Laboratoire de Physico-Chimie des Polymères
LPCP- UMR CNRS 5067

March 7th, 2005

Properties of the insulators:
Influence of the electrical charges

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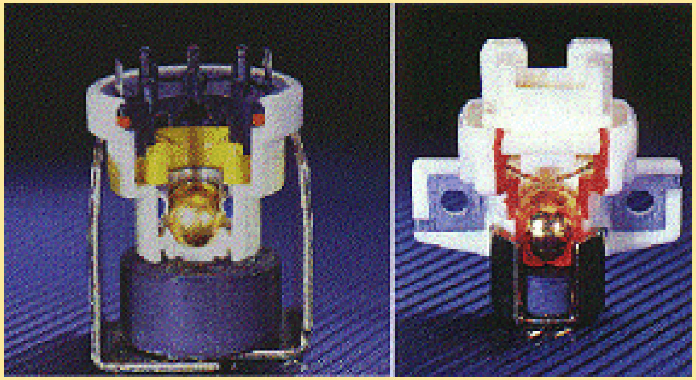
presented by Christelle GUERRET

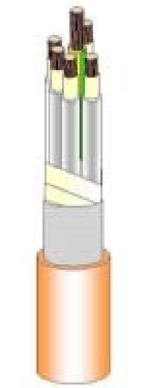
Chargée de recherche du CNRS

to obtain the "Habilitation à Diriger des Recherches"

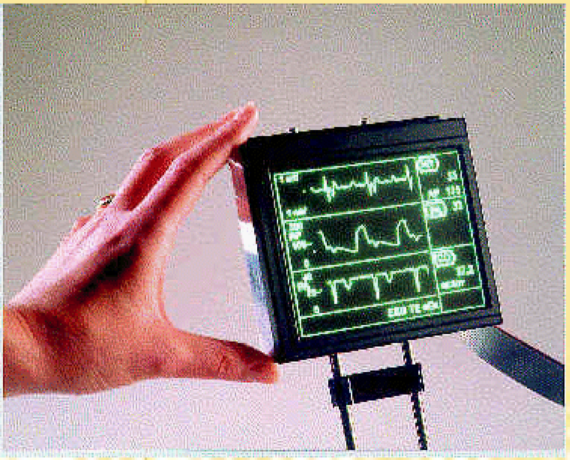


Electromechanical sensor of acceleration for airbag

Spatial vehicles

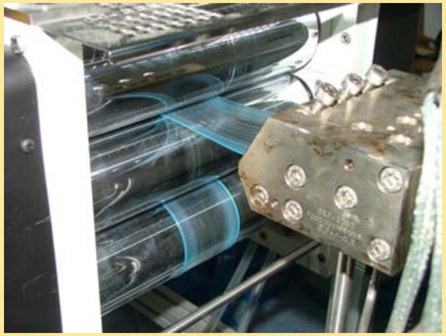


Insulators for cables



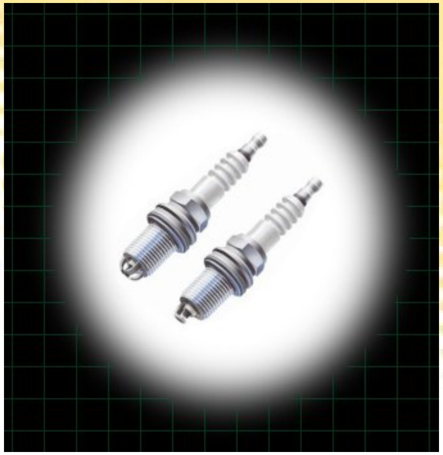
FEG screen

What role for the electrical charges ?

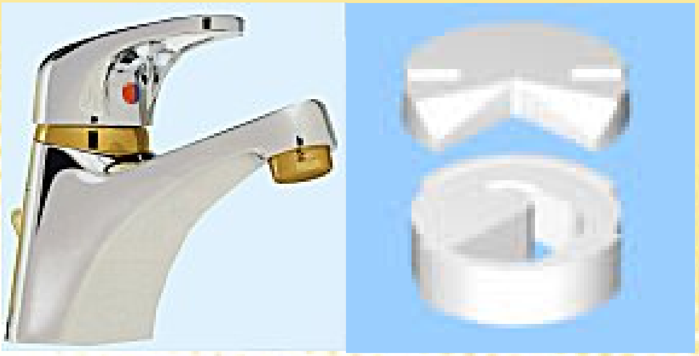


Extrusion of polymers

yarn-guide



Sparking plug



Pieces for mitigation tap

OUTLINE

I. **Examples of industrial applications for the insulators: Evidencing of the role of the electrical charges.**

1. Modification of friction and adhesion
2. Flow and trapping of the electrical charges.

II. **Contribution of the electrostatic forces to the adhesion of the materials:**

III. **Characterization of the properties of charges flow and charges trapping: SEMM method and simulations**

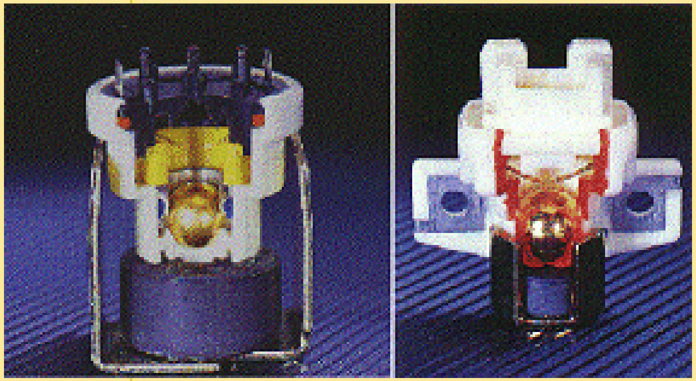
IV. **Conclusions and Prospects**

I.1. Modification of friction and adhésion

Electro-mechanical sensor of acceleration for air-bag

Principle :

- metallic ball in an insulator guide
- maintained by a magnetic field
- during a stron acceleration the ball overcome the magnetic field and establish electrical contact .



utilization ⇨ triboelectrification against the guide ⇨ ball sticked on the guide wall

Inactivation of the sensor because of the adhesion of the ball on the insulating guide wall

⇨ **Fundamental study of the interaction between a charged metallic ball and an insulating plane**

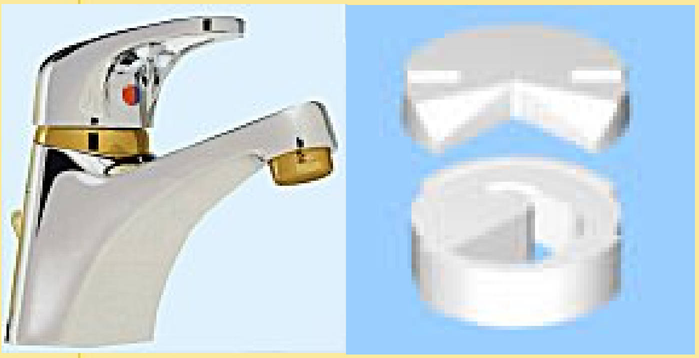
Usefulness of the comprehension of the triboelectrification phenomenon

ACI* (Tribosurfélec)

*Action Concertée Incitative

I.1. Modification of friction and adhésion

Pieces for mitigation tap



Principle :

- simultaneous control of the flow and of the temperature of water

- superposition of the holes of both ceramic disks

- sliding one over the second during the use

utilization ⇨ friction of the two disks ⇨ sticking of the two disks

unusable tap due to the adhesion of the two ceramic disks

⇨ **Usefulness of the comprehension of the triboelectrification phenomenon between two similar materials**

ACI* (Tribosurfélec)

*Action Concertée Incitative

I.2. Transport and trapping of the electrical charges

yarn-guide for textile industries

Performances:

- **strength to abrasion**
- **strength to chemical corrosion**
- **high mechanical characteristics**
- **used materials : Al_20_3, Al_20_3+Zr, $Ti0_2$**

Yarn adhere to the yarn-guide during the use when the friction coefficient is too high

Previous study*:

link between the friction coefficient and the ability of the material to trap charges

→ **Importance of the ability of the material to trap charges : study of $Ti0_2$**

