A review of mechanisms and models accounting for surface potential decay

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Supélec

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Electrostatic research in Supelec

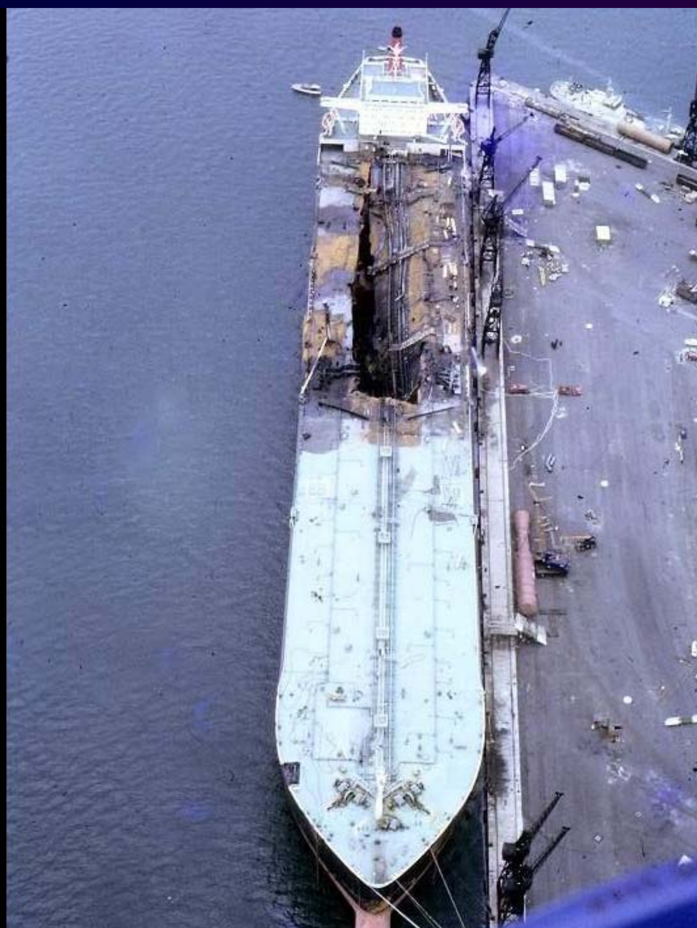
- A diversified experience on material characterization and electrostatics
  - Material characterization for HV engineering
  - Tribocharging in automobile industry (seats, airbags, gasoline)
  - electrets for medecine
  - Charge buildup and decay for space coatings (collaboration with CNES and ONERA)
  - ...

Research in Electrostatics

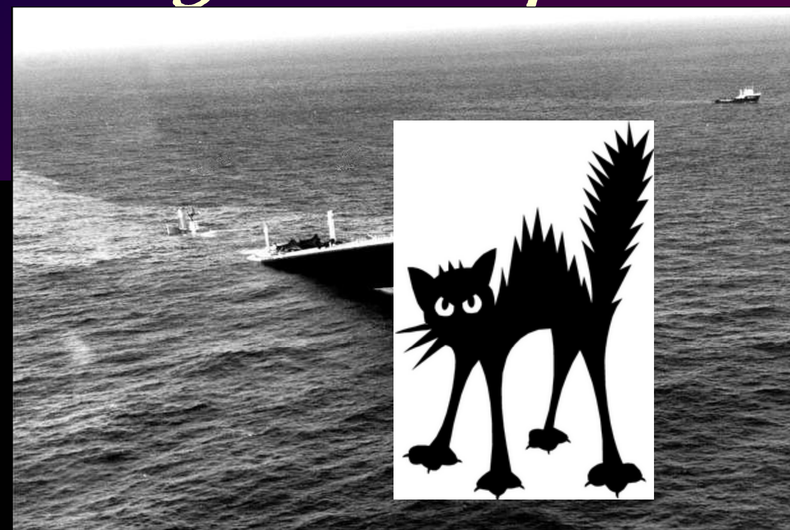
- An important industrial issue
- However research scattered

"…most people do not even think about electrostatics unless they have a problem"

- December 1969



Mactra (2) at Durban after the explosion. **(Photo by Henry van den Heever)**



(Photo collection Anne Niemantsverdriet)

Research in Electrostatics

- An important industrial issue
- However research scattered
- Very few laboratories with Electrostatics in their names
- Structured networks : ESA, ESDA, IEJ, SEG IOP, EWP SEI(EFCE), SFE...
- Spacecraft charging issues should be more present in them!

« Charging in space environment has particular features... »

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yo … -

te

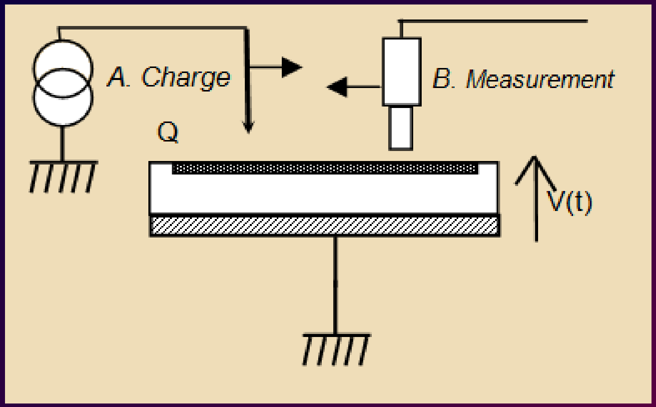
one of them being ...

