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Research progress and application of spherical solar cell in solar car

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Abstract. Along with the economic development of China, all industries have faced new opportunities. However, the fast development of the automobile industry has also negatively impacted environmental resources, such as petroleum resource consumption and environmental pollution. In order to protect the environment and travel green, this paper analyzes the progress of solar energy applied to cars as clean energy. First of all, this paper explains the working principle of solar cars and how to convert the collected solar energy into electric energy to store or provide kinetic energy for the car. Further, since the loss of air resistance of the car accounts for up to 60%, this paper analyzes the modeling and design principles of the solar car through aerodynamics. In addition, this paper focuses on the solar panel-related content, which is the core part of the solar car, puts forward and introduces the spherical solar cell not popular in China, and finally puts forward relevant suggestions for the pilot of the solar car. Reducing the kinetic energy loss caused by air resistance and improving the efficiency of solar energy conversion should be the focus of the future development of solar vehicles.

Keywords: solar car, ball-type battery panel, aerodynamics.

1. Introduction

As the social economy was growing, the frequency of car ownership also increased, which has negatively impacted people's living environment, particularly in terms of energy conservation and environmental protection. The car industry is currently working to develop new energy carriers and reduce their dependence on oil. As a result, the primary research area for the creation of new energy cars is the use of solar energy, wind energy, nuclear energy, and other sources of power for battery capacity, especially solar energy having the greatest development prospects.

Chinese first solar car completed a test firing in 1984. Chinese first solar car, with a maximum speed of over 88 kilometers per hour, was shown in Nanjing in 2006 [1]. Solar energy has not yet become a hot location for renewable power automobiles since it is difficult to generate enough energy, but Tesla is set to break through this assertion and can begin with Cybertruck. Tesla CEO Elon Musk stated that the forthcoming electric pickup truck could feature a solar roof, improving a car's everyday range by 24 kilometers for the first time, and a solar storage system has been built since Musk proposed the idea of a solar roof in 2017. Solar power is not unprecedented for electric cars. The latest Toyota Prius, which has solar panels on the roof, adds two miles (3 km) to the car during the day, but ultimately depends on where and where the car stops. Whether Tesla can break through the limitations of the technology can wait until the Cybertruck is public. There have been many new energy cars with electric systems and gas in China, and the real pure solar cars are still mostly in the experimental stage. Among them, Hanergy has broken through the technical restrictions and has released four solar cars, the world's first thin-film solar power car, which can drive 80-100 kilometers per day, and the maximum range of battery can reach 350 kilometers.

The energy of solar cars is inexhaustible, and solar cars have no exhaust emissions, but how to arrange the solar car solar cells to reach the maximum energy efficiency is the main problem of solar cars. Japanese researchers developed spherical solar cells because the battery is flexible, so the cell can be installed in the body for each surface position. If the sphere 360 degrees rotating Angle effect, combined with the sun tracker, makes the battery by its shape, constantly with the sun to keep maximum energy Angle, it can further improve the efficiency of solar energy conversion and can control the solar cell number on the limited body area, better to carry out the practical solar car body shape design, thus the energy utilization rate of the maximum. With the maximization of solar energy utilization, solar cars can save more energy for daily travel. The Power system controls and manages all the power to enter and exit the system. The storage battery is equivalent to a fuel tank in a conventional car. A solar car uses a storage battery to store the energy that can be used at a certain point later. However, another consideration is how to efficiently convert the collected solar energy into electricity for the car and store, which involves using smart photovoltaic charging systems. The intelligent photovoltaic charging system mainly comprises solar photovoltaic panels, a power monitoring module, STM 32 SCM, an MPPT module and a battery, which converts the collected solar energy into the electric energy needed by the car through a series of transformations. The core control unit of the smart PHOTOVOLTAIC charging system is STM 32, which controls the duty cycle of the inverter circuit in MPPT through the timer of STM 32. The inverter realizes the alternating current into direct current and stores the DC current in the battery, and the charging system is automatically turned off when the power is fully charged. If all the electricity is saved, the solar car range can be enhanced.

2. Construction and principle of solar cars

2.1. Structure of solar cars

A solar car is a car that relies on sunlight to drive it. It is truly zero emissions. As a kind of renewable energy, solar energy has a good application prospect in automobile new energy. Compared with traditional internal combustion engine-driven cars, solar cars lack the exhaust gas generated in fossil fuel combustion. Due to their special contribution to environmental protection and energy conservation, solar cars are gradually entering people's sight and life, and their related industries are also developing with a vigorous attitude. Solar car mainly consists of the body, chassis, motor, control system and, most important solar panels, and the design of the body reduces the air resistance in the process of driving to the minimum, which is one of the initial and most important problems of solar car production so that the car to ensure safety at the same time, the car endurance is better.