ACI
Thèse T. Temga

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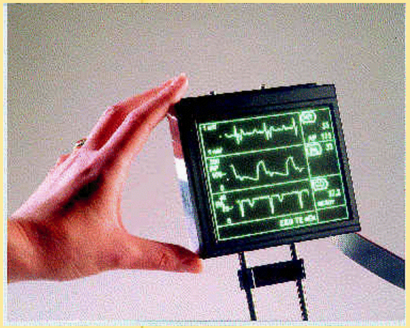
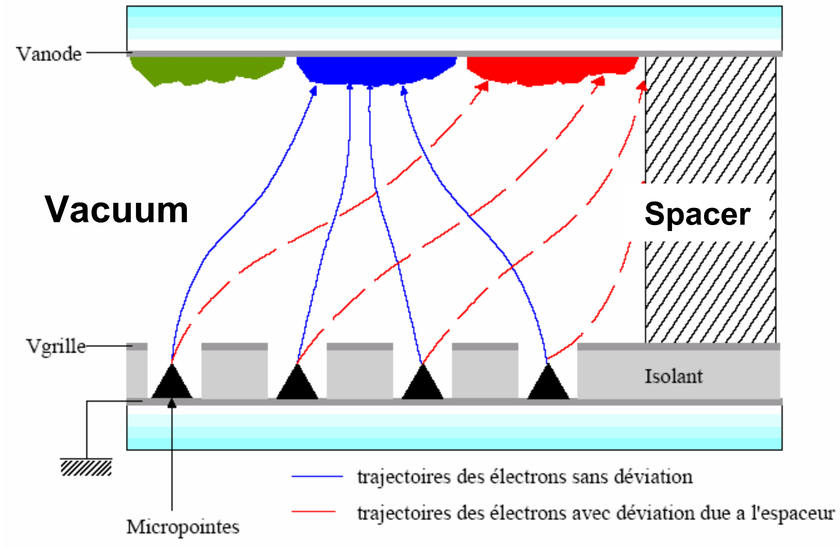
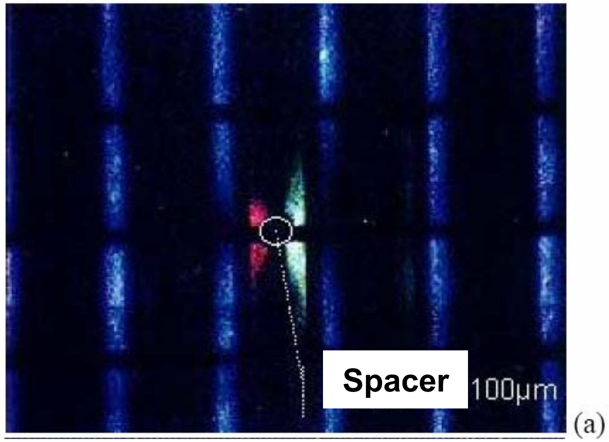
* **J Vallayer, C Guerret, D. tréheux, *Proceedings EUROMAT* 2000**

I.2. Transport and trapping of the electrical charges

FEG flat screen *







Problem of "mixing" of the colors due to the electrostatic fiels created by the charging of the spacers

Definition of "trapping insulators" and "conductive insulators"*

Characterization of the behavior of dielectrics under electronic irradiation: transport and trapping of charges...

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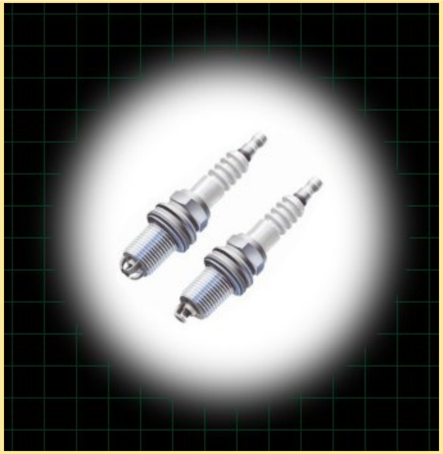
* D. Braga, Mémoire de Thèse, Université Paris XI, 2003.
* * T. Thome, D. Braga, G. Blaise, *J. Appl. Phys.*, 2004, 95 (5), 2619 .

I.2. Transport and trapping of the electrical charges

Sparking plugs



Conditions of use :

- corrosive medium
- strong variations of temperature and pressure
- high voltage
- miniaturization

⇓

Aging of the materials

Strength to dielectric breakdown in different ranges of temperature

⇓

Dielectric breakdown of the sparking plugs

Applications:

- motorbike
- automobiles
- boats
- rockets...

⇒

Transport and trapping of charges...

Links with the dielectric rigidity of insulators

Behavior under aging and temperature variations ...

Thèse X. Meyza*

Thèse M. Touzin*

* PhD thesis of Ecole des Mines de St Etienne, Direction D. Goeuriot

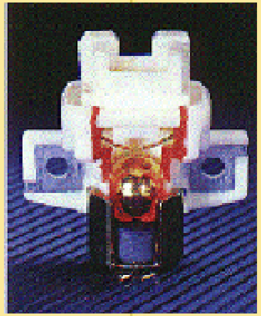
OUTLINE

II. Contribution of the electrostatic forces to the adhesion of the materials:

1. **Example of the charged metallic ball on an insulating plane**
2. **Triboelectrification between two similar materials**

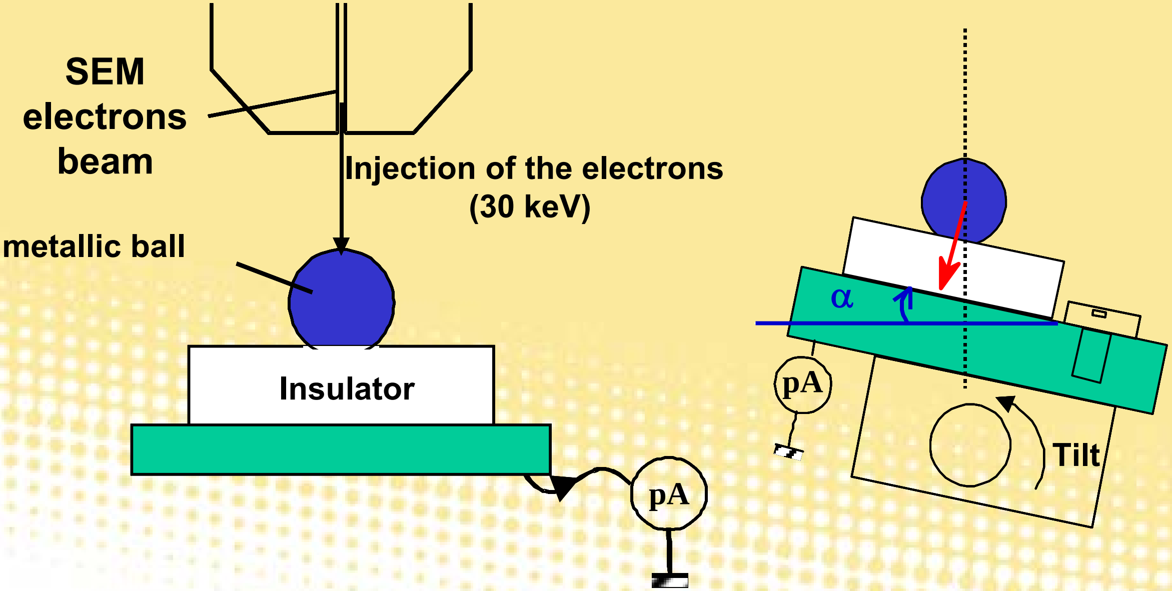
II.1. Charged metallic ball on an insulating plane

Experiences



Objectives of the study:

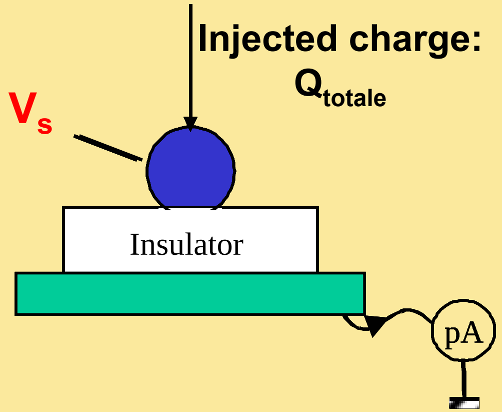
- evidencing of the strength of electrostatic forces
- "soft" injection of the electrical charges in an insulator ?

