Opportunities and Challenges for Solar Cells

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Abstract. With the development of the economy and increasing productivity worldwide, the current demand for resources and energy is continuously growing. This has led to problems such as energy scarcity and environmental pollution, so it is high time to find sustainable development solutions. As a treasure gifted by nature, solar energy provides new development opportunities for the sustainable development of mankind. This article will discuss the main principles of solar cells, focus on analyzing the development prospects and problems of the Chinese photovoltaic industry, and finally discuss the new direction of future space solar energy development.

Keywords: Solar energy; Climate change; Energy transition.

1. Introduction

In recent years, traditional energy such as fossil fuels have become increasingly scarce due to human's continuous exploitation and use. At the same time, the air pollution caused by fossil fuels requires people's attention1. In order to alleviate the shortage of resources and increase energy production, people have started to aim at wind energy, solar energy, biomass energy, water energy, geothermal energy, tidal energy, and so on. Coupled with the implementation of government encouragement and other measures, the proportion of green energy in the energy structure is increasing. With abundant solar resources, China is gradually developing and exploiting them[2]. There are two main methods of solar power generation: photothermal and photovoltaic. The former converts light energy into heat energy and then converts the heat energy into electricity while the latter converts solar energy directly into electricity. This essay mainly focuses on the photovoltaic way of solar cells.

Almost all of the Earth's energy input comes from the sun. Solar energy to the Earth refers to this energy that hits the surface of the Earth itself. This energy goes towards weather, keeping the temperature of the Earth at a suitable level for life, and powers the entire biosphere[3]. If one day people can fully depend on a certain clean energy, then this energy source is very likely to be solar energy.

2. Principle

2.1. The principles of the photovoltaic method

We must first understand the principle of solar power generation[5]: A solar cell uses the semiconductor material silicon, a representative element used in transistors and integrated circuits, to generate electricity through light irradiation [6](i.e. the photovoltaic effect). The operation of a semiconductor solar cell will be illustrated with the example of a p-n junction under illumination.

Where n represents an N-type semiconductor. This semiconductor is a silicone crystal (or germanium crystal) that is mixed with a small number of impurities like phosphorus elements (or antimony elements). Since semiconductor atoms (such as silicon atoms) are replaced by impurity atoms, four of the five outer electrons in the outer layer of phosphorus atoms form covalent bonds with the surrounding semiconductor atoms, and the extra electron is almost unbound and becomes a free electron relatively easily. As a result, N-type semiconductors become semiconductors with a high concentration of electrons, and their conductivity is mainly due to the conductivity of free electrons.

Meanwhile, p represents P-type semiconductors. This semiconductor is a silicone crystal (or germanium crystal) that is mixed with a small number of impurities like Boron elements (or Indium elements). Since semiconductor atoms (such as silicon atoms) are replaced by impurity atoms, when the three outer electrons of the boron atom form covalent bonds with the surrounding semiconductor atoms, a "hole" is created, which may attract bound electrons to "fill" and turn boron atoms into negatively charged ions. In this way, the semiconductor becomes a conductive substance due to the high concentration of "holes" ("equivalent" positive charges).

The P-N junction is an interface between n and p type semiconductors: On a complete silicon wafer, different doping processes are used to form N-type semiconductors on one side and P-type semiconductors on the other. The area near the interface between these two semiconductors will form a P-N junction. In equilibrium, the electrochemical potentials on the two sides of the junction are equal, and there is no net electric current. Under illumination, the energy of the photon is passed to the silicon atom, which makes the electrons move more and becomes a gathered potential difference between the free electrons on both sides of the P-N junctions, see fig 1 for a diagram. Electron-hole pairs are generated in the semiconductor and are subsequently separated by the electric field of the junction. When an external circuit is connected over the P-N junction, under the action of the voltage, the current flows through the external circuit to generate a certain output power[7]. The essence of this process is the process of transforming photon energy into electrical energy.

