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Experimental Study on the Crystallinity of Different Density Polyethylenes on the Breakdown Characteristics and the Conductance Mechanism Transformation under High Electric Field

Zhou Liwei, Wang Xuan, Zhang Yongqi, Zhang Peng, Li Zhi

Key Laboratory of Engineering Dielectrics and Its Application Harbin University Of Science And Technology, Harbin, 150080 China

Abstract: In order to study the crystallinity of different density polyethylenes, the experimental study on the transformation of the conductance mechanism under high electric field was carried out. The X-ray Diffraction(XRD), Different Scanning Calorimeter(DSC), Direct Current(DC) breakdown of Low-density polyethylene(LDPE), Linear low density polyethylene(LLDPE), Medium density polyethylene(MDPE) and High-density polyethylene(HDPE) and the electric field of 5-200kV/mm were tested. Conductivity characteristics experiments, in addition, using the mathematical formula of a variety of conductance mechanisms, the electric field-current density curves of the four kinds of polyethylene were fitted to analyze the conductance transition of the above four kinds of polyethylene in non-ohmic regions under different high field strengths. mechanism. The experimental results show that as the density of polyethylene increases, the crystallinity increases continuously, and the continuous increase of crystallinity causes the electric conduction flow under the same field strength to decrease significantly. The field strength corresponding to the two turning points in the conductance characteristic curve increases simultaneously. Large, the breakdown field strength increases; through analysis, it is found that in the high field, as the electric field increases, the conductance mechanism develops from the ohmic conductance of the low field strength region to the bulk effect of the high field strength region (Poole-Frenkel). Then the electrode effect to the high field strength (Schottky), and the threshold field strength of this conductance mechanism transition increases with the increase of crystallinity.

Keywords: polyethylene; crystallinity; breakdown strength; conduction mechanism; SCLC; Field strength.

1.Introduction

Polyethylene is a partially crystalline solid whose properties is highly dependent on the relative content of the crystalline phase and amorphous phase, i.e. crystallinity. Polyethylene is a polymer polymerized from monomeric ethylene. It is widely used in the insulating material of power cables due to its symmetrical molecular structure and no polar groups, which makes it has excellent electrical and mechanical properties[1,2]. Classified according to different polymerization methods, polyethylene can be classified into linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE), medium density polyethylene (MDPE), and high-density polyethylene (HDPE). Linear low-density polyethylene has a regular short-chain structure, although its crystallinity and density are similar to those of low-density polyethylene, the intermolecular force is larger. The macromolecules of low-density polyethylene have many branches and cannot be closely and regularly arranged with each

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other, and its branching degree is high. The medium-high density polyethylene is a linear macromolecule with low branching degree and regular structure[3].

As an insulating material, polyethylene is easy to cause electrical trees under the effect of high electrostatic voltage field, which eventually leads to insulation breakdown[4]. At present, domestic and foreign scholars generally agree that the space charge effect plays an important role in the insulation aging process[5,6]. The existing research has mainly used space charge limited current (SCLC), Schottky, Poole-Frenkel and hopping conductivity to explain the conductance mechanism of pure polyethylene or polyethylene nanocomposites in high field strength regions (non-ohmic regions). Some scholars believe that the conductivity mechanism of polyethylene under high field strength is not dominated by a single conductance mechanism[8,9], but a variety of conductance mechanisms[10]. Some scholars believe that the charge transport mechanism of doped nano-polyethylene in high field strength region (non-ohmic region) is dominated by ion hopping conductance, and it can be deduced from the formula that the ion jump distance increases with increasing temperature[11,12]. And they pointed out the "pre-electric stress" effect of polymer nanocomposites under high electric field[13,14]; Others believe that it is dominated by electronic hopping conductance, and the jump distance decreases with increasing temperature[15].

Many scholars have done a lot of research on the conductance property of polymer nanocomposites, but most of them have studied the modification of low density polyethylene matrix nano[16-18]. There are very few studies on the conductance property of polyethylene with different densities. In addition, due to the complexity of the structure of polymer materials, there is currently a lack of sufficient understanding of the conductance mechanism of polyethylene. Based on the existing research on polyethylene and polyethylene nano-polyethylene[19,20], this paper studied the effects of different crystallinity on the DC breakdown strength and conductance property of different density polyethylene. The effects of crystallinity of polyethylene with different densities on its conductance property were discussed by XRD and DSC.

2.Experiment

2.1. Experimental materials

The paper selected linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE), medium density polyethylene (MDPE) and high-density polyethylene (HDPE) as test materials. The LLDPE model is LLDPE7042 with a density of 0.922 g/cm^3. The model of LDPE is LD200BW with a density of 0.918 g/cm^3, and the model of MDPE is MDPE157 with a density of 0.935 g/cm^3. The HDPE model is DMDA 8008 with a density of 0.954 g/cm^3.

2.2. Sample preparation

The LDPE sample was pressed by a plate vulcanization machine at 110 ℃, preheated for 5 minutes before pressurization, then pressurized 5 MPa every 5 minutes, and finally pressed at a maximum pressure on 15 MPa. The thickness of the sample used to test the DC breakdown was 60μm, and the thickness of the sample used to test the conductance was 50 μm. The samples of LLDPE, MDPE, and HDPE were prepared in the same manner, but the pressing temperature was changed into 150 ℃. All the samples were made by depositing Aluminium as electrodes on the vacuum membrane plate machine. Finally, the prepared electrode samples were placed in a vacuum drying oven for 24 hours, and the short-circuit temperature was 50 ℃.

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2.3. DSC test

The thermal properties of polyethylene with four different densities were tested by differential scanning calorimeter. During the experiment, 0.005~0.007 g samples were weighed and placed in aluminum crucibles, protected by high-purity nitrogen, and the heating and cooling temperature rate were set to 10 ℃/min. The sample was first heated to 200 ℃ to completely melt, eliminating the influence of thermal history, and then cooled to 40 ℃ to obtain a crystallization process curve, and then heated to 200 ℃ to obtain a melting curve.

2.4. XRD test

Phase analysis of polyethylene with four different densities was carried out using a X-ray diffractometer (X'pert) . The X-ray source was CuK α, the tube voltage was set to 40 kV, the tube flow was set to 40 mA, the phase analysis was performed in the θ-2θ scanning mode, the step size was set to 0.05°, and the time constant was 1 s. The θ-2θ scanning mode is used for fine scanning, the step size is set to 0.02°, and the time constant is 20 s.

