Research on Optimizing Material Structure Based on Optoelectronic Physical Performance System

Dinghan Ma
North China Electric Power University, Baoding 071000, China
201810000513@ncepu.edu.cn

Abstract. High-voltage technology can effectively adjust the crystal lattice and electronic state of optoelectronic materials. It is a feasible means to adjust the physical properties of optoelectronic materials and an important method for synthesizing new optoelectronic materials. This article summarizes the current status of high-voltage research on optoelectronic materials at home and abroad, and introduces the effect of high-voltage on the crystal structure, electronic configuration and physical properties of optoelectronic materials. At the same time, the thesis looks forward to the development of high-voltage research on photovoltaic materials based on the properties of PbS gel mass dot solar cell photovoltaic materials.

Keywords. Optoelectronic materials, physical properties, material structure optimization.

1. Introduction
The development of new energy is one of the important ways to solve the energy crisis. As the top priority of new energy, the development and utilization of solar energy has attracted worldwide attention. Photoelectric materials refer to a class of materials that have the function of converting between light energy and electric energy, including photocatalytic materials, luminescent materials, and photovoltaic materials. For any optical system, it is required to have coaxial stability and structural stability under any conditions, because affecting the coaxial stability and structural stability of the system will reduce the optical performance of the system. The evaluation and prediction of optical performance should include deformation caused by heat and mechanical distortion caused by environmental changes, manufacturing errors and installation strains.

At present, there are many research reports on the influence of pressure on the structure and physical properties of materials, and many novel and unique physical phenomena have been obtained. For example, sodium metal can be transformed into a wide band gap insulator under high pressure, and high temperature superconductivity of hydrogen sulphide gas occurs under high pressure. Transformation, hydrogen shows metallic properties under high pressure. High-voltage technology has excellent stability and controllability [1]. It can not only study the internal relationship between crystal structure and physical properties, but also change and control the physical properties of materials. Therefore, it has huge application potential in the field of photovoltaic devices.
2. Classification of Optoelectronic Materials

2.1. Chalcogenide optoelectronic materials
According to the difference of chemical composition, chalcogenide optoelectronic materials can be divided into two categories: binary chalcogenide compounds, such as III-VI group compounds, III-V group compounds, etc.; multiple chalcogenide compounds, such as CuInSe$_2$, CuIn$_{0.5}$Ga$_{0.5}$Se$_2$ etc. Chalcogenides have abundant structural types and good physical properties, and are currently one of the most widely studied optoelectronic materials. In addition, chalcogenide optoelectronic materials mostly have a layered structure. Compared with other materials, their structure is most susceptible to pressure [2]. Figure 1 shows the structure of chalcogenide optoelectronic materials.

2.2. Perovskite-type metal halide photoelectric materials
Perovskite-type metal halide photoelectric materials have the general formula AMX$_3$, where A is an organic amine cation or an alkali metal ion, M is usually Pb$^{2+}$ or Sn$^{2+}$, and X is Cl$^-$, Br$^-$, I$^-$ or BF$_4$-. The AMX$_3$ perovskite structure consists of an MX$_6$ octahedral framework connected to the vertices and organic ammonium cations interspersed in the gaps of the framework. This type of compound has a complex built-in electric field and superior structural tolerance [3]. It can be replaced by A-site cations, M-position metal ions or halide anions can be used to adjust its photoelectric performance. Due to its lower production cost, better flexible mechanical properties, and higher photoelectric conversion efficiency, perovskite-type metal halides have become a candidate material for new-type solar cells, and therefore have received extensive attention. At present, high-pressure research on perovskite-type metal halides is mainly focused on the following two materials.