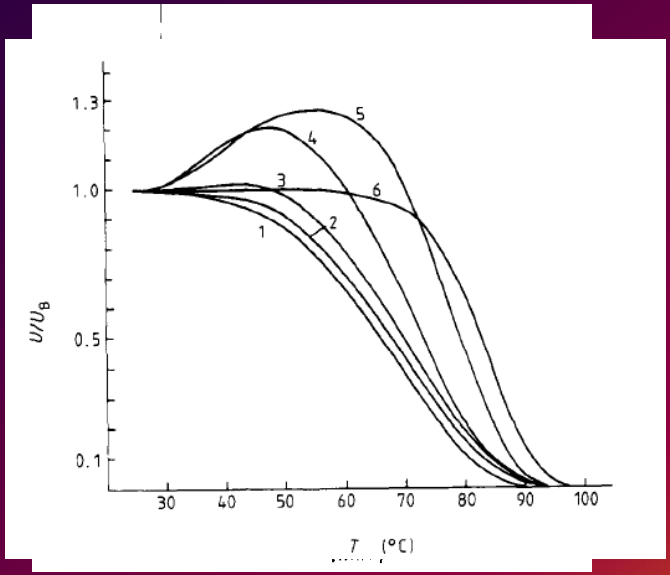
[redacted]

What happens in an insulator after charging ?

- Several tools :
  - Current and charge measurements
  - Charge mapping techniques (LIPP, PEA, etc.)
  - Surface potential decay measurements

A classical experiment

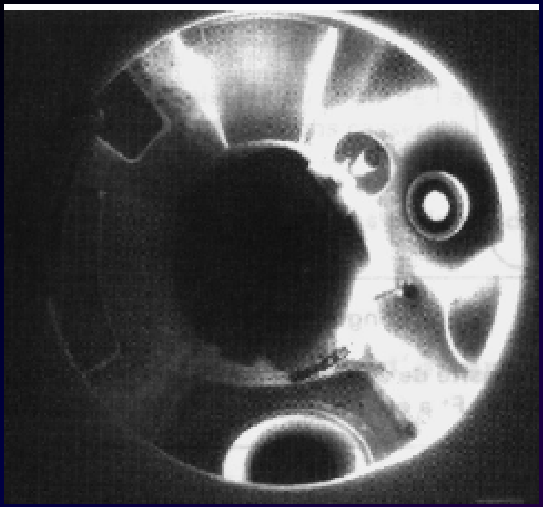


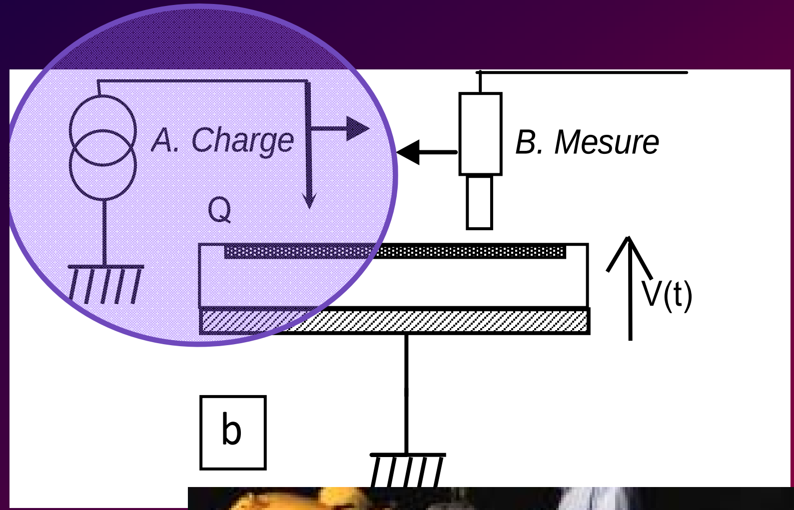


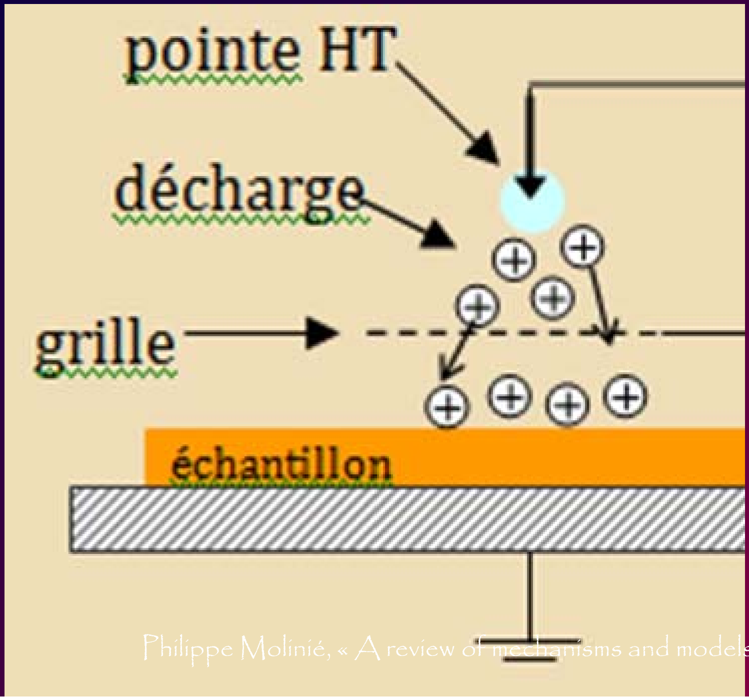
(Von Berlepsch 1989)

(Ieda 1967)