2.5. Conductivity test

The schematic diagram of the electrical conductivity test system is shown in Figure 1. The Keithley 6517B electrometer/high resistance meter (minimum theoretical measurement accuracy 10-15A) and the self-made three-electrode system (measuring electrode diameter 25mm) are used in a vacuum environment (vacuum The pressure inside the box is 0.1 MPa. The pure LLPE, LDPE, MDPE and HDPE with a thickness of 50 μm are measured. The conductivity of the field strength of 5~200 kV/mm is 30 min. Based on the Labview system, the computer realizes the automatic control of the boost voltage, the automatic data acquisition and storage of the high-voltage DC power supply and the 6517B high-resistance meter and the controller, and the automatic control of the protection circuit. The voltage source has a step-up step of 250V each time. For 30min, when the pressurization time reaches 30min, the controller controls the high-voltage relay to operate, and the 6517B high-impedance meter is connected to the measurement loop for 30s current test, collecting 10 data per second, and finally selecting the average value as the voltage. After the measurement, the sample is short-circuited for 25 minutes. Although the literature indicates that the current steady-state needs to pass several hours or several days [21], it is found during the test that it is pressurized or depressurized for 25 minutes. The current basically reaches the steady state, so the influence of the previous low field strength pressurized residual charge on the measurement under the subsequent high field strength is ignored. Then the controller controls the high voltage vacuum relay to operate, and the 6517B high resistance meter continues to be disconnected, and then added again. Press, repeat this.

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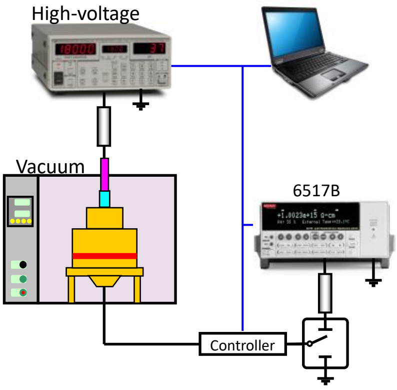


Figure 1. Conductivity test schematic.

3.Experiment results and discussion

3.1. Polyethylene melting characteristics

Figure 2 shows the melting characteristics of four kinds of polyethylene. It can be seen from Fig. 2 that the melting temperature of LDPE is the lowest and the melting peak is small; the melting temperature of LLDPE is higher than that of LDPE, the melting peak is lower than that of LDPE, the melting temperature of MDPE is higher than that of LLDPE, and the melting peak is higher than that of LLDPE; The highest melting temperature and melting peak of HDPE are very similar to MDPE, and the melting peak area is slightly larger than MDPE. Crystallinity (X_c) can be used to characterize the ratio of the crystalline part of the semi-crystalline polymer, and the calculation of X_c is as shown in the formula (1).

$$X_c = \frac{\Delta H_m}{\Delta \mathrm{H}_{100}} \times 100\% \qquad (1)$$

where,ΔH_{m} is the enthalpy absorbed by the test sample during the heating process, $\triangle \mathrm{H}_{100}$ is the enthalpy absorbed by the sample during the crystallization-melting process. The $\triangle \mathrm{H}_{100}$ of polyethylene is 293 J/g[22,23]. The crystallinity of the four kinds of polyethylene was calculated by DSC test software and the results are shown in Table 1. It can be seen from Table 1 that the crystallinity of the four kinds of polyethylene is different, the crystallinity of LDPE is the lowest, the crystallinity of HDPE is the highest, and the crystallinity of MDPE is higher than that of LLDPE. And the crystallinity of LLDPE is slightly higher than LDPE, but the two are very similar. It can be seen that LLDPE and LDPE not only have similar density but also have similar crystallinity. At the same time, it is known from experiments that crystallinity increases with density.

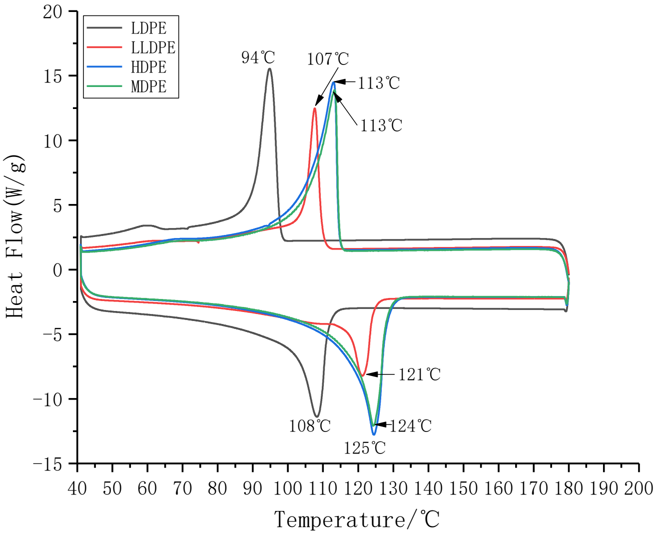


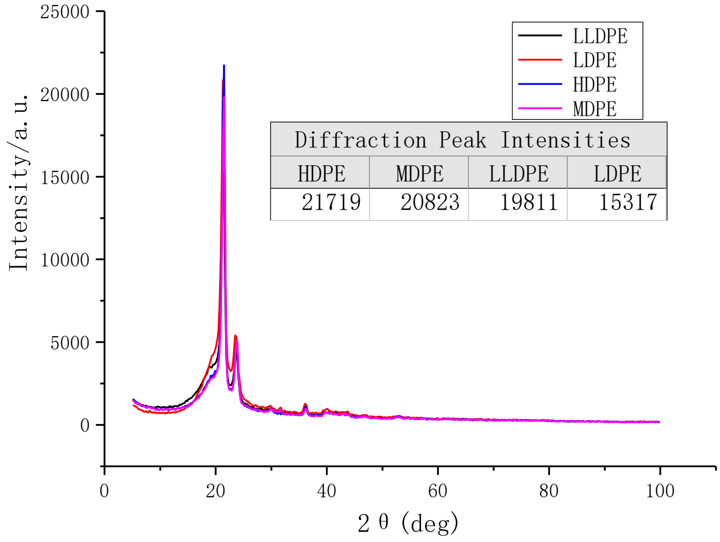
Figure 2. DSC curves of four kinds of polyethylene.

Table 1. Crystallization and melting process parameters of four kinds of polyethylene.

Sample	T_m/(℃)	T_c/(℃)	ΔH_m/(J/g)	X_c/%
LDPE	108	94	113.5	38.73
LLDPE	121	107	115.6	39.45
MDPE	124	113	141.7	48.36
HDPE	125	113	149.9	51.17

3.2. Analysis of the crystal structure of different polyethylene

Figure 3 shows that the four kinds of polyethylene with different densities has obvious diffraction peaks at nearly the same position 2θ=21.42°, indicating that these four kinds of polyethylene have typical crystal structures. Moreover, from the image and data, it can be concluded that the diffraction peak intensities of the four kinds of polyethylene are arranged from small to large: HDPE, MDPE, LLDPE, LDPE. The crystallinity of the polymer is directly proportional to the diffraction peak intensity of the XRD, so it can be concluded that the crystallinity of the four polymers is in order from large to small: HDPE, MDPE, LLDPE, LDPE. The image results of XRD are completely consistent with the results obtained through the DSC data calculation, so the crystallinity of four kinds of polyethylene with different densities can be determined in this experiment.



