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Research and application of electroscope identification for UHV transmission and transformation equipment based on electrochromic materials

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Abstract. At present, due to the relatively large insulation gap of UHV(Ultra High Voltage) equipment, the traditional hand-held capacitive electroscope is difficult to operate; the non-contact electroscope is mainly based on the principle of electromagnetic induction, and the reliability is poor in complex areas such as substations and other electromagnetic environments. The power verification problem of AC/DC UHV transmission and transformation equipment has not been effectively solved. In order to optimize and solve the above problems, this research conducts performance testing and reliability analysis for new inorganic electrochromic materials, and uses the color change of inorganic materials to indicate the electrification state of power transmission and transformation equipment, thereby realizing the electricity inspection function. In this project, ZnS Electro-luminescent materials and GaN luminescent materials were prepared, which were packaged into electroscope identification, and the application scheme of electroscope identification on UHV power transmission and transformation equipment was determined. The field practice shows that the electroscope identification prepared by this project can realize spontaneous luminescence discoloration in the electric field, and can effectively indicate the charging state of the equipment, and the effect is very obvious. Thereby effectively solving the problem of power inspection of UHV power transmission and transformation equipment. The economic and social benefits are huge and the application prospects are wide.

1. Introduction

At present, UHV power transmission and transformation equipment mainly uses non-contact electroscope to conduct electricity detection. Non-contact electroscope realizes the electricity detection function by detecting the electric field or partial discharge related parameters near the charged equipment, but it has some deficiencies in the accuracy, adaptability, cost performance and other aspects. The reliability of non-contact electroscope is poor in complicated electromagnetic environment such as UHV substation and converter station.

Based on the latest technology of non-electromechanical photochromic materials, the proposed UHV transmission and transformation equipment is characterized by high reliability, easy operation and low cost. At the same time, the electric inspection mark of UHV transmission and transformation equipment itself has good weather resistance, can be applied in the outdoor for a long time, and can solve the existing problems in the electric inspection process of UHV transmission and transformation equipment.

2. Performance test of inorganic electroscope materials

2.1. Preparation of inorganic electroscope materials

Inorganic materials ZnS and GaN belong to electroluminescent/field-induced luminescent materials, which is a physical phenomenon in which electric energy can be directly converted into light energy after electric field or voltage is applied around the materials. In terms of luminescence mechanism, Zincsulphide is an intrinsic electroluminescence (also known as high field electroluminescence),the electric field-which is directly excited by the electric field around the material, so that the electron obtains a high energy, and then the high-energy electron and the hole recombine and emit light. GaN is an injection-type electroluminescence (also called low-field electroluminescence)-a luminescence phenomenon-in which electrons-holes are combined to radiate excess energy in the form of light under a low field action [1]. Combined with the characteristics of the ZnS inorganic material and the electrochromic mechanism, this research designed the structure of the ZnS electroscope material. Improve the stability and luminous intensity of the electroluminescent material by processes such as doping and re-firing. A sample of ZnS electroscope was prepared, as shown in Figure 1; This research adopts n-GaAlN/p-GaN:Si basic structure, selects silicon substrate and undergoes chemical etching, GaN material growth, wafer polishing and other processes, and uses metal organic chemical vapor deposition method to prepare GaN electroscope substrate [2]. A GaN electroscope sample was prepared by using a transparent resin body to mount the die on the front surface of the lens structure, as shown in Figure 2.

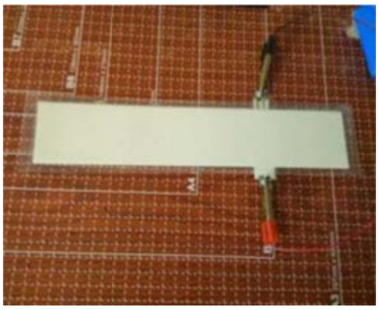

Figure 1. ZnS illuminating sheet material diagram.

Figure 2. Preparation ofGaNelectroluminescent device.