2.1.1. Design of solar car (using aerodynamics). The most special part of the solar car is the body. The body of a solar car comprises several parts, but each car is unique because there are no written standards other than space constraints. The main goal of designing the car body is to minimize air drag and maximize solar energy utilization. Of course, minimizing mass and maximizing safety is also very important. Wind resistance is the biggest aspect of automobile energy consumption. A car running at 80km/h consumes 60% of its energy in wind resistance. Therefore, reducing wind resistance by changing car streamlining is particularly important.

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As can be seen from the body pressure cloud map Figure 1, the airflow is obstructed in the front of the car, which slows down the airflow flow speed, resulting in the maximum positive pressure in the front face of the car body. The flow of air through the car's upper surface changes at the front window, creating a small area of high pressure. Then, when the air flows through the connection between the front wind window and the roof, the direction of the airflow changes, and the airflow begins to flow back along the horizontal direction of the roof while the air flow rate increases and the negative pressure area appears. When the airflow flows through the rear window, the airflow gradually slows down and then separates again, resulting in a small increase in the pressure between the rear window and the trunk cover [2].

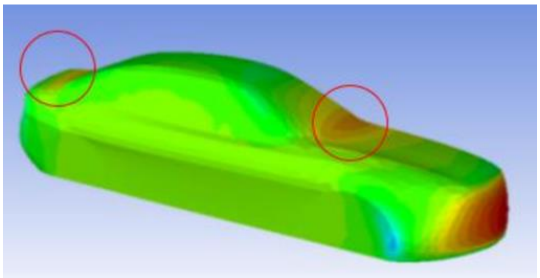

Figure 1. The pressure distribution of a car in motion(a)[2].

The deeper the red value is, the greater the pressure value is. It can be seen from the figure that the pressure value of the head part is the largest, and then the pressure value of the two box selection areas in the above figure is larger. Since the model of the head part is complicated in the modification process, the head part should not be too narrow to be modified [2].

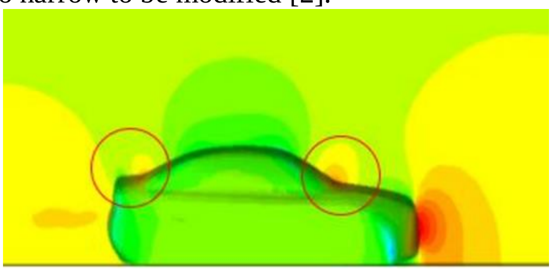

Figure 2. The pressure distribution of a car in motion(b) [2]

As can be seen from the body velocity vector diagram (Figure 2), the airflow at the head and tail of the vehicle is relatively complex. The airflow is obviously blocked at the intersection of the front wind window and the engine hood, and the velocity decreases significantly. Then, when passing through the roof of the car, the airflow velocity increases until the airflow reaches the maximum speed at the rear wind window. The air velocity drops again in the rear wind window and trunk, creating a stagnant zone. Finally, the airflow reaches the tail of the vehicle, and the side airflow and the bottom airflow converge to produce a vortex. As shown in Figure 3, the vortex at the rear of the vehicle can consume a certain amount of energy, which can affect the aerodynamic drag value of the vehicle. Therefore, it is important to reduce wind resistance by changing the car's streamline [2].

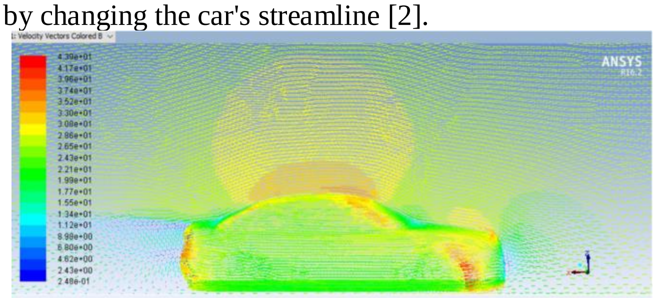

Figure 3. The pressure distribution of a car in motion [2].

Therefore, the overall body shape is related to the size of the wind resistance, in which the change of the three key parameters, the angle of the front window, the angle of the rear window and the angle of the trunk cover, has a great influence on the reduction of the wind resistance coefficient. By reasonably adjusting these parameters, the vehicle shape's design maximizes wind resistance [2].

2.1.2. Automobile exterior pneumatic trim. With the research of aerodynamics in China, the effective measures to reduce the aerodynamic coefficient of the automobile are not only based on the model. Automotive design engineers began to use a variety of pneumatic trim, as shown in Figure 4, such as air dam, full coverage bottom guard plate, front protection duct, tail fin, and automotive exterior decoration commonly used in the form of air dam spoiler, to reduce the coefficient of automotive wind resistance. The future development of automotive exterior parts is mainly from aerodynamics, decoration, integration, lightweight, etc. With the further development of the automobile industry, intelligent pneumatic trim has begun to be used on middle and high-end vehicles, such as the active intake grille that can balance the heat dissipation and drag reduction needs, the active tail that can balance the vehicle handling stability and drag reduction needs, and the active air dam that can balance the low speed and high ground clearance and high-speed drag reduction needs. In addition, the aerodynamic study found that the overall surface of the body smooth can reduce aerodynamic separation, reduce air resistance [3].