Diffraction Peak Intensities

HDPE	MDPE	LLDPE	LDPE
21719	20823	19811	15317

Figure 3. XRD images of four kinds of polyethylene.

3.3. DC breakdown strength test

Figure 4 is a Weibull distribution of DC breakdown strength for four kinds of polyethylene with different densities. The shape parameters and characteristic breakdown strength of four kinds of polyethylene are shown in Table 2. The shape parameter indicates the dispersion of the breakdown data, the characteristic breakdown strength represents the electric field strength when the overall sample reaches a 63.2% breakdown probability. It can be seen from Table 2 that the breakdown strength of the four kinds of polyethylene is different, and the breakdown strength of LDPE is the lowest. The breakdown field strength of HDPE, MDPE, and LLDPE is 37.96%, 28.56% and 15.01% higher than that of LDPE, respectively. It can be concluded that the breakdown strength of the four kinds of polyethylene increases with the increase of crystallinity, mainly because the free volume of polyethylene becomes smaller as the crystallinity increases. Thereby, the free path of electrons is reduced, it becomes difficult for them to accumulate energy in the electric field, and the probability of electrons accelerating under the electric field is lowered so that the breakdown strength is correspondingly increased[24,27]. It can also be seen from Table 2 and Fig. 4 that the larger the shape parameter, the smaller the dispersion of the breakdown strength data, and the polyethylene exhibits more stable dielectric properties.

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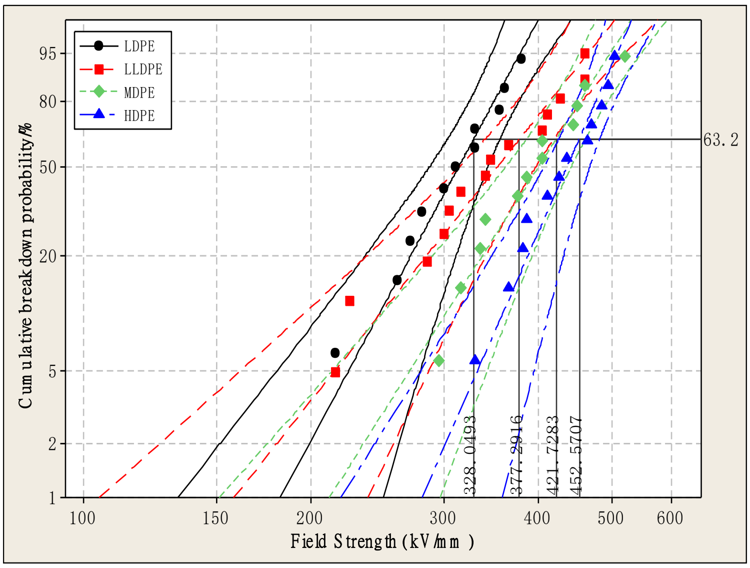


Figure 4. The Weibull plots of the DC breakdown strength of four kinds of polyethylene.

Table 2. Shape Parameter and Breakdown Strength of Polyethylene.

Material	Shape Parameter	Characteristic Breakdown Strength (kV/mm)
LDPE	7.791	328.0
LLDPE	5.277	377.3
MDPE	6.654	421.7
HDPE	9.577	452.6

3.4. Conductivity test

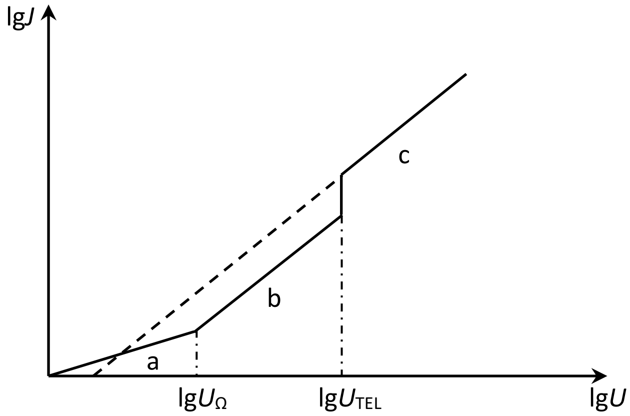
3.4.1. Conduction current Theory

a) traps and space charge

There are many localized states in the forbidden band gap of the polymer. These localized states can capture the carriers in the material to form a space charge, which acts as a trap, so the localized state is also called a trap. Space charge is sometimes referred to as trapped charge. Traps are mainly caused by crystal imperfection, which is caused by structural defects or impurities, or both. Traps are roughly divided into two types, mainly formed by structural defects or chemical defects. It is generally believed that discrete trapping levels are associated with chemical impurities doped in the lattice, and quasi-continuous trapping levels are related to imperfections of crystal structure[25].

b) Space charge limited current (SCLC)

The current-voltage characteristics of the dielectric comply with Ohm's law at low electric fields, ie at the beginning of pressurization. When the voltage (or electric field intensity) reaches a certain value U_{Ω} (or E_{Ω}), the concentration of the injected carriers increases, accumulating a large amount of space charge, causing the space charge limited current. So that the current flowing through the dielectric is transformed from the region of ohmic current to the region of space charge limited current. When the field strength applied to the material exceeds the breakover field strength, a large accumulation of carriers and space charge limited current will occur in the insulation, which may cause various aging conditions. Thus, the breakover voltage U_{Ω}(or electric field intensity E_{Ω}) is sometimes referred to as the electric degradation threshold of the dielectric material, which is the ideal situation without traps. There are inevitably various traps for the actual dielectric materials as mentioned above. When there are traps, the trapping of the injected charge makes the breakover voltage much larger than when there is no trap, and the current is made smaller. As the voltage *U* applied to the material increases, the amount of injected charge increases and the traps in the material are gradually filled. The traps are filled when the voltage reaches a certain value U_m, and the injected electrons will no longer cause trapping so that the current in the insulation increases so sharply that it turns to the region of space charge limited current without traps. At this time, the density J of the space charge limited current follows Calder's law with trap filling or without traps, as shown in Figure 5[26].



a region - Linear region ie Ohmic conduction current region;

b region - Calder's law region of space charge limited current when trapped;

c region - Calder's Law region with trap filling or without traps

Figure 5. Relationship between space charge limited current in dielectrics and the applie voltage.

