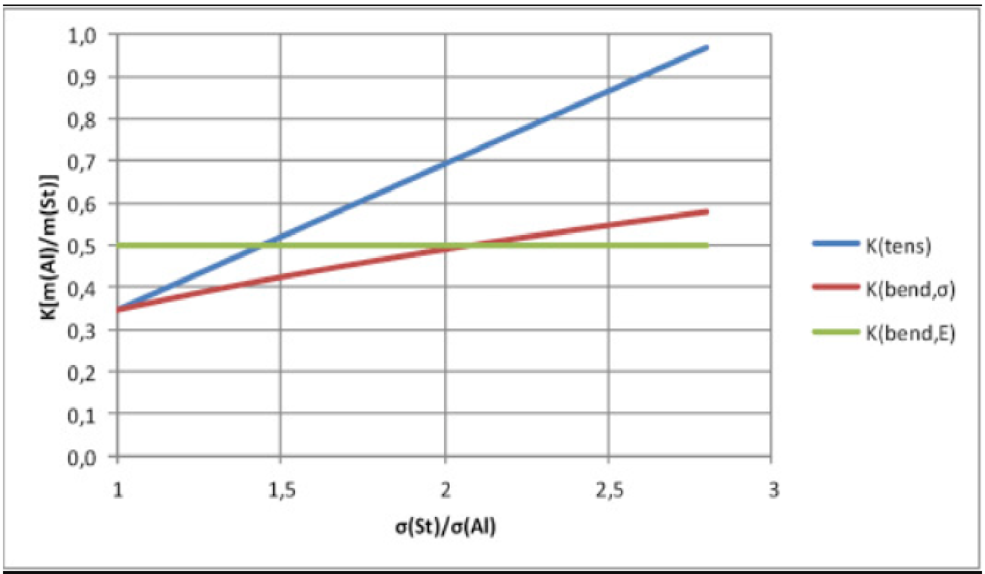

Figure 6. Yield strength vs. density graph of steel and aluminum

3.2.2. Carbon fiber in the car frame

Carbon fiber is a new material with high strength and modulus. It can work in high temperatures, withstand strong acid and alkali environments, has a long service life and is not easy to deform due to temperature changes, making carbon fiber materials have good application in harsh environments.

Although carbon fiber has many excellent properties, it is very sensitive to light, so it must be well protected. Carbon fiber has very good anti-fatigue properties, but this also means that it is difficult for people to detect that the material has reached a critical value. Once damage occurs, the damage will be great. Of course, the material formula of carbon fiber is different, and it can also become very soft. This soft material can be used to make fire-fighting clothes. Because carbon fiber is non-toxic, bio-inert, and permeable to X-rays, it can also be used in the medical field. However, although carbon fiber is non-toxic, it still has certain irritation, so the contact time needs to be limited [25].

3.2.3. Advantages of nanomaterial

With low density, it can meet the requirements of lightweight vehicles, thereby achieving energy conservation and emission reduction and reducing pollution to the environment. It is an environmentally friendly material. Carbon fiber composite materials have good plasticity and can be easily processed into various complex shapes according to the user's needs, including curved shapes that are difficult to be processed by some metal materials, which is conducive to the realization of the integrated overall structure of the automobile body. For example, if all seats in the car are designed as a whole, and metal materials are applied, about 50-60 parts need to be welded. Carbon fiber composite parts must be greatly reduced, simplifying the production process, and improving work efficiency. Carbon fiber composite has good energy absorption performance. When applied to the car body, it can play the role of cushioning, shock absorption, and energy absorption when it is impacted, and the car's safety performance can be greatly improved [26, 27].

3.3. Development of lightweight nanomaterial

In the 1960s, people began to study nanomaterials. In 1963, Uyeda produced metal nanoparticles by gas evaporation and condensation. The development of nanomaterials can be roughly divided into three stages: Before 1990, people mainly explored the fabrication of nanocrystalline or nanophase materials and studied the differences between such materials and ordinary materials. From 1990 to 1994, people began to study and design composite nanomaterials, trying to find out these materials' physical and chemical properties. After 1994, the nano assembly systems became the dominant direction. Their basic meaning is to take nanoparticles and nanowires as basic units and assemble them into nanostructured systems in one, two, and three dimensions. In the 1960s, f1 racing cars first introduced an integral car shell, which significantly improved the stiffness of the vehicle chassis. In the late 1970s, people found that mainstream aluminum materials could not withstand downforce, so the first carbon fiber self-supporting chassis was born [28].

