

Influencing Factor Research of Kerr Effect

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Abstract: This paper presents a model of Kerr effect for the influencing factors research. The influencing factors proposed are Kerr cell voltage, charging duration time and electrode material. The experimental results show that refractive index of transformer oil will rise when Kerr cell voltage become larger; there is a period of 15 minutes called 'polarization time' after the beginning of the experiment and electrode material indeed has an obvious effect on the transformer oil. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Kerr effect, Kerr cell voltage, Duration time, Electrode material, Transformer oil.

1. Introduction

Electro-optical Kerr effect is defined as a kind of phenomenon that the refractive index of a medium changes under the effect of electric field. Generally, light will not produce birefringent phenomenon when it travels along the optical axis in isotropic medium or piezoelectric crystal [1], but some isotropic transparent media do in a strong electric field, namely optical anisotropy. Then, the difference of refractive indexes parallel and perpendicular to the direction of the electric field is proportional to the square of Kerr cell voltage. The optical far-field property of a magnetic medium can be modulated by its magnetization. Specifically, under oblique incidence, the amount of light being transmitted and reflected by the medium varies when the transversal magnetization is flipped [2]. This effect is termed the transverse magneto-optical Kerr effect. In the past few years, several concepts were proposed to combine nano-optics and plasmonics with magneto-optical materials [3], where nano-optical and plasmonic structures were capable of enhancing or even giving rise to new magneto-optical effects.

The optical Kerr effect is a third harmonic generation that corresponds to the effective line refractive index of a material changing with the light intensity it experiences [4]. Nonlinear plasmons can be excited at the metal-dielectric interfaces where the dielectric possesses the Kerr nonlinear response. Only recently have studies of the third-order nonlinearity drawn more attention from researchers. In this way, different structures composed of metal and Kerr type nonlinear dielectric are investigated and properties such as self-focusing of light [5], and optical bistability are discovered. The devices possibilities for photonic crystals will be greatly enhanced by the addition of optical nonlinearities; such possibilities include ultra-fast all-optical switching for communication, and potentially even optical computing [6]. It is significant and worthwhile to explore more characteristics in the Kerr nonlinear photonic crystal domain.

The research results show that electro-optical Kerr effect is very important to measure space charge and study electric field distortion mechanism.

Kerr effect principle is shown in Fig. 1. The light from the light source S enters the Kerr cell through

the polarizer and the analyzer; the applied electric field between parallel electrode plates in the Kerr cell is perpendicular to the direction of optical axis.

When there is no applied voltage, the optical axis of the polarizer is perpendicular to that of the analyzer. The Kerr cell is in the so-called 'off' state and impenetrable to light. Applied voltage changes the polarization of the incident light, producing a portion of the light which can pass through the analyzer; the Kerr cell is in the so-called 'open' state. The author has studied Kerr effect from different sides such as Kerr cell voltage, charging duration time and electrode material.

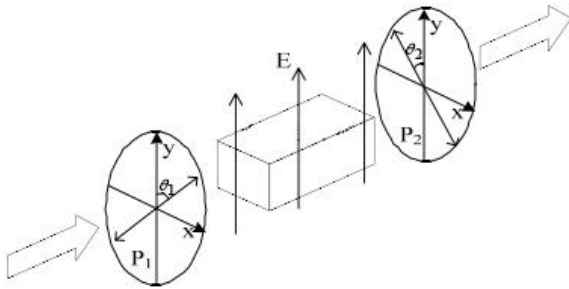


Fig. 1. Kerr effect principle.

2. Preparatory Work of Experiment

First of all, it is necessary to learn some optical basic knowledge involved in the experiment. When the double refraction phenomenon occurs, there is a mathematical expression:

$$n_{\parallel} - n_{\perp} = \lambda B E^2 \quad (1)$$

In Eq. (1), $n_{\parallel}$ and $n_{\perp}$ represent the refractive index parallel and perpendicular to the direction of the electric field respectively. Their difference value is proportional to the square of the electric field intensity E . Besides, λ is the optical wavelength in free space and B is the Kerr constant of the liquid. When the electrode length is L , the skewness of the two polarized light path is:

$$\delta = 2\pi \int_0^L B E^2 ds = 2\pi B E^2 L \quad (2)$$

Eq. (2) shows that under the Kerr effect, the phase difference of two polarized light has nothing to do with the direction of the electric field.