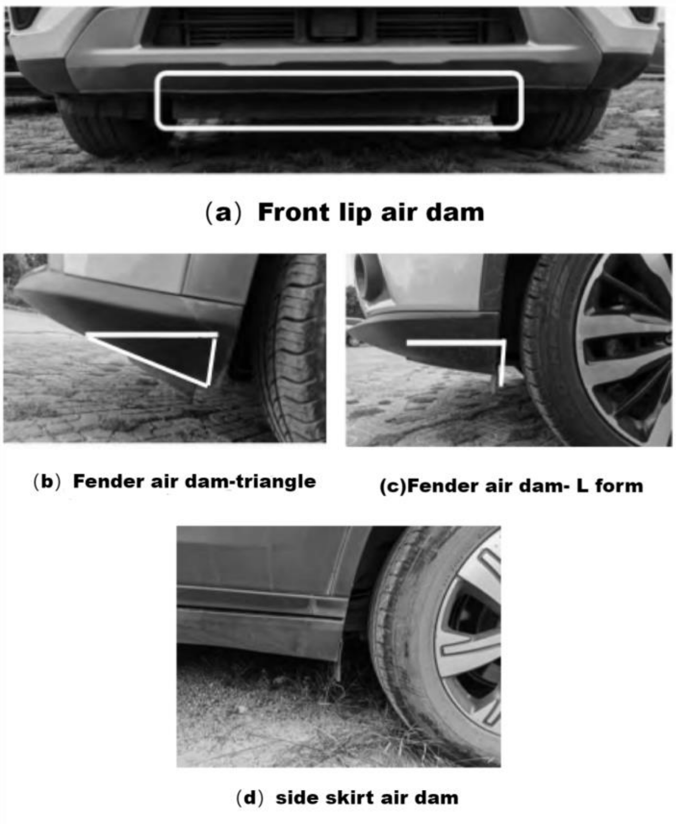

Figure 4. Different kinds of air dam [3].

2.1.3. Full coverage bottom guard plate. However, with the pursuit of consumers for styling personality and beauty as well as the requirements of the basic functions of the car, the visible surface of the body without accessories can not be realized, so the bottom of the body is smooth and flat, has become the first choice to reduce the coefficient of wind resistance. However, the complex structure of the chassis can have a great impact on the airflow at the bottom of the car. As shown in Figure 5, adding pneumatic trim to the bottom of the car has become a common solution for the full coverage of the bottom guard plate of a model to achieve the smooth and flat bottom of the body to the greatest extent [3].

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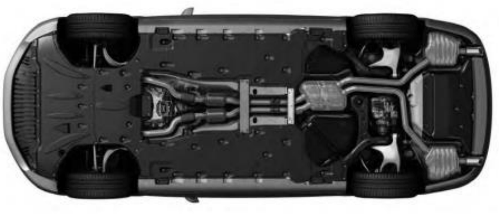

Figure 5. Full coverage bottom guard plate [3].

2.2. Electric motor of solar cars

As shown in Figure 6, the working principle of a permanent magnet synchronous motor is electromagnetism. When plugged in, the coil in the motor can create a magnetic field and then rotate due to the internal magnets repelling each other. The greater the current, the faster the coil rotates. What's more, the advantage of using a permanent magnet synchronous motor is its small size and light mass, which can save much space; in addition, the use efficiency of a permanent magnet synchronous motor is extremely high, for its high power density guarantee the working efficiency of the motor can reach 97%, which ensures the power and acceleration for the car. But the disadvantage of the permanent magnet synchronous motor is that it is expensive and requires rare earth, a scarce resource, as a material. And as is known to all, China has the least rare earth storage among all countries in the world, and in the meanwhile, China's total production of magnetic materials accounts for 80% of the world, so domestic electric vehicles basically use permanent magnet synchronous motors, such as BAIC New Energy, BYD and Xiaopeng Automobile.

Figure 6. Permanent magnet synchronous motor.

As shown in Figure 7, different from permanent magnet synchronous motor, though AC asynchronous motor can be regarded as the principle of electric magnetism, it adopts the design of coil and iron core, which can emerger magnetic field after electrification, and the direction and size of the magnetic field can change with the change of current.

Although there is no high power of permanent magnet synchronous motor, the price of an AC asynchronous motor is relatively low; therefore, it can get an ideal prime cost. However, the large volume also takes up a certain amount of car space, in addition to high energy consumption is also a big disadvantage, resulting in very low operating efficiency. Therefore, the ac synchronous motor is used in new energy buses, and Tesla is also a car brand mainly using AC asynchronous motors.