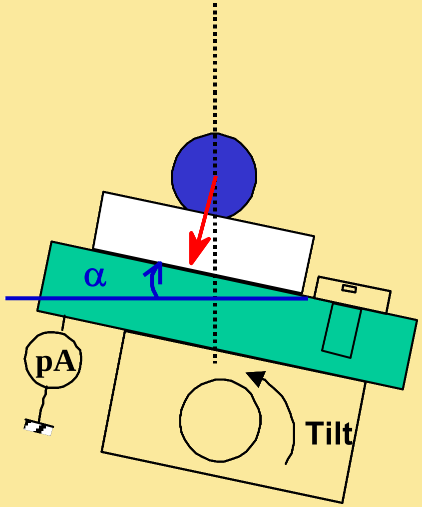


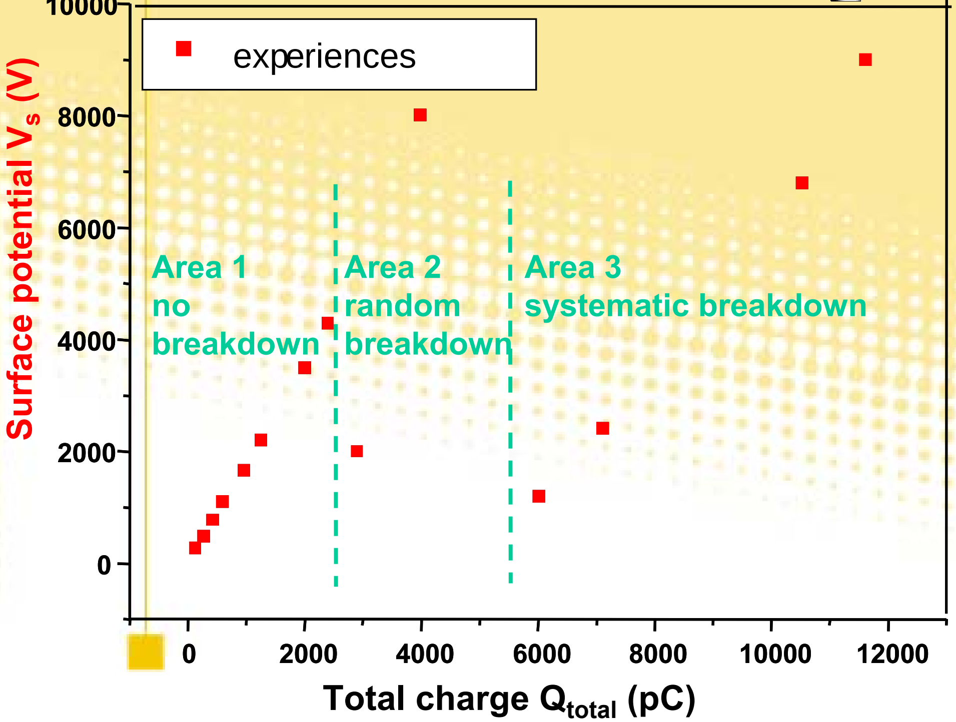
$$\sin\alpha - k\cos\alpha = \frac{k}{mg}F$$

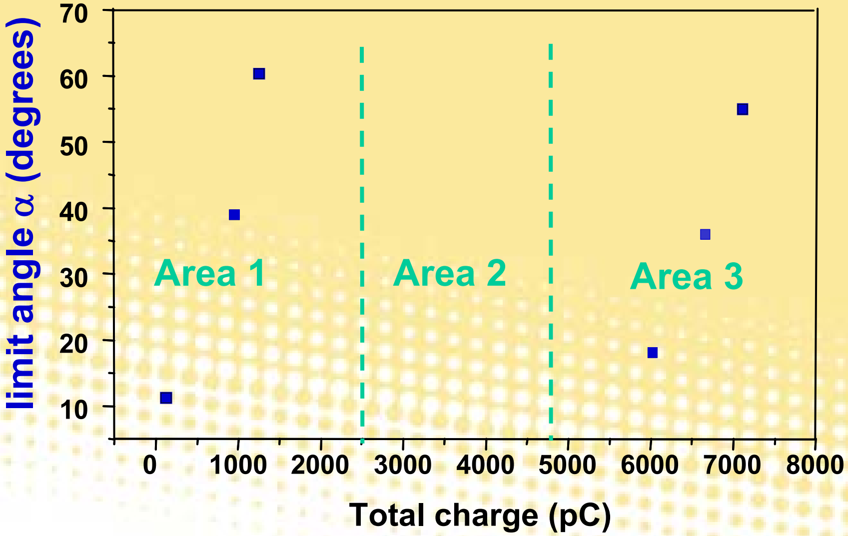
II.1. Charged metallic ball on an insulating plane

Experiences









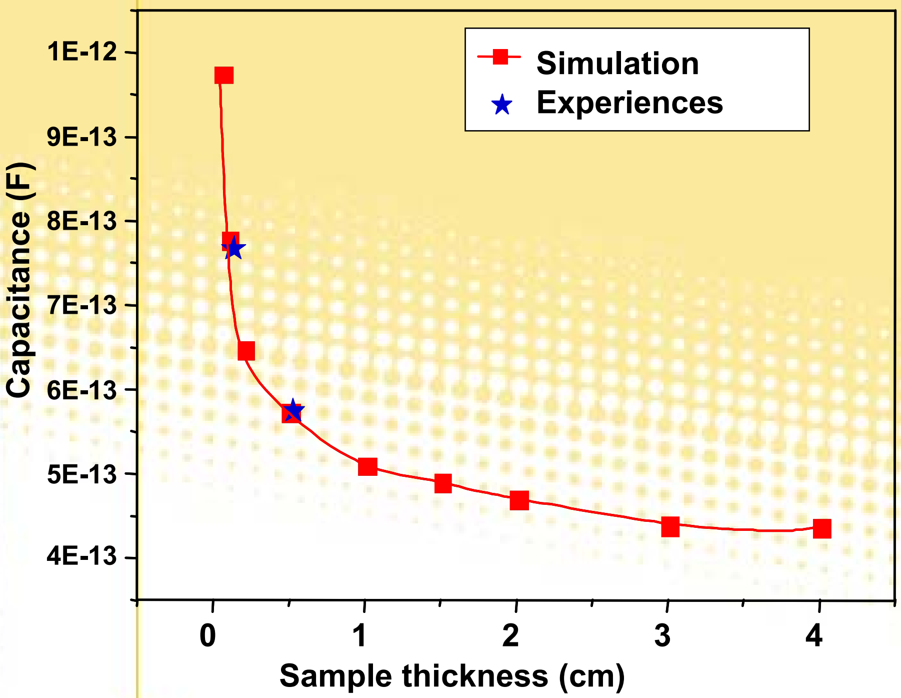
II.1. Charged metallic ball on an insulating plane

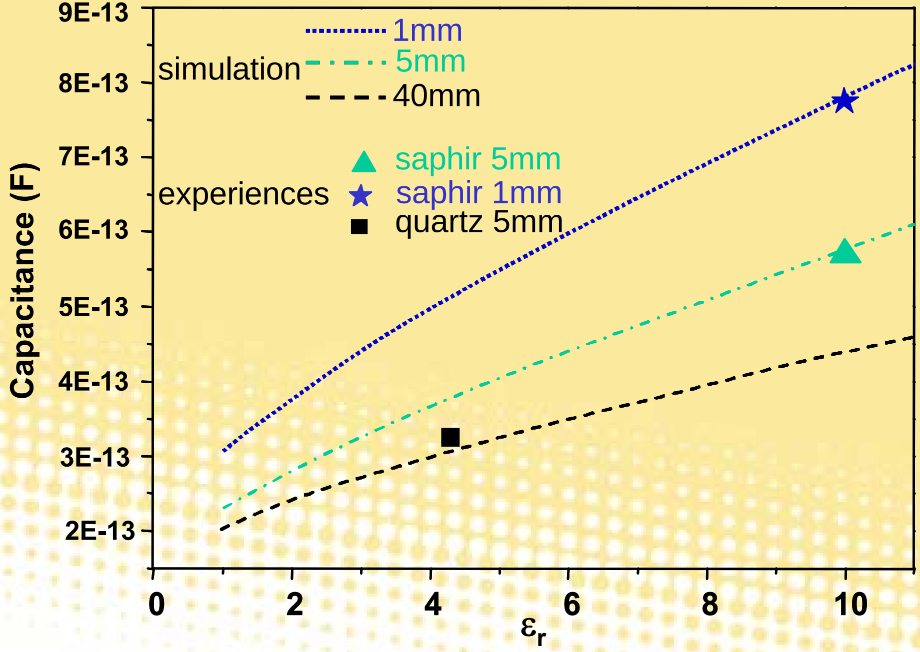
Simulations (Flux 2D)

Numerical Model* :

- axial symmetry, charge in the ball Q_i, potential V_s
- ball on an insulating disk (ε_r) thickness h (R=20mm)
- insulator on a grounded metallic plane plan

$\rightarrow$ $Q_i = C\ V_s$





Influence of the sample holder

Dominant role of ε_r

* collaboration with N Burais, CEGELY, EC Lyon

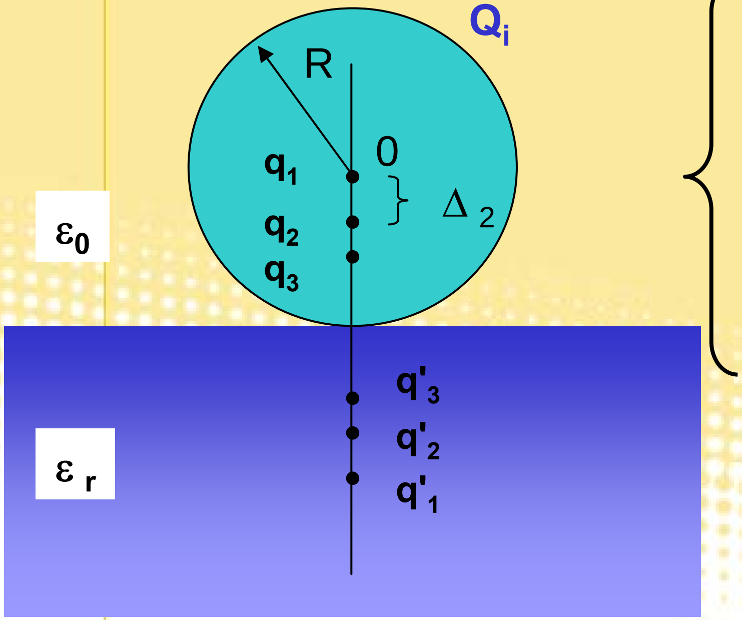
II.1. Charged metallic ball on an insulating plane

