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Investigation of Surface Charge Accumulation and Dissipation Mechanisms Based on Solid Conductivity and Dielectric Relaxation for The Insulator of GIL Under DC Voltage

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1. Abstract

In this paper, the mathematical model of solid conductivity based on electric field and temperature has been studied, and the model of volume current density and charge density has been reestablished in combination with dielectric relaxation. When the solid side is dominant, the temperature, electric field and dielectric relaxation characteristics of surface charge accumulation and dissipation are simulated and analyzed. The results indicate that the steady state value of surface charge density increases exponentially with the increase of the initial value of electric field and temperature, and the charge saturation time also increased. The increase of the electric field intensity change rate leads to a exponential decrease of the steady state value of surface charge density and the saturation time. The saturation time increases by 3% and the steady state value of surface charge density increases by 0.9% in the influence of dielectric relaxation. Considering only the charge dissipation of the solid side, the higher the temperature, the more favorable for the dissipation of the surface charge. Moreover, the dissipation rate increases exponentially with temperature. The effect of field strength on charge dissipation depends on the initial charge density .Dielectric relaxation slows the dissipation rate by 28%.

2. Conductivity of Solid Dielectrics

$$\sigma(E(t),\mathrm{T}) = \sigma_0 e^{\beta E(t)+\alpha T} \quad (1)$$

Where σ_0 is the conductivity at the initial temperature and electric field strength; α is the temperature coefficient of the conductivity; β is the field strength coefficient of the conductivity; E(t) is the electric field strength; T is the temperature.

$$\beta = \ln\left(\frac{\sigma_1}{\sigma_2}\right)/(E_1 - E_2) \quad (2)$$

σ_1 is the conductivity when the field strength is E_1,σ_2 is the conductivity when the field strength is E_2 . Where the temperature is a fixed value.

$$\alpha = \ln\left(\frac{\sigma_1}{\sigma_2}\right)/(T_1 - T_2) \quad (3)$$

σ_1 is the conductivity when the temperature is T_1, σ_2 is the conductivity when the temperature is T_2. Where the field strength is a fixed value.

3. Dielectric relaxation

In the process of charge accumulation and dissipation, the surface electric field changes in real time, so the influence of dielectric relaxation cannot be ignored.

$$\mathrm{P}(t) = \varepsilon_0(\varepsilon_\infty - 1)E_0 + \varepsilon_0 \int_{-\infty}^{t} f(t-\tau)E(\tau)d\tau \quad (4)$$

Where $P(t)$ is the polarization strength, ε_0 is the vacuum dielectric constant; σ is the conductivity of the dielectric; E_0 is the initial electric field strength; $E(t)$ is the electric field strength; $f(t)$ is the dielectric relaxation function.

$$f(t) = Bt^{-n} \quad (0<n<1) \tag{5}$$

Where B and n are constants, $0<n<0.5$ low frequency, $0.5<n<1$ high frequency.

4. Solid side Current Density Model

$$j(t) = \sigma E(t) + \frac{\partial D(t)}{\partial t} = \sigma_0 E(t) + \varepsilon_0 \frac{\partial E(t)}{\partial t} + \frac{\partial P(t)}{\partial t} \tag{6}$$

Where $D(t)$ is the surface charge number of the electrode.

Correction of Solid Current Density Model:

$$j(t) = \sigma_0 e^{\beta E(t)+\alpha T} E(t) + \varepsilon_0 \varepsilon_\infty \frac{\partial E(t)}{\partial t} + \varepsilon_0 \frac{\partial \left(\int_{-\infty}^{t} f(t-\tau)E(\tau)d\tau \right)}{\partial t} \tag{7}$$