Figure 7. Asynchronous AC motor.

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2.3. *The driven way of solar cars*

The drive and transmission systems of solar cars are very different from traditional cars. The drive and transmission of a solar car are through the motor power transmitted to the drive parts of the drive wheel. Due to less power generated (less than 5 hp), only the wheels behind a car are usually driven by an electric motor. There is no limit on the type of motors used in solar cars, and the driving force is generally between 2 and 5 hp. The most widely used in solar cars is a brushless double-curved DC motor, which is quite light and can achieve efficiency at 98% at a certain rotational speed.

For automotive photovoltaic systems, the ideal equivalent internal resistance of the photovoltaic array is a fixed value. If the equivalent load of the vehicle is also considered as a fixed value, then the automotive photovoltaic system and the vehicle load can be regarded as a simple linear circuit, as shown in Figure 8.

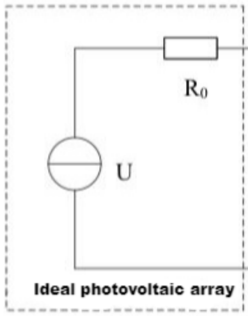

Figure 8. The equivalent linear circuit of the auto PV system and vehicle load.

In Figure 8, Ro is the equivalent internal resistance of the photovoltaic array, and R is the equivalent resistance of the automotive load. According to circuit theory, the output power of the photovoltaic system is the power of resistor R.

$$P_{R_i} = \left(\frac{U}{R_0 + R_i} \right)^2 \times R_i \tag{1}$$

As shown in Figure 9, the solar photovoltaic panels directly convert solar energy into clean energy, and then the STM 32 SCM system brings a current sensor and applied voltage sensor to monitor the power of solar photovoltaic panels in real time. When the charge state of the battery is greater than 90%, the power supply is not needed; when the battery charge state is less than 90%, the SCM can issue instructions to control the charging system. The MPPT module uses the algorithm to track the maximum power point of the solar photovoltaic panels. The core control unit of the smart photovoltaic charging system is STM 32 SCM, which controls the duty cycle of the inverter circuit in MPPT through the timer of STM 32, and then the inverter converts the AC power into DC power and stores it in the battery, so the charging system can automatically turn off when the power is fully charged [4].

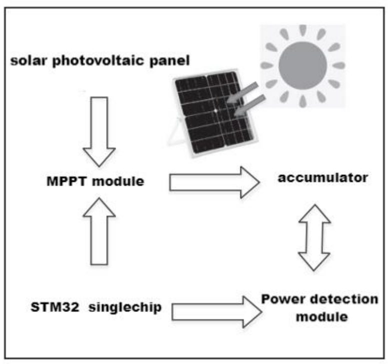

Figure 9. Smart photovoltaic system [4].

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2.4. The operational principle of solar car

As shown in Figure 10, under the control of the solar tracker, the solar panels receive the sun's light and convert it into electricity, stored in the high-energy battery of the power system, and then powered by the motor to drive the car, that is, the solar energy-electric energy-kinetic energy conversion mode. In addition, some solar cars, in the starting process, can also be part of the solar energy through the current converter directly into the engine, using the dual-coil AC brushless machine system to drive the car, namely the solar-kinetic energy conversion mode.

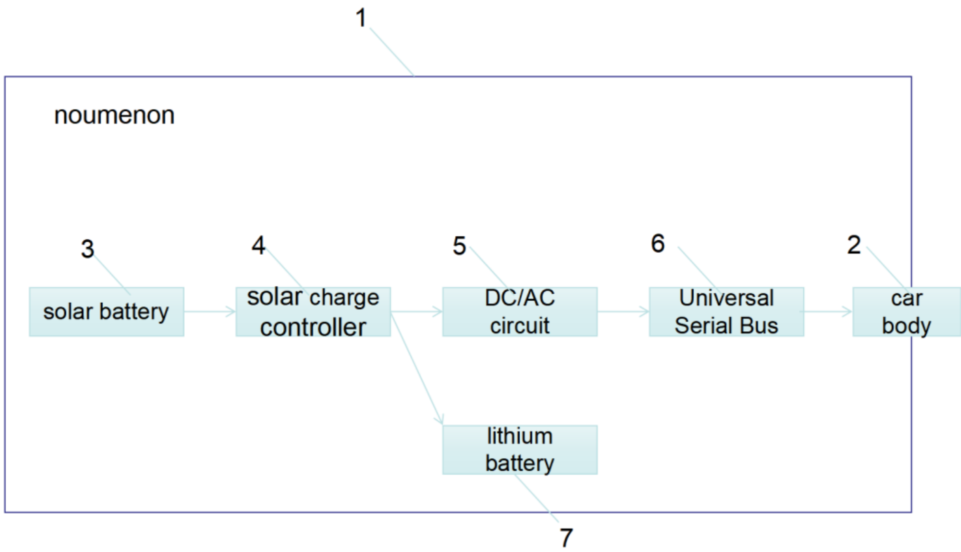

Figure 10. The operational principle of the solar car [5].