Analytical approach

Hypothesis of the calculation:

- **conducting ball holded on a semi-infinite dielectric**
- **case (a): charged sphere Q_i, non chargedplane**
- **case (b): charged sphere Q_i, charged plane Q_t**
- **Q_t ponctual charge**

Case (a) non charged plane: 2 infinite series of image charges



$$\begin{cases} q_{i+1} = A^i * q_1 * \frac{1}{i+1} \\ q'_i = -A^i * q_1 * \frac{1}{i} \\ \Delta_{i+1} = \frac{i}{i+1} R \end{cases}$$

$A=(\varepsilon_r-1)/(\varepsilon_r+1)$

due to the interface vacuum/dielectric

Δ_i = distance q_i - center O

q'_i symetric of q_i / interface

$$q_1 = \frac{-A}{\ln(1-A)} * Q_i$$

$$V_s = \sum_{i=1}^{\infty} \frac{q_i}{4\pi\varepsilon_0 * (R-\Delta_i)} = -\boxed{\frac{1}{4\pi\varepsilon_0 R} \frac{A}{\ln(1-A)}} Q_i$$

Capacitance C

$$F = \frac{1}{4\pi\varepsilon_0} \sum_i \sum_j \frac{q_i q'_j}{(2R-\Delta_i-\Delta_j)^2} = \boxed{\frac{1}{4\pi\varepsilon_0 R^2} \left(\frac{A}{\ln(1-A)}\right)^2 * Q_i^2 * K_\varepsilon}$$

$$K_\varepsilon = \sum_i \sum_j A^{(i+j)-1} \frac{ij}{(i+j)^2}$$

sapphire (ε_r=10) K_ε=4.69, quartz (ε_r=4.3) K_ε=0,91

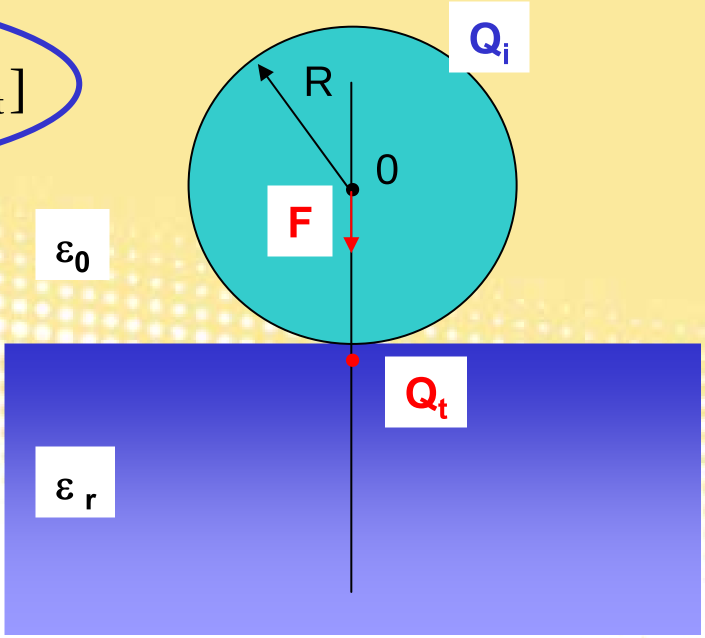
II.1. Charged metallic ball on an insulating plane

Analytical approach

Case (b) charged plane Q_t: 4 infinite series of image charges

$$V_s = \sum_{i=1}^{\infty} \frac{q_i}{4\pi\varepsilon_0 * (R - \Delta_i)} + \sum_{i=1}^{\infty} \frac{q_i^d}{4\pi\varepsilon_0 * (R - \Delta_i^d)} = -\frac{1}{4\pi\varepsilon_0 R}\left[\frac{-A}{\ln(1-A)} Q_i + \frac{2}{\varepsilon_r + 1} Q_t\right]$$

$$F = \frac{1}{4\pi\varepsilon_0 R^2}\left[\left(\frac{A}{\ln(1-A)}\right)^2 * Q_i^2 * K_\varepsilon - \frac{2}{\varepsilon_r + 1} * Q_i * Q_t\right]$$



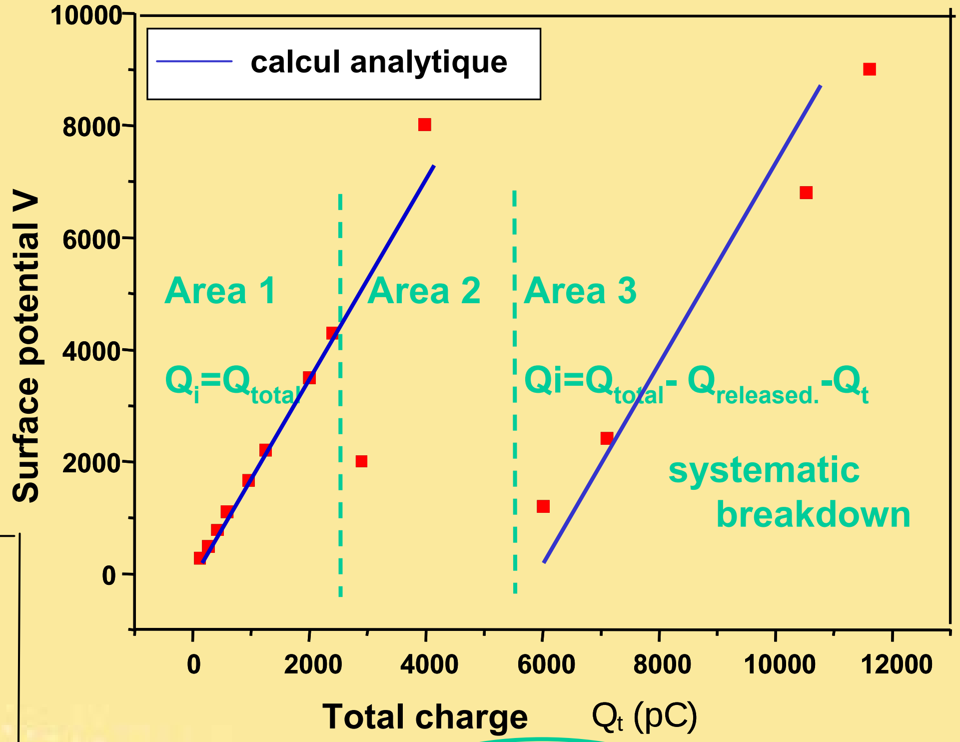
II.1. Charged metallic ball on an insulating plane

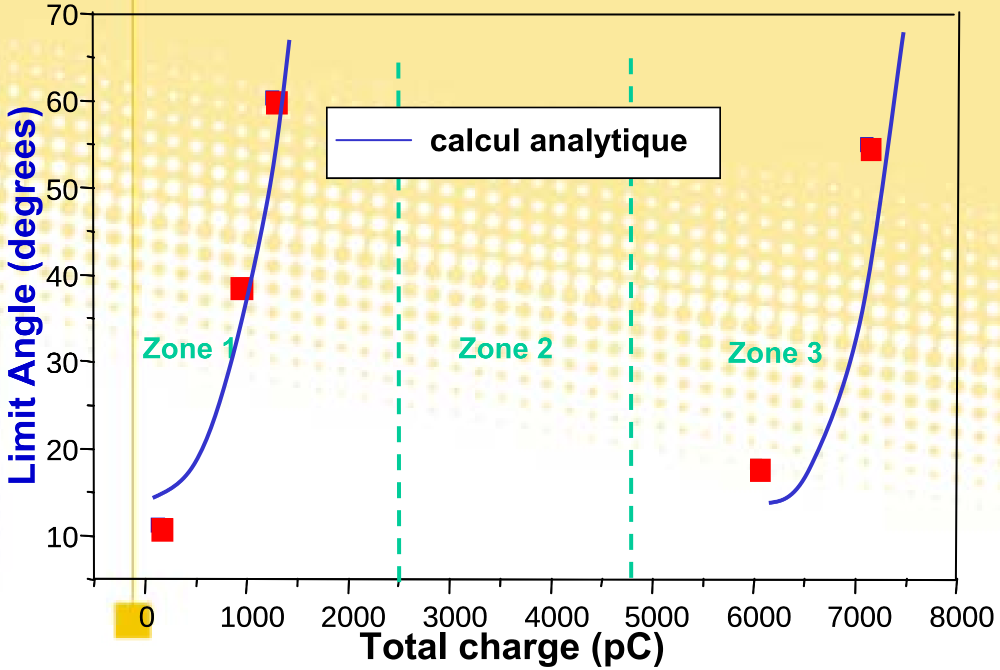
Ananlytical approach

Area 1: $Q_i=Q_{totale}$

Area 2: Random breakdown

Area 3: $Qi=Q_{total}- Q_{released}-Q_t$
Systematic breakdown
($Q_{released}$=6000pC, $Q_{injected}$=200 pC)