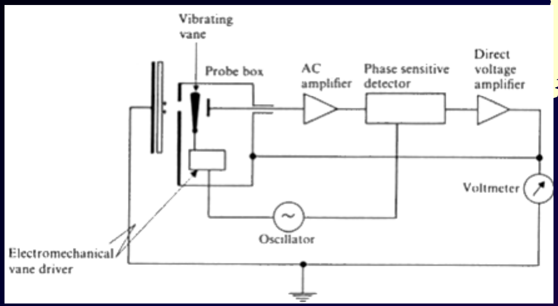
Charge

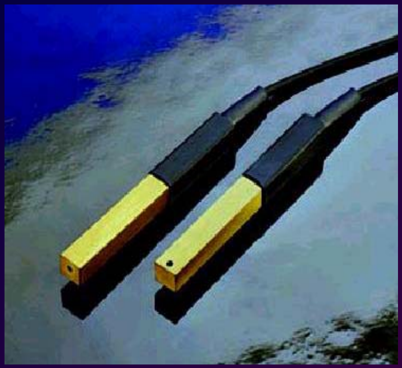


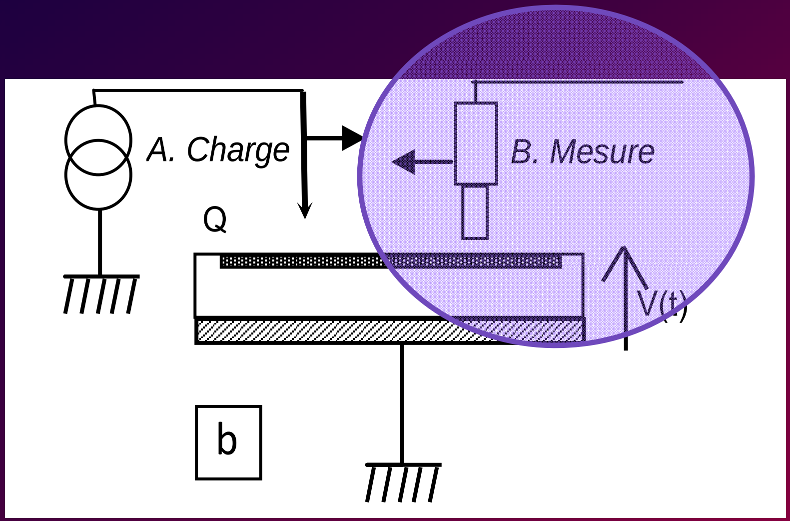

A. Charge
B. Mesure
Q
V(t)
b

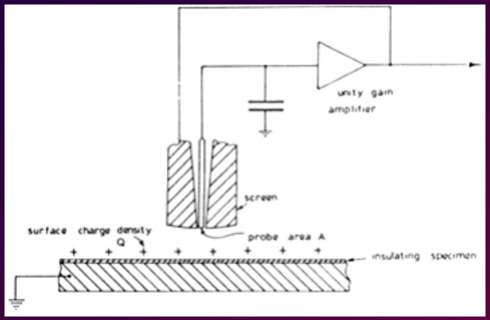

pointe HT
décharge
grille
échantillon

Measurements



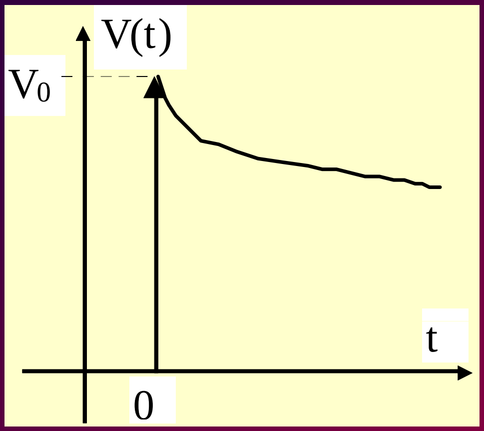






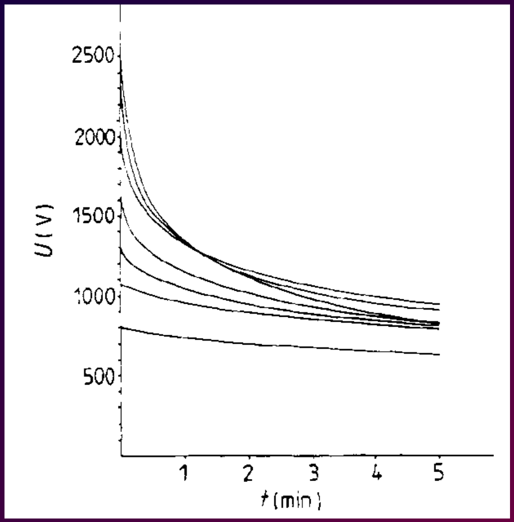
Modelling

- Input : V(t)
- What can we do with that ?
- Here : not a particular model but review of the main types
- Based on more than 250 papers gathered and studied in Supelec since 1980



Surface potential decay models : where are they coming from ?

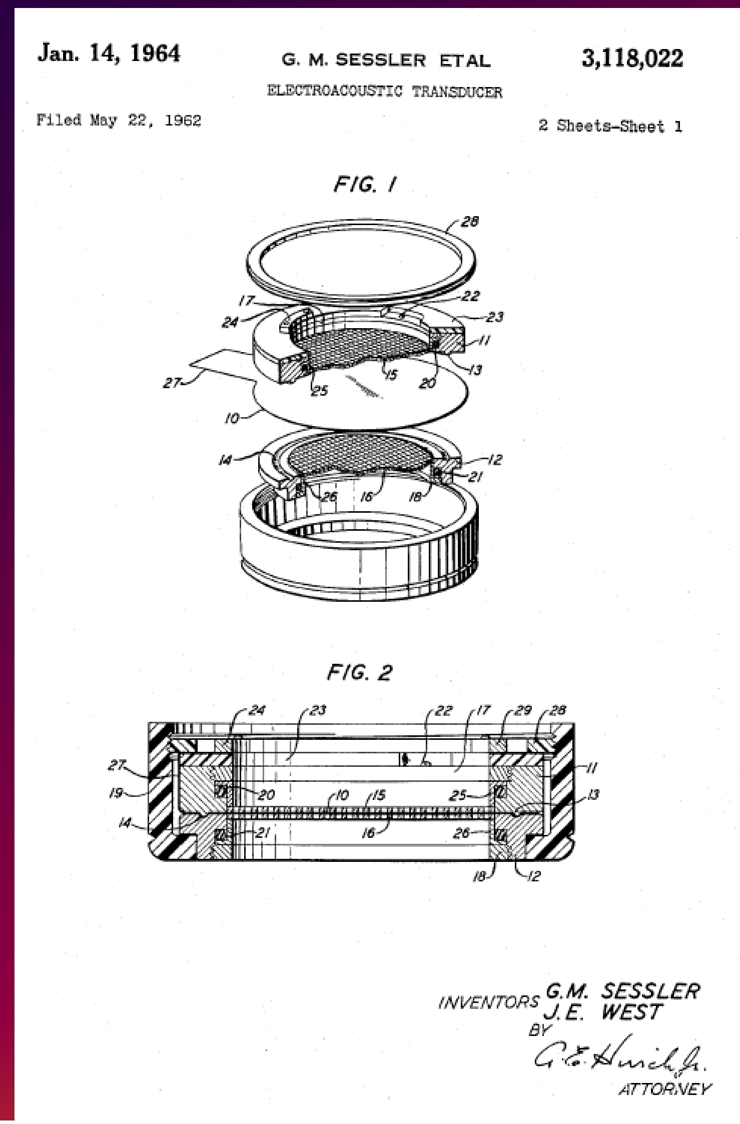
- Electrical engineering
  -> mastering space charge