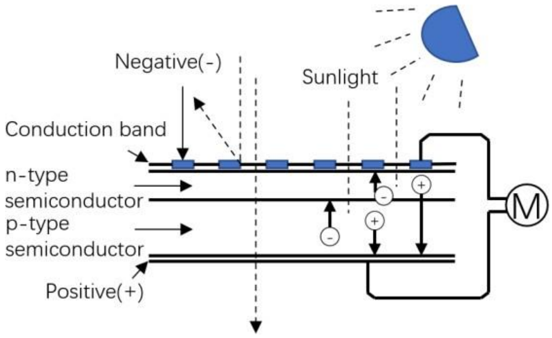

Fig. 1 The operation of a semiconductor solar cell

2.2. The principle of the photothermal method.

Solar thermal conversion also plays a very important role in the application of solar energy and can provide a great deal of convenience in our daily lives. By relying on the principle of solar thermal conversion, it is possible to convert thermal radiation into other forms of energy that we need. The basic working principle of photothermal conversion is that a specially[7] designed solar surface is used to capture and absorb as much of the sun's radiant energy as possible that hits the surface, and the collected radiant energy is then used to heat substances such as water or air.

The principle of solar thermal power generation is to use a large array of parabolic or disc- shaped mirrors to collect solar energy, see fig 2 for a diagram. This technology is mainly divided into four categories: fresnel type, tower type, butterfly type, and trough type[8]. Among them, Fresnel and trough belong to linear focusing systems, while tower and butterfly belong to point focusing systems. Compared to linear focusing systems, point-focused systems have a higher concentration rate, resulting in higher temperature solar heat, and higher thermoelectric conversion efficiency and lower electricity costs.

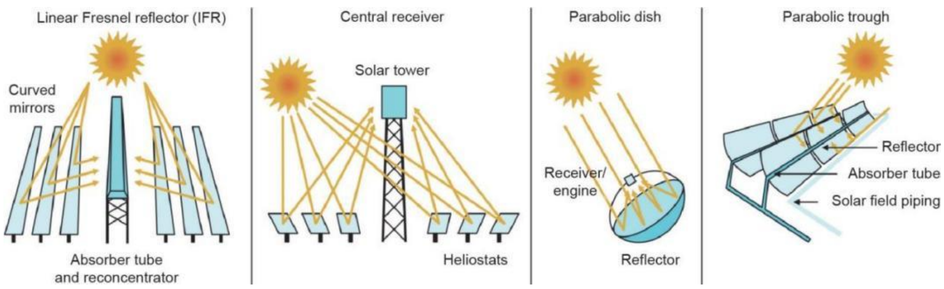

Fig. 2 Four main ways of solar thermal conversion

3. Current situation

The International Renewable Energy Agency (IRENA) released the World Energy Transition Outlook:1.5°C Pathway in March 2021, which clearly states that the share of renewable energy generation will increase to 90% by 2050, with photovoltaic and wind power accounting for 63% By that time, the global PV installation will exceed 14000 GW [9].

In May 2021, the International Energy Agency (IEA) released ‘Net Zero Emissions 2050: A Roadmap for the Global Energy Sector’, which specifies that by 2050 about 90% of electricity will come from renewable sources, with solar and wind accounting for about 70%.

With the global goal of reducing carbon emissions, countries are responding positively, and the following is an analysis of the prospects and barriers to photovoltaic energy production in China.

3.1. Prospects in China

3.1.1 Rich in solar energy resources

In the utilization of solar energy, the intensity of solar radiation and the number of sunshine hours is extremely important, and they depend on geographical location, climatic conditions, and environmental influences. China is rich in solar energy resources. The annual total solar radiation is 930-2330 kWh/square meter, see fig 3 for a diagram. The sunshine hours are as high as 3000-3300 hours every year[10], which is more favorable for the heat utilization and photoelectric conversion of solar energy. If solar energy is used, it can make up for the shortage of conventional energy sources.