The expression of the density of the space charge limited current is as follows:

$$J=(\frac{9}{8}\varepsilon_r\varepsilon_0\mu\frac{U^2}{d^3})\theta \tag{2}$$

where ε_0 is the vacuum dielectric constant, ε_r is the relative dielectric constant, μ is the permeability, d is the dielectric thickness, θ is the control parameter of the trap. $\theta=n/(n+n_t)$, which is the ratio of the free carrier concentration to the total carrier concentration. n_t is the trapped carrier concentration, n is the free carrier concentration ,since $n_t>>n$, $\theta\approx n/n_t$, usually $\theta\leq10^{-7}$[24].

The breakover voltage U_Ω of the space charge limited current can be expressed as equation (3), n_t can be expressed as formula (4):

$$U_\Omega=\frac{8end^2}{9\varepsilon_r\varepsilon_0\theta} \tag{3}$$

where e is the amount of electron charge.

$$n_t=\frac{9\varepsilon_r\varepsilon_0U_\Omega}{8ed^2} \tag{4}$$

Equation (5) can be obtained after taking alogarithm of both sides of equation (2):

$$\ln J=\ln\frac{9\varepsilon_r\varepsilon_0\mu}{8d^3}+2\ln U \tag{5}$$

It can be seen from equation (5) that the current density and the applied voltage of the SCLC is linear in the double logarithmic coordinate with a slope of 2.0.

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3.4.2. Test results of conduction current

Figure 6 and Figure 7 show the E-I characteristic curves of the electrically conductive flow of four different density polyethylenes of LDPE, LLDPE, MDPE and HDPE and the logarithmic curves in the lg*I*-lg*E* coordinate system, and the data is segmented in Figure 7. Hehe. It can be seen from the fitting results of Figure 7 that the conductivity curves of the four kinds of polyethylene have two turning points, namely, point A and point B, and three areas, namely, T1 area, T2 area, and T3 area, and four different density clusters. The field strengths corresponding to the A and B points of ethylene are given in Table 4. The slopes of the fitted straight line of the T1, T2, and T3 regions are given in Table 3. In addition, according to the EI curve of four different density polyethylenes in Figure 6, we can know that the electric conductivity values of LDPE, LLDPE, MDPE and HDPE respectively decrease in the same field strength, so the conductivity is in the same field strength. The next is also reduced in turn. The carrier mobility is related to the migration barrier and the jump distance. As the density of polyethylene increases, the thickness and convergence of polyethylene platelets increase [27], and the molecular chains of MDPE, HDPE, LLDPE and LDPE are tight. The degree of compaction is weakened, and the compactness of the platelets is weakened in turn, so the height of the migration barrier is sequentially decreased. The jump distance is related to the thickness of the platelet. As the crystallinity increases, the thickness of the platelets increases, and the average jump distance increases, so carrier migration The rate is significantly reduced as the crystallinity of the polyethylene increases.

According to the data in Table 3, we can see that the slope of the T1 region, ie, the low field strength region (ohmic region), is approximately 1 and remains substantially unchanged; while the slope of the T2 region, ie, the high field strength region (non-ohmic region), increases with density. The height gradually decreases, but the slope values are all greater than 2; the slope of the LDPE in the T3 region is close to 2, and the slopes of the remaining three clocks are close to 1.

According to Table 4, the corresponding field strength at the first turning point A in the conductance characteristic curve of LDPE, LLDPE, MDPE and HDPE in the lgI-lgE coordinate system is gradually increased, and it can be seen that with the crystallization of polyethylene The degree gradually increases, and the electric field threshold from the ohmic zone to the non-ohmic zone gradually increases. Some scholars believe that there are many local states in the forbidden band gap of polymers. These local states can trap carriers in materials to form space charges [7]. According to space charge limiting current theory, from ohmic region to space charge Limiting the transition voltage of the current region corresponds to the electric field strength that the space charge begins to accumulate. The reason for the above phenomenon may be that the LDPE electrical conduction flow is the largest, the most effective carriers, and the LLDPE, MDPE and HDPE are decreased in the four materials at the same field strength in the ohmic region. Therefore, the LDPE may first start the accumulation of space charge. The field strength corresponding to the turning point in the high field strength region (non-ohmic region), that is, the point B, is gradually increased, and the field strength corresponding to the B point is continuously increased as the crystallinity of the polyethylene increases. Some scholars believe that the turning point in the high field strength region (non-ohmic region) may

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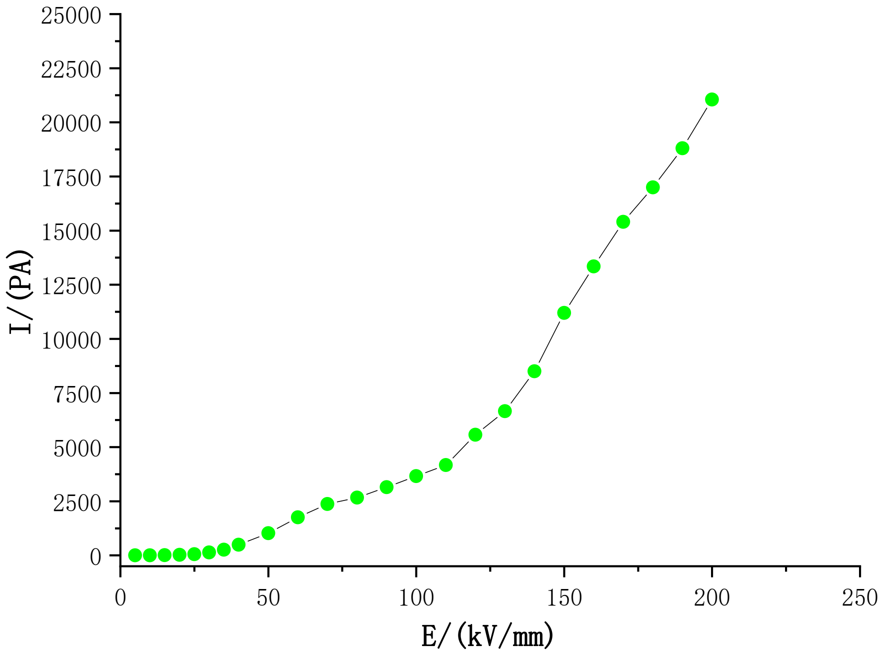
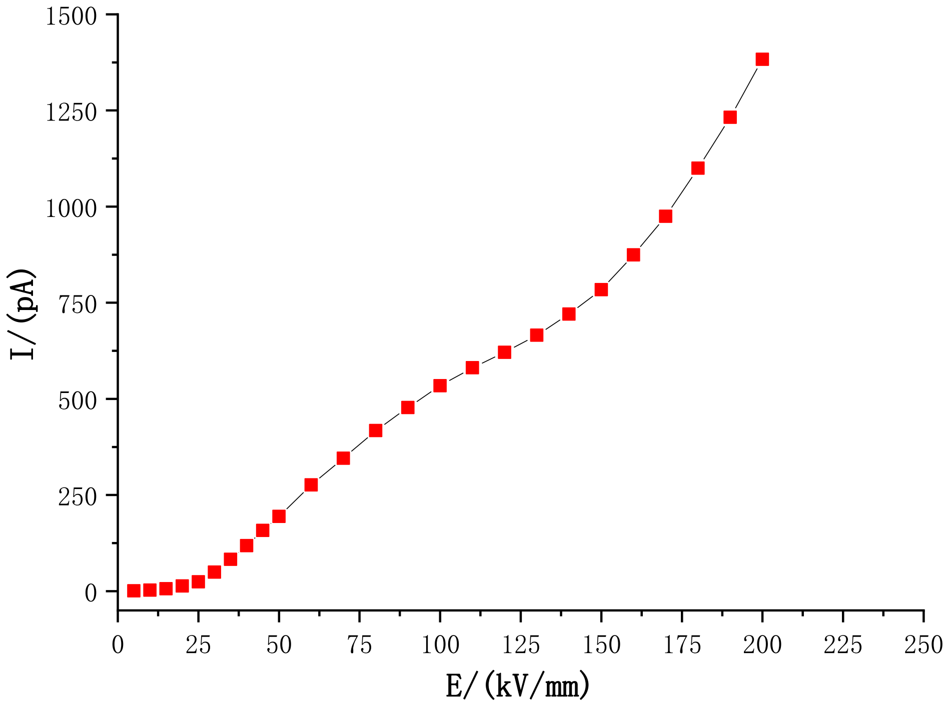
be due to the tunneling effect under the charge filling area or high field strength [28].