5. Solid Side Surface Charge Accumulation and Dissipation Model

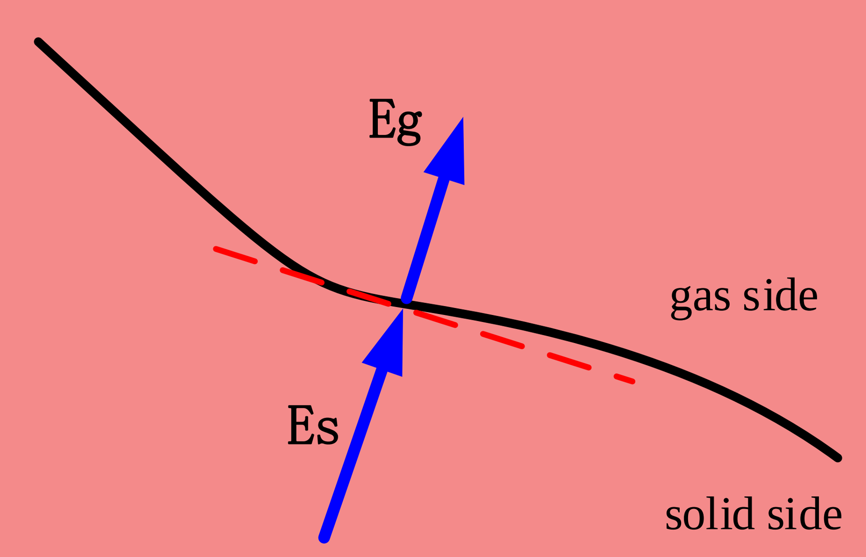

Figure 1. Schematical representation of the normal vectors on the insulator surface.

The surface charge density accumulated on the solid side is:

$$\rho_s(t) = \int_0^t j_s(t)\,dt \tag{8}$$

The surface charge density dissipated on the solid side is:

$$\partial_t \rho(t) = -j(t) \tag{9}$$

The complete model is:

The surface charge density accumulated on the solid side is:

$$\rho_s(t) = \int_0^t \sigma_0 e^{\beta E_s(t)+\alpha T} E_s(t)\,dt + \varepsilon_0\varepsilon_\infty E_s(t) + \varepsilon_0 \int_0^t f(t-\tau)E_s(\tau)d\tau \tag{10}$$

The surface charge density dissipated on the solid side is:

$$-\partial_t \rho(t) = \frac{\sigma_0}{\varepsilon} e^{\beta\frac{\rho(t)}{\varepsilon}+\alpha T}\rho(t) + \frac{\varepsilon_0\varepsilon_\infty}{\varepsilon}\partial_t\rho(t) + \frac{\varepsilon_0}{\varepsilon}\frac{\partial \left(\int_{-\infty}^{t} f(t-\tau)\rho(t)d\tau \right)}{\partial t} \tag{11}$$