2.2. Application performance analysis of ZnS electroscope identification

2.2.1. Analysis of luminescence characteristics of ZnS electroscope identification. Brightness is the primary optical property of ZnS electroluminescent materials. Accurate measurement of this parameter is an important factor in the correct valuation of the electroluminescence electrographic identification.
(1) Relationship between brightness and voltage

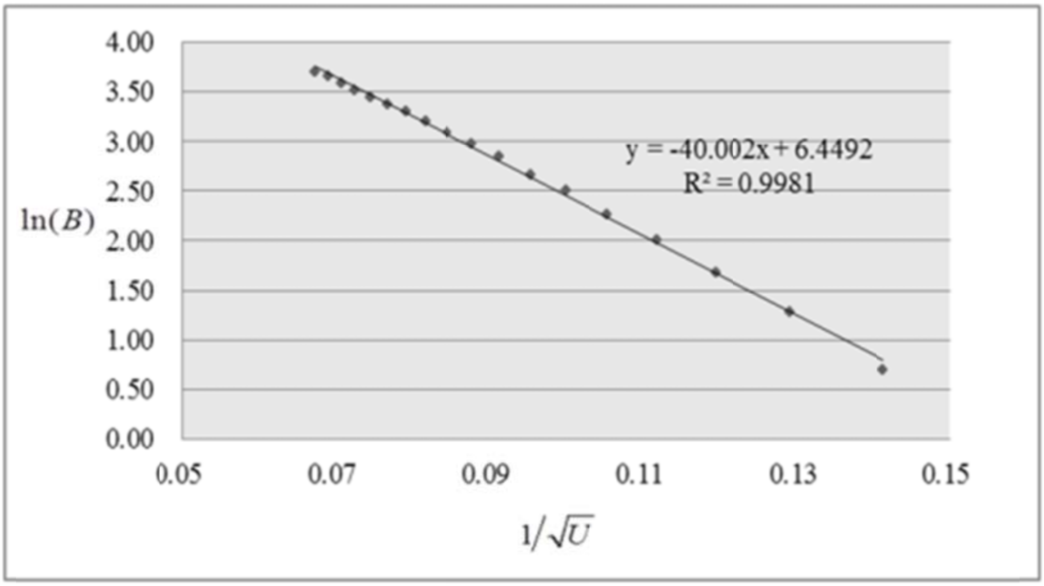

Figure 3. Relationship between luminance and voltage of ZnS electroscope.

The voltage-luminance characteristic of the electroluminescent material (the relationship between brightness B and voltage U) satisfies the empirical formula $B = B_0 \exp(\frac{-b}{\sqrt{U}})$, b is a constant at a given temperature and frequency,B_0 is slightly dependent on voltage. In the extreme case of scattering only on these uneven fields, the probability of obtaining sufficient ionization energy is proportional to exp $(\frac{constant}{\delta m})$ (δm is the maximum of the strength of the electric field) [3]. So the Brightness relation $B = B_0 \exp(\frac{-b}{\sqrt{U}})$ In addition, the expression $B = B_0 \exp(\frac{-b}{\sqrt{U}})$assume that the initial number of electrons entering the field strength zone is independent of the electric field.In fact, if the electrons cross the barrier into the high field region of the crystal (such as the barrier formed at the boundary between the ZnS and the conductive phase), the above assumption holds [4]. But if electrons enter the crystal through the barrier, the number of electrons will depend on the voltage. Therefore, the empirical relationship between luminance and voltage can also be explained by the relationship between the initial electron number and voltage falling in the strong field region [5].

The measured values of the brightness and voltage of the prepared ZnS electroscope identification are shown in Figures 3. The test results show that the electroscope identification under different manufacturing processes has different parameters B_0 and b. The measured relationship indicates that the b value changes as the activator of the luminescent material changes. At the same time, when the excitation frequency is constant, Long-term continuous operation increases the b value. When the electroscope mark is prepared using the ZnS separated by the particles, the b value increases as the crystal grain increases [6].

(2) Relationship between brightness and temperature.

On the surface of power transmission and transformation equipment, when the equipment is not charged, the electricity inspection indicator does not emit light, indicating that it is not charged; when the equipment has working voltage, but is not in working condition, the conductor does not heat up, there is no temperature rise, it is most beneficial The ZnS electroscope identifies the luminescent color. When the device is in working condition, the surface voltage of the device rises to 890 degrees Celsius due to the heating of the conductor, which will reduce the brightness of the electroscope identification. The experimental test shows the brightness of the ZnS electroscope at different temperatures as shown in Figure 4.

