The Tony Davies High Voltage Laboratory

UNIVERSITY OF Southampton
School of Electronics and Computer Science

A new electro-thermal aging model

based on trapping and De-trapping process in polymeric materials

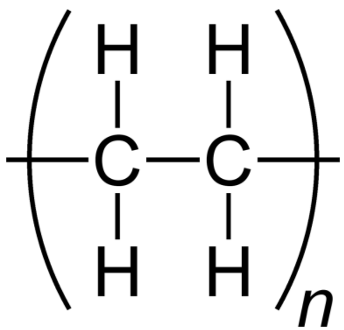
Hisham Alghamdi

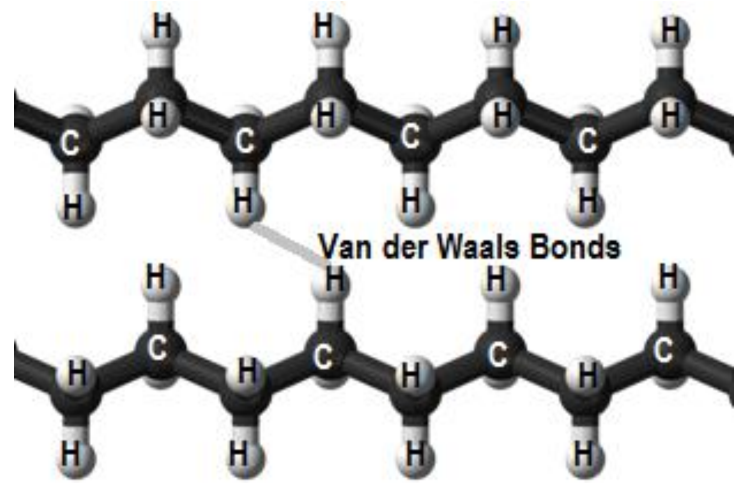
11th April 2013

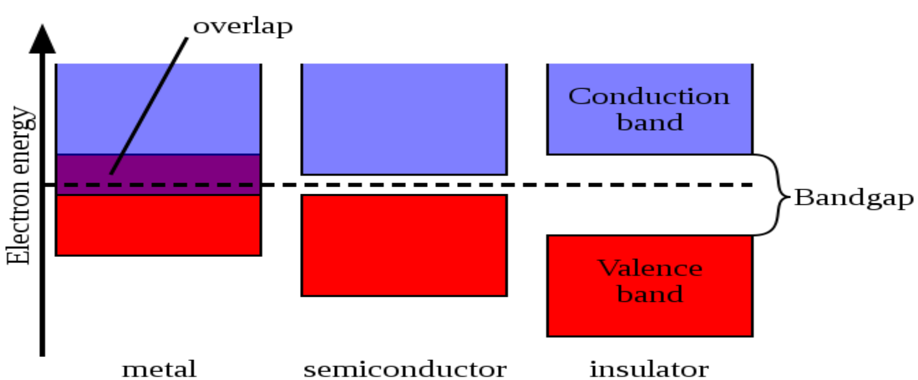
Outlines

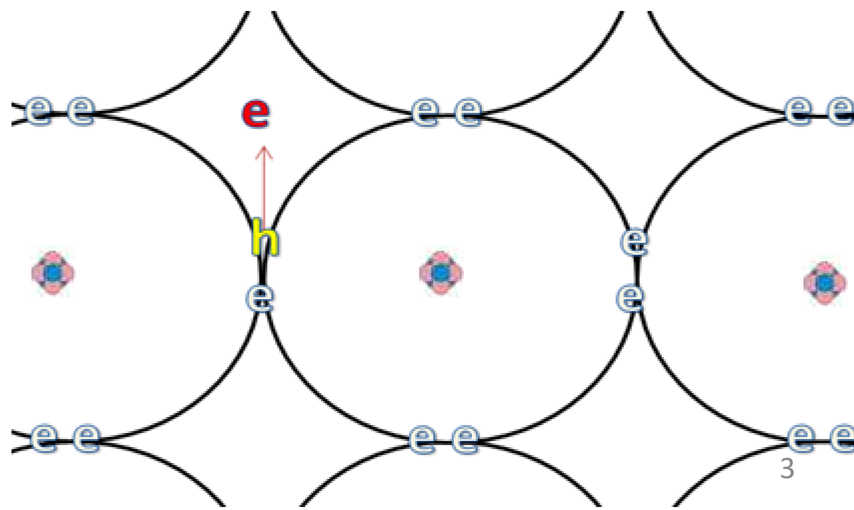
- Energy barrier and its affected parameters
- Producing the energy term
- Kinetic equation of the trapping and detrapping process
- Developing the model