6. Charge accumulation characteristics simulation analysis

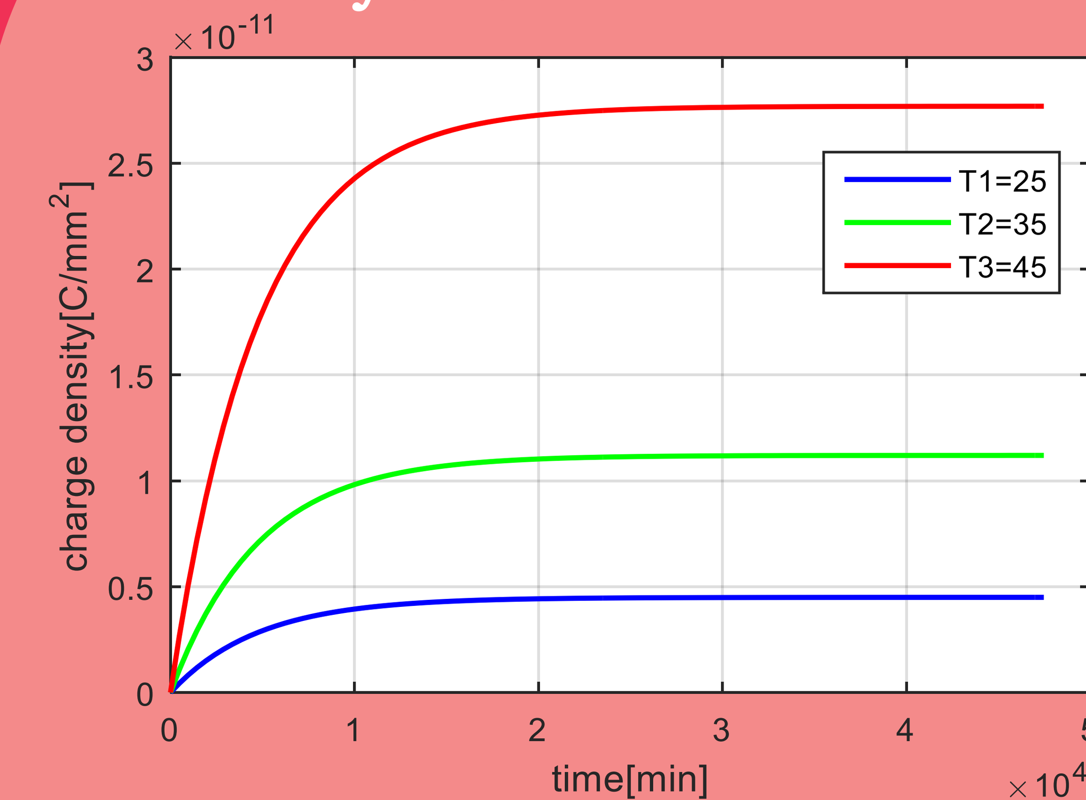

Fig. 2. The accumulation of surface charge density simulated with different temperature.