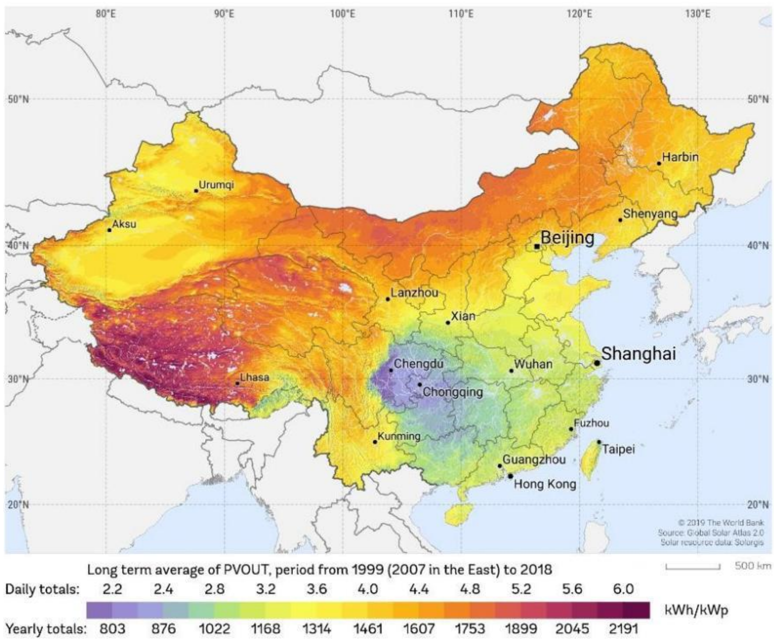

Fig. 3 A map displaying the average available solar energy in China[10]

3.1.2 Manufacturing capabilities continue to grow

China has taken a high share of the global scale in all segments of the photovoltaic (PV) industry chain[11]. In 2007, China jumped to the number one position in the world in terms of solar cell production, and still holds that record and is in a distant second place in terms of photovoltaic energy production. By the end of 2018, Chinese cumulative production of PV modules accounted for more than 2/3 of the total global PV module production[11]; by the end of 2020, Chinese annual PV module production had been the global leader for [14] consecutive years. In 2020, Chinese production of polysilicon, silicon wafers, crystalline silicon solar cells, and PV modules reached 392,000 t, 161.3 GW, 134.8 GW, and 124.6 GW respectively[12]. In addition, the scale and strength of Chinese PV manufacturing enterprises also rank among the world's top, with polysilicon production ranking first in the world for [10] consecutive years. With the technological improvement of polysilicon manufacturing enterprises and the release of new production capacity, Chinese polysilicon production will reach 450,000 t in 2021[13].

3.1.3 Rising level of technification

In recent years, the photovoltaic conversion efficiency of mass-produced solar cells has been increasing at a rate of about 0.5% per year, see fig 4 for a diagram. On the 31st of May in 2021, the Jinko Solar Research Institute achieved a world record photovoltaic conversion efficiency of 25.25% for a large area N-type monocrystalline silicon solar cell[14].

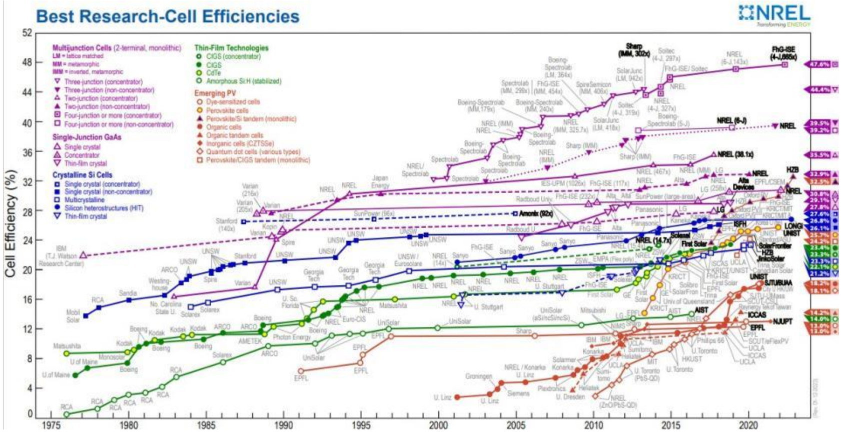

Fig. 4 Efficiency maps for a range of photovoltaic technologies[15]

Fig 4 contains information on a range of different photovoltaic (PV) cell technologies discovered and developed over the past 50 years. It tracks the continuous improvement of traditional solar cells, such as silicon cells, and the exciting rise of some emerging technologies, such as perovskite solar cells.

3.2. Problems in the current promotion

'Double carbon' is a two-stage goal of carbon emission reduction put forward by China. Carbon dioxide emissions are projected to reach their peak in 2030[16] and China will strive to achieve carbon neutrality in 2060[16]. In the process of achieving this goal, Chinese solar energy utilization technology will face challenges in various aspects.

3.2.1 Insufficient supply of professionals

Solar energy utilization technology involves a number of fields, covering disciplines such as physics, chemistry, materials science and engineering, electronic information engineering, electrical engineering, and automation. Therefore, there are high requirements for research and development in personnel's learning and innovating ability. However, the Chinese current division of university disciplines still follows the Soviet Union's discipline settings, and the division of disciplines is relatively fragmented[17], which is not conducive to the cultivation of a comprehensive knowledge structure and comprehensive quality of complex talents. It is difficult to match the supply of professional talents for solar energy utilization technology with demand.

