Institut d'Electronique du Sud, Group « Energy et Materials »

UNIVERSITÉ MONTPELLIER 2
SCIENCES ET TECHNIQUES

JICABLE HVDC 13

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Electrical Phenomena Modeling In Polyethylene

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Plan

- 1-Introduction
- 2- Thermal Step Method (T.S.M.)
- 3-Influential parameters in PE under DC
- 4- Pure Polarisation and thermo-stimulated current
- 5-Polarisation and Injection
- 6-Strong Injection and Thermal stimulated current
- 7-Conduction
- 8-Conclusion

1-Introduction

- PE structure

Conduction Band : 8-9 eV

Localized levels : from 0.3 to 2.0 eV under CB and above VB

- Space Charges Measurements
  - Giving evidence of different states: polarization, injection at high electric field and links with conduction, ageing, breakdown…

The Methods of measurements

- The Pressure Waves:
  - – LIPP, PEA

The Thermal Waves

-LIMM, TP, FLIMM, FLAMM, TSM, MOTA,

TSM

- -Created in 1986
- Easy to apply and sensitive
- -Applied in numerous solid insulating materials: pure and composites
- -Electrical Engineering: slabs, films, cables
- -Installed in Industries

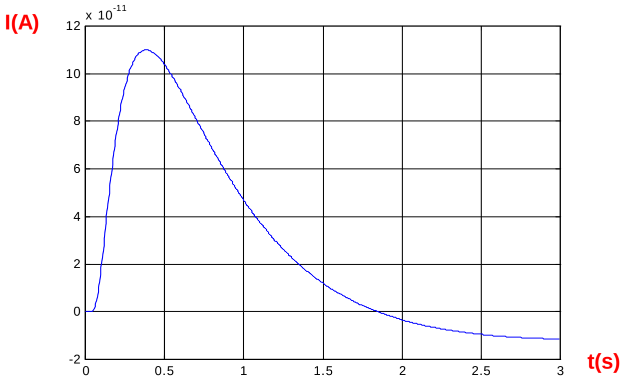
TSM in Short Circuit Conditions

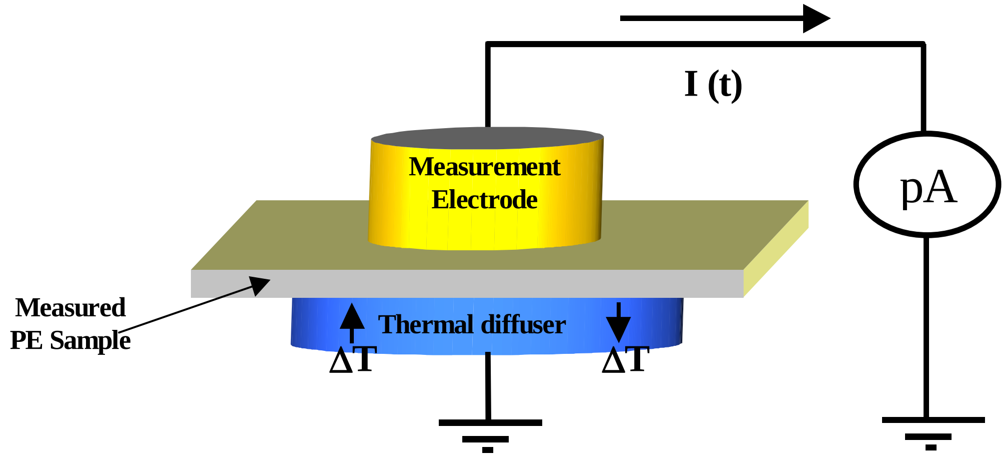
1. Short circuited sample

2. Applying the thermal step

$$dx' = dx(1+\alpha_x \Delta T)$$

$$\varepsilon' = \varepsilon(1+\alpha_\varepsilon \Delta T)$$





Balance changed

Re-balancing

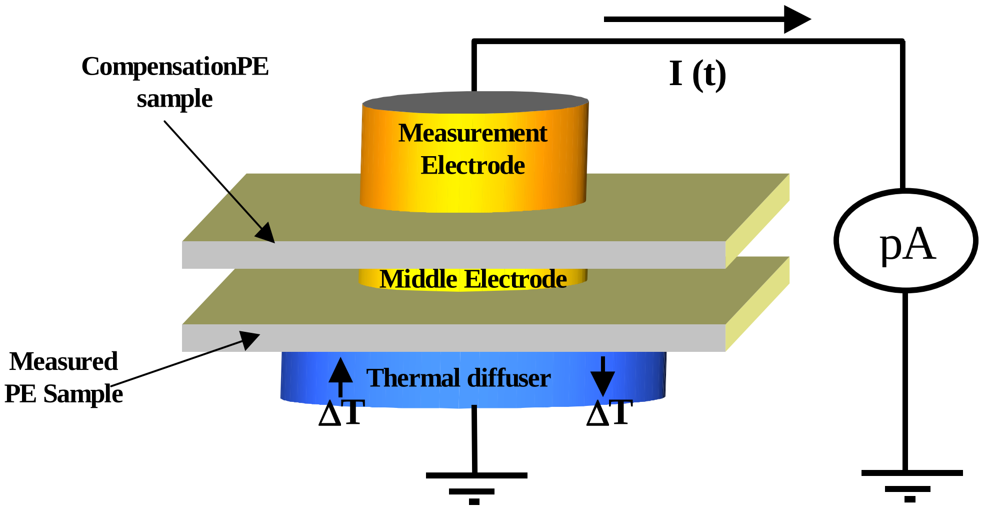
$$I(t) = \frac{\partial Q_1}{\partial t}$$

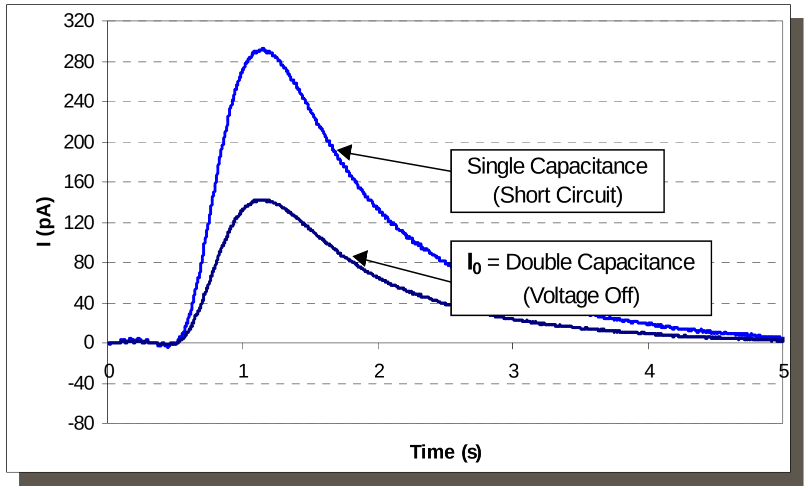
$$I(t) = -\alpha C \int_0^D E(x) \frac{\partial \Delta T(x,t)}{\partial t} dx \rightarrow \rho(x) = \varepsilon \frac{\partial E(x)}{\partial x}$$