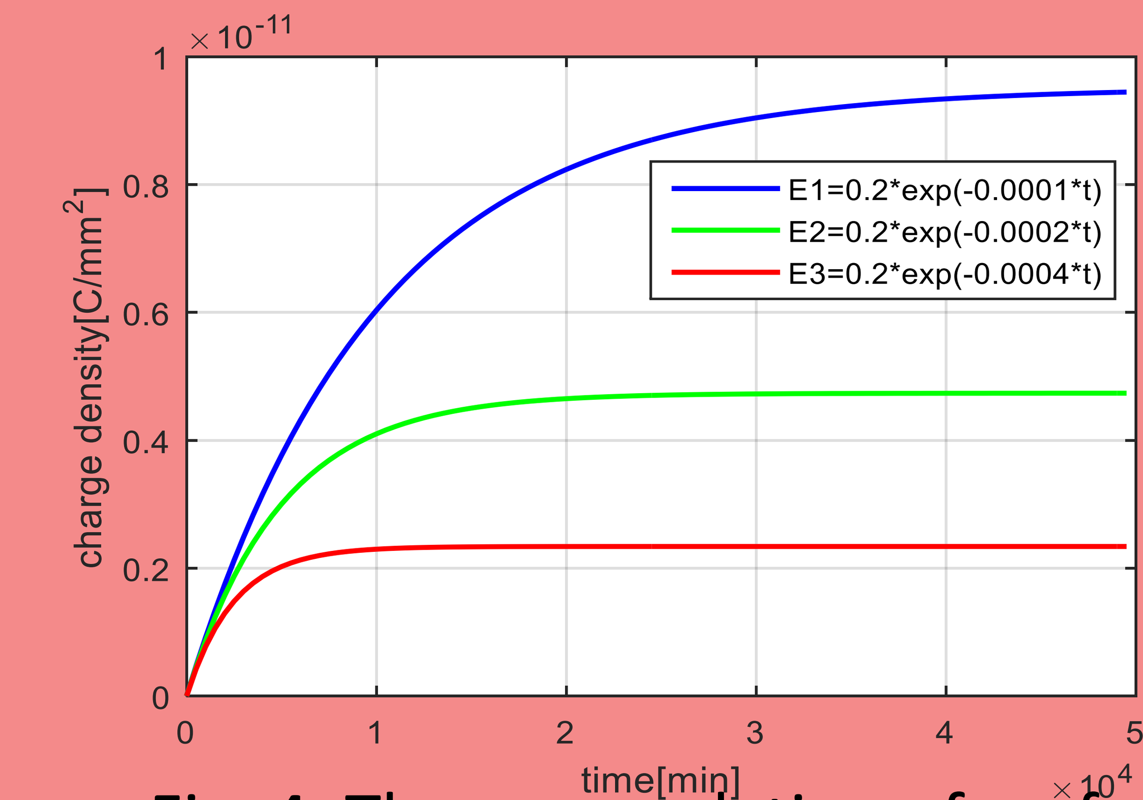

Fig. 4. The accumulation of surface charge density simulated with different electric field rate.

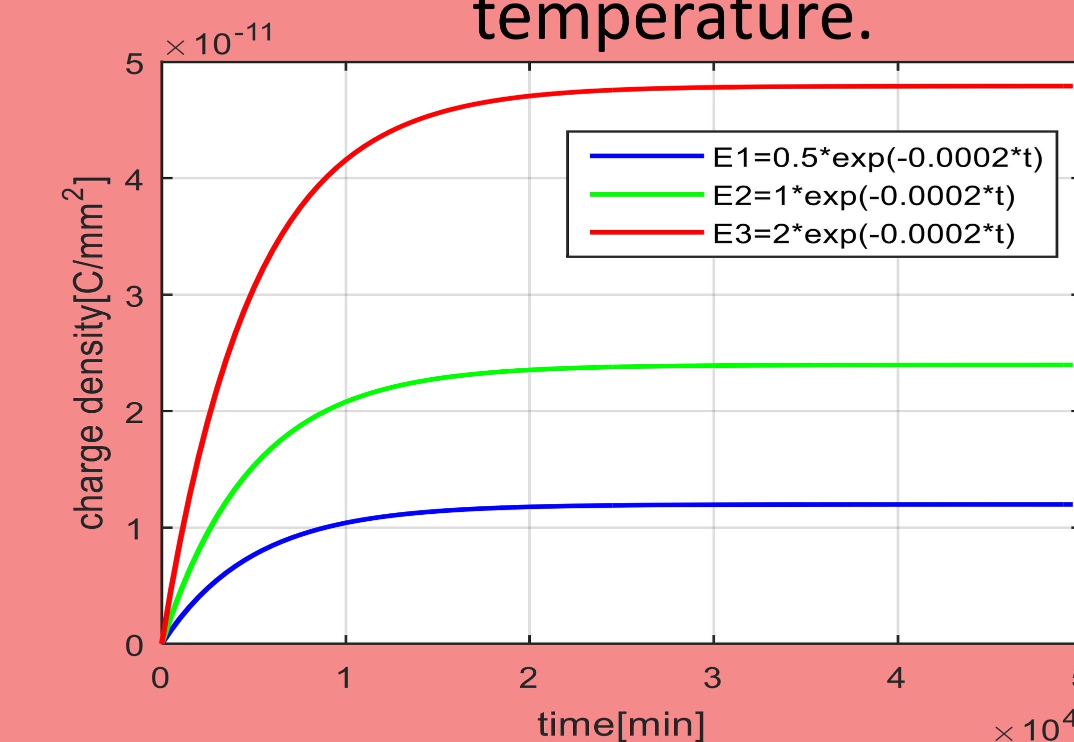

Fig. 3. The accumulation of surface charge density simulated with different electric field amplitude.