(Ieda, 1967)

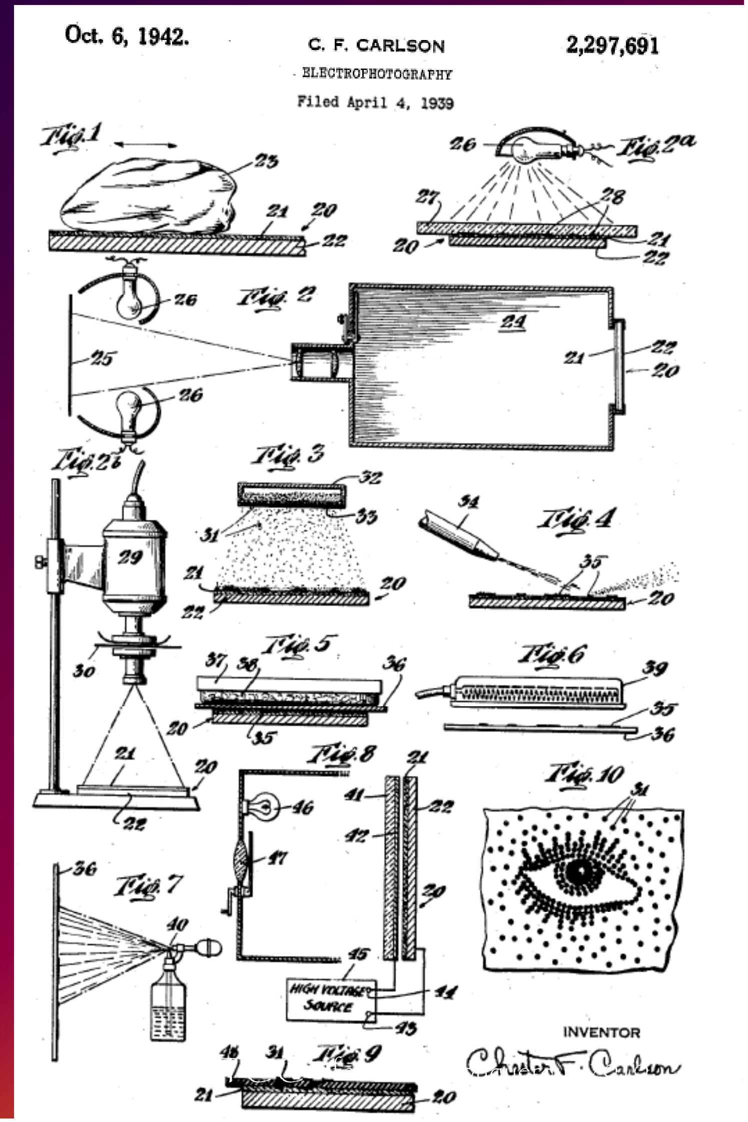
Surface potential decay models : where are they coming from ?

- Electrets
  - -> removing conductivity
  - -> enhancing trapping



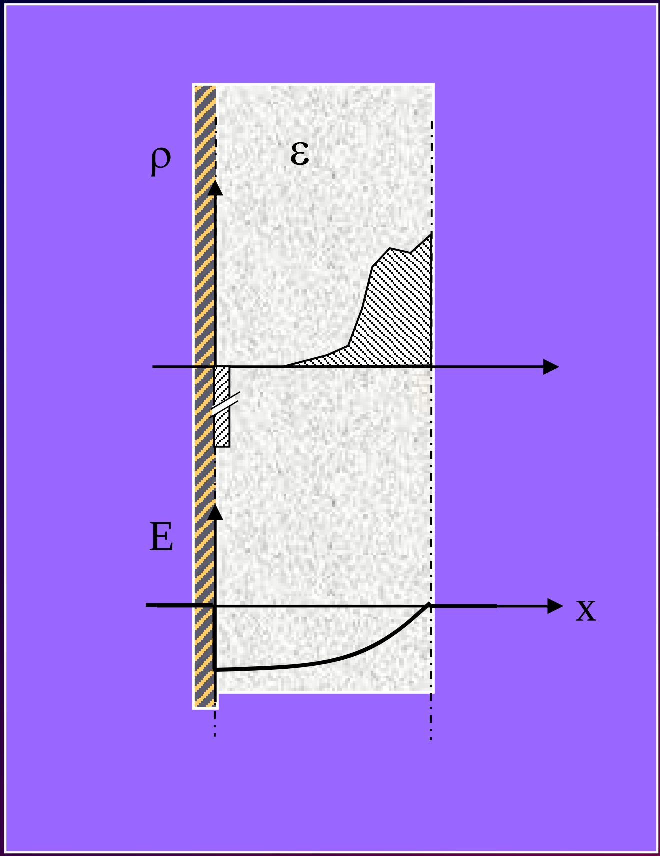
Surface potential decay models : where are they coming from ?