Sample is not discharged = 100% Repeatability

TSM under Applied DC Field
Principle of the "Double Capacitor"

Solution : 2 samples with the same capacitance C





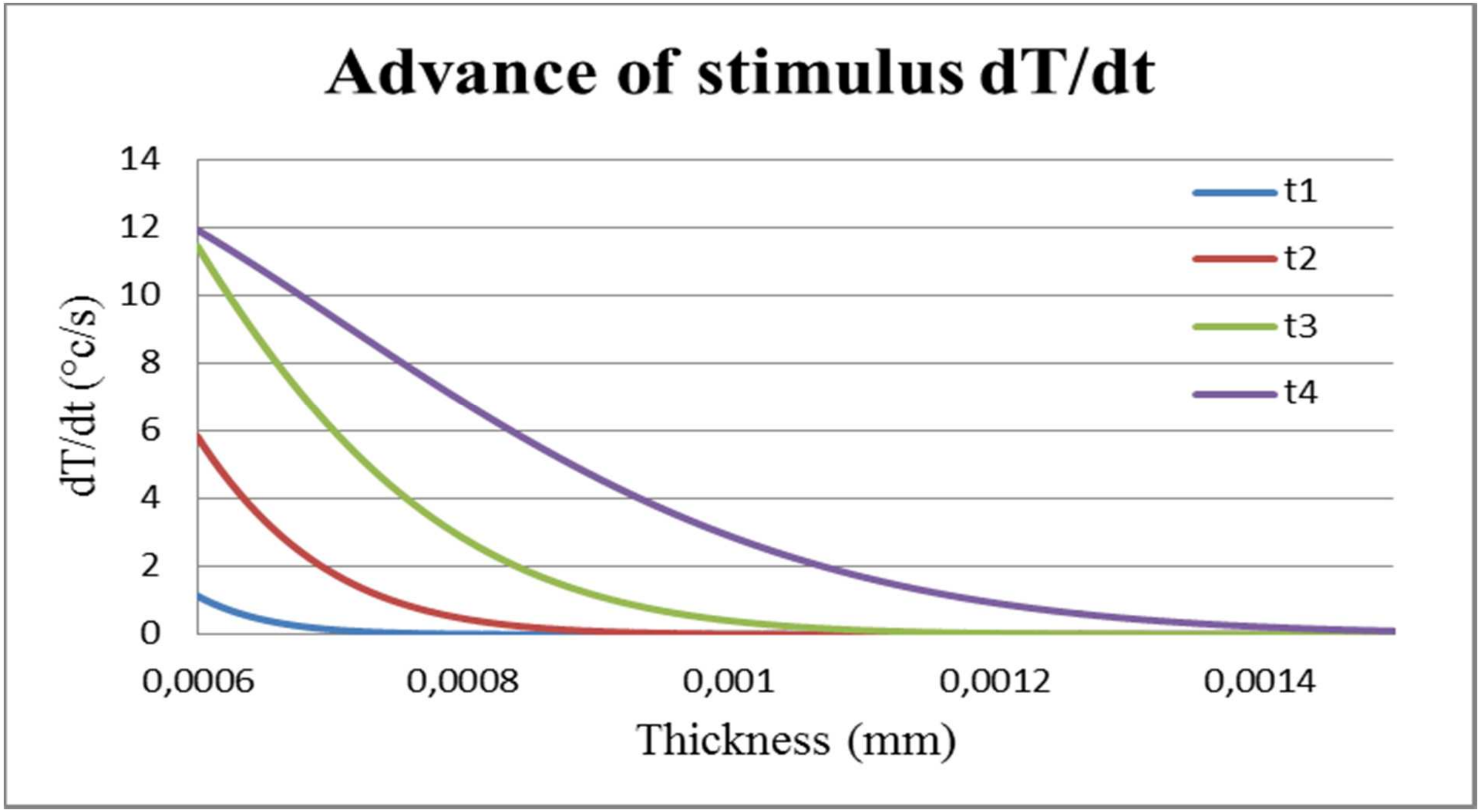
In this case $$I_{UF}(t) = -\alpha C_2 \int_0^D E(x) \frac{\partial \Delta T(x,t)}{\partial t} dx = \frac{I(t)}{2}$$ **with** $$C_2 = \frac{C}{2}$$