3.2.2 Polysilicon manufacturing technology is not mature enough

Although China has become one of the largest photovoltaic industry bases in the world, the overall development level of the photovoltaic industry is still at a low level. The quality of polysilicon is relatively poor, and the energy consumption is relatively high, which is harmful to the environment[18,19].

3.2.3 Renewable energy policy changes

The Chinese government's policy on renewable energy changes frequently, which is an uncertain factor for photovoltaic companies. At the same time, policy changes have led to an unstable investment environment for enterprises, which has had a great impact on the development of enterprises[20].

3.2.4 Insufficient standardization capacity

As the "world factory" of the solar power industry, China needs various standards and specifications for the production, manufacture, and supervision of equipment. However, there is still a large gap between Chinese standardization work and that of developed countries in Europe and the US. As most of the national standards or industry standards for solar energy utilization technology in China were implemented earlier, some of the standards for solar energy utilization technology are missing and technical indicators are lagging behind, which cannot meet the technical development needs of today's solar power industry[18]. Compared to the internationally accepted IEC standards, Chinese solar energy utilization technology has not yet developed a complete standard system.

3.2.5 A lack of large public research and testing platforms

China lacks public R&D platforms and large scientific equipment in the field of solar energy utilization technology. Developed countries that are leaders in solar energy utilization technology, they all have national public R&D platforms and use them as support for scientific and technological R&D, such as the National Renewable Energy Laboratory (NREL) in the US, Fraunhofer Laboratories in Germany and the New Energy Industry Technology Development Organization (NEDO) in Japan. Most of Chinese key laboratories for solar energy utilization are affiliated with enterprises and are not sufficiently capable of solving international-type frontier problems in science and technology[21].

4. Exploration of the possibility of deploying solar panels in space

Due to the absorption and scattering of the ground solar energy, the attenuation of clouds and rain, and the influence of seasons and day and night, the energy density varies greatly and is very unstable[22]. The construction of space solar power plants in geosynchronous orbits can achieve stable reception of solar radiation and uninterrupted fixed-point transmission of power through wireless energy transmission, which has important application prospects in ground power supply, space power supply, emergency disaster reduction, and planetary detection[23].

A space solar power plant is a super-large power generation system that converts sunlight into electricity in space and then transmits it to the ground through wireless energy transmission[24]. In order to achieve efficient and continuous solar power generation, American scholar Glaser published a paper in Science in 1968, proposing for the first time to convert solar energy into electrical energy in space through a large solar cell array[25]; which is then transmitted to the receiving antenna on the ground; finally, the ground receiving antenna converts the received microwaves into electrical energy, which is input into the power grid for users to use. The international research work in the field of space solar power plants has lasted for more than 40 years, and the main power supply forms proposed can be divided into two types: non-concentrating and concentrating[26]. Among them, the non-concentrated type can be divided into centralized power supply mode and distributed power supply mode according to the form of power supply[27].

The non-concentrating centralized power supply space solar power plant is represented by the 1979 reference system proposed in the USA in 1979[28]. The main technical feature of this conceptual scheme is that the whole system consists of two major parts: the solar array, and the microwave transmitting antenna, the solar array and the microwave transmitting antenna are in a separate state, and the microwave transmitting antenna is powered by a centralized power supply, and in order to maintain the solar array's orientation to the sun and the transmitting antenna's orientation to the earth, a GW-class super-powerful conductive rotating joint must be used, making the power transmission and management technology extremely complex[27].

Non-concentrating distributed power supply space solar power plants are represented by the concept of distributed rope solar power plants proposed in Japan[29]. This solution integrates the solar array, power transmission and management, and microwave transmitting antenna sections into an integrated sandwich structure form, which significantly reduces the complexity of the power transmission and management system. The biggest drawback of this concept is that the integration of solar arrays and microwave transmitting antennas makes it impossible to achieve continuous solar orientation in an orbital cycle, resulting in the whole system only achieving fluctuations in power generation from zero to maximum power, which does not reflect the advantages of space solar power plants.