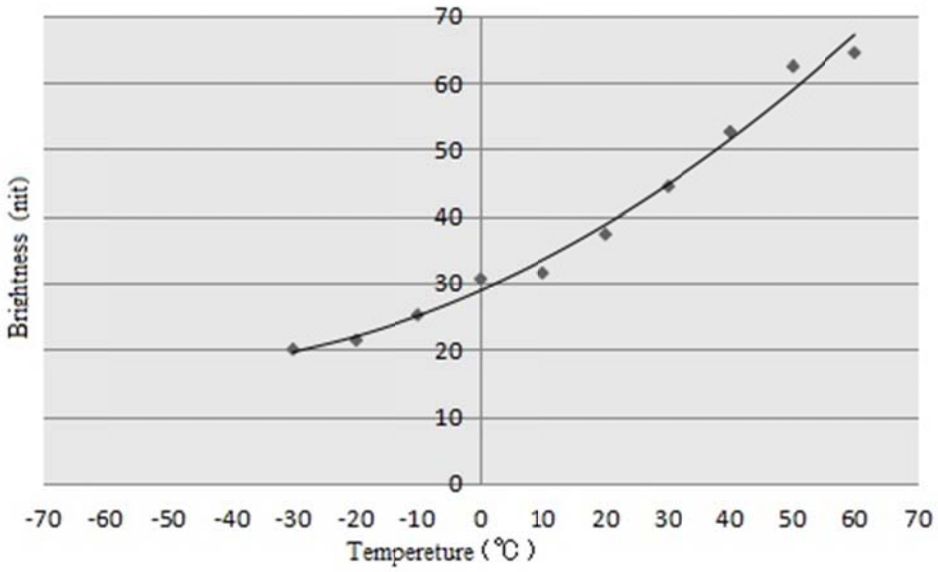

Figure 4. Relationship between luminous brightness and temperature of ZnS electroscope(1nit=1cd/m^2).

2.2.2. Analysis of weather resistance of ZnS electroscope identification. At the site of power transmission and transformation equipment, the ZnS electrochemical identification is affected by external conditions such as light, temperature changes, wind and rain. The electroscope identification can correctly indicate the electrification status of the power transmission and transformation equipment under various conditions, which is the basic requirement for the reliability of the electroscope identification. This research has verified the functional verification of ZnS electroscope in different environments, including high temperature, low temperature ice coating, damp heat, high and low temperature cycle weathering test. The test proves that the ZnS electroscope identification can adapt to various environments, and the field test photos are shown in Figure 5.

(a) test on site (b) data collection

Figure 5. Field test chart of ZnS electroscope identification.

2.2.3. ZnS electroscope identification electric field test test.
(1) External power supply test.

The ZnS electroscope identification junction is connected to the external power supply for testing. The luminous physical diagram is shown in Figure 6. During the test, it was found that ZnS began to have a visible color change at 12v, and the current flowing through ZnS was about 0.22 mA. When bright blue-green light appears at 60V, the current flowing through the ZnS device is about 1 mA. The volt-ampere characteristics of the ZnS device were tested and the data are shown in Table 1.

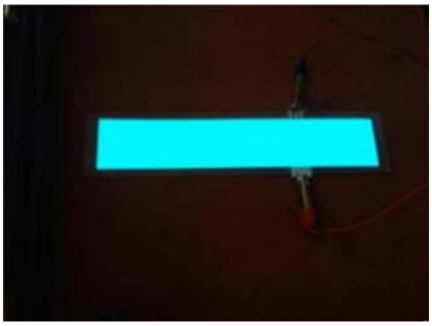

Figure 6. Electroscope identification light map.

Table 1. volt-ampere characteristics of electroscope identification.

Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
200.0	3.71	130.0	2.12
190.0	3.47	120.0	1.90
180.0	3.22	110.0	1.70
170.0	3.00	100.0	1.50
160.0	2.76	90.0	1.31
150.0	2.55	80.0	1.14
140.0	2.32	70.0	0.97

(2) High voltage electric field test.

When the ZnS device is placed close to the surface of the high-voltage power transmission and transformation equipment, a strong electric field will penetrate the layers of the electrochromic device. From the analysis, the internal field strength of the device can reach 105V/m.

High-voltage power transmission and transformation equipment, when charged, there will be a strong electric field near the surface. It is expected that under the action of a strong electric field, electrons inside the material can be accelerated to hit the illuminating center and cause luminescence. Therefore, the prepared ZnS device was directly placed in a high voltage electric field for testing [7]. However, during the experiment, ZnS did not emit eclipse under the action of an electric field. The voltage is continuously increased until the air is broken down, and neither ZnS emits light. As shown in Figure 7.

Figure 7. ZnS high voltage electric field test experiment.