LDPE I-E



LLDPE I-E

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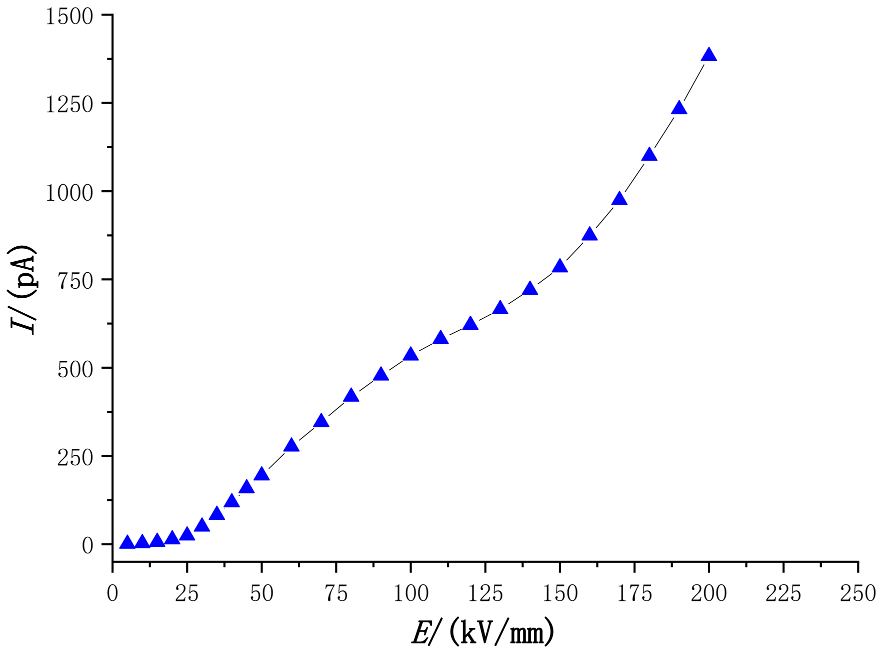
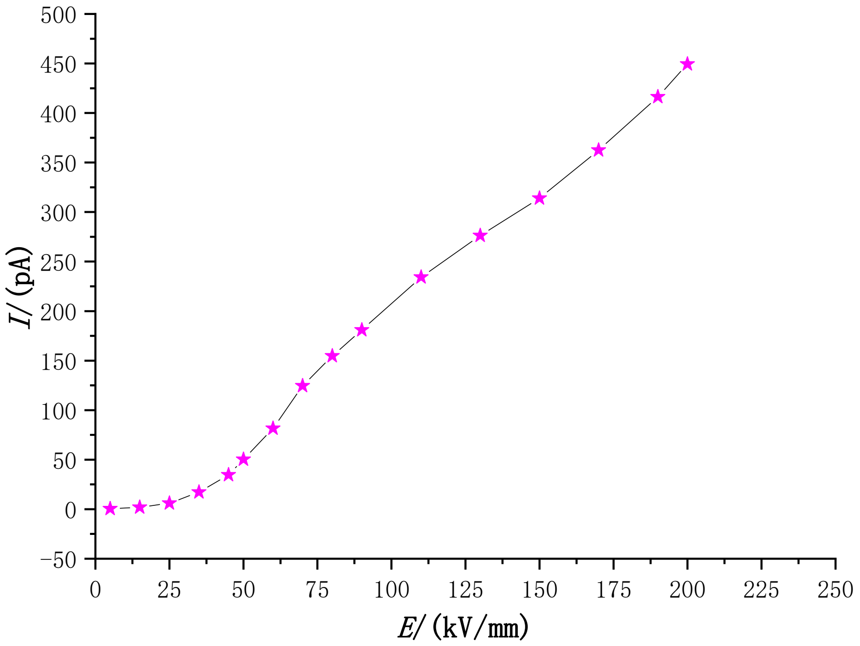


MDPE I-E



HDPE I-E

Figure 6. Conduction current characteristic curve of polyethylene with different densities.

