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Dielectric Polarization and Loss Theory

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Abstract

Based on the classical theory of dielectric physics and recent developments in dielectric polarization and loss, we conduct experiments and perform microscopic analyses. In this paper, the different polarizations of dielectrics are mainly explained, and the field strength and polarization strength are calculated and derived. The characteristics of dielectric loss under different conditions are analyzed. The original dielectric constant and loss tangent measurement methods have been optimized and improved.

Keywords

Dielectric; Polarization; Dielectric Loss; Dielectric Constant.

1. Introduction

Electric fields can exist both in vacuum and in physical media. Under the action of the electric field, the medium will produce different degrees and forms of polarization. There are polarization differences under constant and alternating electric fields. What is the loss of different dielectrics under different influencing factors? What are the improvements and conclusions from existing dielectric constant and loss tangent measurements? However, there is no article that definitively answers these questions.

Aiming at the above problems, this paper analyzes the calculation of the field strength and polarization strength of the dielectric polarization. At the same time, we carry out numerical and graphical analysis of dielectric loss by combining various factors. For the measurement of dielectric constant and loss tangent, we improved the existing bridge method and proposed the measurement of resonance method.

2. Polarization of the Dielectric

2.1 Polarization of Dielectric under Constant Electric Field

Dielectric under the action of electric field, on the one hand, induced dipole moment, on the other hand, induced bound charge on the dielectric surface. The surface induced bound charge also indicates the degree of polarization of the dielectric under the electric field. These bound charges are the same as free charges and generate additional electric fields in both internal and external space of the dielectric. The electric field at any point in space is the vector sum of the electric field generated by the applied electric field and the bound charge.

2.2 Polarization of Dielectric under Alternating Electric Field

Under alternating electric field. According to the polarization response time, polarization can be divided into two categories: Instantaneous Displacement Polarization (polarization intensity is expressed by P_∞) and Relaxation Polarization (polarization establishment time is longer, this kind of

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polarization is a slow polarization process, and polarization intensity is expressed by P_r). In the medium, both Instantaneous Polarization and Relaxation Polarization exist.

$$P_r = P_{rm}(1-e^{-\frac{t}{\tau}})$$

$$P = P_\infty + P_{rm}(1-e^{-\frac{t}{\tau}})$$

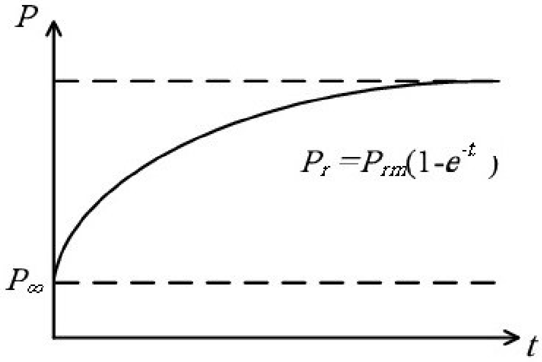

Fig. 1 Polarization

According to the Clausius equation:

$$\vec{P}_\infty = \varepsilon_0(\varepsilon_\infty - 1)\vec{E}$$

For electron displacement polarization:

$$\vec{P}_\infty = \varepsilon_0(\varepsilon_\infty - 1)\vec{E}$$

Relaxation polarization intensity $\vec{P}_r$ can be expressed as:

$$\vec{P}_r = \vec{P} - \vec{P}_\infty = \varepsilon_0(\varepsilon_s - \varepsilon_\infty)\vec{E}$$

The strength of the electric field applied to each polarized particle:

$$\vec{E}_i = \vec{E} + \frac{\beta}{\varepsilon_0}\vec{P}$$

In establishing the transition of polarization, the polarization intensity $\vec{P}$ is a function of time, so is the electric field intensity $\vec{E}_i$ acting on the microscopic particles.

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3. Dielectric Loss

3.1 Loss of Gaseous Dielectric

In addition to the two types of loss of gas medium, conductivity and polarization, there are also losses caused by gas dissociation. When the field strength is not enough to produce collisional dissociation, the loss in the gas is mainly caused by the conductance, and the loss is extremely small ($\tan\delta < 10^{-8}$), so the gas (Such as air, carbon dioxide, nitrogen, sulfur hexafluoride) is often used as the medium of the standard capacitor. The gas dielectric loss can be ignored in engineering, but when the field strength exceeds the value required for the ionization of gas molecules, the gas medium will be ionized, the dielectric loss will increase greatly, and with the increase of voltage, the loss will increase rapidly.

3.2 Loss of Liquid Dielectric

The polarization of non-polar and weakly polar liquid media is mainly electron displacement polarization. The relative permittivity is independent of frequency ($\varepsilon_r = \varepsilon_s$), and the dielectric loss mainly comes from the conductance. Dielectric loss tangent:

$$\tan\delta = \frac{\gamma}{\omega\varepsilon_0\varepsilon_r} = 1.8\times10^{10}\frac{\gamma}{f\varepsilon_r}$$

The relationship between ε, p, $\tan\delta$ and frequency (ω) of liquid medium at low frequency.