When the ZnS was directly placed in an electric field for experiments, the experimental results were not satisfactory, and the ZnS device did not emit light. This research hypothesis is believed to be due to insufficient electric field strength inside the material. Therefore, measures are taken to connect the metal conductors in two stages of the ZnS sheet in order to increase the internal field strength of the material.

Experiments have shown that the internal field strength of the material has been superimposed enough to be much larger than the normal field strength of the material, because after the electric field is applied, the inside of the material is partially broken down and burned, and many discharge marks appear. The reason why the analysis material does not emit light under the action of a strong electric field is because the material is suspended in the air, and there is no path for the current to flow, and the material cannot be supplied with sufficient energy, so that the electric energy cannot be converted into visible light energy.

In the previous experiment, in one experiment, the sheet had already illuminated, but only after the light was emitted, the air was broken down. The guess is that during the rise of the experimental voltage, the free charge flowing through the sheet in the air gradually increases, and the leakage current in the air gradually increases until it increases to a certain moment, causing the material to illuminate, accompanied by air breakdown. Therefore, the analysis believes that if the prepared ZnS device is normally illuminated, in addition to applying a sufficiently strong electric field to the material, it is necessary to provide a considerable amount of current.

In the experiment, it was found that the ZnS failed to emit light by using the chip capacitor in parallel with the ZnS sheet. Therefore, this project uses a large-area metal plate in parallel with the ZnS, and puts the parallel copper plate and the device into the electric field. In this way, the current flowing through the material is increased while increasing the internal field strength of the material. Hang a copper plate that is 40cm long and hang it in an electric field. The ZnS device was connected to the above-mentioned suspended copper plate for test analysis. During the test, when the voltage on the conductor with the electroscope is 60kV, the ZnS electroscope logo begins to emit bright green-blue light, as shown in Figure 8.

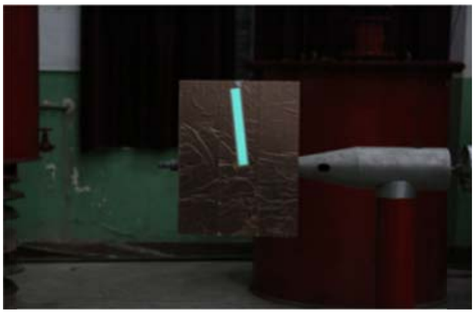

Figure 8. ZnS electroscope identification test chart.

According to the analysis, when the voltage is lower than 50kV, ZnS has already illumined in the electric field, but the emitted light is relatively weak. In the process of testing and observation, for the sake of safety, the observer is far away, and during the test, Due to the bright experimental environment, the light emitted by ZnS is covered by natural light, so the light emitted by ZnS is not recognized by the naked eye. Therefore, this research tested the ZnS device in the dark environment at night. During the test, the discoloration of the ZnS device was observed.

2.3. Application performance analysis of GaN electroscope identification

2.3.1. Analysis of Luminescence Characteristics of GaN Electroscope Mark

(1) Relationship between brightness and voltage.

The test of the relationship between brightness and voltage is performed on the GaN electroscope identification. The test results are shown in Figure 9:

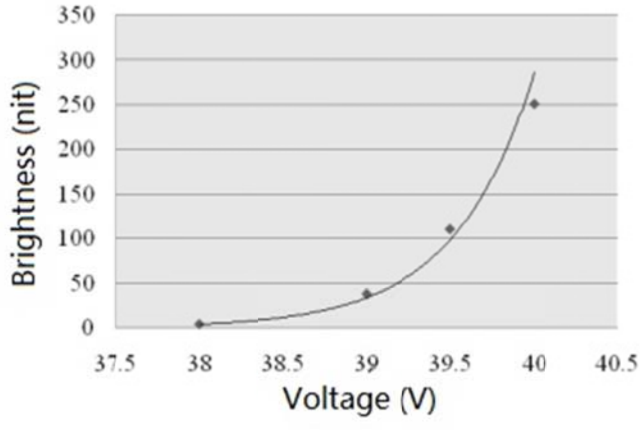

Figure 9. Relationship between luminance and voltage of GaN electroscope(1nit=1cd/m^2).

(2) Relationship between brightness and temperature.

The test of the brightness of the GaN electroscope identification with temperature is shown in Figure 10.