3. Solar panel

3.1. Crystalline silicon solar cells and thin-film solar cells

When it comes to solar cars, you can't get around the solar panels, and we can call them the soul and core of the existence of solar cars. According to the classification of semiconductor materials, the usual solar panels are divided into flexible gallium arsenide cells, cadmium sulfide cells, monocrystalline silicon cells and so on. Among them, the monocrystalline silicon panel has the most widespread use and the advanced gallium arsenide membrane cell, created by Alta Solar Thin Film Technology manufacturer, has the highest conversion efficiency, with the highest conversion efficiency of 31.48%. These different kinds of photovoltaic panels collect sunlight in the sunlight and convert it into electricity, and then partly supplied to the engine and partly stored in the battery to provide the necessary power source for subsequent driving, achieving a true sense of zero-emission. The solar car is mainly composed of a solar panel circuit system, drive system and control system. In a single sentence, the specific role of solar cars--when sunlight shines on solar arrays, cells can produce currents.

Solar panels are composed of multiple monomer solar cells connected together by series or parallel solar panels to provide electricity for cars, which are divided into three parts. The first part is to protect the panels from toughened glass, which requires high light transmittance and needs super white toughened processing to ensure the efficiency of solar panels' receiving from sunlight. The second part is EVA to bond and fixes toughened glass and cells. The third part is also the core part. It is the body of the power generation, which is the battery. The rest is to support, seal, and protect the power generation system, such as the backplane, aluminum alloy protective laminating parts, junction box, etc. As shown in figure 11, most of the cells that have been put into production and used today are crystalline silicon solar cells and thin-film solar cells.

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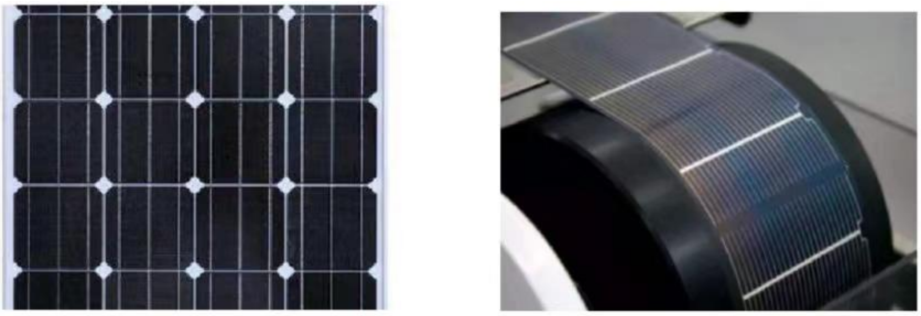

Figure 11. Crystalline silicon solar cells (left) and thin-film solar cells (right) [5].

Both have advantages in terms of manufacturing cost, photoelectric conversion efficiency and battery consumption. For now, crystalline silicon, especially monocrystalline silicon photovoltaic material, is the mainstream material in solar panel production, and it has a low cost in manufacturing and high efficiency of up to 24% in photoelectric conversion, but also it can have the life lasting for 25 years under the toughened glass and waterproof resin seal, making it is the mainstream material of the production of solar panels. Compared with crystalline silicon solar cells, another kind of amorphous silicon panels greatly simplified the process, represented by the new membrane solar panels, but also can generate electricity in low light conditions. However, the efficiency of photoelectric conversion is very low, generally not used as a car driving force, but it is believed that it can be used in part of the internal system of vehicles, such as audio, air conditioning and low energy consumption equipment. In membrane cells, the other solar cell is a cell composed of diversified material, assuming cadmium sulfide solar cells, arsenide solar cells, copper steel selenium solar cells, etc. These multiple semiconductor materials can expand the solar absorption spectrum and improve the photoelectric conversion efficiency, but it is still at the end of industrial production. Among them, gallium arsenide thin film technology is mastered by Hanergy Solar Automobile Company, and its highest conversion efficiency can reach more than 30%. In contrast to conventional solar cells is the flexible thin-film solar cell, whose PVC back and ETFE film cover, as the name suggests, omits the glass plate and supports these weight objects, reducing its weight by 80% [6]. In addition, spherical solar cells developed in Japan have high transparency, and a high volume ratio can be applied to a variety of curved surfaces, as well as solar panels that can change the reception Angle according to the sunlight exposure and so on. However, compared with these flat batteries, better spherical batteries can be used in future cars, which have a higher solar utilization rate.

3.2. Spherical solar panels

Recently, spherical solar cells have drawn attention mainly because spherical solar cells, which are produced directly from molten silicon, significantly reduce the waste of raw materials by eliminating "Kerf loss" caused by slicing silicon ingots into wafers in the conventional method [7]. As shown in Figure 12, the spherical solar panel Sphelar was developed by Sphelar Power of Japan through microgravity. Through different connections, you can pattern a single spherical solar cell into the style you want.