As shown in Fig. 1, when the parallel light pass through polaroid P_1 , Kerr dielectric and polaroid P_2 , if the angle between E and the y axis is 0° , the Angle of P_1 - y and P_2 - y are respectively θ_1 and θ_2 , theta, the ratio of the output light intensity I and the input light intensity I_0 is as follows:

$$\frac{I}{I_0} = \cos^2(\theta_1 - \theta_2) \sin^2(\theta_1) \sin^2(\theta_2) \sin^2 \frac{\delta}{2} \quad (3)$$

If $\theta_1 = 45^\circ$, $\theta_1 - \theta_2 = 90^\circ$, namely $P_1 \perp P_2$, it is the crossed polarizer, CP for short. If $\theta_1 = \theta_2$, then it is the Aligned Polarizer, AP for short. So it can be seen that:

$$\frac{I}{I_0} = \begin{cases} \sin^2 \frac{\delta}{2} \dots (CP) \\ \cos^2 \frac{\delta}{2} \dots (AP) \end{cases} \quad (4)$$

The first time when the light intensity become maximum under the condition of CP or minimum under AP, Define then electric field intensity on the Kerr dielectric as E_m which is usually called Kerr component constant and whose value depends the geometric size and birefringence of Kerr dielectric.

$$E_m = (2BL)^{-1/2} \quad (5)$$

and

$$\delta = 2\pi B E^2 L = \pi \left(\frac{E}{E_m} \right)^2 \quad (6)$$

So there is

$$\frac{I}{I_0} = \begin{cases} \sin^2 \left[\frac{\pi}{2} \left(\frac{E}{E_m} \right)^2 \right] \dots (CP) \\ \cos^2 \left[\frac{\pi}{2} \left(\frac{E}{E_m} \right)^2 \right] \dots (AP) \end{cases} \quad (7)$$

Thus, the maximum light intensity under CP or the minimum one under AP becomes when $E/E_m = 1, \sqrt{3}, \sqrt{5}, \dots$. The minimum light intensity under CP or the maximum one under AP becomes when $E/E_m = 0, \sqrt{2}, \sqrt{4}, \dots$.

If use photomultiplier and oscilloscope to record the trajectory change of the relative intensity, the ratio of the electric field under test and E_m can be obtained with the number of maximum, minimum and relative light intensity values. When the relatively light intensity are squarely in the n th maximum or minimum value,

$$E_n / E_m = \sqrt{n} \quad (8)$$

When the output light intensity does not reach the maximum or minimum, its electric field intensity can be deduced by Eq. (9) and Eq. (10).

As relative light intensity gradually increases:

$$E_n / E_m = \left[n + \frac{2}{\pi} \arcsin(I / I_0)^{\frac{1}{2}} \right]^{\frac{1}{2}} \quad (9)$$

As relative light intensity gradually declines:

$$E_n / E_m = \left[(n+1) + \frac{2}{\pi} \arcsin(I / I_0)^{\frac{1}{2}} \right]^{\frac{1}{2}} \quad (10)$$

If the Kerr cell is made up of parallel plates and Kerr liquid, according to the poisson equation, The

relative charge density between the parallel plate electrodes can be indicate with ρ , and:

$$\rho(x) = \varepsilon_0 \varepsilon_r dE / dx \quad (11)$$

In Eq. (11), ε_0 and ε_r are respectively vacuum dielectric constant and relative dielectric constant, x is the distance between the two parallel electrode plates. If the change rule of I can be measured, electric field intensity E and the space charge ρ between parallel plates can be determine.

Fig. 2 shows the block diagram of measuring devices for Kerr effect. He-Ne gas laser produces the laser light whose wavelength is 632.8 nm with good optical homogeneity, monochromaticity and spatial coherence [7], as a light source (the maximum output power is 10 mW). The polarizer is used to generate the polarized light, iris diaphragm to shrink light beam and analyzer to receive light. The transformer applies 0 ~ 50 kV step-less adjustable dc voltage on the parallel electrodes in Kerr cell. Luminous power meter acts as the luminous power measurement device.