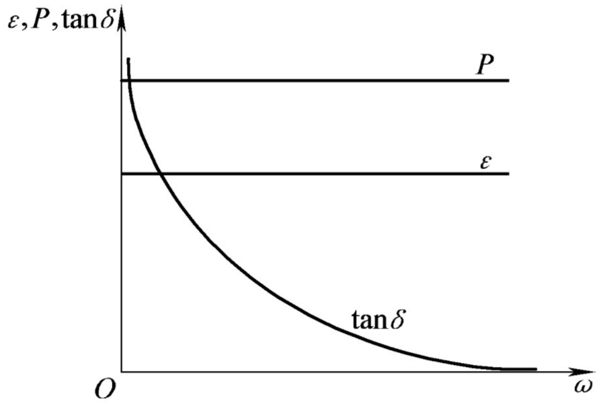

Fig. 2 The relationship between ε, p, $\tan\delta$ and frequency (ω)

The dielectric loss of polar liquid media is related to viscosity. The polar molecules move thermally in the viscous medium. Under the action of the alternating electric field, the electric field torque will make the polar molecules rotate towards the direction of the external field. During the directional rotation process, the energy loss is caused by frictional heating.

3.3 Loss of Solid Dielectric

The non-polar organic medium only has electron displacement polarization under the action of external electric field, and the dielectric loss is mainly caused by the conductance of impurities. The conductivity is generally small, and the value of $\tan\delta$ is also small.

In the polar organic medium, ε does not increase with the increase of temperature, but decreases in the softening range, and the maximum value of $\tan\delta$ appears at the same time. The loss of this type of medium is mainly determined by the relaxation loss of the polar base, and the loss at high frequency is also very large, so it cannot be used as a high frequency medium.

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4. Measurement of Dielectric Constant and Loss Tangent

The measurement methods of relative permittivity and loss tangent of insulating materials are divided into two categories: bridge method and resonance method.

The principle of the bridge method: The sample is used as a bridge arm, the impedance of the other three bridge arms is known, and the bridge is adjusted to achieve balance. Therefore, according to the equilibrium conditions, the parallel equivalent capacitance and resistance of the sample can be obtained, and the relative permittivity and loss tangent of the sample can be calculated.

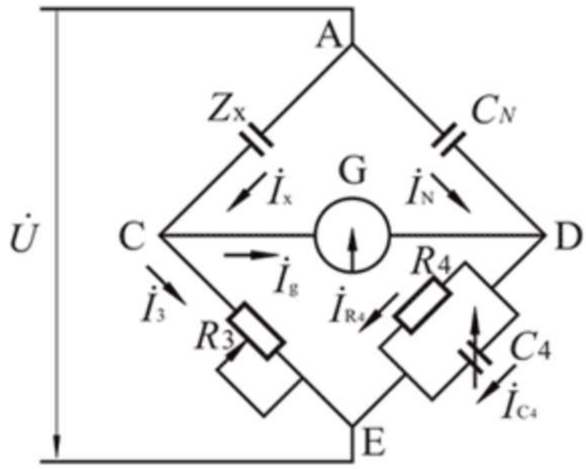

Fig. 3 High-voltage Cillin bridge

$$\begin{cases} \dfrac{1}{Z_x} = \dfrac{1}{R_x} + j\omega C_x \\ Z_N = \dfrac{1}{j\omega C_N} \\ Z_3 = R_3 \\ \dfrac{1}{Z_4} = \dfrac{1}{R_4} + j\omega C_4 \end{cases}$$

Solve the equation:

$$\tan\delta_x = \omega C_4 R_4$$

$$C_x = \frac{R_4}{R_3} C_N$$

The sensitivity of the high-voltage Xilin bridge is mainly determined by the sensitivity of the measuring voltage and balance indicator. The measurement error, that is, the relative error of the capacitance and the absolute error of the loss tangent, also mainly depends on the sensitivity of the balance indicator and the measurement voltage.

Resonance method: When the measurement frequency is increased to kHz, the resonance method is widely used for the measurement of the relative permittivity and loss tangent of insulating materials.

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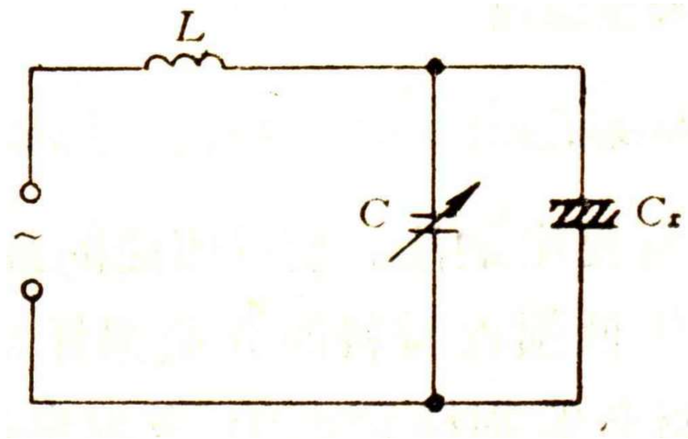

Fig. 4 LC resonant tank

5. Conclusion

We analyze the polarization of dielectrics under constant and alternating electric fields, and derive the effects of bound and free charges inside and outside the medium under constant electric fields. At the same time, the medium is classified under the alternating electric field and the calculation and analysis of the polarization intensity and electric field intensity are carried out.

Based on the different types of dielectrics, we have analyzed and calculated the losses of gas, liquid and solid dielectrics respectively. Graphs show changing trends for influencing variables.

For the measurement of dielectric constant and loss tangent, we first summarize the commonly used bridge method and resonance method, and make our improvements and optimizations at the same time. Limited by existing knowledge, it can only be carried out to the current extent.

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