Dielectric Breakdown

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Dielectric Breakdown of Gases

- Average velocity of the charge carrier in a gas

$$\boxed{v = \mu E}$$

where μ = Mobility of the charge carrier
E = Applied electric field

Condition of Ionization

$$\boxed{E.\lambda = V_i}$$

where V_i = Ionization potential
λ = Mean free path

- Electron ionization coefficient (Townsend breakdown process)

$$\boxed{\alpha = \frac{1}{\lambda} e^{-(V_i/E\lambda)}}$$

where, α = Townsend's first ionization coefficient or ionization coefficient of electrons

$$\boxed{\lambda \propto \frac{1}{\text{Pressure}}}$$ .....at constant temperature

$$\boxed{n_d = n_o\, e^{\alpha d}}$$

where, n_d = Number of electrons striking the anode per second

- Secondary ionization coefficient

$$\boxed{n = \frac{n_0 e^{\alpha d}}{1 - \gamma\left(e^{\alpha d} - 1\right)}}$$

where, n = Total number of electrons arriving at the anode
n_0 = Number of primary photoelectrons per second emitted from cathode
d = Distance between anode and cathode
γ = Townsend's second ionization coefficient

Townsend criterion for spark breakdown

$$\boxed{\gamma\left(e^{\alpha d} - 1\right) = 1}$$

Note:

The avalanche breakdown develops over relatively long period of time over 1 μs and does not generally occur with impulse voltage.

Dielectric Breakdown of Liquids

- Colloidal theory

$$\frac{\epsilon - \epsilon'}{\epsilon + 2\epsilon'} \cdot r^3 E^2 \geq \frac{kT}{4}$$

where
r = Radius of insulating particle
ϵ = Permittivity of insulating material
ϵ' = Permittivity of oil
E = Field strength
k = Boltzmann's constant
T = Absolute temperature

- Bubble theory

$$E_i = \frac{3\epsilon E_0}{2\epsilon + 1}$$

where
E_i = Electric field in a gas bubble which is immersed in a liquid
ϵ = Permittivity of liquid
E_0 = Electric field in the liquid in absence of the bubble

- Break down due to liquid globules

$$E = 487.7\sqrt{\frac{\sigma}{R\epsilon_1}} \text{ V/cm}$$

where
E = Critical field at which the globule looses its stability
ϵ_1 = Permittivity of the liquid medium
σ = Pressure due to surface tension, dyne/cm
R = Radius of globule

Dielectric Breakdown of Solids

- Theory of Von Hippel

$$E_c = \frac{2\pi^2 v e m}{h}\left[\frac{1}{n_\infty^2} - \frac{1}{\epsilon}\right] \text{ V/m}$$

where
E_c = Critical field at which the breakdown occurs
v = Optical frequency of lattice
n_∞ = The index of refraction for infinite wave length
ϵ = Dielectric constant
m = Effective mass of electron
e = Electron charge
h = Plank's constant

Thermal breakdown

- Heat generated per unit volume in unit time

$$W = E^2 f \cdot \frac{\epsilon_r \tan\delta}{1.8 \times 10^{12}} \text{ Watts/cm}^3$$

where
E = Uniform electric field
f = Frequency of applied voltage
δ = Loss angle
ϵ_r = Relative permittivity

For direct voltage

Power dissipated per volume is given by

$$W = \frac{E^2}{\rho} \text{ Watts/m}^3$$

where ρ = Resistivity of the insulation, ohm-m

- Power loss

$$\epsilon \tan\delta = \epsilon' \tan\delta' \cdot e^{c(T-T')}$$

where
$\epsilon \tan\delta$ = Loss factor of the dielectric at a temperature
$\epsilon' \tan\delta'$ = Loss factor of the dielectric at the initial temperature T'
c = Coefficient depending on the properties concerned

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