For measuring under field → measurement electrode insulated from the HV source

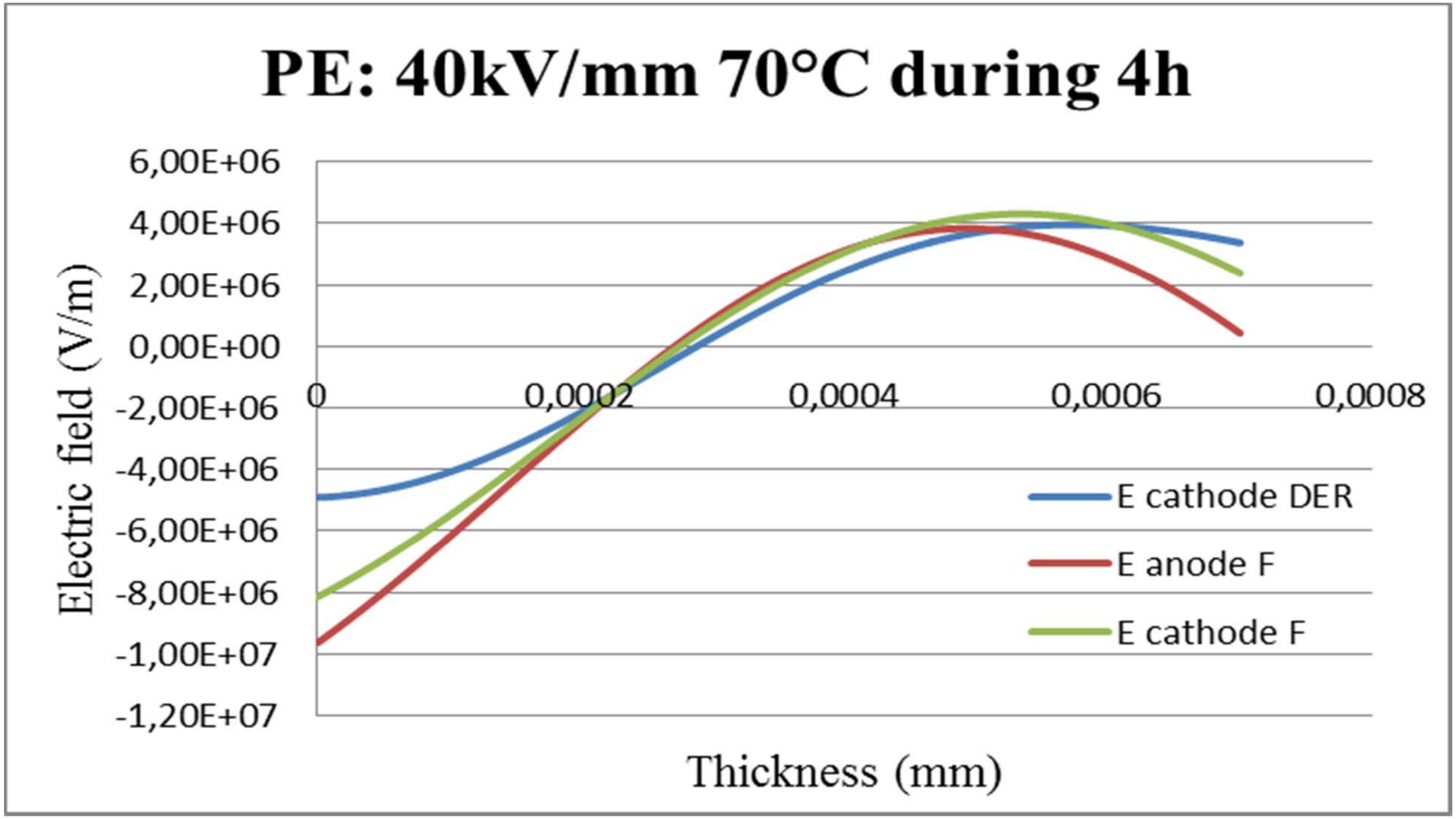
Numerical Treatment

- Different numerical treatments are used:
- -Derivative of fit current taking account that the stimulus crosses the sample versus time
- - Using odd and even Fourier functions versus the two currents on two faces
- -FFT : the current is a Laplace Transform of Electrical Field : this property proves the unicity of the solution

Derivative: dT/dt advanced

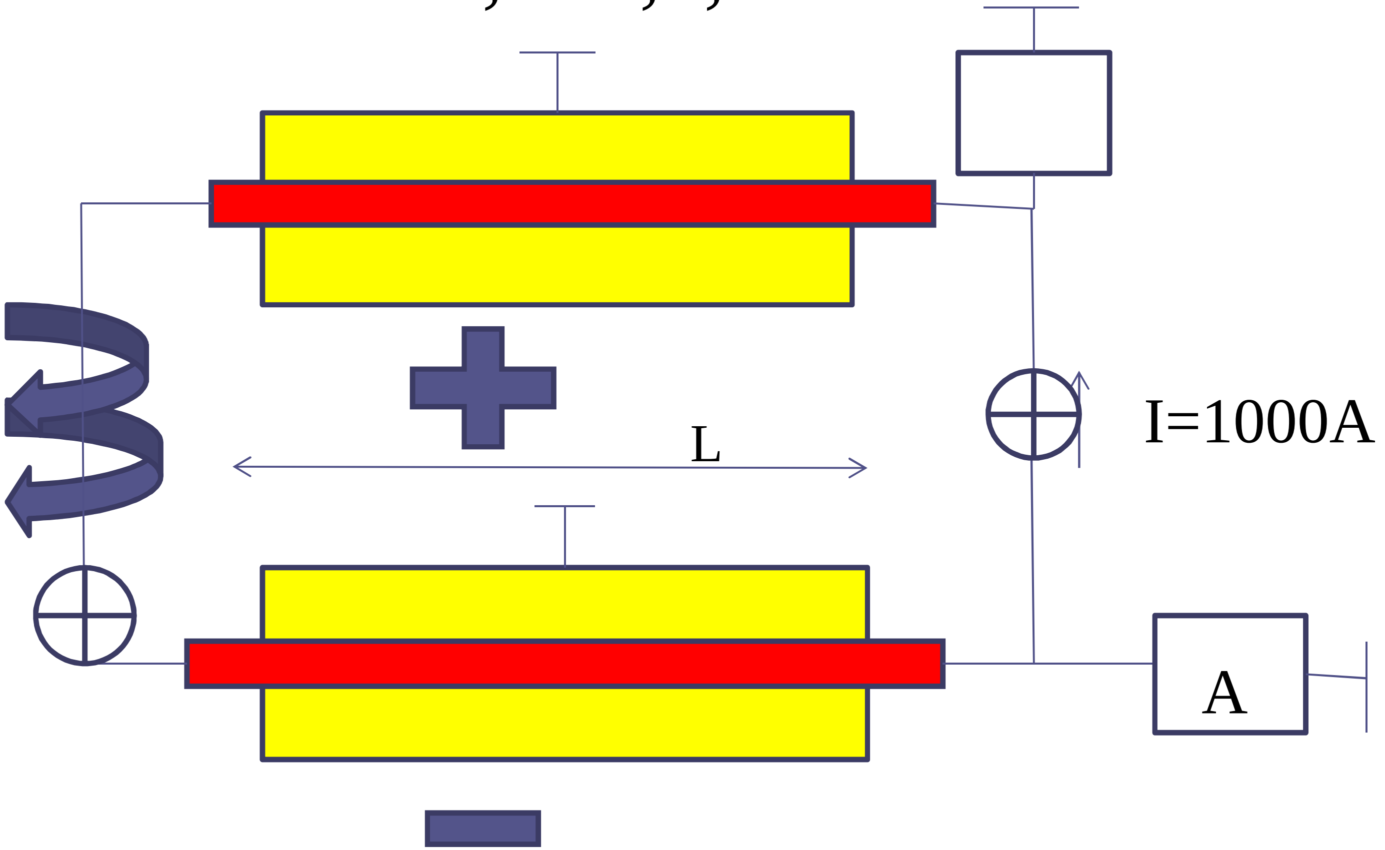


Treatment Comparison



Cable Analysis HVDC + et -

- I=1000A AC ,t= 1,2,3 sec



Effects at the contact

For Schottky effect:

$$J_S = A_S T^2 \exp\left(-\frac{\Phi_0 - \beta_S(\gamma E)^{1/2}}{kT}\right) \quad (4)$$

with $A_S = \frac{4\pi q m k^2}{h^3}$ and $\beta_S = \sqrt{\frac{q^3}{4\pi\varepsilon_0\varepsilon_r}}$

With E = applied electric field ; Φ_0 = energy barrier at the contact; γ: correction factor; γE: real electric field at the contact; T=Temperature.