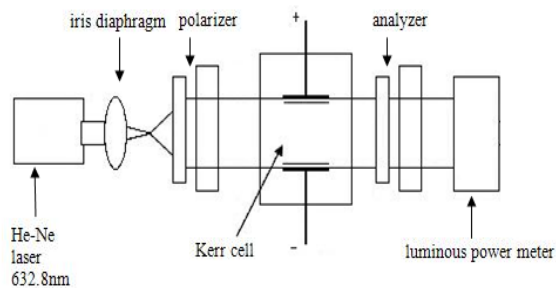


Fig. 2. Block diagram of test system.

In the experiment, it is significant to choose Kerr liquid according to voltage amplitude, the higher tested voltage amplitude is, the liquid with lower Kerr constant should be chosen. So, interference fringes between the electrodes will not to be so dense because of high voltage that it can't be identified. Pure water and oil are suitable for the test under millions of volts voltage. The lower tested voltage amplitude is, the liquid with higher Kerr constant should to be chosen to enhance the sensitivity of measurement system and measure the space charge distribution under the lower electric field. The typical Kerr electro-optic measuring system requires long light path to offer enough optical path difference which can improve the sensitivity of the test. But academic research on the liquid with low Kerr constant is less, so the experiment selects transformer oil with lower Kerr constant as Kerr liquid.

Transformer oil has so large resistivity ($108 \sim 1012 \Omega \cdot m$) and small conductivity current (Kerr cell steady-state current is less than 0.2 mA) that there is almost no heat produced in the measurement process. And the oil is reusable when

filtered by the filter paper under normal temperature and atmospheric pressure [8]. When the experiment is running, adjust the light path to minimize the measurement data of the luminous power meter. Respectively turn the polarizer and the analyzer to 60° , 70° , 80° and 90° ; the Kerr cell voltage is set orderly to 0 kV, 5 kV, 10 kV, 15 kV, 20 kV, 25 kV and 30 kV. The relationship of luminous power and Kerr cell voltage is shown in Fig. 3 and Fig. 4.

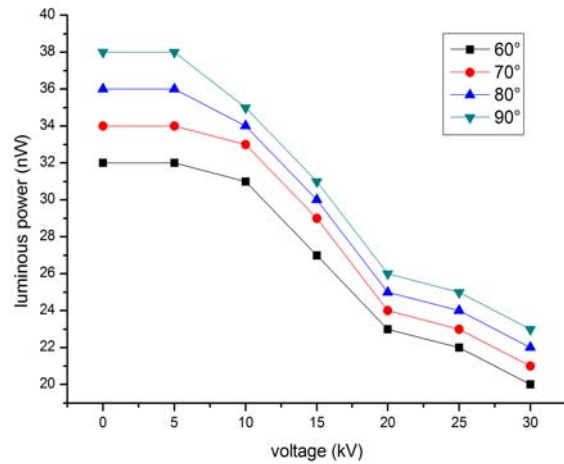


Fig. 3. Turn the polarizer.

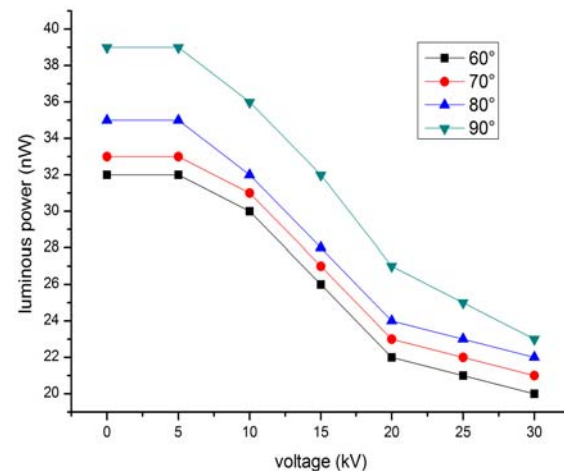


Fig. 4. Turn the analyzer.

From Fig. 3 and Fig. 4, conclusions come out that the change trend of the experimental data producing by adjusting the polarizer is as same as that by adjusting the analyzer, so the experimental light path is enough stable to take the next step of the experiment. Fig. 3 and Fig. 4 also show that with the increase of Kerr cell voltage, the luminous power detected gets weaker. When Kerr cell voltage changes from 0 to 5 kV, luminous power almost constant, and when Kerr cell voltage ranges from 5 kV to 20 kV, as Kerr cell voltage increases, luminous power dropped quickly, and when Kerr cell

voltage larger than 20 kV, uminous power changes slowly. We also obtain that the larger the angle of the polarizer, the greater the luminous power. The reason for this result is that He-Ne laser beam is assumed to propagate along a straight line [9], but the larger Kerr cell voltage becomes, the greater refractive index of transformer oil changes, the more laser beam deflecting loss is and the less luminous power detected gets. So the curves in Fig. 3 and Fig. 4 are on the decline.