4. Batteries

4.1. Current situation and development trend of electric vehicle battery

Gaston Plante invented the lead-acid battery in 1859. Most batteries in today's fuel vehicles use lead-acid batteries, mostly used to ignite, or increase engine power (electric power assist). Table 1 shows the performance and application of lead-acid batteries. The data for electric vehicle battery packs in the table are drawn from data published by some Chinese electric vehicle battery manufacturers and made available in the document [29].

The nickel hydroxide anode in the nickel-hydrogen battery is composed of multiple alloys of vanadium and other metals. Table 2 shows its performance indicators and application in electric vehicles [30]. Compared with a lead-acid battery, the specific power of NiMH battery is increased by 10 times, and the energy density is increased by 3 times. It also shows faster charging and discharging performance, safer overcharging technology and higher specific capacity.

Table 1. The data of electric vehicle battery pack module of 6DM150 sealed lead-acid battery for electric vehicles [29].

The lead-acid battery	Data
Specific Energy/(Wh/L)	30-50
Energy volume density/(Wh/L)	60-75
Specific energy/(W/kg)	90-200
The number of cycles	500-800
Monomer volt/V	2.105
The capacity of the battery pack/(Ah)	150
Mass of battery pack/kg	42
Battery cell voltage/V	12

The nickel-hydrogen battery is the most competitive in the application of electric vehicles [31, 32]. Nickel zinc batteries produce dendritic crystals more easily than nickel-cadmium batteries, so their service life is very short. So, it is the most widely used. Some methods to improve the performance of these batteries include charging with the third electrode and adding corrosion inhibitors to the electrolyte, but these require increased costs and support from other technologies [33]. This is mature battery technology at present. The current battery cannot meet the demand, so the nano battery materials need to be updated.

Table 2. The data of the electric vehicle battery pack module of QNFG90 nickel-hydrogen battery for electric vehicles [30].

Nickel hydrogen battery	Data
Specific Energy/(Wh/L)	30-100
Energy volume density/(Wh/L)	140-490
Specific energy/(W/kg)	250-1200
The number of cycles	500-1500
Monomer volt/V	1.2
The capacity of the battery pack/(Ah)	90
Mass of battery pack/kg	2.2
Battery cell voltage/V	1.2

4.2. Study on nanomaterials for batteries

First, nanotechnology materials have a high specific surface area, leading to extremely high activity. Its activity mainly comes from the atomic force on the surface of nanoparticles. The internal atoms of the substance and the atoms on the surface of the substance are subject to different forces. The internal atoms are in the mutual balance of various forces. In contrast, the atoms on the surface of the substance particles have extremely high unsaturated properties due to the existence of many dangling bonds and are extremely easy to combine with their adjacent atoms to form a stable state, so they have extremely high activity [34]. In addition, the smaller its size is, the more effectively it can resist the mechanical damage of particles and electrode layers. Moreover, the faster the charging and discharging speed, the greater the stress. In order to effectively control the stress generated by the lithiation reaction, the particle size should be smaller than this critical particle size to reduce particles' cracking and crush behavior [34]. Finally, with strong specific surface-active energy and good electrical conductivity, when participating in the electrochemical reaction, nanoparticles form a new active material core inside the electrode plate, greatly improve the electrochemical reaction surface of the electrode, enhance the electrode structure, and reduce the energy barrier of electrochemical reaction [34].

4.3. Amprius' 100% silicon nanowire batteries

The chemical reaction is the main reason for the slow improvement of the battery. In traditional lithium-ion batteries, graphite is mostly used as the anode, but the research and development of graphite are approaching the limit. As shown in Figure 7, the high-precision image of silicon nanowires is given.