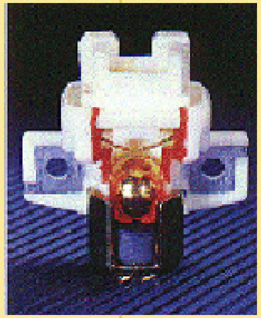
$$V_s = -\frac{1}{4\pi\varepsilon_0 R}\frac{A}{\ln(1-A)}Q_i$$

$$F = \frac{1}{4\pi\varepsilon_0 R^2}\left(\frac{A}{\ln(1-A)}\right)^2 * Q_i^2 * K_\varepsilon$$

II.1. Charged metallic ball on an insulating plane

Summm up*

Applicative results: **Adhesion of the ball is an electrostatic phenomenon**



$$F_{\text{électrost}} = \frac{1}{4\pi\varepsilon_0 R^2}\left(\frac{A}{\ln(1-A)}\right)^2 * Q_i^2 * K_\varepsilon = \boxed{\frac{\text{Cte}}{4\pi\varepsilon_0 R^2} Q_i^2}$$

sapphire ($\varepsilon_r=10$), Cte = 1,08
quartz ($\varepsilon_r=4.3$) Cte = 0,36

Choice of the dielectric: nature, thickness
Dimensions of the ball

Fundamental results:

Mechanism of the ball-plane interaction under electronic injection: 3 steps

1- Small quantities of charges injected in the ball: all the charges stay in the sphere

2- Breakdown of the surrounding medium , Release of the charges present in the ball.

3- Systematic breakdown coupled with partial injection in the insulating plane and followed by a recovery of the injection in the ball

Remarks: **- stable volume trapping**
- unusable for a "soft" injection

* C. Guerret, D. Juvé, D. Tréheux, N. Burais *Journal of Applied Physics* , Vol 92 (12), p 7425, 2002

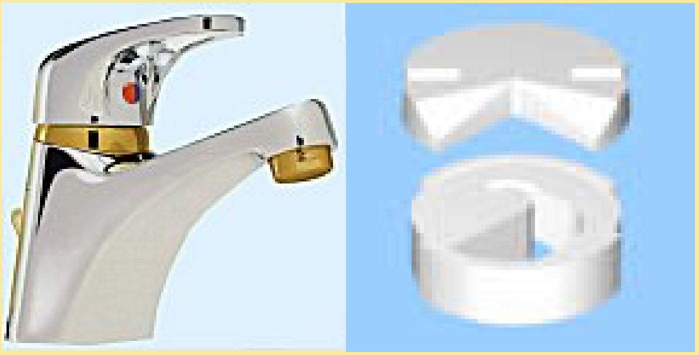
OUTLINE

II. Contribution of the electrostatic forces to the adhesion of the materials:

1. **Example of the charged metallic ball on an insulating plane**
2. **Triboelectrification between two similar materials**

II.2. Triboelectrification between two similar materials

Position of the problem *



- **Triboelectrification between 2 different materials: well-known mechanism in the case of two metals , no clear mechanism as soon as one of the material is an insulator**

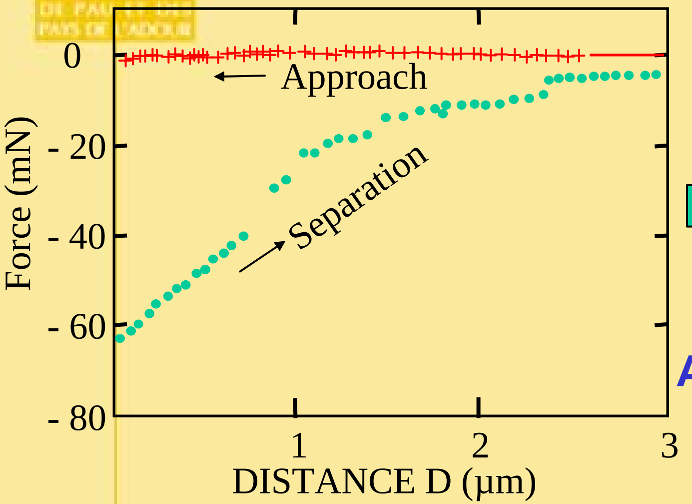
- **Triboelectrification between 2 similar materials: not understood, not evidenced at the microscopic scale**

- **Numerous studies, due to recent development of the apparatus (SFA, AFM, EFM)**

*** C. Guerret, S. Bec, D. Tréheux, C.-R. de l'Académie des Sciences. Paris, t2, Série IV, p. 1-14 2001**

II.2. Triboelectrification between two similar materials

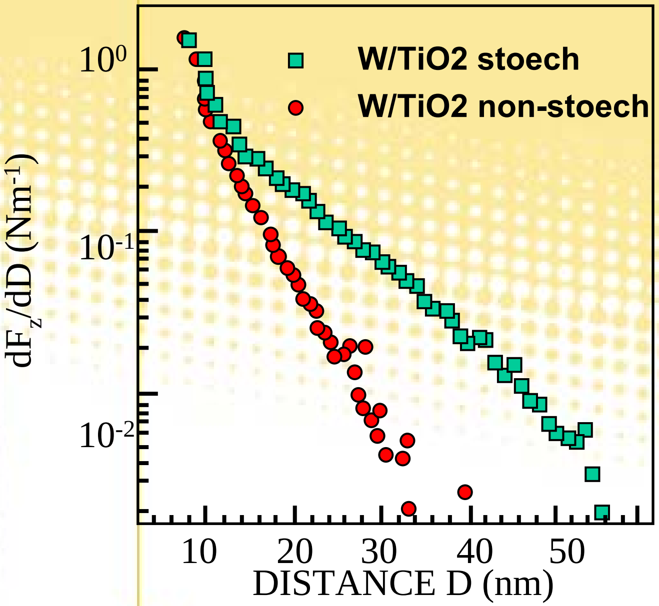
Results of the literature



Suface Force Apparatus : Mica/Silica, in dried N_2

Horn R.G. and Smith D.T *Science* 256, (1992)

- ➢ **attraction at long distance (>3 µm)**
- ➢ **density of the electrical charges: 10 mC/m²**



AFM: Tungstene/ TiO2 stoech. or non/stoech, Ultravacuum

Sounilhac S., Barthel E., Creuzet F. , *J. Appl. Phys.*, 85 (1) (1999)

- ➢ **<15nm : van der Waals forces are dominant**
- ➢ **>15nm: Electrostatic forces for TiO_2 stoech**
- ➢ **density of the electrical charges : 10^{-3} mC/m²**

AFM: Stability of charges in thin layer of $Al_2 0_3$.

N. Felidj, J. Lambert, C. Guthmann, M. Saint Jean *Eur. Phys. J. A. P.* 12 (2000)
J. Lambert, C. Guthmann, M. Saint Jean *J. Appl. Phys.*, 93 (9) (2003)

- ➢ **deposit of charges on the oxyde surfaces, by application of a potential or by friction**
- ➢ **density of the electrical charges : 10^{-5} mC/m²**

II.2. Triboelectrification between two similar materials

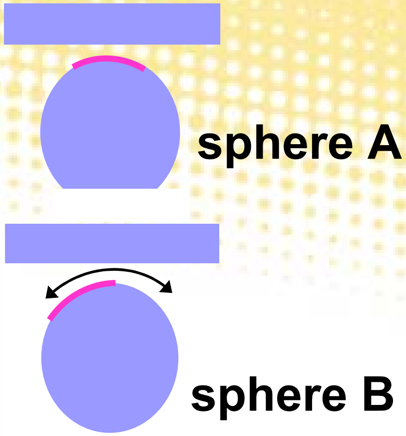
Adhesion between two similar insulating surfaces*

OBJECTIVE :

- Evidencing of the triboelectrification between two **similar materials**
- Characterization of the contribution of the **resulting electrostatic force** on the **adhesion**

EXPERIENCE :

- **Surface Force Apparatus of Ecole Centrale de Lyon (SFA)**
- **2 antagonists in monocrystalline alumina (sapphire)**