For Fowler Nordheim effect:

$$J_{FN} = A_{FN}(E_C)^2 \exp\left(-\frac{\beta_{FN}}{E_C}\right) \quad (5)$$

with $A_{FN} = \frac{q^3}{8\pi h \Phi_0}$ and $\beta_{FN} = \frac{4\sqrt{2m^*}\Phi_0^{3/2}}{3\hbar q}$

With Ec = real electric field at the contact.

The Hopping

- W:energy level, λ: distance between traps
- Time constant in a trap : $\tau = \tau o \, Exp[W/kT]$
- τo is about 10^{-13} sec
- E : local electric field, q=elementary charge
- Decreasing of W by E : $q \, E \, \lambda/2$
- Probability of detrapping by sec
- $p = 2 \, Sinh[qE\lambda/2kT] \, / \, \tau$

Detrapping Time at 300 and 340° k

W= 0,70 eV , 58ms, 2,0 ms

W=1,00 eV , 2 hours, 50 s

W=1,30 eV , 22 years, 15 days

Influential Parameters:Materials

- Materials:

  LDPE, HDPE, XLPE: distribution of traps
- Links Time , Energy W in measurement
- New materials
- Nanodielectrics
- Improvements on cables

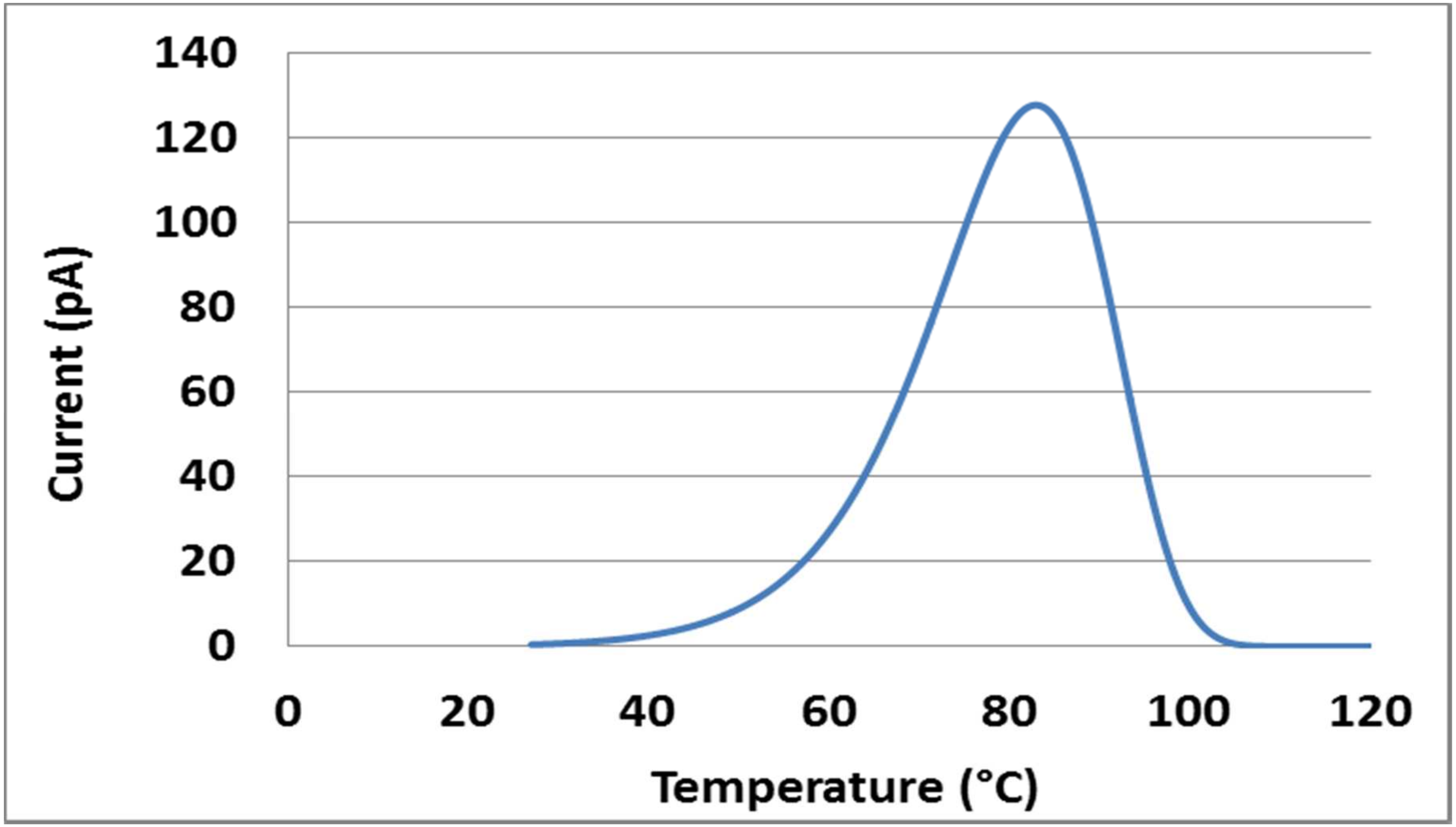
Influential Parameters : Electric Field

- ELECTRIC FIELD :
- Less than 1-2 MV/m: polarization only
- Some MV/m to 20 MV/m : polarization and injection are apparent
- More 20-30 MV/m : only injection is apparent
- More 40 MV/m double injection

Influential Parameters: Temperature and Time

- TEMPERATURE :
- It is a parameter very active
- Polarization and injection and conduction are increased strongly after 60° C
- TIME:
- The hopping concerns the traps from 0.3 to 1.4eV giving a large scale : from ms to years !