3. Influence of Charging Duration Time

Choose 15 kV as Kerr cell voltage and 50 nW as the initial luminous power for this experiment. Turn the polarizer to 0° , 15° , 30° and 45° respectively, record the luminous power in 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes and 30 minutes in sequence. The relationship of the luminous power and the duration time of Kerr cell voltage is shown in Fig. 5.

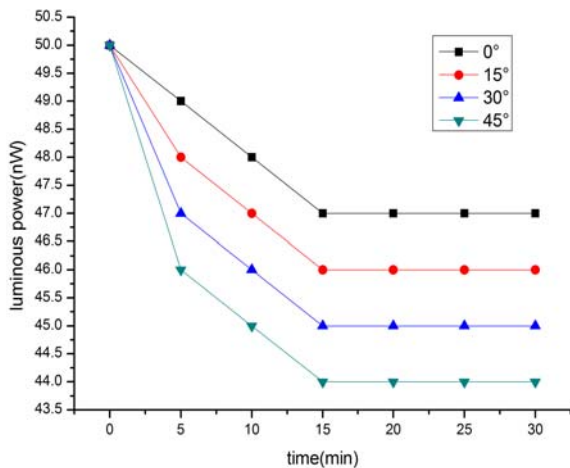


Fig. 5. Influence of charging duration time.

It can be seen from Fig. 5 that when the Kerr cell voltage is fixed, within a certain period of time, as the time extended, the luminous power tends to be weaker; Over the period of time, the luminous power will no longer change. The first 15 minutes is defined as 'polarization time' during which the transformer oil is polarized. When the polarization is completed, the refractive index of transformer oil changes no longer, so does the luminous power detected. And Fig. 5 also shows that the larger the angle of the polarizer, the more rapidly decreased the luminous power from 0 to 5 minutes. And then, the rate of luminous power declining is not affected by the angle of the polarizer.

The space charge at the interface of electrode and liquid is pushed into liquid dielectric by mirror force or Coulomb force. This leads to the electricity fluid motion of the Kerr dielectric so the liquid between the parallel plate electrodes form vortex flow. The movement has the time cumulative effect, if the

charging duration time prolong, the liquid will flow more violently, which leads to fuzzy light intensity figure. High field intensity near electrode edge makes local liquid heating, and heat leads to the formation of temperature gradient in the liquid. So heated liquid molecules move into some dielectric with lower temperature which also leads to fuzzy light intensity figure.

The negative space charge in the liquid transform to the positive charge, what is worse, there may be even not space charge injection. Because of the effect of long-time voltage, the electrodes have the same probability to inject holes and electrons into the liquid dielectric. But the number of injected holes and electrons are different, and a single-steady state will form eventually. The impurities and electronics in the liquid between electrodes are pulled by electric field force and adsorbed on the surface of the positive electrode. After the voltage polarity was changed, the anode's polarity becomes negative. To stainless steel electrode under pulse voltage, main charge injection is negative. At this time, the cathode surface is covered with a layer of adsorbate, which avoids the cathode launching electrons into liquid dielectric [6]. Therefore, the space charge in liquid dielectric may be negative or there may be no space charge injection.

4. Influence of Electrode Materials

First, use two pieces of iron plates as electrodes (the sizes of both plates are the same), Kerr cell voltage goes from 0 kV to 30 kV with a step-length of 5 kV; The range of polarizer turning angle is from 0° to 90° with a step-length of 30° and the initial luminous power is 50 nW. Fig. 6 is the relationship of the luminous power and Kerr cell voltage. Turn plates combination respectively into 'ferruginous cathode, aluminous anode', 'ferruginous cathode, brass anode', 'ferruginous anode, aluminous cathode' and 'ferruginous anode, brass cathode' to get Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