Sphere-plane contact (R=3mm)

sphere A : **very smooth area of contact** (R_m=qq nm)

sphere B : **presence of asperities in the contact area**

*** Action Concertée Incitative, " Tribosurfélec" , collaboration IFoS- LTDS**

**** C. GUERRET-PIECOURT, J. VALLAYER, D. TREHEUX Wear, Vol 254, p 950-958, 2003**

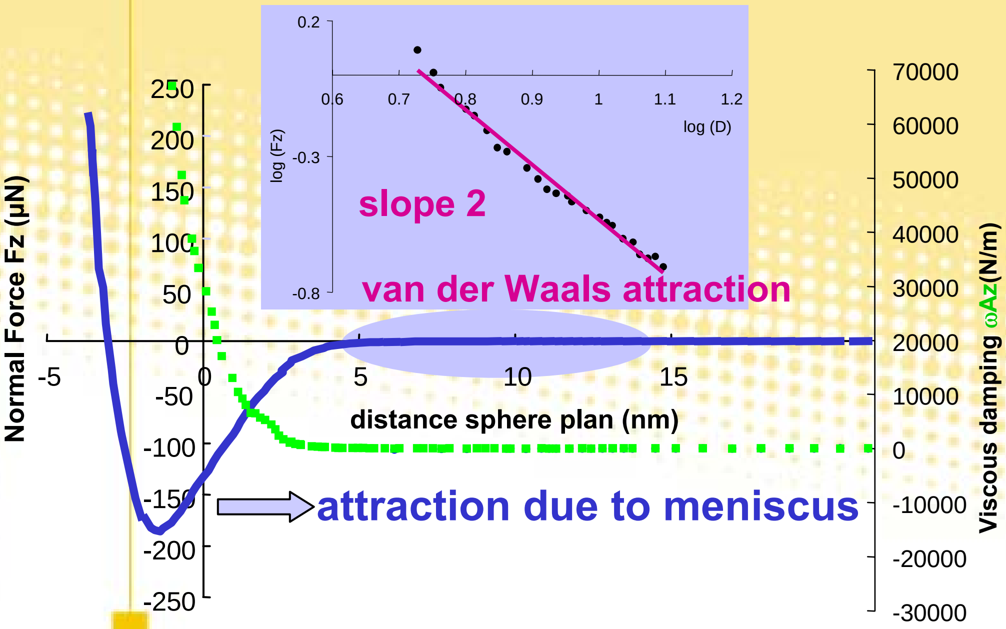
II.2. Triboelectrification between two similar materials

Case of the smooth sphere A

- **Before friction:** - attraction due to van der Waals forces $$\frac{F_z}{R} = \frac{-A}{6D^2}$$

  - apparition of a viscous damping due to the formation of a water meniscus ⇨ vacuum non suffisant to remove the remaining water

- ***After friction*** : - apparition of a long distance force, electrostatic charges

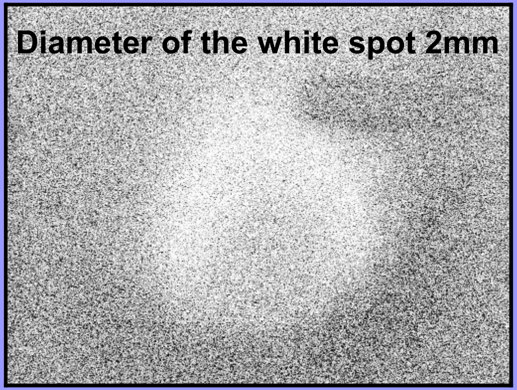


slope 2

van der Waals attraction

⇨ attraction due to meniscus

Before friction



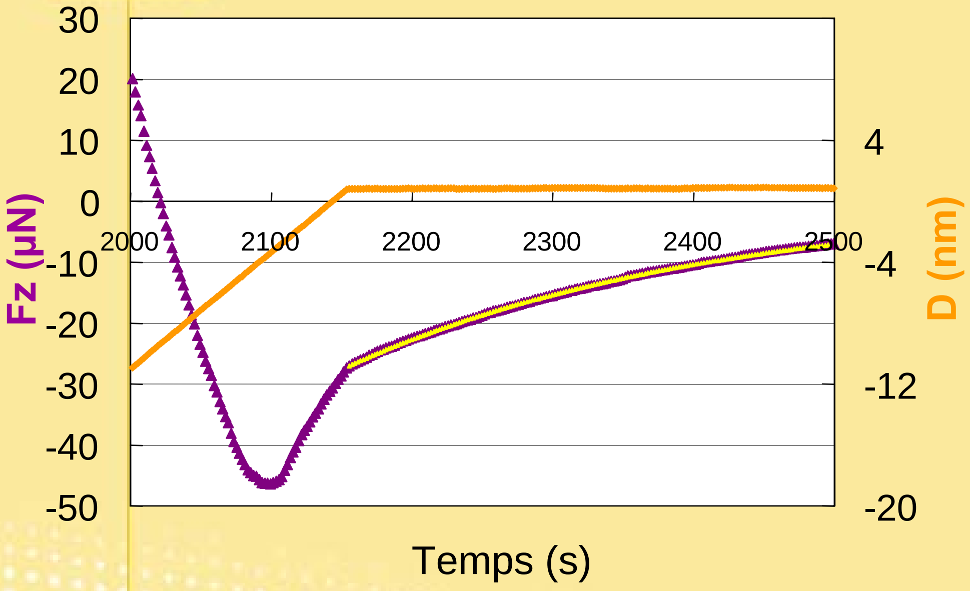
SEM Observation

Negatives charges

After friction

II.2. Triboelectrification between two similar materials

Case of the sphere B : attraction after friction

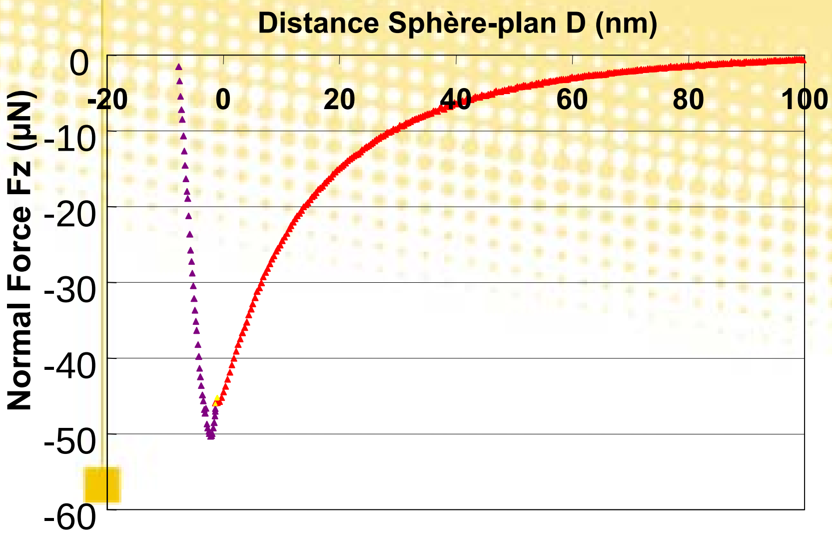


Stop of the unloading, at imposed distance :

attraction decreases with time

$$F_z = F_o \exp\left(-\frac{(t - t_o)}{\tau}\right)$$

$$\tau = 256 \text{ s}$$



Specific way to measure the force during a small time of unloading (some s) :

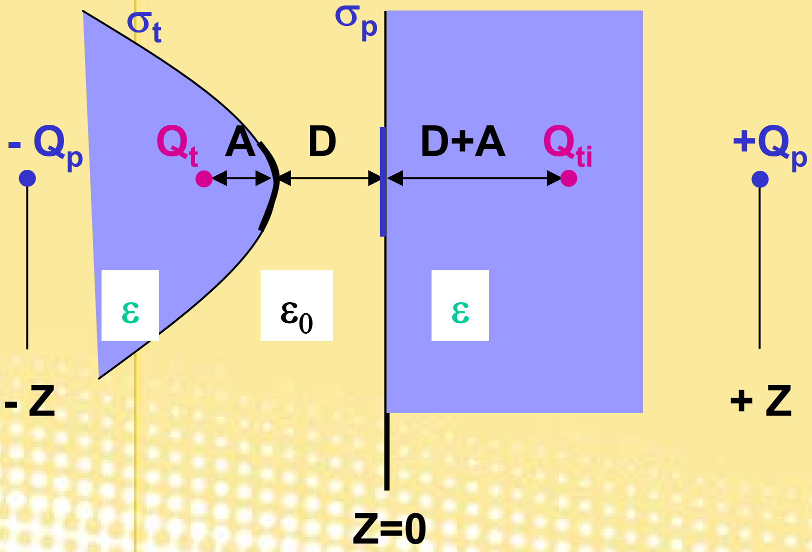
attraction decreases with distance

II.2. Triboelectrification between two similar materials

Attraction after friction : Model of Burnham & al

Model of Burnham, Colton et Pollock (BCP)

Burnham N.A., Colton R.J., Pollock H.M., *Phys. Rev. Lett*. vol 69, n°1 (1992)



1st term:

- **due to the vacuum/dielectric interface**
- **always attractive**

2nd term:

- **depends on the signs of Q_t and Q_p**
- **even if Q_t and Q_p have the same sign, at low distance the first term dominates**