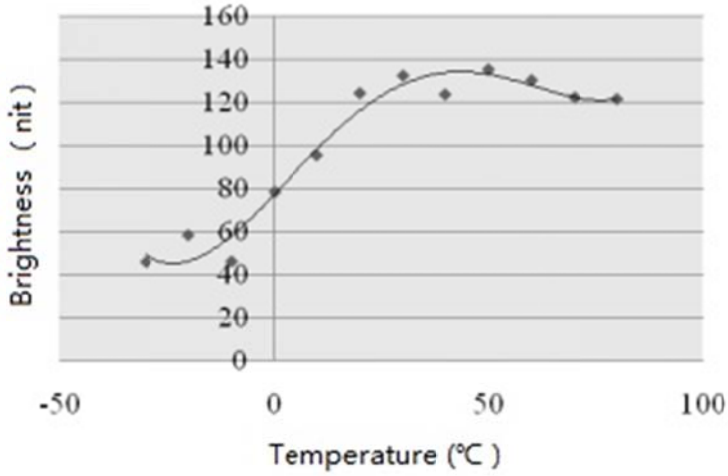

Figure 10. The relationship between the brightness of GaN electroscope identification and temperature(1nit=1cd/m^2).

The test results show that the GaN electroscope mark can be excited by the electric field to change color, and its color change brightness increases with voltage and temperature. The brightness increases exponentially with the increase of voltage, so in the process of use, in order to increase the visual effect of the GaN electroscope identification, the field strength applied to the color-changing material should be increased. At the same time, when the wire is in the working state, since the wire will generate heat, the temperature rise can increase the light-emitting brightness of the color-changing material, and has a certain promoting effect on the color change of the electricity-inspection mark. Moreover, the electroscope identification can effectively work normally at a low temperature of -30 ° C, and the luminance of the illumination is forty nits, and the compensation decreases with further decrease in temperature.

2.3.2. Weathering analysis of GaN electroscope identification. The GaN electroscope identification is affected by external conditions such as light, temperature changes, wind and rain, etc. at the power transmission and transformation equipment. The electroscope identification can correctly indicate the electrification status of the power transmission and transformation equipment under various conditions, which is the basic requirement for the reliability of the electroscope identification. Functional verification of the ZnS electroscope identification in various environments, including high temperature, low temperature ice coating, damp heat, high and low temperature cycle weathering test. The test proves that the GaN electroscope identification can adapt to various environments, and the field test photos are shown in Figure 11.

(a) test on site (b) data collection

Figure 11. GaN field test chart.

2.3.3. GaN electroscope identification electric field test test

(1) External power supply test.

The prepared GaN has a good illuminating effect, and when it is powered by an AC variable frequency adjustable power supply, when the voltage reaches 24.5V, it can emit dazzling blue light, as shown in Figure 12.

Figure 12. Laboratory test GaN luminescence.

(2) High voltage electric field test.

When the electroscope identification is placed directly in the electric field near the surface of the high-voltage electrified body, it can emit light under the action of the electric field, but the emitted light is weak, and there is only a slight color change at the center position, which requires careful close-up. Observation can only be seen.

Since the luminescence of GaN is very weak, it cannot be observed and recognized by the naked eye in the natural light state during the day. Therefore, this research still uses the method of placing the plate in the electric field to increase the electric field and current acting on the GaN material by electric field superposition. During the test, GaN was observed to emit significant light, which can effectively indicate the charging status of the high-voltage power transmission and transformation equipment, as shown in Figure 13.

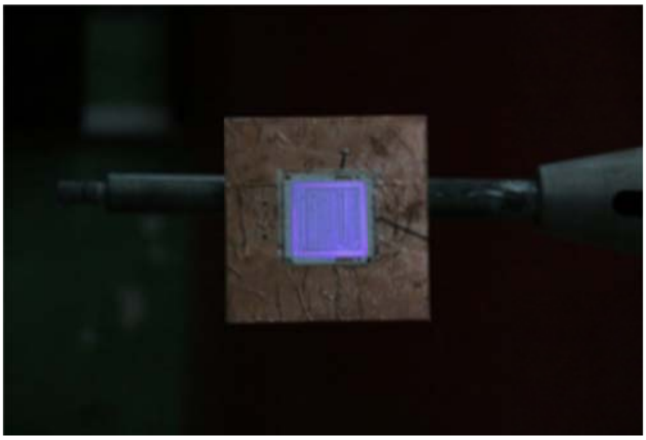

Figure 13. Experimental Hall Testing GaN

In the experimental process of high voltage electric field, the relationship between voltage and current flowing through GaN is shown in Table 2.

When the applied voltage reaches 16kV, the current flowing through GaN is 38uA, and the phenomenon of GaN discoloration and luminescence can be observed by the naked eye, thereby identifying the charging condition of the device and realizing the electroscope function.