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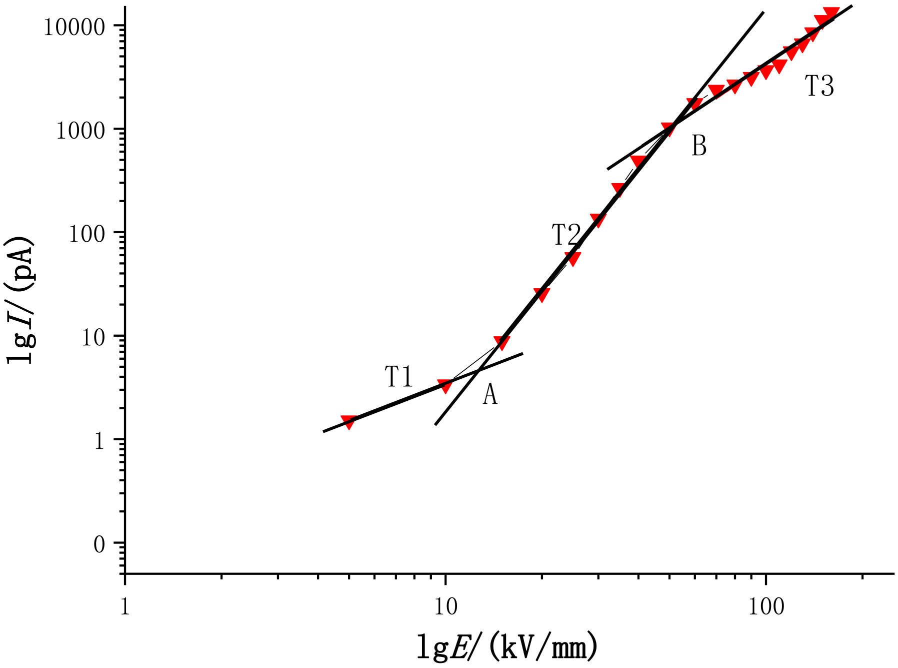
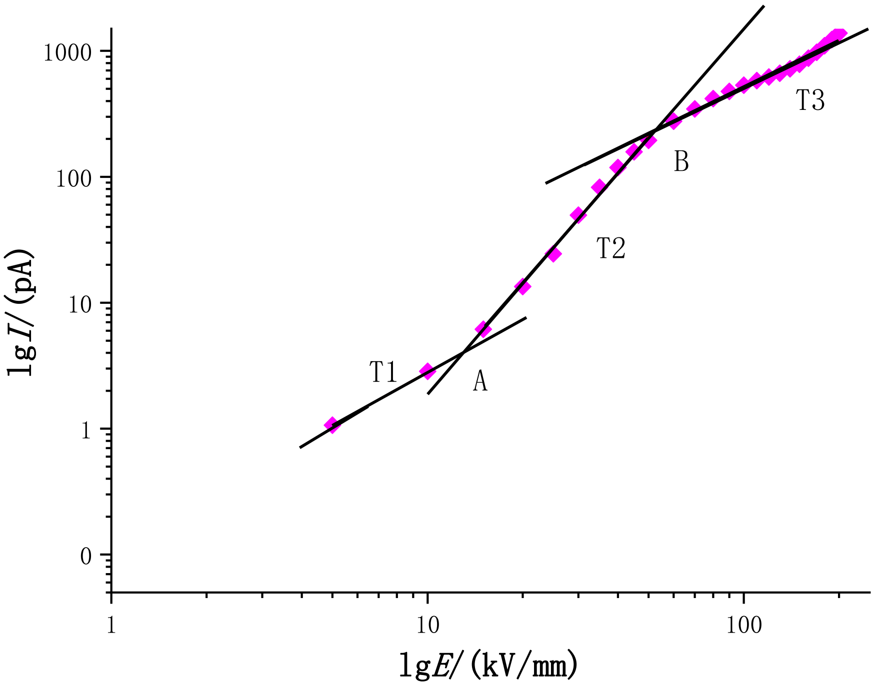


LDPE lg*I*-lg*E*



LLDPE lg*I*-lg

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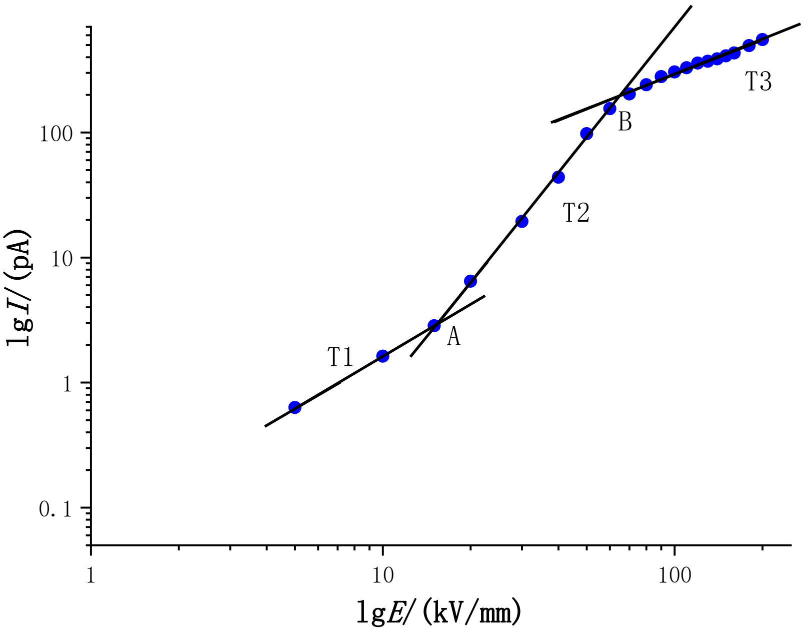
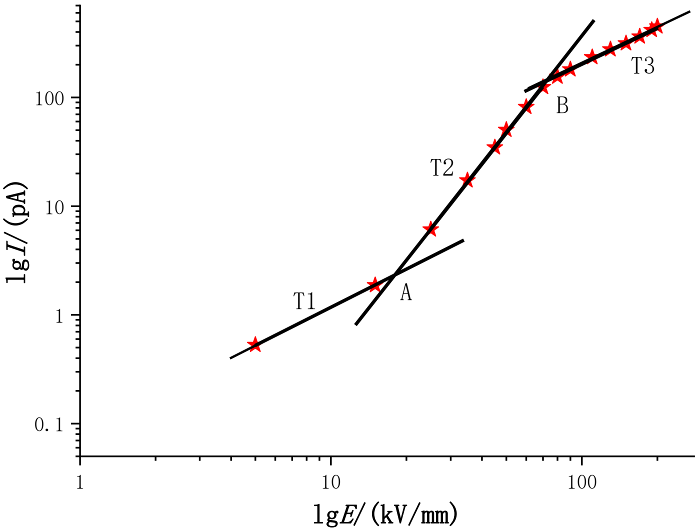


MDPE lg*I*-lg*E*



HDPE lg*I*-lg*E*

Figure 7. Logarithmic form fitting diagram of electrical conductivity flow of four different density polyethylenes

Table 3. The slope of the line in different areas of different materials.

Different Areas	T1	T2	T3

LDPE	1.16	3.94	2.13
LLDPE	1.42	2.93	1.23
MDPE	1.36	2.89	0.89
HDPE	1.15	2.83	1.12

Table 4. The corresponding field strength at different turning points of different materials.