Thermally-Stimulated Current in Pure Polarization



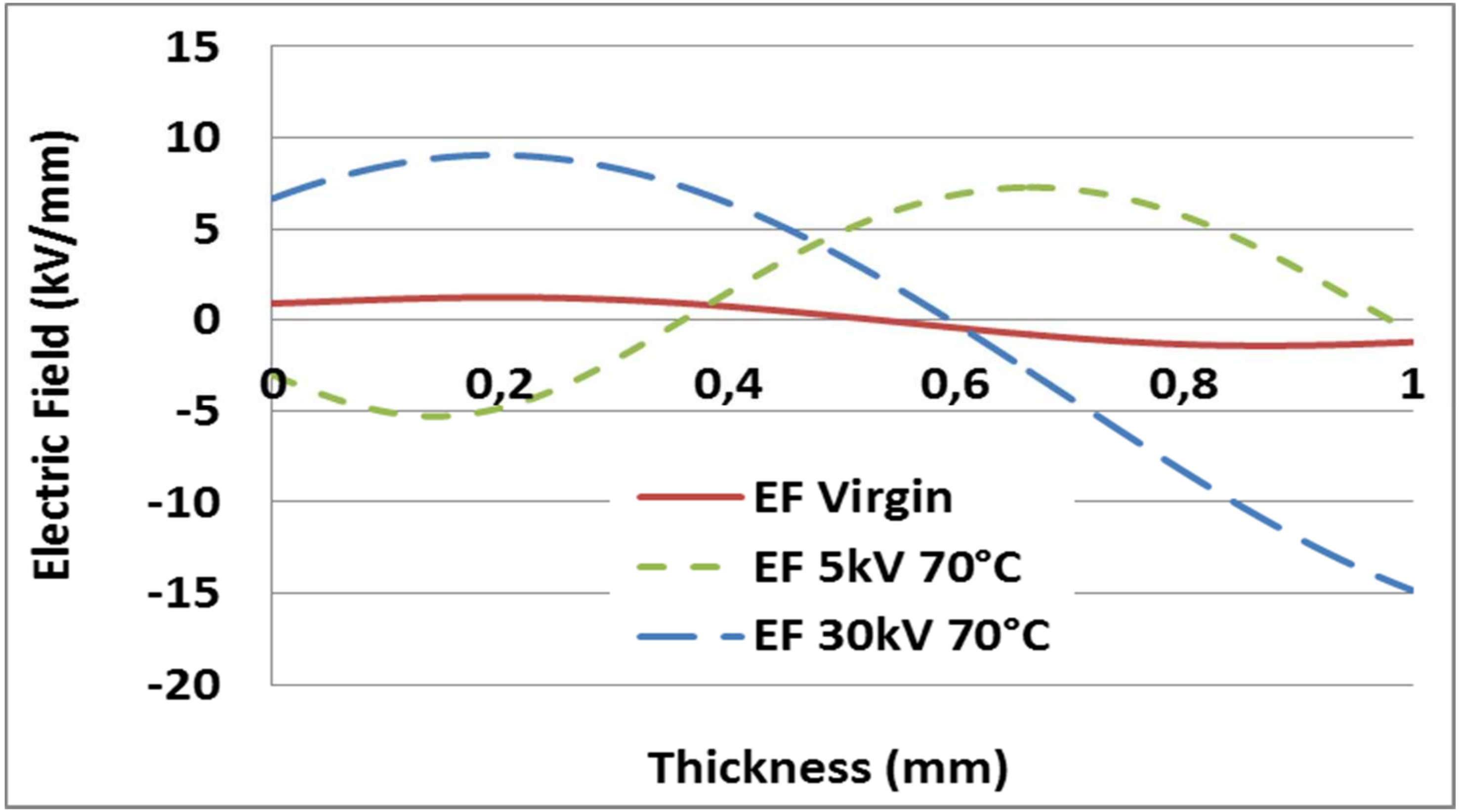
Results with pure Polarization

- Charge of Polarization, sample PEBD 200 microns thick, 30 mm diameter
- Qf=Nt q S λ tf 2 Sinh[q λ E/k T] /τf
- Thermostimulated Discharge Current:
- It=-dQ/dt, dQ/Q=-dt/τ ; It max Tm=83°C
- Nt=3.0 $10^{23}\ m^{-3}$; Qf=1.0$10^{-7}$ C
- λ=15 nm ; W=1.08 eV