Table 2. Current flowing through GaN.

Applied voltage (kV)	GaN current (mA)
4	-
8	-
12	0.015
16	0.038
20	0.055
24	0.074
28	0.086
32	0.101
36	0.115
40	0.128
44	0.143
48	0.156
52	0.17
56	-
60	-

3. Inorganic electroscope material coating application technology research

3.1. ZnS electroscope identification coating scheme

A thin film electroluminescent device was prepared on the basis of preparing a ZnS-doped electroluminescent phosphor by a high temperature solid phase method.

Firstly, the metal pin is inserted into the outer lead portion of the electroluminescent device, and some conductive adhesive is applied to make the outer lead of the light emitting device and the metal pin reliably connect and conduct electricity. Then apply a layer of insulating glue on the outside to fix it. Finally, the metal pins can be directly soldered to the circuit board or directly inserted into the socket of the circuit board. For the convenience of installation, the stamped pins are arranged at a certain distance. Therefore, the pin pitch is preset. Select a metal pin with a 2.0mm gauge.

3.2. GaN electroscope identification coating program

At present, the light-emitting device is fabricated by MOCVD epitaxial process. The GaN material light-emitting device epitaxial layer is composed of upper and lower confinement layers and an illuminating active region, and the top layer is a heavily doped layer for making ohmic contacts. Generally, The epitaxial layer of the GaN red light-emitting device is grown on a lattice-matched and conductive GaN substrate， and red light produced by using an AlInGaP material on a GaN substrate is used in the process technology, so that the device has a top and bottom structure, that is a device. The positive and negative electrodes are made on the front and back of the device [8]. A light-emitting device is an electroluminescent device that converts electrical energy into light energy. When a minority carrier injected under forward bias is combined with a majority carrier, excess energy is released as light, thereby directly converting electrical energy for light energy.

However, the ZnS electroscope identification developed by this research can perform luminescence discoloration in the electric field, indicating the electrification status of the high-voltage transmission and transformation equipment, but the disadvantage is that ZnS is a high-field luminescent substance, and the required energy is relatively large. Further, the energy-receiving plate produced is relatively large.

3.3. On-site application scheme for electricity inspection identification

The electroscope material developed by this project can emit color and change under the action of strong electric field. When using, just press the power inspection mark against the live conductor. In the field application mode, this project selects the way to fix the electroscope identification on the live conductor by using the clamp.

After the test, the inorganic electro-inspection identification materials developed by the State Grid Zhejiang Electric Power Company Jinhua territory UHV tower double-circuit line and UHV AC test base on-site application of inorganic electroscope materials, the field application photos shown in Figure 14 – Figure 15.

(a)Unpowered state (b)Live state

Figure 14. Application photo of inorganic electroscope identification material for UHV line.

(a)Unpowered state (b)Live state

Figure 15. Application photo of inorganic electroscope identification material for UHV substation equipment.

From the field trial situation, after the inorganic electroscope material is installed in the substation equipment and the line, obvious discoloration occurs, which can indicate the equipment and the line charging condition. In the application of the UHV AC test base, after the equipment and lines are powered off, the inorganic electroscope materials are restored to the original color, which can realize the color reversal after the power failure and meet the requirements of the electricity inspection instructions.

4. Conclusions

This project has studied the mechanism and preparation technology of various inorganic electroscope materials, prepared samples of inorganic electroscope materials, selected the GaN inorganic electroscope solution through performance test, and applied it on site, through this research research. Concluded as follow:

(1) The ZnS electroscope identification prepared by this project can achieve stable luminescence discoloration and self-recovery function, and can be used as an ultra-high voltage transmission and transformation inorganic inorganic electroscope material. The disadvantage is that ZnS is a high field luminescent material required energy. Relatively large, the energy-making board produced is relatively large, which is not convenient for on-site installation;

(2) The single crystal type electrodeless electroluminescent material prepared by using GaN material as the substrate has good luminescence discoloration performance under the action of electric field. Because it belongs to low field electroluminescent material, the fabricated energy absorbing plate is relatively Smaller, easy to install on site, and can effectively indicate the live state of the device;

(3) The prepared GaN inorganic electroscope marking material has been applied on the actual line and substation equipment, which can effectively indicate the system charging condition, thus effectively solving the electroscope problem of UHV power transmission and transformation equipment, economic benefit and the social benefits are huge and the application prospects are wide.

Acknowledgments

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