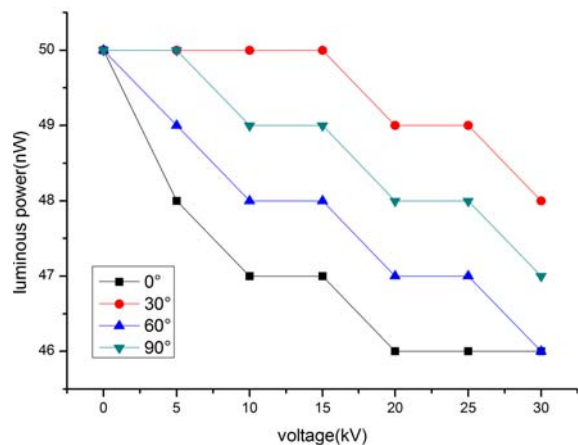


Fig. 6. Both ferruginous electrode.

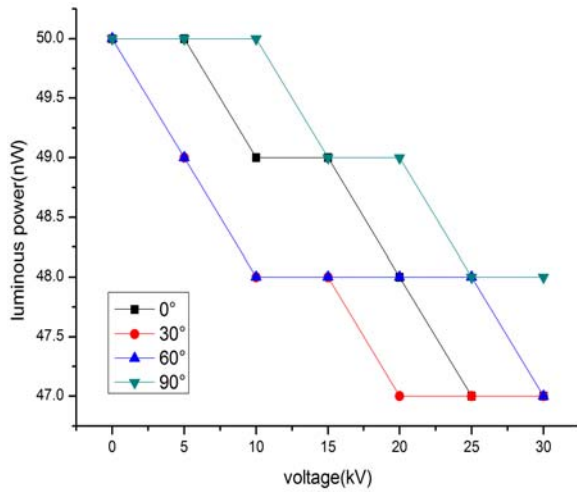


Fig. 7. Ferruginous cathode, aluminous anode.

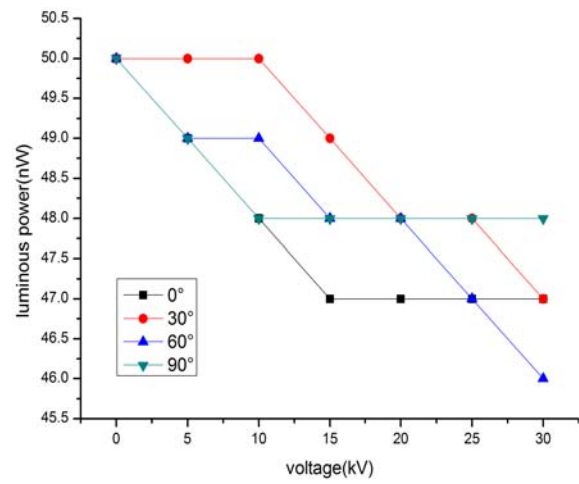


Fig. 8. Ferruginous cathode, brass anode.

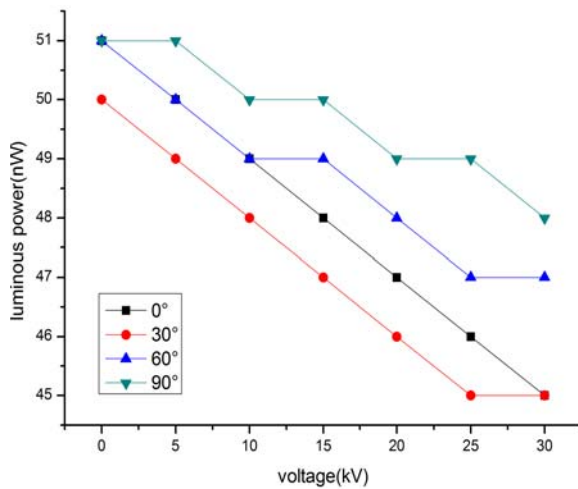


Fig. 9. Ferruginous anode, aluminous cathode.