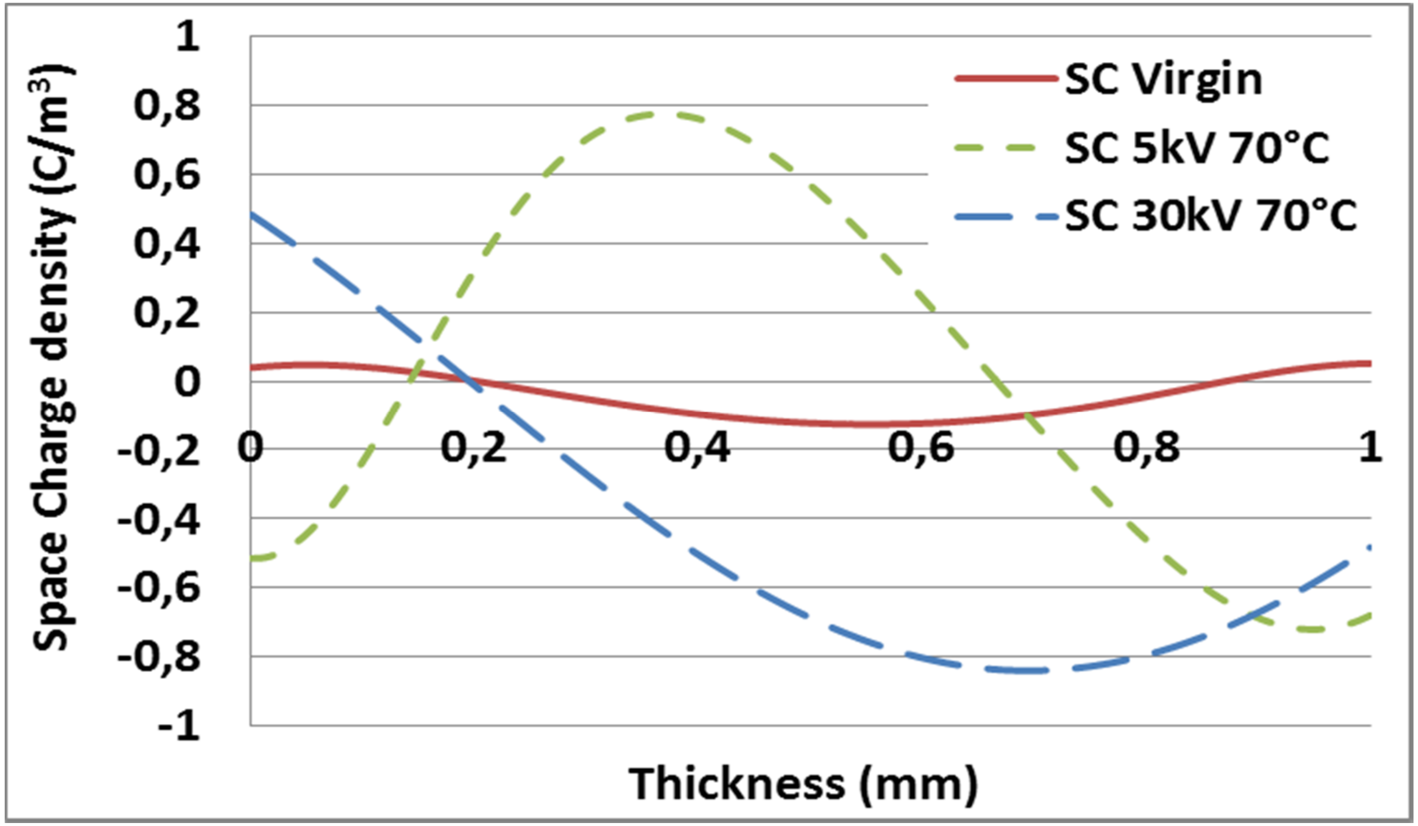
Polarization and injection

- HDPE
- 1mm thick, diameter :40 mm
- Electrodes : deposited Aluminium
- Poling : 5 and 30 MV/m at 70° C, 40 hours
- Short-circuit 30 mn; we see traps W > 1,0 eV
- Electric and Space charge measurements in 3 cases : virgin, 5 MV/m, 30 MV/m

Remaining Electric Field in 3 cases



Space charges in 3 cases



Strong injection

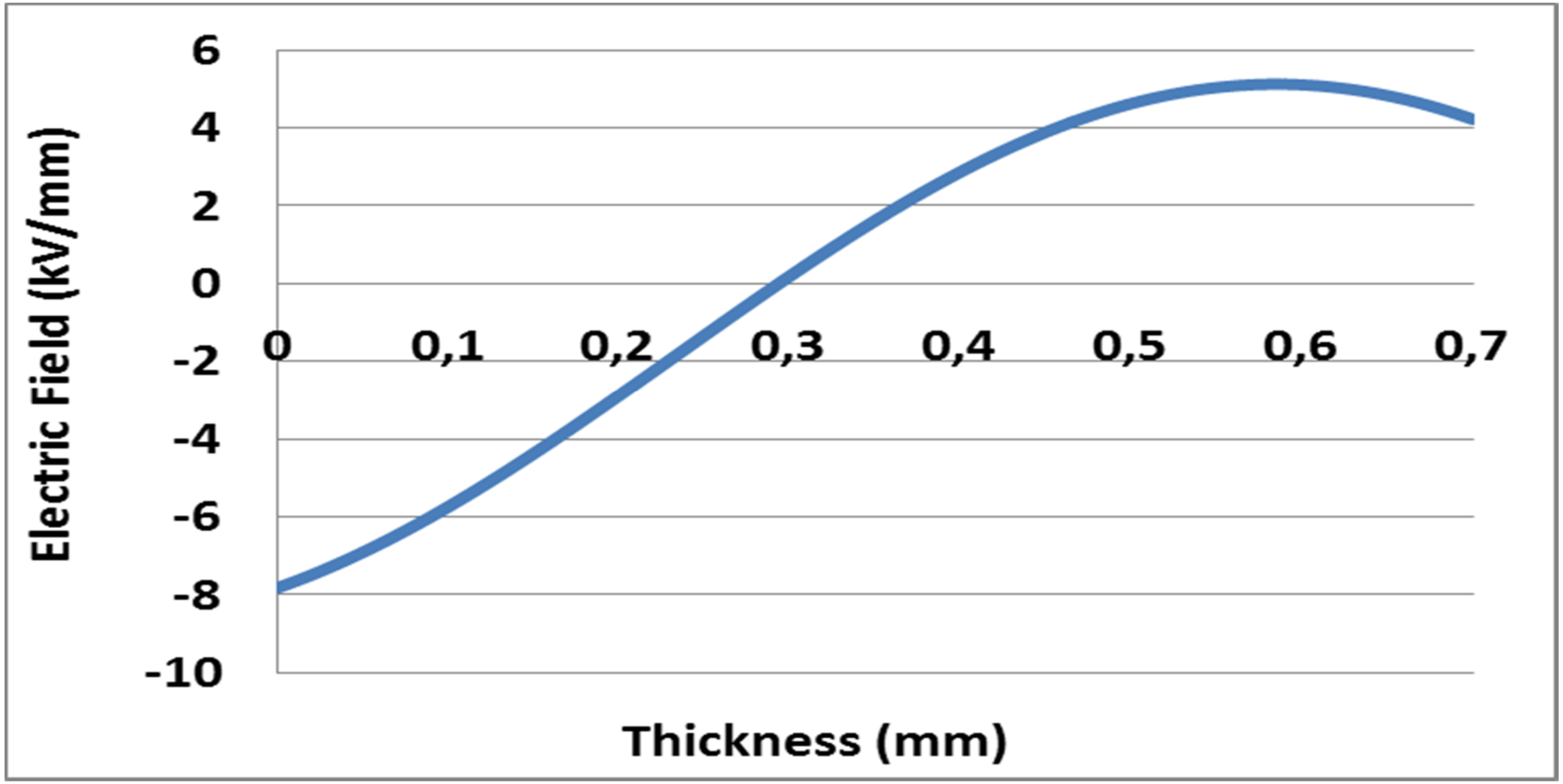
- PE sample
- 0.7 mm thick, Diameter : 40 mm
- Electrode : semiconductor