The turning point	LDPE	LLDPE	MDPE	HDPE
A	12.76 kV/mm	13.33 kV/mm	15.68 kV/mm	18.37 kV/mm
B	50.88 kV/mm	53.61 kV/mm	65.34 kV/mm	71.89 kV/mm

4.Discussion

4.1. High field slope change

We generally believe that the non-ohmic current of a solid dielectric in a high electric field mainly appears as a space charge limited current (SCLC), mainly due to the rapid proliferation of carrier concentration with the enhancement of the electric field. Both the electrode effect and the bulk effect cause nonlinear propagation of carriers in the medium, causing the carrier concentration in the medium to become a function of the electric field strength. Therefore, the high electric field non-ohmic current characteristics may have two phenomena of electrode characteristic control and body characteristic control [21, 24, 29]. Since the solid dielectric is low in bulk conductivity, it is generally believed that the transport process of carriers in the ohmic conductance region of the weak electric field is dominated by the hopping conductance of the impurity ions [7, 12, 24], and the current belongs to the bulk limiting process. However, when the conditions (temperature, electric field) change, the high-field non-ohmic conductance will change from the body effect limit to the electrode effect limit, and the high electric field download stream transport process belongs to the amorphous state. Lord [30, 31]. In theory, the slope of the space charge limited current zone should be 2 in the double logarithmic coordinates. From the measurement results of the non-ohmic region of the T2 region of Fig. 7, it can be seen that the slope of the high field strength curve of the four different density polyethylene materials ranges from 2 to 4 regardless of the voltage form, and the slope gradually increases with the increase of crystallinity. reduce. The slope of the high field strength conductance curve for polyethylene and its nanocomposites is reported to vary from 2 to 5 [7, 31, 32]. Montanari studied the conductance mechanism of different kinds of polyethylene. It is believed that the slope of the curve in the logarithmic coordinates of the high field strength region is greater than 2, and there is a space charge limiting current limiting effect [29]. And the slope of the high field strength region can not be used to judge the quality of the material, only the difference in the conductivity mechanism of the material [22]. In the T3 region, the electric field strength is further increased to a maximum of 200kV/mm. According to Fig. 5, we can see that the slope value of the T3 region is supposed to be 2 according to the theory. However, according to Table 3, we can see that the results obtained in the experiment are: Only the slope of LDPE in the T3 region is about 2.132, which is very close to 2, while the slopes of LLDPE, MDPE and HDPE in the T3 segment are close to 1. This phenomenon may be

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due to the deeper traps in the dielectric material when the field strength is particularly high. Excited, so when the field strength reaches the electric field corresponding to the second inflection point in the conductance characteristic curve, the carrier may be trapped by the deeper trap, which leads to the slope of the conductance characteristic curve of the T3 region being much smaller than that of the T2 region.

4.2. High field conductance theory

At present, the proliferation process of carriers in the high electric field region is dominated by Schottky (electrode effect) and Poole-Frenkel (body effect) [33], and the charge transport mechanism is dominated by electron jump conductance [34].]. In order to study the change of the conductivity mechanism of four different density polyethylenes under high field strength at room temperature (25 °C), the mechanism of the above two high field strengths is briefly introduced.

1) For the Schottky effect, the current density is controlled by the carriers injected into the medium by thermal excitation. The formula is as follows:

$$j = AT^2 \cdot \exp[-\frac{\varphi - \sqrt{e^3 E/4\pi\varepsilon_0\varepsilon_r}}{kT}] \qquad (5)$$

Where: ε_r is the relative dielectric constant; ε_0 is the vacuum dielectric constant; A is the Richardson-Dushman constant; φ is the work function of the metal.

It can be seen from equation (5) that at high field strength, if the conductance mechanism is Schottky effect, the conductance characteristic curve will be linearly distributed in the ln$j$-$E^{1/2}$ coordinate system [28].

2) For the Poole-Frenkel effect, the conductance change can be described as

$$\frac{j}{E} = \sigma = \sigma_0 \cdot \exp[\frac{\sqrt{\frac{e^3 E}{\pi\varepsilon_0\varepsilon_r}}}{kT}] \qquad (6)$$

where: σ is the volume conductivity; σ_0 is the initial conductivity.

It can be seen from equation (6) that at high field strength, if the conductance mechanism is the Poole-Frenkel effect, the conductance characteristic curve is linearly distributed in the ln$j$-$E^{1/2}$ coordinate system [29].

4.3. Data segmentation fitting result

The carrier propagation of polyethylene in the high field strength region is a process from the limitation of body effect to the limitation of electrode effect. There are many interactions of conductive mechanisms [10, 21], which cannot be fitted by a single conductive mechanism [7, 21, 32]. It can be seen from Fig. 7 that the current characteristics of the four different density polyethylenes in the high field strength region are not dominated by the space charge limiting current SCLC. If polyethylene is synergistically acted by a variety of conductance mechanisms in the high field strength region (non-ohmic region), for the two carrier propagation processes (Schottky effect or Poole-Frenkel effect) in the high field strength in Section 4.2, Then the distribution in the ln$j$-$E^{1/2}$ coordinate system may have no obvious law. However, if a certain conductivity mechanism plays a dominant role in a fixed temperature range and a certain field

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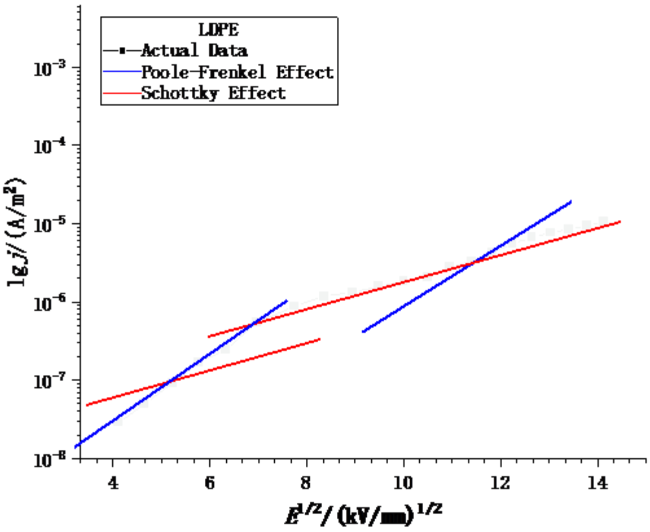
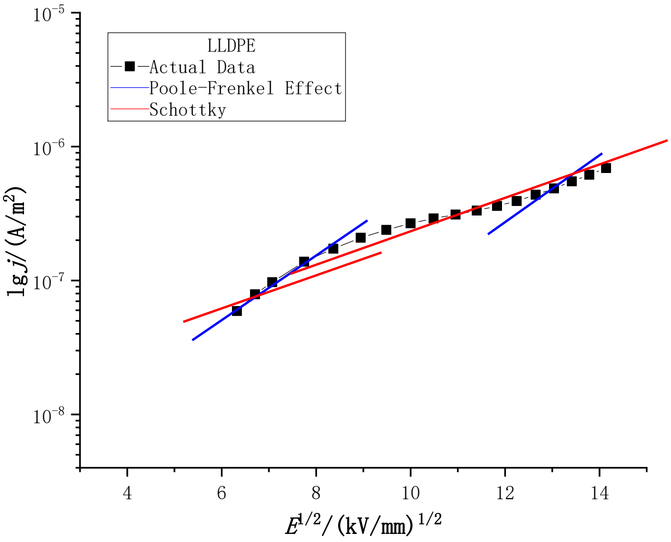
strength, the corresponding data in the range will exhibit a linear distribution in the ln$j$-$E^{1/2}$ coordinate system. In order to verify the above reasoning, the data of four different density polyethylenes in the high field strength region (non-ohmic region) are plotted in the ln$j$-$E^{1/2}$ coordinate system, and the Poole-Frenkel effect and Schottky effect are more intuitively reflected. Leading conduction mechanism, segmentation fitting of image, set polyethylene relative permittivity ε_r=2.35, when the slope is fixed, select the best intercept and compare it in lnj-E1/2 coordinate system The result is shown in Figure 8.