➢ Energy Barrier



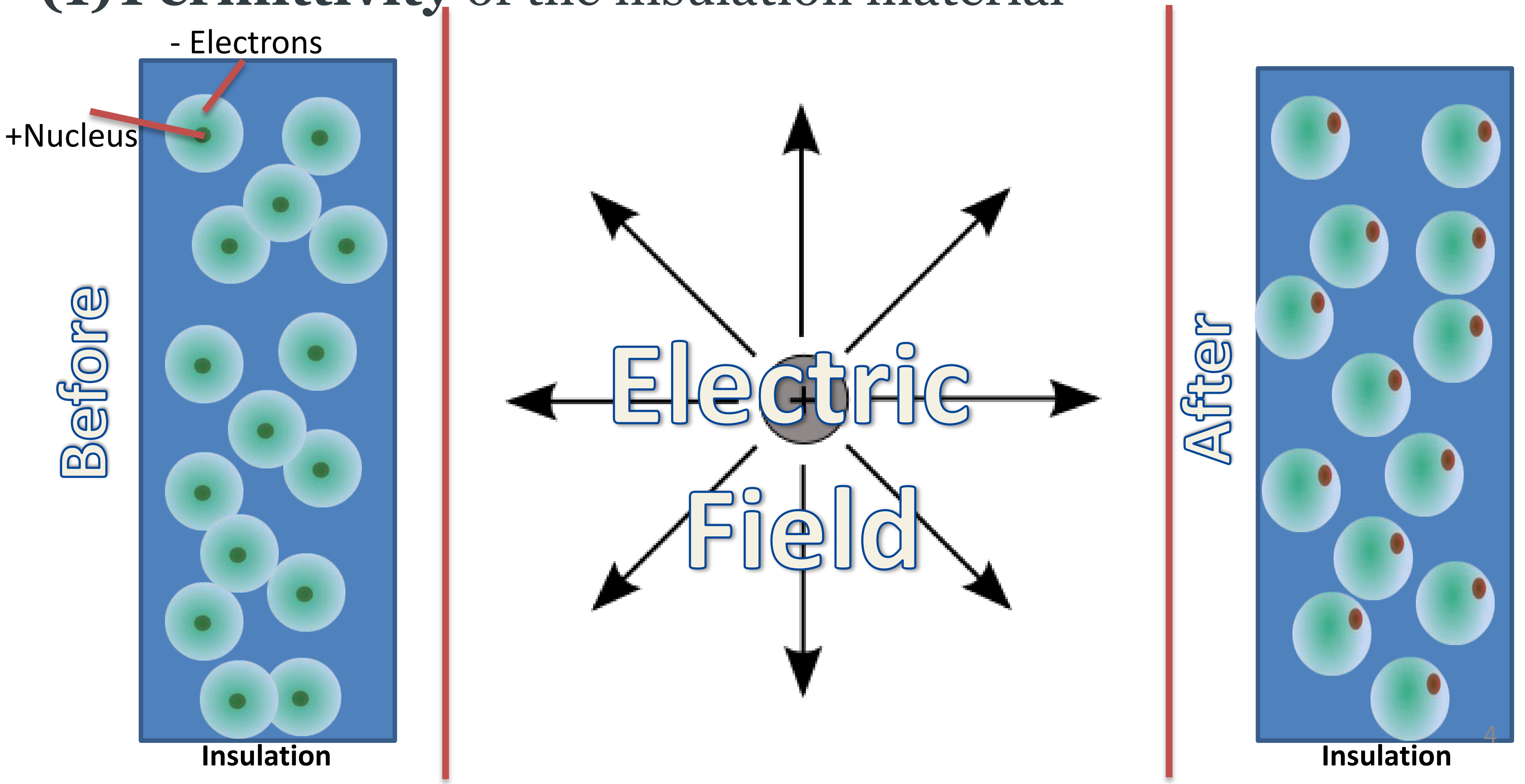






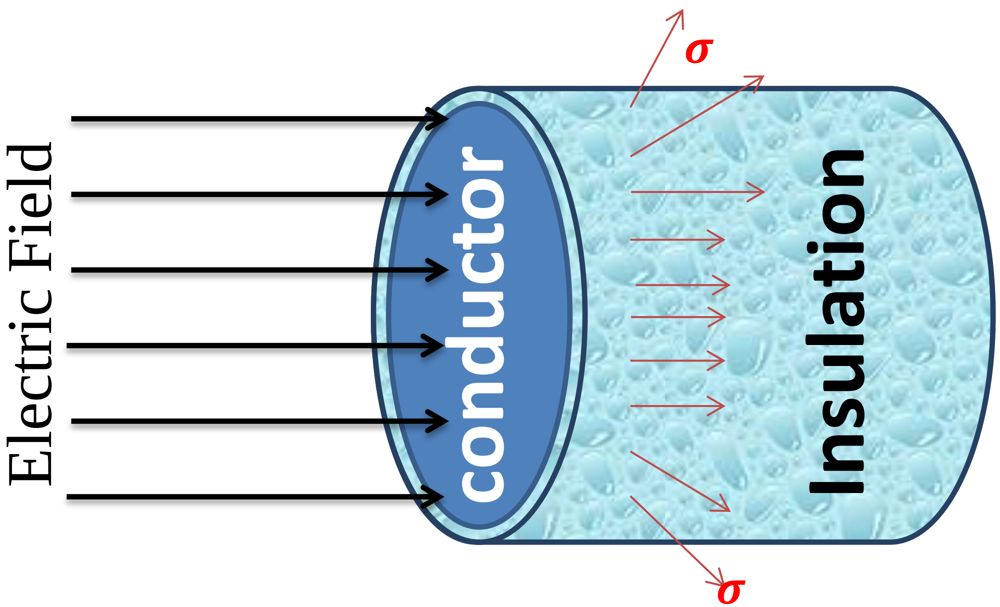
➢ Affected Parameters

(1) **Permittivity** of the insulation material



➢ Affected Parameters

(2) Tension of the insulation material



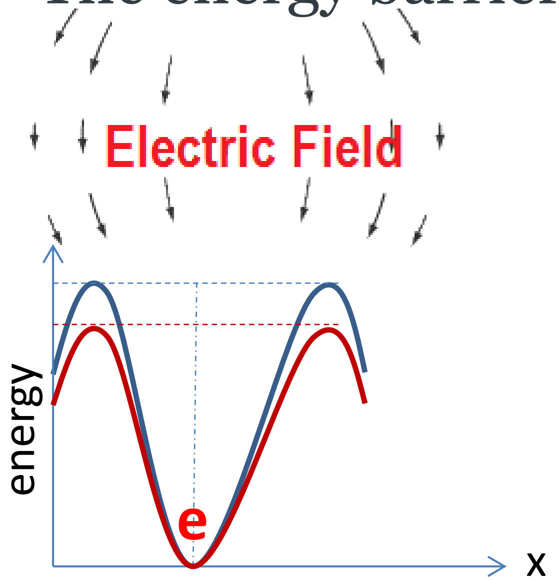
mechanical stress (σ) ***induced when the electric filed is applied***

➢ Producing the energy term

The mechanical stress induced by electrostatic field is:

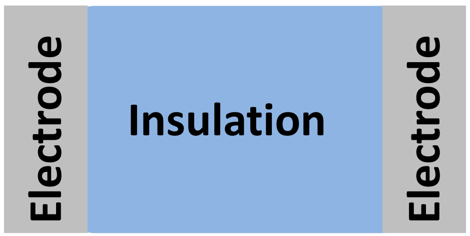
$$\sigma = \frac{1}{2}\varepsilon E^2$$