2.3. Metal oxide photoelectric materials
Metal oxide photoelectric materials have good physical and chemical properties, and the preparation process is simple, and they have good application prospects in the fields of photocatalysis and solar cells. Among them: Binary metal oxides (such as TiO$_2$, ZnO, SnO$_2$, Ta$_2$O$_5$ and GeO$_2$, etc.) have been extensively studied in the field of environmental protection and dye-sensitized solar cells due to their excellent photocatalytic and photoelectric properties; and ferroelectrics Oxides are widely used in photovoltaic cells, optical drivers, and optical sensors because of their advantages such as high output voltage and good electric field regulation and photovoltaic performance [4]. Compared with traditional photovoltaic materials, ferroelectric oxide photoelectric materials have the following advantages: (1) Different from the built-in electric field of traditional photovoltaic materials through the interface PN junction, the ferroelectric electric field can effectively reduce the recombination rate of photogenerated electrons and holes, thereby greatly improve the photoelectric conversion efficiency of photovoltaic materials; (2) The PN junction open circuit voltage of traditional photovoltaic materials is generally less than 1V, and in ferroelectric materials with specific electrical domains, the photovoltaic voltage can break through the material forbidden band width; (3) The preparation process of the ferroelectric
material is simple, the production cost is lower, and it is easier to realize mass production. Figure 2 shows the ferroelectric photoelectric material structure.

![Figure 2](image)

**Figure 2.** Ferroelectric photoelectric material structure

### 3. Specific analysis of PbS glue mass sub-dot photoelectric materials

The colloidal quantum dot (CQD) material can be directly synthesized in an aqueous solution, and a solid film is formed on the substrate by layer-by-layer spin coating. It is a very high-quality third-generation solar cell material with low cost, simple method, and large area laying advantage. The theoretical efficiency of the CQD battery can reach 40%. To realize the large-scale use of this battery, its efficiency should reach more than 15%. Figure 3 shows the principle of the PbS glue mass dot photoelectric material.

![Figure 3](image)

**Figure 3.** The principle of PbS glue mass dot photoelectric material

#### 3.1. Working model and main parameters

The electron-hole pairs generated by absorbing photons in the CQD film must be effectively separated and collected by their respective electrodes in order to generate photocurrent and photovoltage. At present, researchers use a simplified model-semiconductor PN junction to describe the working characteristics of quantum dot batteries, and approximate the CQD film as a uniform semiconductor with parameters such as average electron and hole mobility, carrier lifetime, and dielectric constant. Medium [5]. The model can successfully describe the operating characteristic curve of quantum dot batteries, which indicates that the Shockley-Quesel energy conversion efficiency theoretical limit model applied to traditional P-N junction solar cells can also be used to calculate the theoretical efficiency of CQD cells. When the P-N junction solar cell is working, if the battery and the load resistance are connected to form a path, the current density through the load should be:

$$J = J_L - J_0 \left[ \exp \left( \frac{q(V + JR_s)}{A_i kT} \right) - 1 \right] - \frac{V + JR_s}{R_{\text{load}}},$$

(1)
In the formula, $V$ is the photogenerated voltage; $J_L$ is the photogenerated current density; $J_0$ is the reverse saturation current density; $A_0$ is the diode ideality factor; $R_s$ is the series resistance including the sheet resistance of the diffusion layer, the resistance of the base material itself, the contact resistance between the electrode and the semiconductor, the resistance of the electrode, etc.; $R_{sh}$ is the parallel resistance, which is mainly related to the recombination loss of carriers [6]. Equation (1) is the relationship between the current on the load resistance and the voltage ($J$-$V$), that is, the volt-ampere characteristics of the battery. In the case of an open P-N junction, the voltage across the junction is the open-circuit voltage $V_{oc}$, which is the maximum voltage that the solar cell can generate, reflecting the difference between the quasi-Fermi energy levels of the p-type and n-type materials at both ends of the P-N junction. The current density obtained when the P-N junction is short-circuited is the short-circuit current density $J_{sc}$, which represents the maximum number of photo-generated carriers per unit area that can be collected from the battery.