- Electrophotography (copiers, laser printers)
  - -> mastering charge transport
  - -> mastering photoconductivity



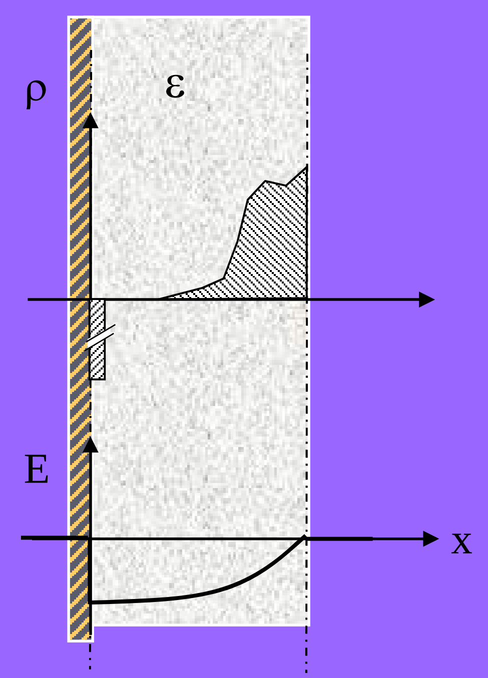
Philippe Molinié, « A review of mechanisms and models ... »,

Modelling



- 1D problem
- Boundary condition : E=0 outside

Modelling



- Poisson equation

$$divE = \frac{\rho}{\varepsilon_0} \qquad divD = \rho \qquad D = \varepsilon_0 E + P$$

- Continuity equation

$$\frac{\partial \rho}{\partial t} + divj = 0 \qquad div\left(\frac{\partial D}{\partial t} + j\right) = 0$$

... in open circuit :

$$\frac{\partial D}{\partial t} + \left(\sigma + \sum_i \mu_i \rho_i\right) E = 0$$

- Calculation of V :

$$V_s = -\int_0^d E dx$$

Possible causes of the SPD

$$\frac{\partial D}{\partial t} + \left(\sigma + \sum_i \mu_i \rho_i\right) E = 0$$

$$D = \varepsilon E$$

- Dipolar Polarisation / relaxation

$$\frac{\partial D}{\partial t} = 0$$

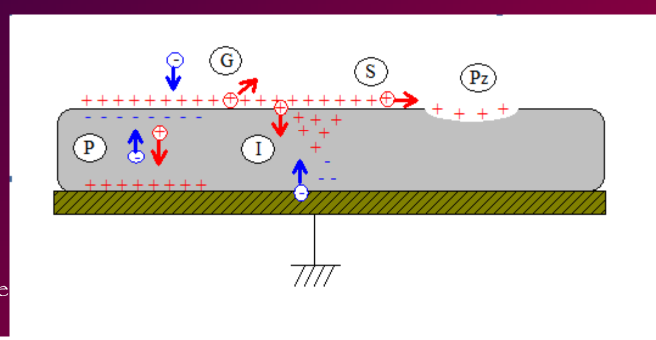
$$\frac{\partial P}{\partial t} > 0 \qquad \frac{\partial E}{\partial t} < 0$$

- Charge injection

$$\varepsilon \frac{\partial E}{\partial t} + \sum_i \mu_i \rho_i E = 0$$

- Conduction (internal carriers)

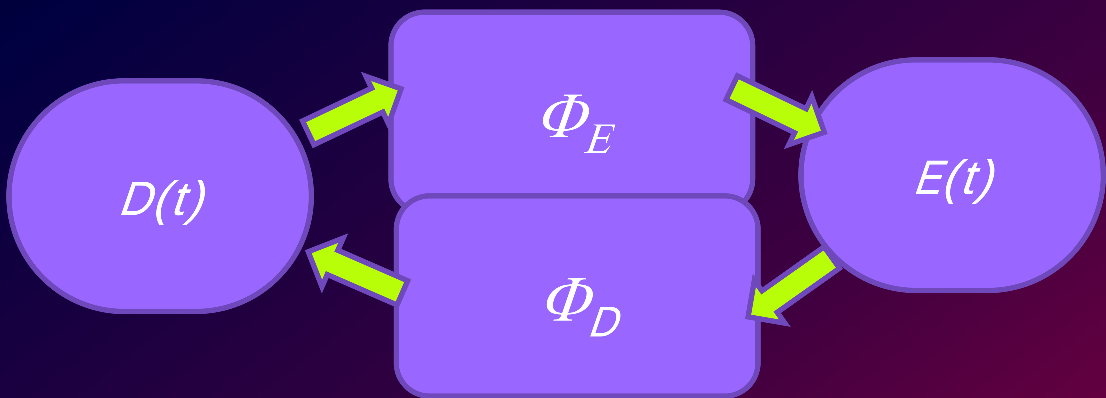
$$\varepsilon \frac{\partial E}{\partial t} + \sigma E = 0$$



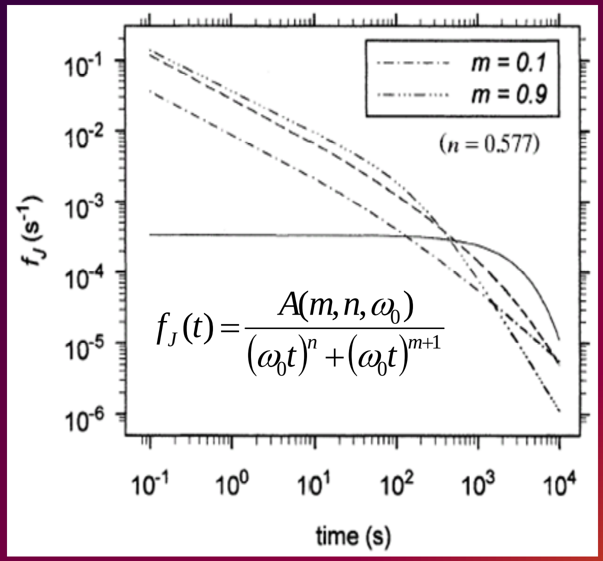
Relaxation – dipolar polarization

- Linear model (transfer function)