The energy barrier is lowered by the mechanical energy as:



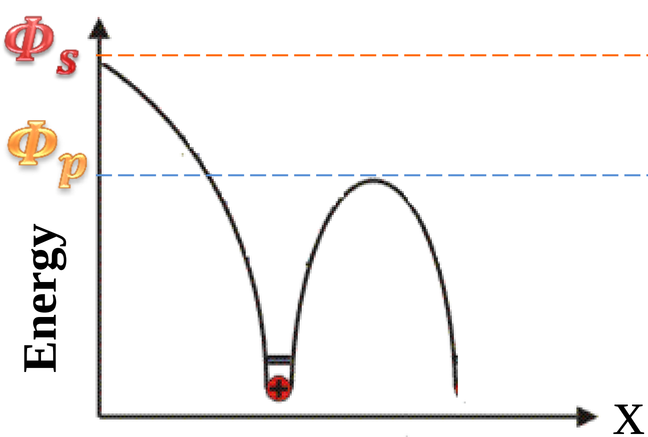
$$W_m = \frac{1}{2Y}\sigma^2 = \frac{\varepsilon^2 E^4}{8\,Y}$$

➢ Current density



The current has a different mechanism on **interfaces** than the **bulk**

$$J = A_0 T^2 \exp\left(-\frac{\Phi_D - \boldsymbol{\Phi}_{eff}}{kT}\right)$$



$$\boldsymbol{\Phi}_{eff} = \boldsymbol{\Phi}_s = \left(\frac{q^3 E}{4\pi\varepsilon}\right)^{1/2}$$ ***Schottky*** **mechanism**

$$\boldsymbol{\Phi}_{eff} = 2\boldsymbol{\Phi}_s = \boldsymbol{\Phi}_p$$ ***Poole–Frenkel*** **mechanism**