3.2. Performance analysis

Although in the battery J-V characteristic curve analysis, the CQD film material is approximated as a uniform semiconductor material, there are still differences that cannot be ignored. First of all, in the semiconductor CQD film, the quantum dots are filled with insulating colloidal materials, so the photogenerated carriers are largely confined inside the quantum dots, and it is difficult to break free from the quantum confinement and move freely. The carrier transport of the CQD film the mechanism is tunnelling or jumping, rather than diffusion caused by the difference in carrier concentration in traditional semiconductors [7]. Secondly, because PbS CQD is a nearly spherical nanocrystal block, there are a huge number of quantum dots in a thin film material, resulting in a very large internal area ratio, and the spherical surface of each quantum dot is in contact with the surrounding colloidal matrix. This situation greatly affects the doping level and defect state concentration of the material.

4. Photoelectric physical performance tracking system

4.1. The composition of the photoelectric physical performance tracking system

The photoelectric physical performance tracking system consists of a stand, a turntable, a target source, a target intensity controller, and a console. This system is an experimental platform for verifying algorithms and is built in the laboratory [8]. The time parameters of the acceleration and deceleration algorithm are measured by a stopwatch; the accuracy parameters of the pulse are calculated by the time of the oscilloscope and the stopwatch measuring the turntable.
4.2. Working principle of photoelectric physical performance tracking system

After the system is powered on, enter the test system or calibration system selection menu. After selecting the working mode, enter the speed, radius, distance and other parameters from the keyboard. The single-chip microcomputer C8051F005 is the control core of the system, which receives and processes the data on the keyboard, and controls the acceleration, deceleration and rotation of the motor. After the motor reaches the set speed, the maximum speed and maximum acceleration in the horizontal and vertical directions, as well as the maximum angular velocity and maximum angular acceleration of the measured target are sent to the LCD for display.

5. Conclusion

So far, due to the problems of low photoelectric conversion efficiency and high production cost, there are fewer photoelectric materials that can be practically applied. High-voltage technology can effectively control the crystal structure and physical properties of optoelectronic materials, and is also an important method for preparing new optoelectronic materials. In recent years, high-pressure technology has been widely used, and many unique results have been obtained. High-voltage technology has great development potential in the preparation of new optoelectronic materials and regulation of optoelectronic properties, and is a new way to develop new and efficient optoelectronic materials in the future.

References

[1] Ostroverkhova, O. Organic optoelectronic materials: mechanisms and applications. Chemical reviews, 116(22) (2016) 13279-13412.
[2] d'Ischia, M., Napolitano, A., Pezzella, A., Meredith, P., & Sarna, T. Chemical and structural diversity in eumelanins: unexplored bio - optoelectronic materials. Angewandte Chemie International Edition, 48(22) (2009) 3914-3921.
[3] He, X., Qiu, Y., & Yang, S. Fully - inorganic trihalide perovskite nanocrystals: a new research
frontier of optoelectronic materials. Advanced Materials, 29(32) (2017) 765-775.

[4] Li, Z., Kong, J., Wang, F., & He, C. Polyhedral oligomeric silsesquioxanes (POSSs): An important building block for organic optoelectronic materials. Journal of Materials Chemistry C, 5(22) (2017) 5283-5298.

[5] Ran, Z., Wang, X., Li, Y., Yang, D., Zhao, X. G., Biswas, K., ... & Zhang, L. Bismuth and antimony-based oxyhalides and chalcohalides as potential optoelectronic materials. npj Computational Materials, 4(1) (2018) 1-7.

[6] Fu, Y., Zhu, H., Chen, J., Hautzinger, M. P., Zhu, X. Y., & Jin, S. Metal halide perovskite nanostructures for optoelectronic applications and the study of physical properties. Nature Reviews Materials, 4(3) (2019) 169-188.

[7] Lipunova, G. N., Nosova, E. V., Charushin, V. N., & Chupakhin, O. N. Functionalized quinazolines and pyrimidines for optoelectronic materials. Current Organic Synthesis, 15(6) (2018) 793-814.

[8] Chan, J. M. Pentafluorosulfanyl group: an emerging tool in optoelectronic materials. Journal of Materials Chemistry C, 7(41) (2019) 12822-12834.