$$E(t)=\frac{1}{\varepsilon_0}\int_{-\infty}^{t}D(\tau)\phi_E(t-\tau)d\tau$$



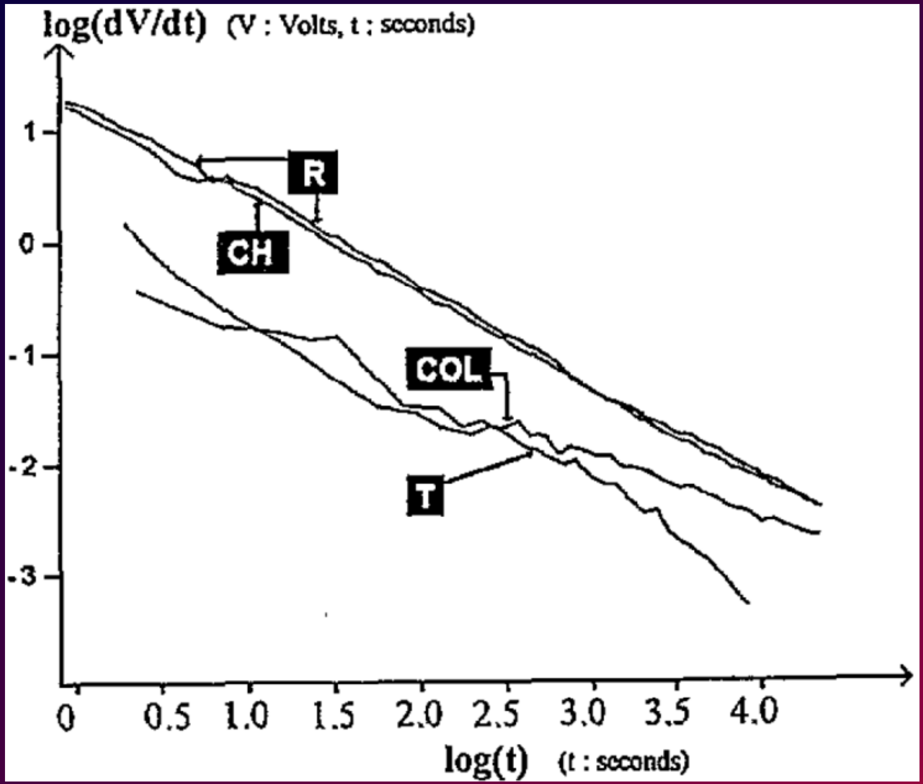
$$D(t)=\varepsilon_0\int_{-\infty}^{t}E(\tau)\phi_D(t-\tau)d\tau$$



- DP can be deduced:

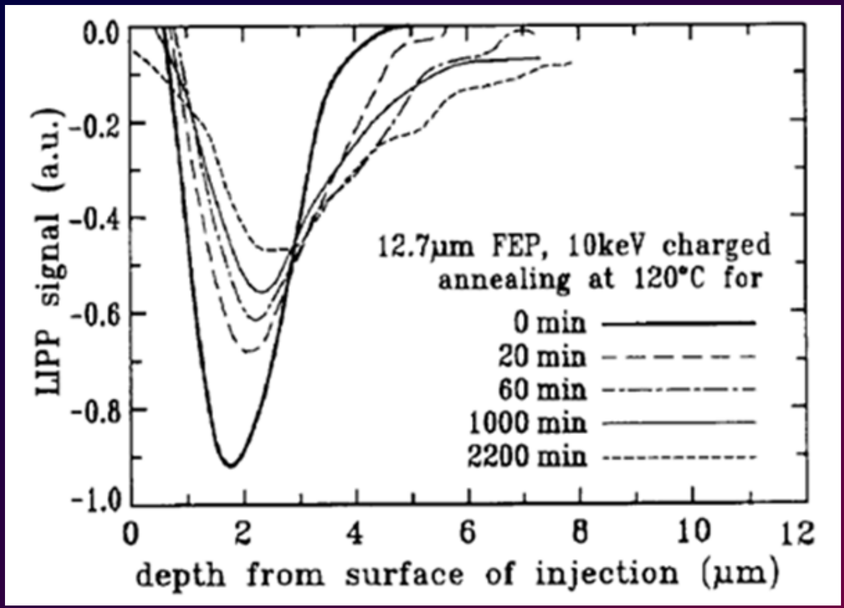
$$\frac{dV(t)}{dt}=-\frac{1}{L}\frac{dE}{dt}=-\frac{Lq_0}{\varepsilon_0}\frac{d}{dt}\int_0^t\phi_E(\theta)d\theta=-\frac{Lq_0}{\varepsilon_0}\phi_E(t)$$

Relaxation – dipolar polarization



Molinié 1995 (epoxy)