Figure 12. Spherical solar cells [8].

Texas Instruments (TI) has studied a similar approach, using spherical silicon to produce solar cells. As shown in Figure 13, the TI researchers proposed making spherical solar cells to form p-n junctions to allow direct contact by two isolated layers of aluminum foil on a flat substrate, each p and n surface spherical cells made of broken silicon wafers. Unlike traditional photovoltaic cells, spherical solar cells do not need to cut wafers from large ingots or lose material during the cutting process, which saves silicon material. After silicon is melted, uniform size droplets form, which enters the spherical grain once the droplets cool and are stable. They are the core of the spherical micro solar cells, and the key step is the P-N junction formed on the silicon grain surface, and then form the positive and negative contacts on one side and the other side so that each battery is ready to power [8].

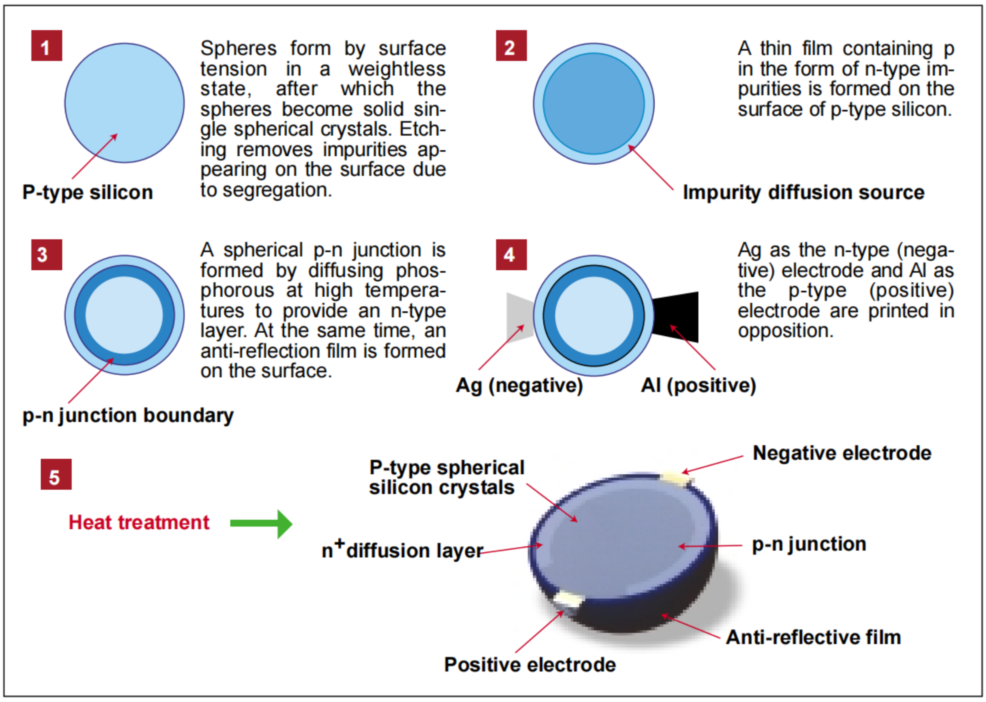

Figure 13. The manufacturing process of spherical solar cells [7].

As shown in Figure 14, compared to traditional solar cells, spherical cells can capture light from all directions, and spherical cells can be more effective and continue to receive sunlight more consistently than traditional flat-panel solar cells. In addition, this technology brings innovation to module design. Due to the module structure being based on tiny cells, the sphere has flexibility in designing electrical specifications and module shapes. The spherical shape is less dependent on the incident light angle and is more productive in terms of energy output. That's why a sphere can apply traditional solar energy even if it doesn't make any sense. Some academic studies have proved that a spherical shape can provide better performance under adverse conditions such as cloudy or high latitudes. Different product development projects are underway.

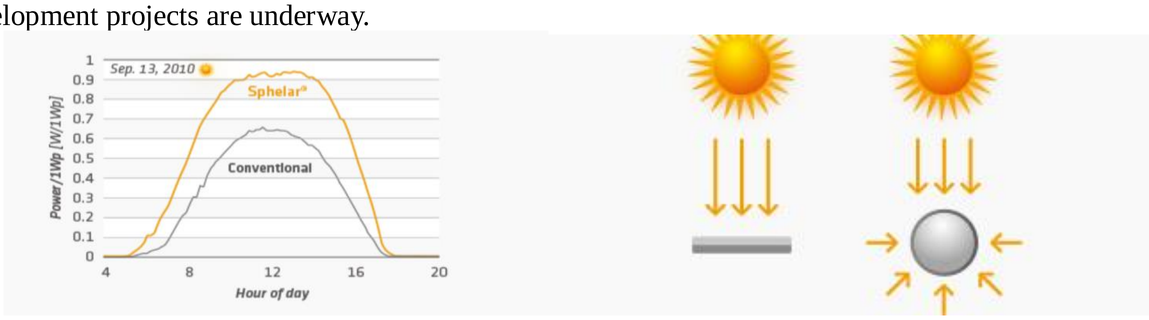

Figure 14. Comparison diagram of spherical solar cells and ordinary solar cells.