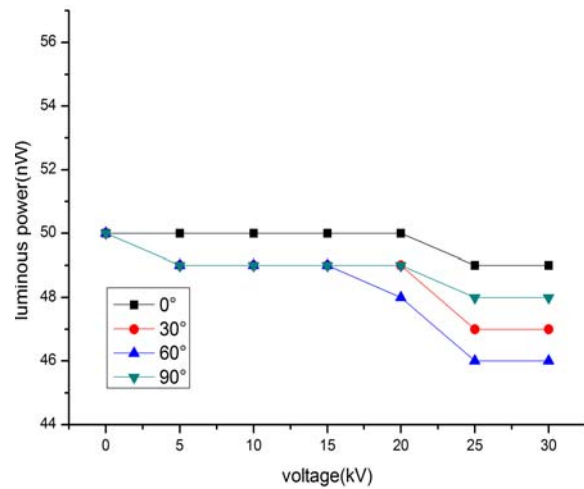


Fig. 10. Ferruginous anode, brass cathode.

It can be seen that if anode and cathode have the same material, difference angles have less influence on the trend of curves by comparing Fig. 6 with subsequent four pictures. Four curves decline or keep stable almost at the same time; but the influence of different angles is larger on the absolute value of luminous power. When materials of anode and cathode are different, changes of the four curves seem not to be in noteworthy synchronization; the fluctuations of curves are so weak that most parts of the four curves are overlapped. When the cathode material is iron, regardless of anode material is aluminum or brass, the curves show little change. When the anode material is iron, if cathode material is aluminium, with the rise of the Kerr cell voltage, the luminous power decreases significantly; if cathode material is brass, luminous power changes little.

5. Conclusions

Electro-optical Kerr effect has a good prospect, but it has not been controlled exactly. This paper studies

the influence of Kerr cell voltage, charging duration time and electrode material. At the same time, 'polarization time' and the trend of voltage-luminous curves are confirmed. The experimental results show that when Kerr cell voltage become larger, the refractive index of transformer oil will rise. Experimental materials and environment factors will have an impact of transformer oil.

According to space charge effect theory, as a result of the net charge injection, uneven electric field appears between parallel electrode plates, electric field line slope is proportional to the net charge density. When injected charge is positive, the slope raise, this kind of injection is called anode positive charge injection, otherwise, when injected charge is negative, the slope decline, this kind of injection is called cathode negative charge injection. For single-stage injection, when the electrode is injected with some charge of the same polarity, the electric field intensity near the electrode will decrease. At the same time, near the electrode without charge injection, the electric field intensity will increase. And the average electric field intensity between electrodes remains the same. The distortion

degree of the electric field line depends on the space charge injection density of the electrode.

When a certain electrode is injected with space charge infinitely, the electric field intensity near this electrode will be close to zero. When the parallel electrodes have the same material, transforming the polarity of the pulse voltage, the polarity of injected space charge into the Kerr liquid will also change. Because of the effect of space charge, the electrode surface is changed in a way, influencing the emission ability of space charge between parallel electrodes.

With the development of nanotechnology, transformer oil mixed with different types of nano-material are drawing academia's attention thanks to their excellent electrical properties. However, now, diverse research institutions add various nano-materials and get unlike results. So there is not a universal rule about the impact characteristic. At the same time, in terms of the test results, the impact breakdown characteristic of the transformer oil and other liquid dielectric is closely related to the distribution of space charge and the effect mechanism of different types of nanoparticle on space charge are also different, the nanoparticles relaxation principle and charge potential well theory are yet to be confirmed via test.

In the transformer oil under Impulse voltage, the space charge distribution changes rapidly. At the same time, due to the atypical characteristic of liquid, it is difficult to use solid polymer space charge measurement methods such as pulse acoustic method or laser induced pressure pulse method to measure the space charge inside the liquid. According to a small amount of foreign existing research results, making use of the Kerr electro-optic effect of liquid dielectric under the electric field, the interference of liquid internal electric field can be measured. But this way is very applicable for some liquid with high Kerr constant. To transformer oil, because of its lower Kerr constant, the phase difference generated by Kerr electro-optic effect is not obvious to be captured and measured.

Therefore, according to the research status at home and abroad, if mix nano-particles into the propylene carbonate whose Kerr constant is higher

than transformer oil to do experiment, Begin with exploring the impact breakdown characteristic of propylene carbonate, study its preparation method and get its macro impact breakdown characteristics. Combined with the space charge electro-optic effect measurement technology, compare the regularity of space charge distribution in the breakdown process of propylene carbonate mixed with nano-material. And provide the theoretical foundation [4] for internal insulation optimization design of large power transformer and the improvement of grid overvoltage.

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