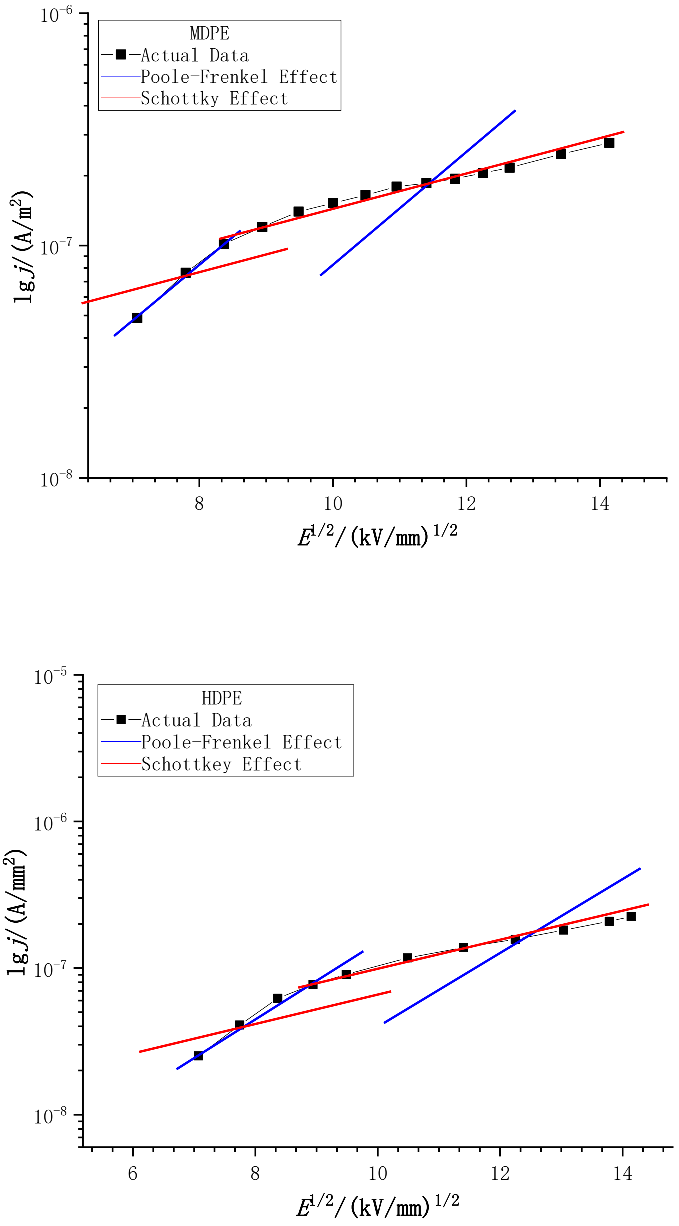


Figure 8. Piecewise fitting curve of four kinds of polyethylene in lnj-E1/2 coordinate

Tab.5 Threshold field strength of four different density polyethylenes in the high field strength region from body effect to electrode effect

Temperature/(℃)	Threshold field strength of LDPE/(kV/mm)	Threshold field strength of LDPE/(kV/mm)	Threshold field strength of LDPE/(kV/mm)	Threshold field strength of LDPE/(kV/mm)
25	44.89	54.76	72.25	77.44

It can be seen from Fig. 8 that the fitted line of the Poole-Frenkel effect is in the low field strength range of the high field strength region, and the degree of coincidence with the experimental data is higher, and the fitting line with the Schottky effect is lower. When the field strength rises above a certain threshold, the slope of the experimental data decreases, which reduces the fit of the fitted line with the Poole-Frenkel effect, and the coincidence with the fitted line of the Schottky effect is significantly improved. The fitting results show that during the field strength increase, the conductance mechanism of the high field strength non-ohmic region changes from the Poole-Frenkel effect to the electrode (Schottky) effect. And we can see in Table 5 that as the crystallinity of different density polyethylene increases, the threshold field strength of the conductance mechanism transition also increases, because the high electric field download stream transport process belongs to the local state in the amorphous region. The electronic jump conductance is dominated by [30, 31]. The higher the crystallinity of polyethylene, the smaller the free volume and the smaller the free travel of electrons. Therefore, the field strength corresponding to the occurrence of electrode limiting effect is higher.

5. Conclusion

In this paper, the experiments based on XRD, DSC, DC breakdown and conductance characteristics of 5-200kV/mm for four different density polyethylenes (LDPE, LLDPE, MDPE, HDPE) at room temperature (25 °C) were measured:

(1) Four different densities of polyethylene, crystallinity increases with increasing density；

(2) With the increase of crystallinity, the corresponding breakdown field strength of four kinds of polyethylenes with different densities also increased greatly. At the same time, we found that the larger the shape parameter, the more the dispersion of the breakdown strength data. Small, polyethylene exhibits more stable dielectric properties；

(3) In the test of conductivity characteristics of four different densities of polyethylene, the electric field threshold of the ohmic region (T1 region) corresponding to LDPE, LLDPE, MDPE, HDPE to the non-ohmic region is gradually reduced, and the turning point of the non-ohmic region is B. The corresponding field strength is also gradually reduced. The mechanism may be that the conductivity of the four materials gradually decreases, and the number of carriers decreases correspondingly under the same field strength. Therefore, the number of carriers may be the first to reach the turning point;

(4) In the image in the lg*I*-lg*E* coordinate system, after segmentation fitting, the slopes of the conductivity curves of the four materials in the T1 region are very close to 1, which is almost the same as the theoretical value; the slope value range of the T2 region is 2~4, indicating that there is SCLC effect in this region; the slope of the conductance characteristic curve of T3 region is much lower than the slope of the curve in T2 region, which may be because the region is not filled with traps, but because of the electric field strength applied in the non-ohmic region. The further improvement stimulates the deeper trap of the dielectric material, and the carrier again enters the trapping process, resulting in the slope of the T3 region being smaller than the slope of the conductance characteristic curve of the T2 region；

(5) The conductivity mechanism of four different densities of polyethylene in the high field has a transition from the Poole-Frenkel effect to the Schottky effect, and the conductivity mechanism increases with the crystallinity of polyethylene. The corresponding field strength

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threshold of the transition gradually increases；

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