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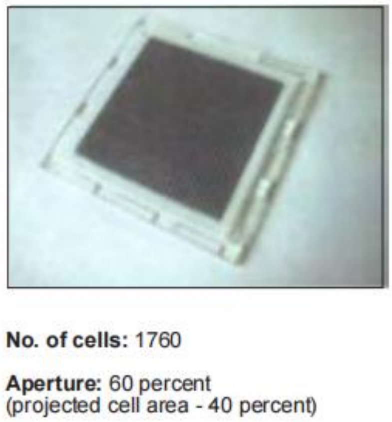

Figure 15. Trial produced spherical silicon micro solar cell module [8].

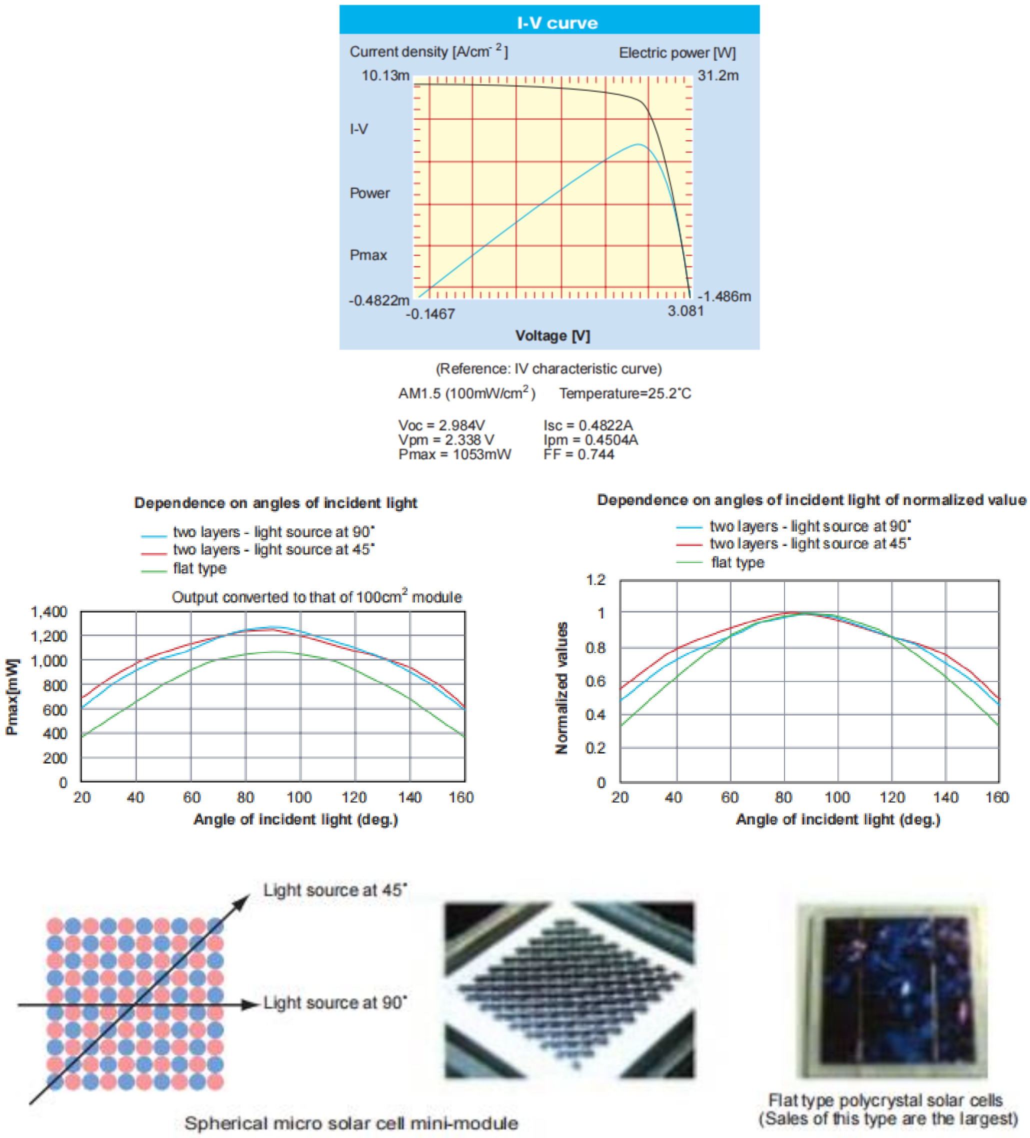

Figure 16. Comparison diagram between spherical solar cell and plane solar cell [9].