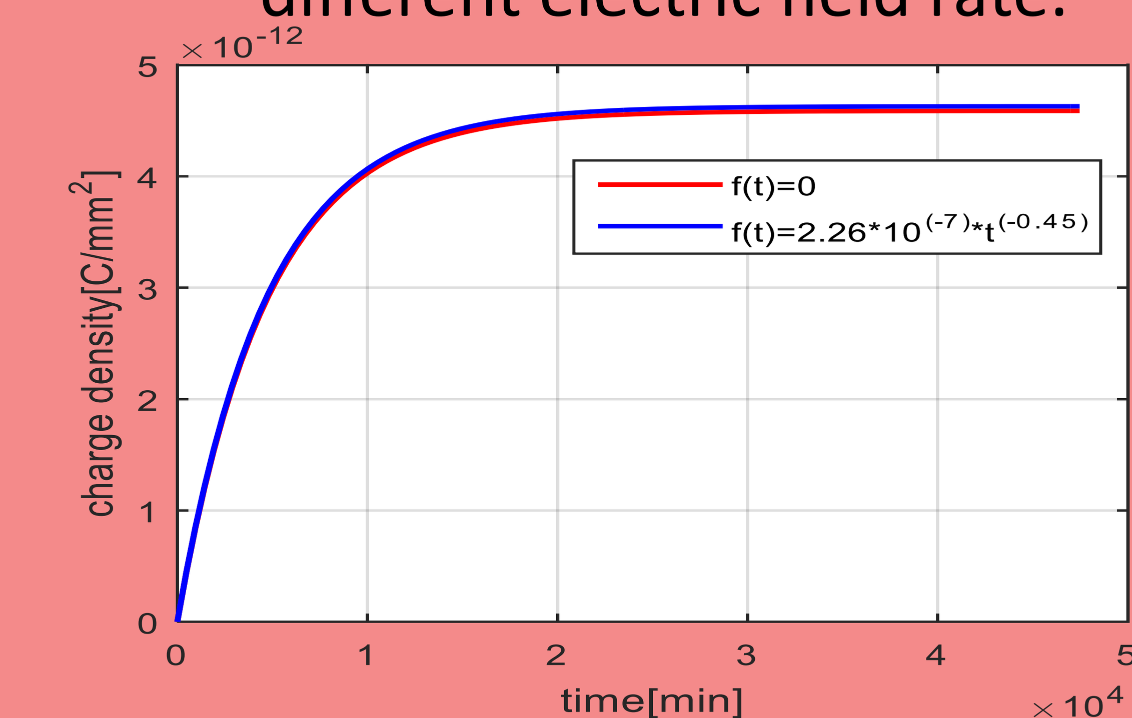

Fig. 5. The accumulation of surface charge density simulated with polarization relaxation,constant.