Poling 40 MV/m at 70° C, 40 hours

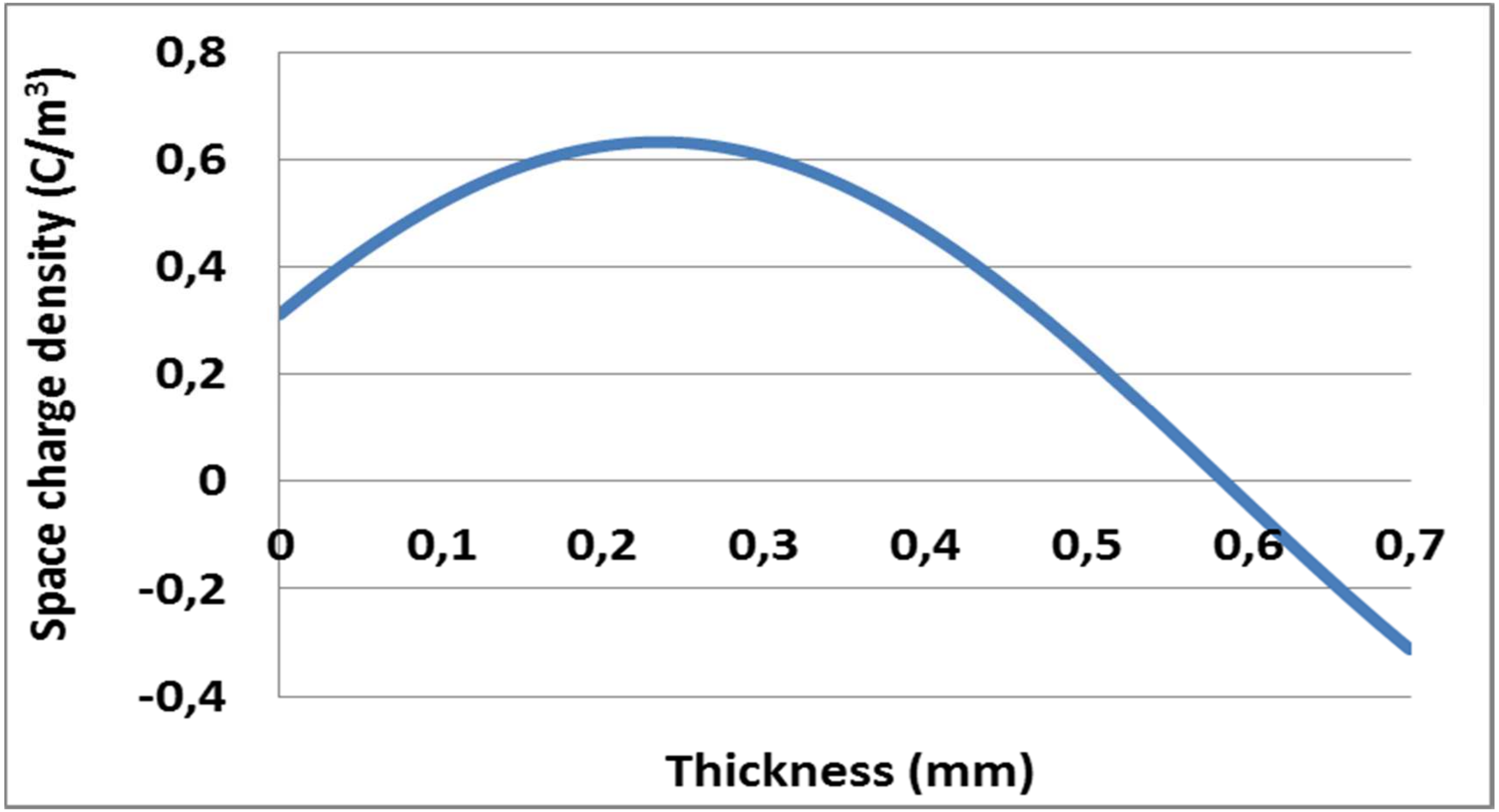
Short circuit 15 mn : traps concerns W>1.0 eV

Discharged by thermostimulated current

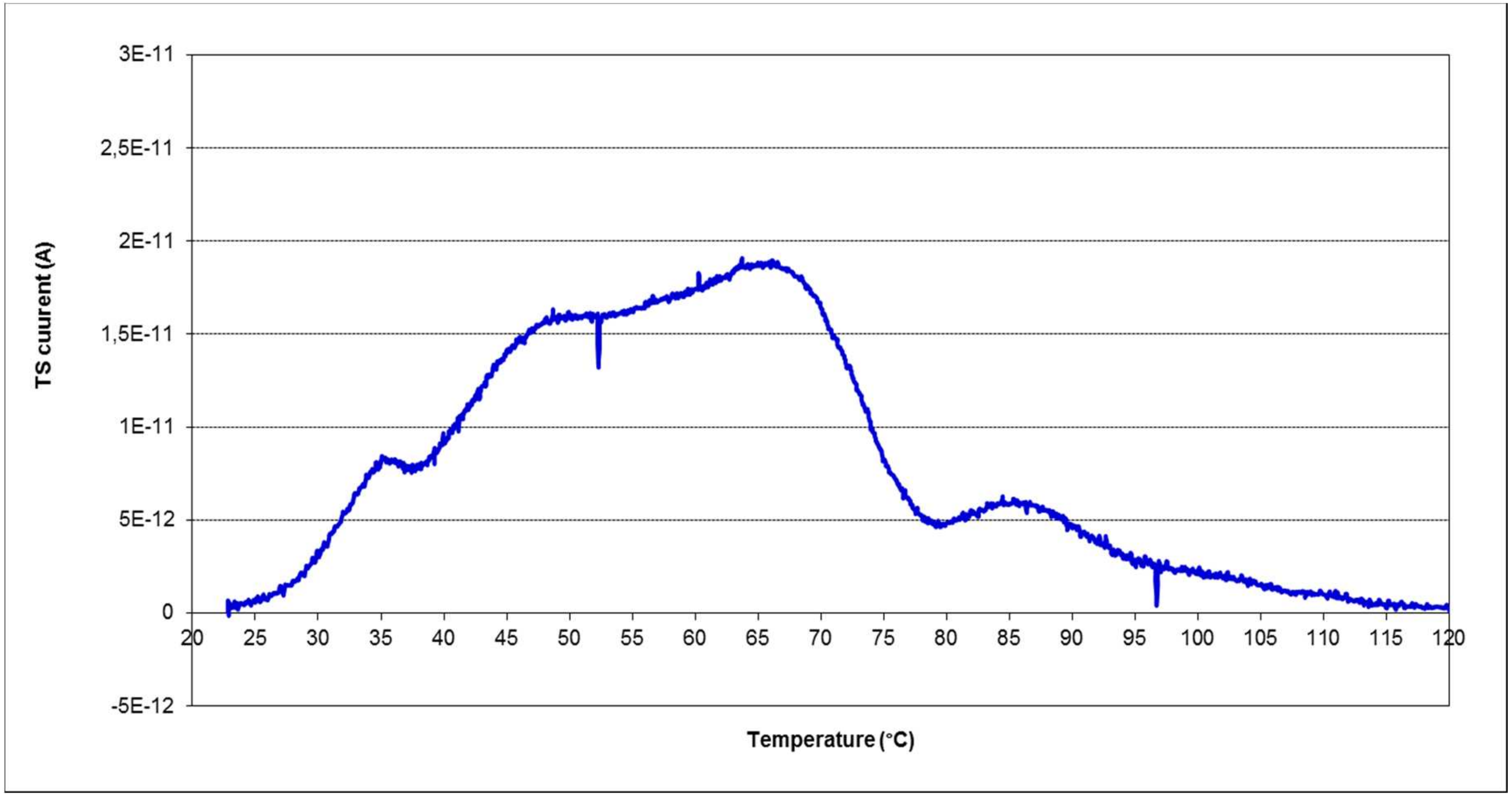
Remaining Electric Field in strong injection