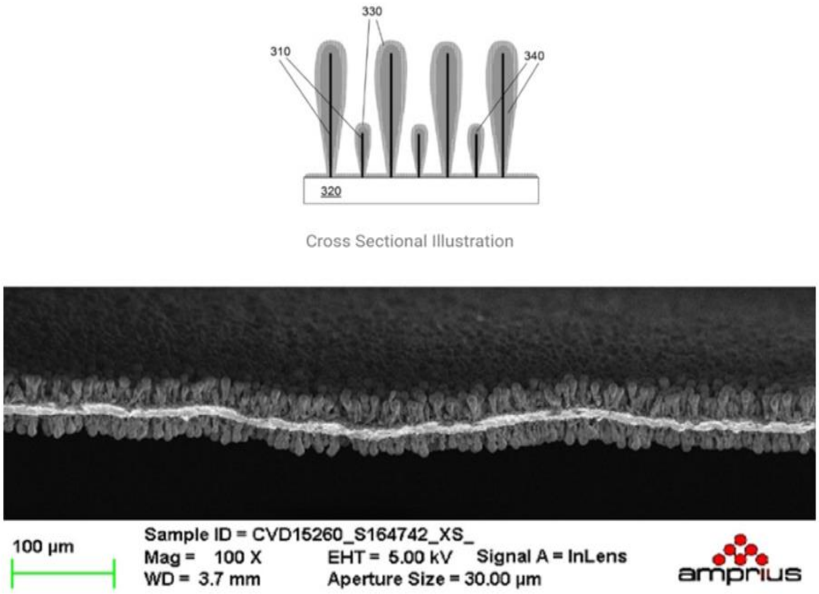

Figure 7. Cross-sectional image of an anode of a silicon nanowire material [35].

Due to the high expectations of various industries for lithium-ion batteries, a new anode material, silicon, is needed to improve battery performance. Compared with graphite, silicon can store up to 10 times lithium, providing more battery energy. However, when the silicon is charged with lithium, it will expand rapidly, which will cause the silicon to break and stop working. Silicon has a specific capacity of 4200 mAh/g, more than 10 times that of carbon-based materials. It is the highest specific capacity known negative electrode material at present. However, carbon-based materials are currently the most widely used negative electrode materials, with a theoretical specific capacity of 372 mAh/g. So, silicon nano anode materials can provide a higher battery capacity than lithium-ion batteries [35].

Because of the unique nature of nano battery materials, they can be quickly charged and discharged at low temperatures. So, nanowire technology can achieve the highest energy-to-power ratio [35]. It has excellent cycle life, and the silicon nanowire battery is constantly improving. It has been proven in the practical application of many companies and enterprises [35]. Silicon nanowire batteries are now partially used in various applications, and their high energy density and long battery life make them useful in many industries. Such as electric cars, aircraft, military, and collapsible devices. As shown in Figure 8, it can be used in these fields. It may enter every household in the future and serve all walks of life [35].

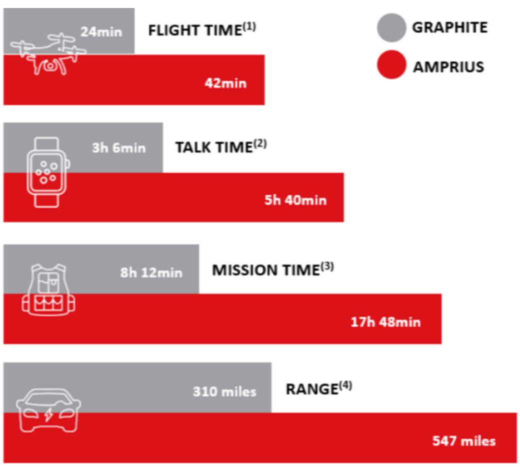

Figure 8. (1) Flight Time-estimated based on customer-generated models for a balanced power and energy cell design. (2) Talk Time -customer reported data for an energy cell design. (3) Mission Time-results from Conformal Wearable Battery developed for US Army for an energy cell design. (4) Range-estimated for a Tesla Model 3 long-range battery specifications for an energy cell design [35].

5. Conclusion

New energy vehicles have become the future development trend. In order to further improve the vehicle performance, the vehicle body structure, batteries, and surface coatings have been improved. Nanomaterials are regarded as a key research object.

Super hydrophobic coating is becoming more and more important for vehicles. It can make the vehicle body easier to clean and prevent the vehicle from freezing at low temperatures. This material is usually used on the vehicle surface and glass. Nanomaterials have become the main development direction in the future because of their high temperature and corrosion resistance. The main research direction in the future is how to reduce the cost of hydrophobic coatings and improve materials' hydrophobicity.

Carbon fiber is a nanomaterial commonly used in car body structures, which has good fatigue, heat, corrosion, and many other properties. However, it is relatively brittle and sensitive to light, so it is necessary to study the protective measures of carbon fiber and the emergency plan in case of fracture in the future.

At present, lead-acid battery is commonly used for ignition and increasing engine power of vehicles, but they cannot meet the demand for electric vehicles. Compared with traditional materials, nanomaterials have high specific surface-active energy and excellent conductivity and can enhance the electrode structure. Silicon nano anode materials are commonly used as nano electrode materials, providing higher lithium-ion battery capacity. Nano battery has excellent cycle life, high energy conversion efficiency and other advantages, and will play a role not only in automobiles but also in home appliances and other diverse fields in the future.

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