Concentrating space solar power plants are one of the key directions of international research in recent years, represented by the arbitrary phased array space solar power plant (ALPHA-SPS)[30] and symmetrical secondary reflective power plants[31] proposed in 2012 in the USA. The main idea of this conceptual scheme is to use a special concentrating system and the overall configuration of the sandwich structure, and through a reasonable design of the concentrating light path, to simultaneously achieve the sunward orientation of the concentrating system and the earthward orientation of the microwave transmitting antenna, and without the use of conductive rotating joints. At the same time, a high light concentration rate can be achieved with the concentrator system, significantly reducing the area of the solar cell required. The main technical challenges for the development of this concept include the design and control of a high-precision concentrating system and the heat dissipation in sandwich structures with high concentration ratios.

In 2015, China took the non-concentrating space solar power station as the research object and proposed an overall design scheme for the multi-rotary joint space solar power station, which innovatively solved the technical problem of extremely high-power conductive rotary joints existing in the traditional non-concentrating solar power station. It also avoids the single-point failure problem of a single conductive joint, see fig 5 for a diagram. This scheme replaces the traditional monolithic solar cell array with multiple independent solar cell subarrays and replaces the traditional extremely high-power rotary joints with multiple medium-power conductive rotating joints.

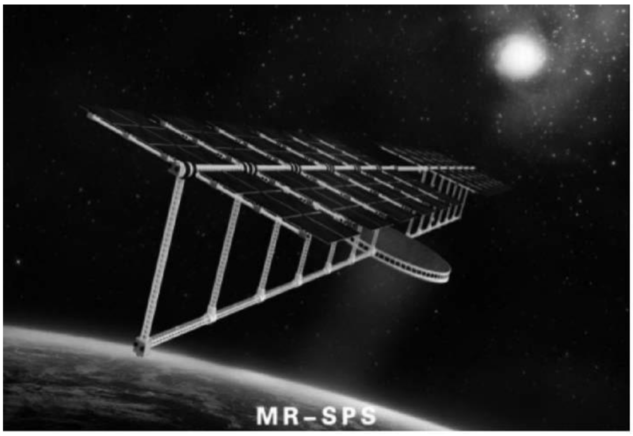

Fig. 5 Multi-rotation joint space solar power plant

In the future, when huge solar power stations float in space, sending large amounts of energy to all parts of the planet, the electricity used by people will be obtained and sent back from space power stations. By then, people will no longer be worried about the lack of electricity, nor will they be anxious about power cuts, the goal of net zero emissions will be achieved, the pollution of the planet will be drastically reduced, the atmosphere will be fundamentally improved and mankind will be able to enjoy clean energy from solar.

5. Conclusion

Solar energy utilization technology is a low-carbon, efficient, and sustainable energy, which will become an inevitable choice for the transformation and upgrading of energy structure. This work analyzed the development status of solar energy, and introduced the rapid progress of aerospace technology, space solar energy, a new type of large-scale solar energy development method. The current status of China's solar energy production, research, and policy was discussed as well as future avenues for improvements. These technologies have the potential to make great breakthroughs in the green energy transition.

References

[1] Asif Afzal, A. B., Ravindra Jilte, Saboor Shaik, Abdul Razak Kaladgi, Muslum Arıcı, Chew Tin Lee, Sandro Nižetić , Optimizing the thermal performance of solar energy devices using meta-heuristic algorithms: A critical review, Renewable and Sustainable Energy Reviews, Volume 173, 2023, 112903, ISSN 1364-0321.

[2] Bilal Hussain, S. A. A. N., Sofia Anwar, Muhammad Usman, Effect of wind and solar energy production, and economic development on the environmental quality: Is this the solution to climate change? Gondwana Research,2023, ISSN 1342-937X.

[3] Education, E. Solar energy to the Earth. https://energyeducation.ca/ (2023).

[4] Fang, Y. P. & Wei, Y. Q. Climate change adaptation on the Qinghai-Tibetan Plateau: The importance of solar energy utilization for rural household. RENEWABLE & SUSTAINABLE ENERGY REVIEWS 18, 508-518, doi:10.1016/j.rser.2012.10.037 (2013).

[5] Rojas, D., Rivera, M., Wheeler, P. & Ieee. in 2021 IEEE CHILEAN CONFERENCE ON ELECTRICAL, ELECTRONICS ENGINEERING, INFORMATION AND COMMUNICATION TECHNOLOGIES (IEEE CHILECON 2021) 88-93 (2021).

[6] Zhang Chen, X. Y., Zhang Hongxia, Gu Yujie, Zhang Xiongwen, Optimal design and performance assessment for a solar powered electricity, heating and hydrogen integrated energy system, Energy, Volume 262, Part A, 2023, 125453, ISSN 0360-5442.