7. Charge dissipation characteristics simulation analysis

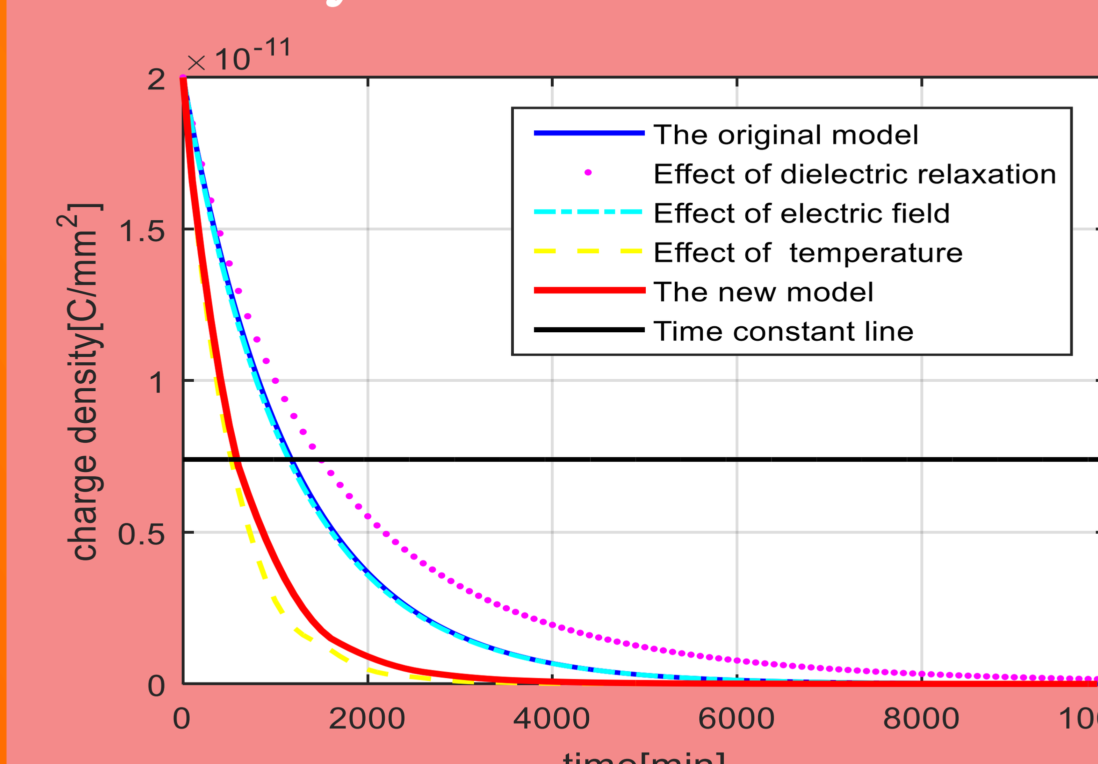

Fig. 6. The dissipating of surface charge density simulated with different influence factors.

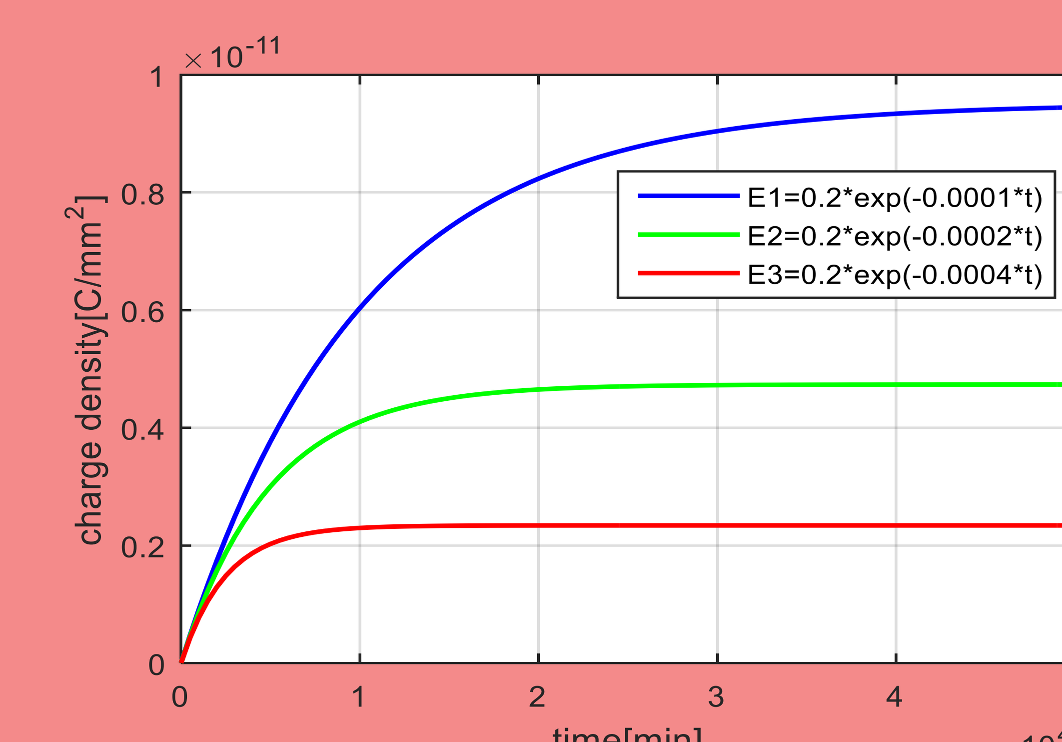

Fig. 7. The dissipating of surface charge density simulated with different temperature.