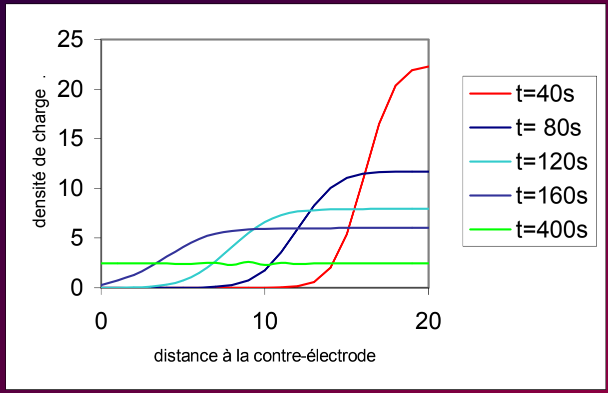
Charge injection



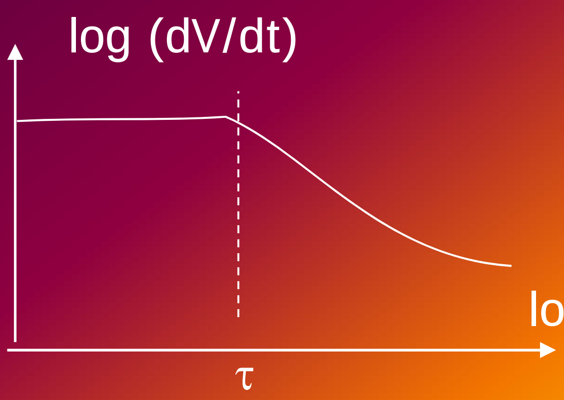
Sessler 1999

« Electrostatic » models

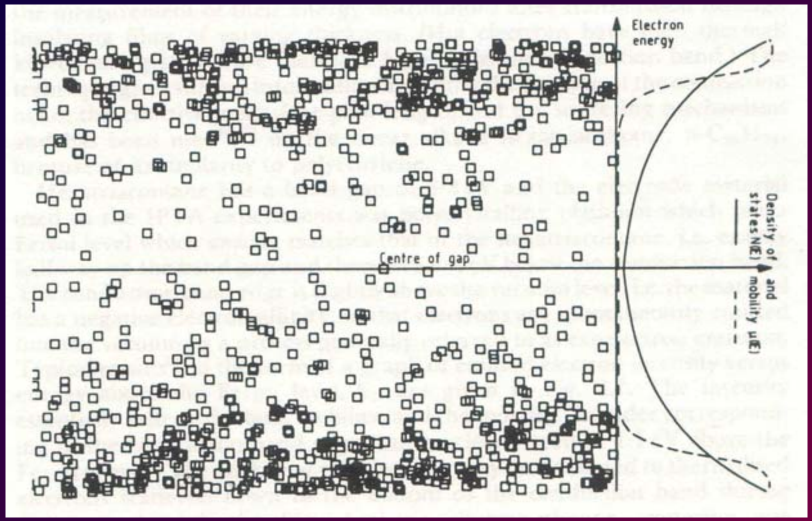
- Mobility μ



=> dV/dt constant for t<transit time

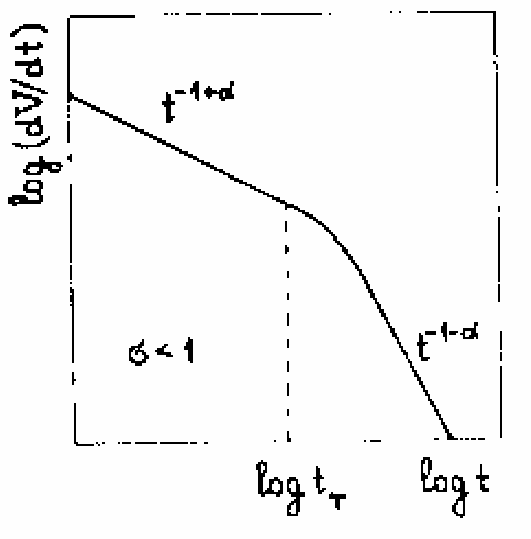


Introducing trapping



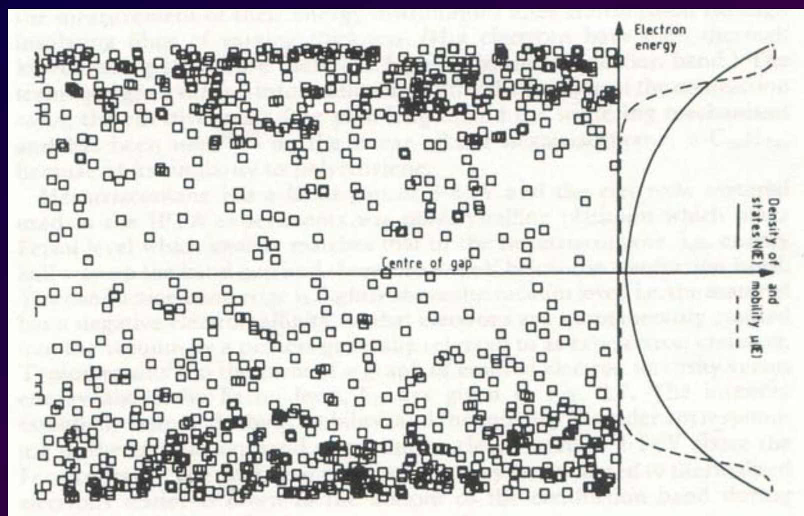
(Dissado, Fothergill)

=> dispersive transport

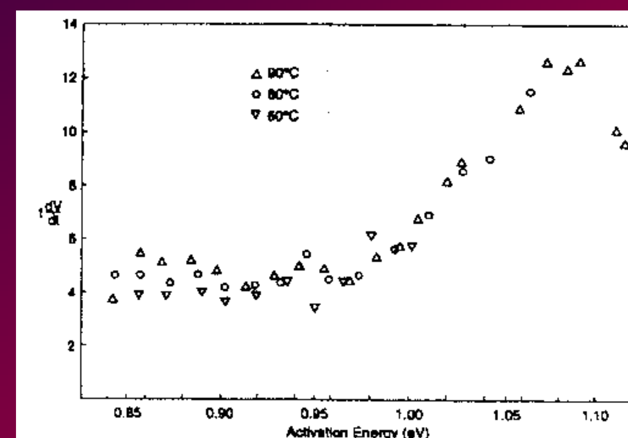


Detrapping controlled decay

- demarcation energy models



(Dissado, Fothergill)