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Kinetic Equation

*Kinetic equation of **trapping** concentration*

$$\frac{dn_T}{dt} = -\boldsymbol{K_T n_T} + \boldsymbol{K_D n_D}$$

*Kinetic equation of **detrapping** concentration*

$$\frac{dn_D}{dt} = -\boldsymbol{K_D n_D} + \boldsymbol{K_T n_T}$$

where $\boldsymbol{K_T} = \frac{\sigma_T}{q} A_0 T^2 \exp\left(-\frac{\Phi_D - \boldsymbol{\Phi_{eff}}}{kT}\right)$

$$\boldsymbol{K_D} = N_c v_{th} \sigma_c \exp\left(-\frac{E_t - W_m}{kT}\right)$$

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Kinetic Equation

The progress of detrapping process can be described through a normalized variable X as:

$$X = \frac{n_D}{N}$$

where $(N = n_T + n_D)$ is the total concentration of trapping and detrapping. Therefore,

$$1 - X = \frac{n_T}{N}$$

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Kinetic Equation

The reaction kinetics can be written in term of X as:

$$\frac{dX}{dt} = K_T - (K_T + K_D)X$$

Assuming the insulation is un-trapped at t=0, we can reach:

$X(t) = C\{1 - \exp[-(K_T + K_D)t]\}$ where $C = \frac{K_T}{K_T+K_D}$

C is the equilibrium parameter, and at threshold the electric field is described as: $C(E_{th}, T_{th}) = C^*$

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The life expression

The corresponding life expression can be described by setting $X(t) = C^*$, which will lead to:

$$L(T,E) = (K_T + K_D)^{-1} \ln\left[\frac{C}{C - C^*}\right]$$

Or in another form:

$$L(T,E) = \left[\frac{q * \exp\left(\frac{\Phi_D + E_t}{kT}\right)}{\sigma_T A_0 T^2 \exp\left(\frac{E_t + \Phi_{eff}}{kT}\right) + q\, N_c v_{th} \sigma_c \exp\left(\frac{\Phi_D + W_m}{kT}\right)}\right] \times \ln\left[\frac{C}{C - C^*}\right]$$

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➢ The life expression

$$L(T,E) = \left[\frac{q * \exp\left(\frac{\Phi_D + E_t}{kT}\right)}{\sigma_T A_0 T^2 \exp\left(\frac{E_t + \Phi_{eff}}{kT}\right) + q\, N_c v_{th} \sigma_D \exp\left(\frac{\Phi_D + W_m}{kT}\right)}\right] \times \ln\left[\frac{C}{C - C^*}\right]$$

v_{th} is the electron thermal velocity = $\sqrt{3kT/m}$

N_c is the effective density of states in the conduction band = $2(2\pi m^{e^*} kT/h^2)^{3/2}$

A_0 is the emission constant for Richardson-Dushman effect = $(1 - R)\, 4\pi q m_e k^2/h^3$

➢ The life expression

$\boldsymbol{\sigma_T}$ is the trapping cross section. It is calculated from equation

$$\boldsymbol{K_T} = \frac{\boldsymbol{\sigma_T}}{q} A_0 T^2 \exp\left(-\frac{\Phi_D - \boldsymbol{\Phi_{eff}}}{kT}\right)$$

where $\boldsymbol{K_T}$ is calculated from

$$1 - X(t) = \frac{n_T}{N} = 1 - \frac{K_T}{K_T + K_D}\{1 - exp[-(K_T + K_D)t]\}$$

where $n_T = Q_T/(S * d * q)$

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➢ The life expression

$\boldsymbol{\sigma_D}$ is the detrapping cross section. It is calculated from equation

$$\boldsymbol{K_D} = N_c v_{th} \sigma_c \exp\left(-\frac{E_t - \boldsymbol{W_m}}{kT}\right)$$

where $\boldsymbol{K_D}$ is calculated from

$$X(t) = \frac{n_D}{N} = \frac{K_T}{K_T + K_D}\{1 - exp[-(K_T + K_D)t]\}$$

where $n_D = Q_D/(S * d * q)$

➢ Conclusion

- Deal with electrode-insulation interfaces and bulk of the insulation
- Consider space charge as an explicit affected parameter for the aging process
- Comprehensive of the main mechanisms such as mechanical stress, material strain, space charge, trap depth and movement of the electrons as trapping and detrapping.

Thanks ☺