Space charge in strong injection



Thermostimulated current after strong injection



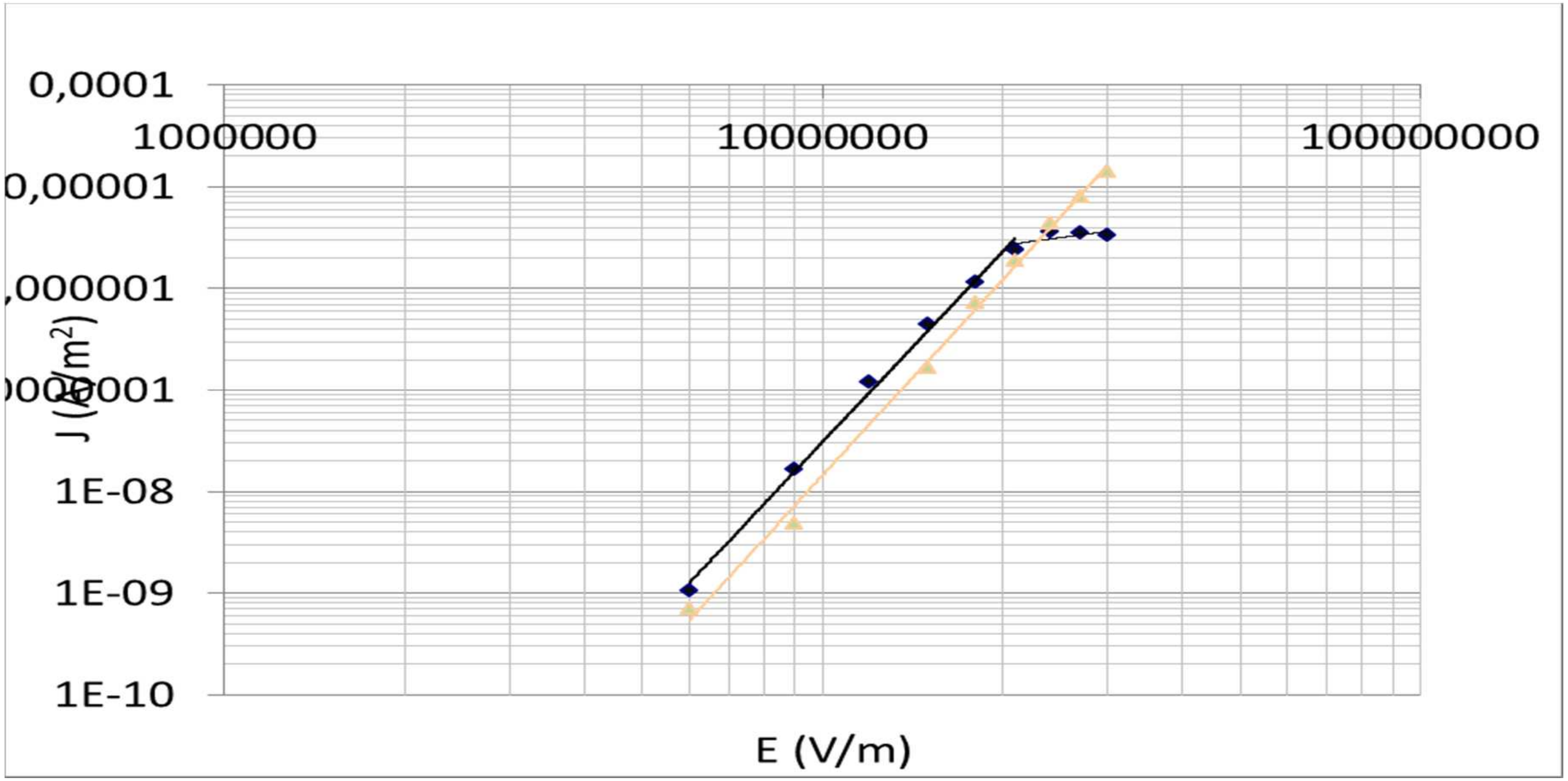
Interpretation for TSC

- Positive dominant charges
- Electric fields cuts pratically the sample in the middle
- Two opposite currents to anode and to cathode: result gives a weak total current
- Possible reverse of this current due to each contibution to turn
- W>1.0 eV, density < 1C/m3

Conduction

- HDPE sample
- 1 mm thick, diameter : 40 mm
- Electrode : deposited aluminium
- Voltage : from 6 to 30 MV/m
- Temperature 70° C
- Time : 2 hours for each point (W<1.20eV)
- Current saturation at 30 MV/m

Conduction and simulation in PE



Conduction

- Interpretation by exponential distribution
- m = T/Tc ; Tc: Temperature parameter of the distribution ; Ntc: Trap total density ;
- d= do Exp[-(w-w1)/kT] trap density
- w1: first level; do=Ntc/kTc;
- Nc=total density in CB
- μo = mobility in CB

Conduction

- Then the current density is given by :
- J(V)=C1 C2 μoqNcExp[-w1/kT] $Ea^{1+1/m}$
- Ea=V/L:applied field;L:thickness;V:voltage
- $C1=(\varepsilon Sin(m\pi)/qNtcL(1+m)m\pi)^{1/m}$
- $C2=(2+m/1+m)^{1+1/m}$

Conduction results

- m = T/Tc = 0.19 ; W1= 0.30 eV
- 1+1/m = 6.3 ; Nc = $10^{26}\ m^{-3}$
- Ntc = 9 $10^{20}\ m^{-3}$; T= 343 ° k
- Tc = 1822 ° k ; µo = 5.0 10^{-4} m^2/V s
- do = 3.57 $10^{40}\ j^{-1}\ m^{-3}$
- 0.3 eV < W < 2.0 eV

CONCLUSION 1

The pure polarization inside the chains at very low electric field : Temperature only can make trapping then detrapping : Nt, λ, are evaluated

- At high electric field, the injections of two types of charges at the contact by Schottky effect facilated by level stairs (step by step)
- Development of space charges in traps by detrapping due to Electric field and Temperature

CONCLUSION 2

- At high field > 20 MV/m: Injection of electrons
- At very high field > 40 MV/m : double injection
- Conduction associated with exponential distributions of traps in ordered zones : Ntc
- Links between time and energy W

CONCLUSION 3

- The consequences for the future:
- Elaboration of new materials which evacuate the space charge
- Be careful about thermal runaway
- This work is very complex : chemical, physical, electrical aspects
- The tight collaboration between universities and industrials

THANK YOU FOR

YOUR ATTENTION