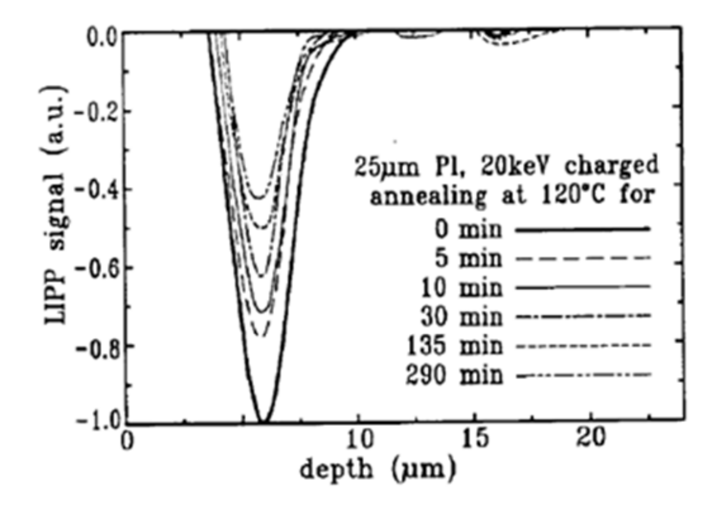
(Watson)

Internal conduction

- Homogeneous conduction models

$$\frac{\partial \rho}{\partial t} + divj = 0 \quad \Rightarrow \quad \frac{d\rho}{\rho dt} = -\frac{\sigma}{\varepsilon}$$

Charge screening



Sessler 1999

Internal conduction

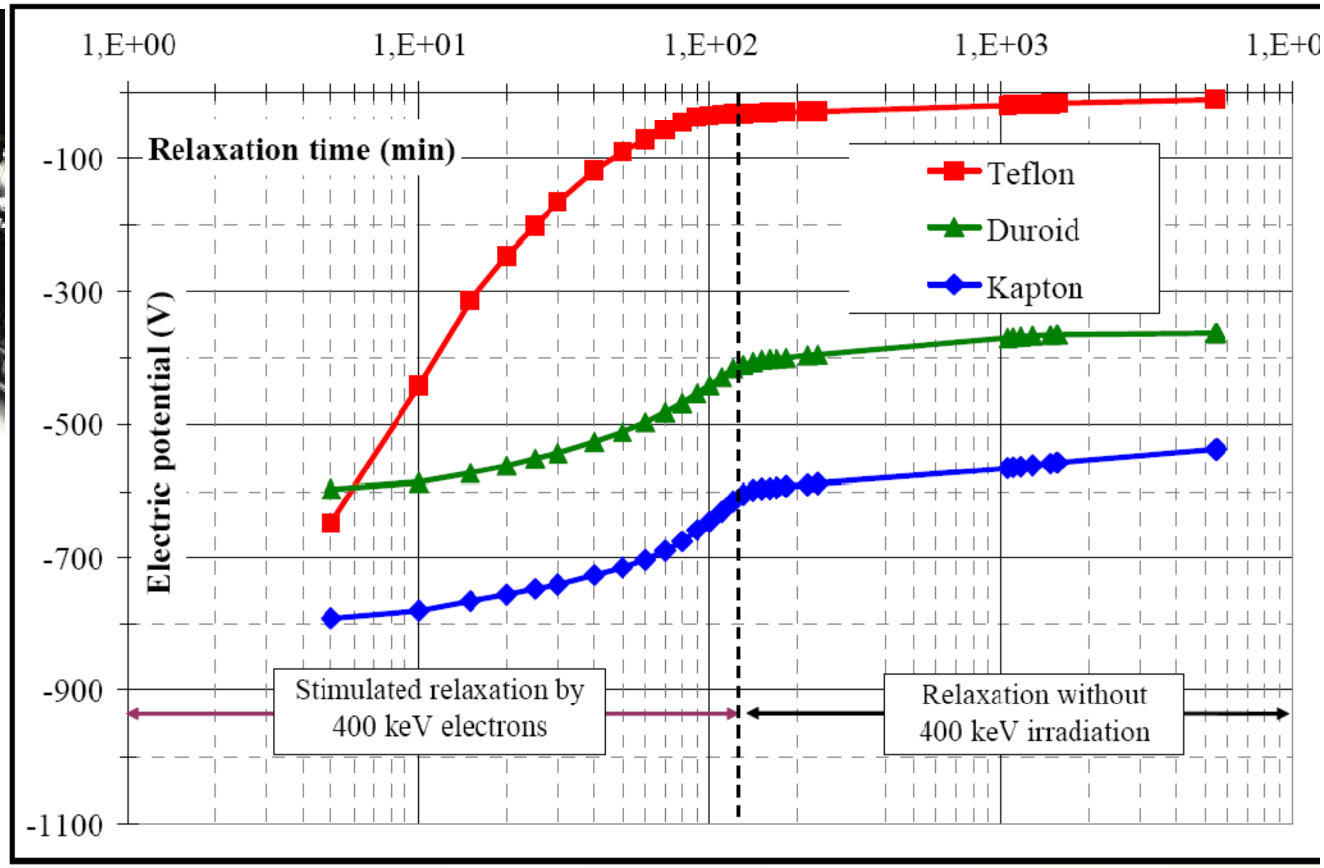
- Homogeneous conduction models

$$\frac{\partial \rho}{\partial t} + divj = 0 \quad \Rightarrow \quad \frac{d\rho}{\rho dt} = -\frac{\sigma}{\varepsilon}$$

Charge screening

- Carrier generation and recombination
- Radiation-induced conductivity

RIC : Application to Teflon FEP and Kapton polyimide



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THE FRENCH AEROSPACE LAB

cnes
De l'espace pour la Terre

Radiation-induced conductivity

- A difficult dynamical problem
  - Trapping profile and polarization will depend on time (as any SPD experiment)
  - + introducing a charge carrier generation parameter also depending on time (beam on/off) and space (absorption)

Summary

- The behavior of insulator is complex !
  - ... cannot be described by a single figure as « resistivity »
- Difficulty to interpret surface potential decay experiments
  - ... because of many possible mechanisms
- multiple experiments to be performed
- appropriate plot for the data
- complementary techniques to be coupled (LIPP, PEA...)
- MORE INFORMATION ON MY DETAILED PAPER*

*except on space cats research, which is classified