The trial-produced spherical silicon micro solar cell module has a simple structure (Figure 15). The module is connected in series and parallel with thin copper wire and installed on a white resin reflector. The surface of the reflector is covered with transparent resin. Its size is 130×130×10mm, and there are 57 units in series and 30 units in parallel. On a sunny day and under direct sunlight, its voltage is about 25v, and its power is 1W (maximum). Figure 16 shows the dependence data of the output of the spherical miniature solar cell module arranged in two layers (upper and lower layers) and the flat-plate silicon polycrystalline solar cell module with the same light receiving surface on the incident light angle, as well as the external view of these modules. In the battery arrangement of the miniature solar cell module used for measurement, the gap between adjacent cells is filled by other cells, and there is a white reflection area at the bottom. If solar cells are used to generate electricity outdoors, the angle of the incident light can change with time. Therefore, it is inappropriate to compare the efficiency of solar cells from the aspect of photoelectric ratio only when the solar simulator is in the vertical direction relative to the module. Instead, the comparison should be based on the amount of electricity the sun generates daily. The output attenuation of spherical miniature solar modules is small. Even if the incident light angle is small, the power generation of spherical solar modules is higher than that of flat solar modules [7].

4. Outlook and growth

Due to the special geographical location of China, the average sunshine hours in about two-thirds of the country exceed 240 hours. As shown in Picture 17, the distribution characteristics are less in the southeast and more in the northwest, increasing from the southeast to the northwest. Among them, Inner Mongolia, Qinghai, Tibet, Xinjiang and other regions are particularly rich in sunshine, so the new solar energy vehicles can be firstly piloted in these regions. And the models used in the pilot can be sightseeing cars with fixed routes and some models with less power.

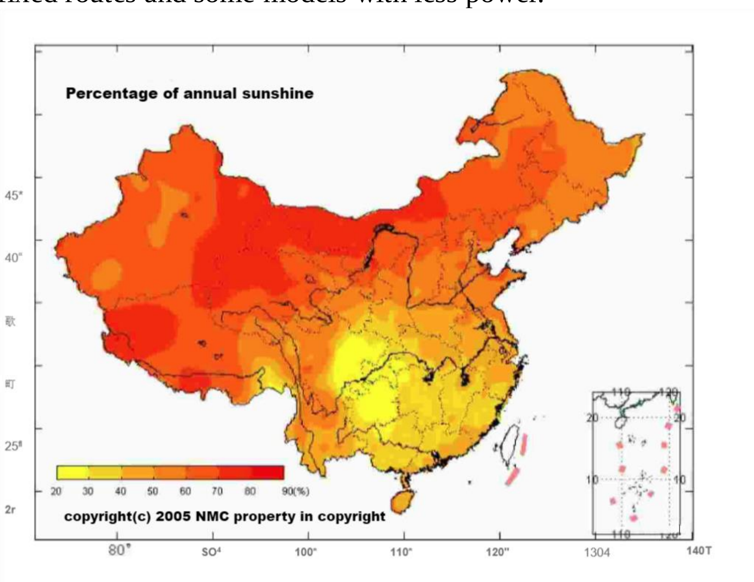

Figure 17. Percentage of annual sunshine in China [10].

In terms of current development, solar energy technology is not mature enough to meet the energy supply of vehicles when driving alone. Therefore, it is necessary to develop and produce new energy vehicles based on other mature new energy sources and supplemented by solar energy. After that, solar energy can be gradually used as the main energy, and finally, a new energy vehicle powered by solar energy can be invented and manufactured.

5. Conclusion

In this paper, the existing solar cars are analyzed. From the structure of solar cars, the body structure is studied according to the wind resistance during driving; The advantages and disadvantages of the two

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kinds of motors that are most used in solar cars are analyzed; The driving mode of solar energy, the charging system and energy conversion in solar cars are introduced; The advantages and disadvantages of crystalline silicon solar panels and non-silicon crystalline solar panels are analyzed. But when using traditional solar panels, it is necessary to use a heliotropic tracking system. In this paper, a spherical solar panel, which can receive sunlight from all angles without using a heliotropic tracking system has been introduced. It can better and more continuously receive sunlight than traditional solar panels. Solar cars should be vigorously researched on solar panels, body design, and wind resistance characteristics. Under the premise of ensuring safety, vehicle life should be upgraded to save energy.

Under the current development situation in China, in order to save resources and build an eco-friendly ecological society, China need to give full play to the leading role of the electric vehicle industry and strengthen the research and development capacity and application fields of electric vehicles. It has greatly promoted the huge development prospect of electric vehicles, which has a great impact on the future development of China. So the development trend of solar cars in the future is very good.

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