[7] Taubkin, I. I. Photoinduced and thermal noise in semiconductor p-n junctions. PHYSICS- USPEKHI 49, 1289-1306, doi:10.1070/PU2006v049n12ABEH006134 (2006).

[8] Thiam, A., Mbow, C., Faye, M., Stouffs, P. & Azilinon, D. Assessment of Hybrid Concentrated Solar Power-Biomass Plant Generation Potential in Sahel: Case Study of Senegal. Natural Resources 08, 531-547, doi:10.4236/nr.2017.88033 (2017).

[9] O'Neill, S. Global CO2 Emissions Level Off in 2019, with a Drop Predicted in 2020. Engineering 6, 958-959, doi:10.1016/j.eng.2020.07.005 (2020).

[10] Li Fei, S. D., Li Xue, Quanxi Liang, Wangzhou Yang, Energy consumption-economic growth relationship and carbon dioxide emissions in China, Energy Policy, Volume 39, Issue 2, 2011, Pages 568-574, ISSN 0301-4215.

[11] Jiang Hua, a., Yuki, wait. On the advantages and disadvantages of the development of PV industry in our country [J] . Solar energy, 2019(9) : 15-17.

[12] Wong Pak Wah. Review and 2021 outlook of Chinese PV industry in 2020[R] . Beijing: China Photovoltaic Industry Association.

[13] China photovoltaic industry association. Roadmap for the development of PV industry in China (2002)[R] . Beijing: China Photovoltaic Industry Association.

[14] Stoker, N.-t. c. e. r. c. a. J. s. n. r. o. B., June 1 & Manufacturing, C. P.

[15] Supplemental Material,the National Renewable Energy Laboratory (NREL) <https://www.nrel.gov/pv/cell-efficiency.html/> (2022).

[16] China, c. p. o. Complete and accurate to fully implement the new concept of development to do a good job of carbon of peak carbon neutral opinion. the Xinhua News Agency (2021).

[17] ka-pin, l. Reflections on and construction of the classification method of higher education institutions in China. Huazhong University of Science and Technology (2011).

[18] feng, x. Under the new situation, our PV industry policy development and research [D]. .Jilin provincial party committee party school of the communist party of China (2022).

[19] Shiyu, W. A study on the impact of policy transformation of PV industry on its development potential in our country [D]. Beijing Technology and Business University (2021).

[20] Bai Yongliang, Z. Q., Wang Yue. Research on low-carbon policy orientation based on the perspective of China's energy policy change [J]. Frontier (2011).

[21] Meicheng, L. The development status and prospect of solar energy utilization technology in our country under the“Double carbon” target [J]. Solar Energy (2021).

[22] Jackson, C. M. & Ieee. in 2020 IEEE SPACE HARDWARE AND RADIO CONFERENCE (SHARC)20-23 (2020).

[23] Kuznetsov, V. D. Space Research of the Sun: Current State and Prospects. GEOMAGNETISM AND AERONOMY 51, 848-854, doi:10.1134/S0016793211070103 (2011).

[24] Howell, J., Mankins, J. C. & Davis, N. J. Overview of NASA 27s Space Solar Power Technology Advanced Research and Development Program. (2001).

[25] McSpadden, J. O. & Mankins, J. C. Space Solar Power Programs and Microwave Wireless Power Transmission Technology. IEEE MICROWAVE MAGAZINE 3, 46-57, doi:10.1109/MMW.2002.1145675 (2002).

[26] Hou Xinbin, W. L., Zhu Yao are equal. Development status of International Space Solar power plants [J] . Journal of solar energy, 2009,30(10) : 1263-1268.

[27] Hou X B, W. L., Gao J.Analysis and comparison of various SPS concepts[C].The 62nd International Astronautical Congress,Cape Town,South Africa,October 3-7,2011.

[28] Lyndon B.Satellite power system concept development and evaluation program ［R].NASA-TM-58232.

[29] Sasaki S, T. K., Higuchi K,et al.A new concept of solar power satellite:Tethered-SPS ［J].Acta Astronautica,2006,60:153-165.

[30] LLC.2012.9., J. C. M. S.-A. T. f. p. s. p. s. v. a. l. p. a. R. A. I. M. S.

[31] Meng Xian-long, C. X., Xia Xin-lin,et al.Energy transfer characteristics of symmetrical space two stage reflected solar concentrator[J].Journal of Astronautics,2013,34 (9):1288-1294