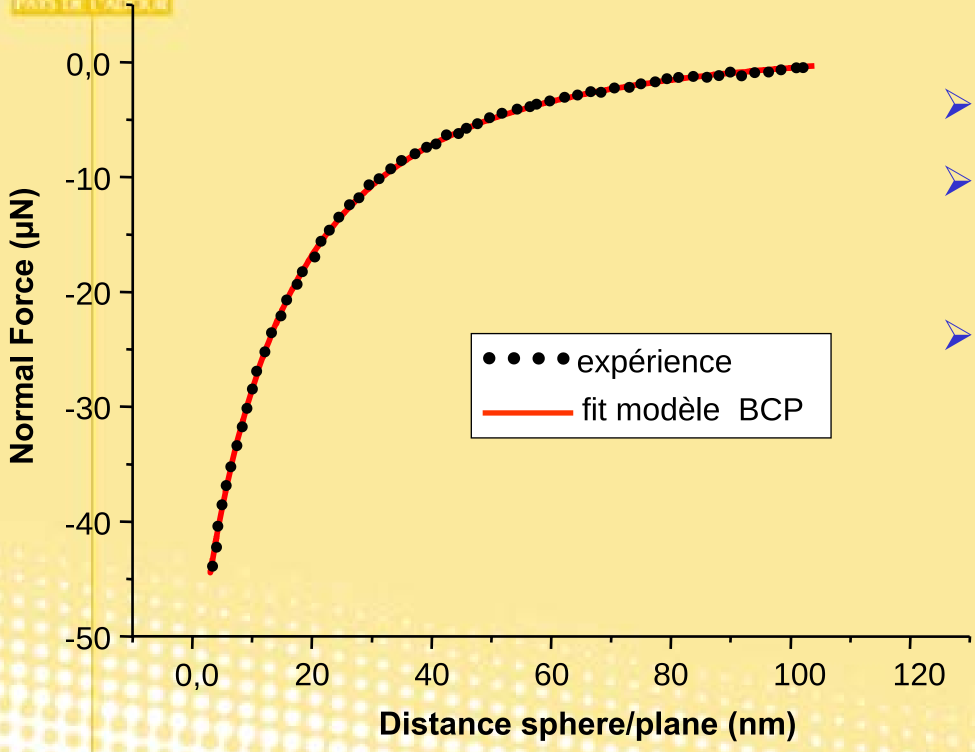
In our case :

$$4\pi\varepsilon_0 F = -\frac{Q_t^2}{4(D+A)^2}\left(\frac{\varepsilon-1}{\varepsilon+1}\right) + \frac{RQ_tQ_p}{z(2D+A+R)^2}\left(\frac{\varepsilon-1}{\varepsilon+1}\right)^2$$

ε =10 for Al_2O_3

II.2. Triboelectrification between two similar materials

Attraction after friction : Model of Burnham & al



- **Sapphire-sapphire friction**
- **Best fit between 0 and 100 nm :**
  - **Charges of the même signe**
- **Parameters of the fit :**
  - **Q_t= 4,76 10 $^{-15}$ C, => σ_t=9,2 10^{-2} mC/m^2**
  - **A=26nm**
  - **Q_p/Z=2,2 10^{-7}C/m**

For comparison :

- **Burnham et al : diamond/graphite**
  - **Q_t= 2 10 $^{-16}$ C, => σ_t=4 10^{-5}e/Å^2**
  - **A=10 nm,**
  - **Q_p/Z=4 10^{-8}C/m=> σ_p=8 10^{-7}e/Å^2**
- **Sounilhac et al : tungstene/TiO_2**
  - **Q_t=0,54 10^{-15}C**
  - **A=68nm**
  - **charges of the same sign**

II.2. Triboelectrification between two similar materials

Modification of the adhesion due to triboelectrification*

Sum up

(1) Instantaneous measurement, Force at low distance (0-100nm) :

- **Adhesion is modified by the presence of an electrostatic force,**
- **Quantification of the charges (BCP model)**
- **Charges are mobiles on the surface: t= 256s,**
- **Comparable time with diffusion's times found in the literature on wet alumina surfaces or on polluted one's $\tau \approx 200$s .**

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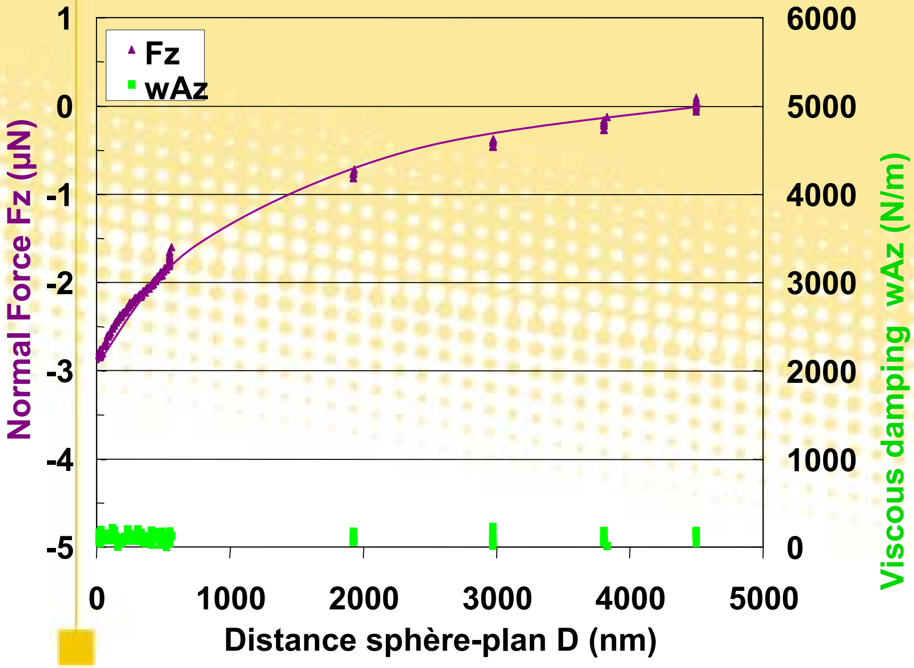
* C. GUERRET-PIECOURT, S. BEC, F. SEGAULT, D. JUVÉ, D. TRÉHEUX, A. TONCK Eur. Phys. Jour. AP, Vol 28 (1) 2004

Modification of the adhesion due to triboelectrification*

(2) Long time, Force at long distance (1- 5µm):

- **attraction at long distance in the friction area**
- **observed on the two types of sphere (smooth or with asperities)**
- **mesurable several days after the friction test**
- **charge observed with a SEM**



* C. GUERRET-PIECOURT, S. BEC, F. SEGAULT, D. JUVÉ, D. TRÉHEUX, A. TONCK Eur. Phys. Jour. AP, Vol 28 (1) 2004

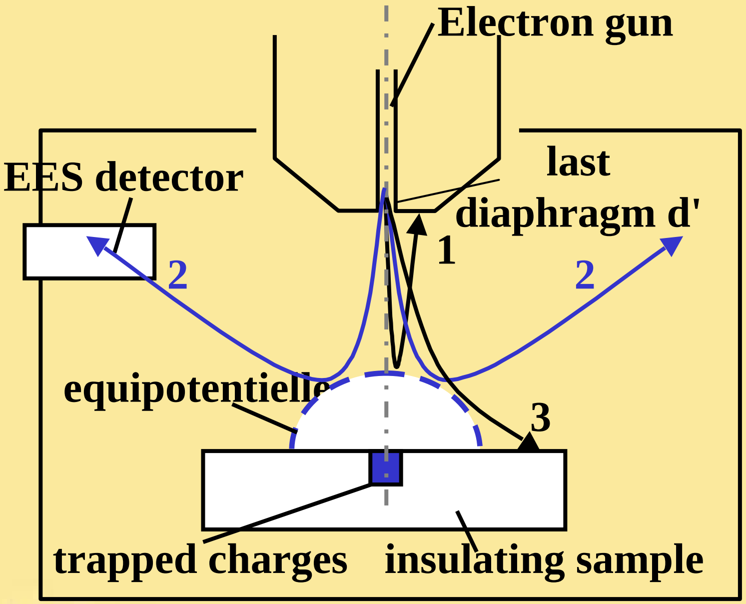
OUTLINE

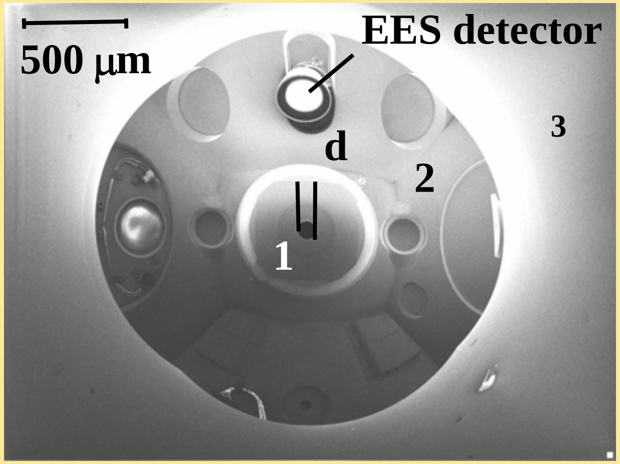
III. **Characterization of the properties of charges flow and of charges trapping : SEMM method and simulations**

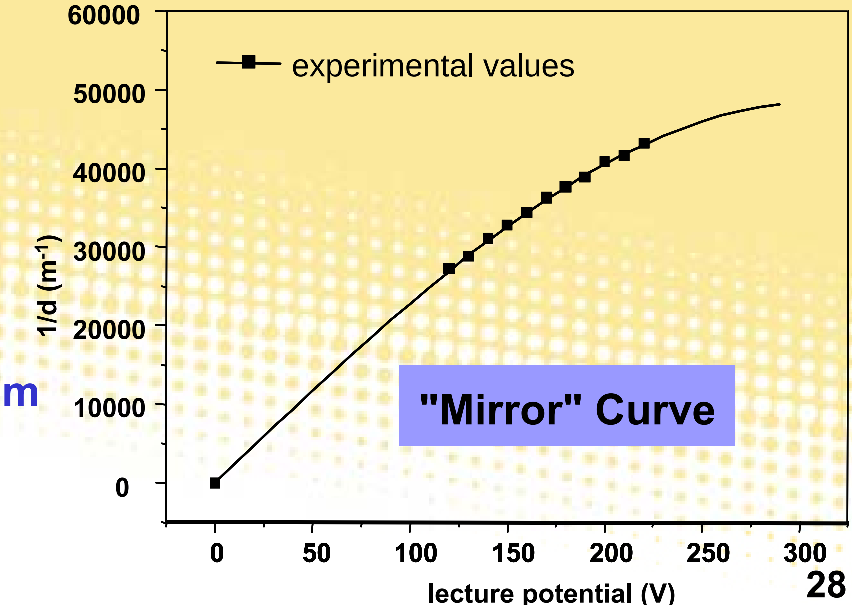
1. **"Miror" method and influence current**
2. **Simulation of the injection of electrons**

III.1. Mirror method and influence current

Mirror method (SEMM)







"Mirror" Curve

2 Steps:

- **injection of high energy electrons (10-30 keV)**

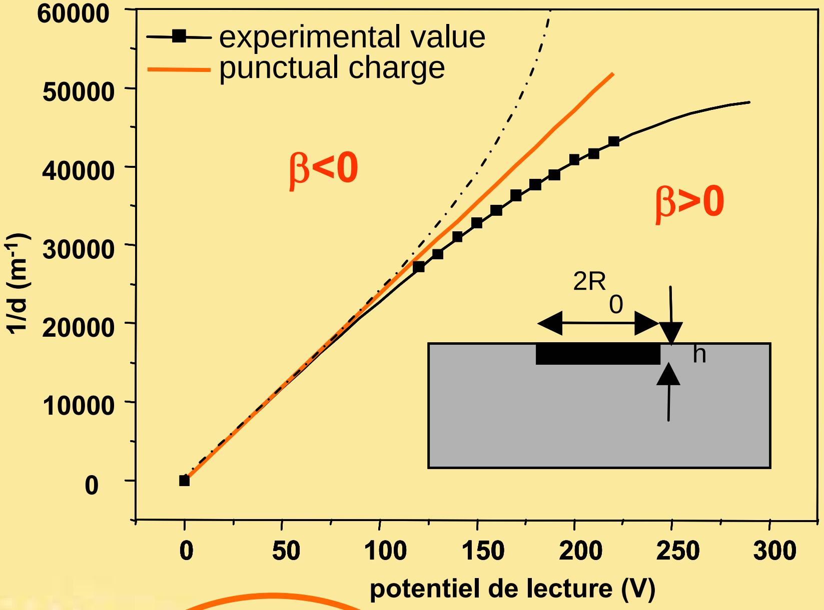
  ⇨ **trapping of charges in the insulator**

- **lecture by a low energy beam (300-1keV)**

  ⇨ **deviation of the electron of the lecture beam**

III.1. Mirror method and influence current

Mirror method (SEMM)



Approximation of a punctual charge

$$\frac{1}{d}=\boxed{\left(\frac{4\cdot L}{d'}\cdot\frac{1}{A_\infty Q_p}\right)}\cdot V_i \qquad A_\infty=\frac{1}{2\pi\varepsilon_0(\varepsilon_r+1)}$$

Evaluation of the quantity of trapped charges

Multipolar development (isotropic material)*

$$\frac{1}{d}=K\left\{\frac{V}{AQ_p}-\boxed{2\beta R_0^2}\left(\frac{V}{AQ_p}\right)^3\right\}$$

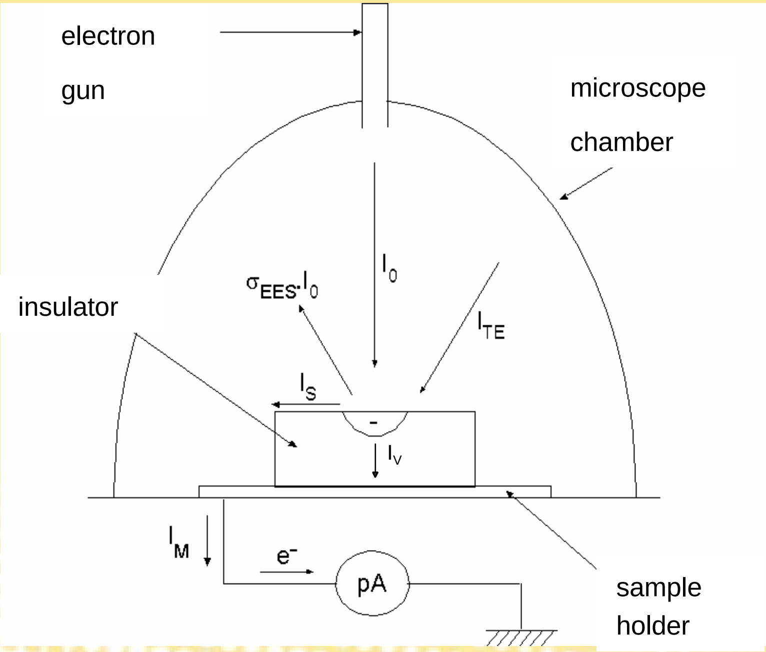
Form of the charges distribution :
β>0 : charges on the surface
β<0 : charges in the depth

---

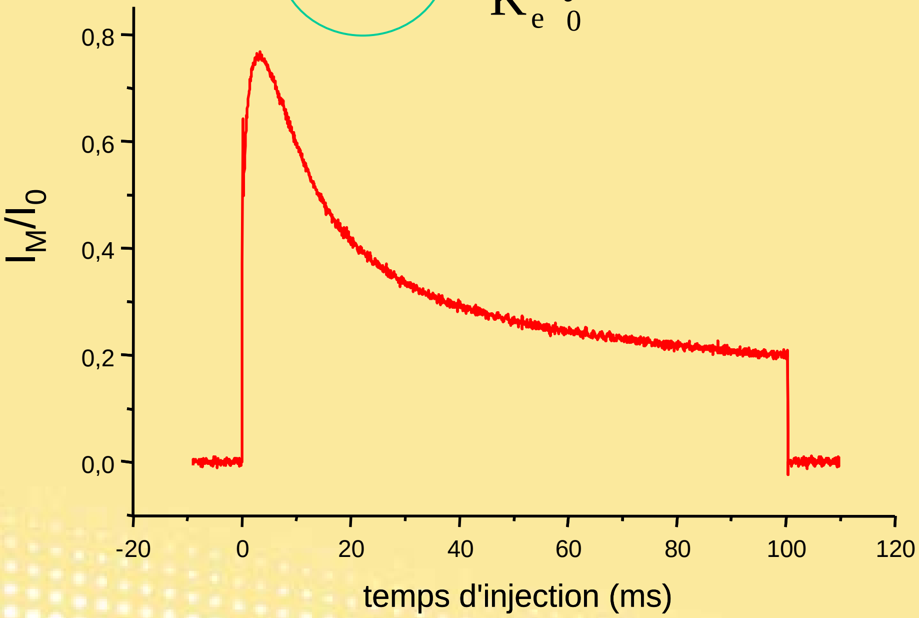
*Attard C., et al Proceeding of the 2nd Conference on Electrostatics, Montpellier July 10-11, 2000: p. 77.

III.1. Mirror method and influence current

Method of the influence current (ICM)



$$\boxed{Q_M(t)} = \frac{1}{K_e}\int_0^t I_M(t)\cdot dt$$

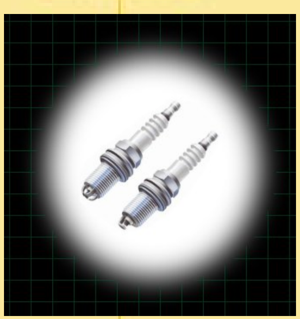


charges injected in the material ⇒ **influence charges on the sample holder**

$$I_M = (1-\sigma_{EES})\cdot I_0 + I_S + I_V + I_{TE}$$

III.1. Mirror method and influence current

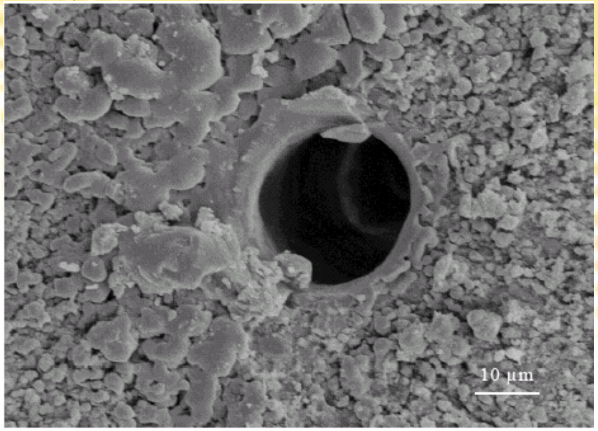
Characterization of polycrystalline alumina samples*

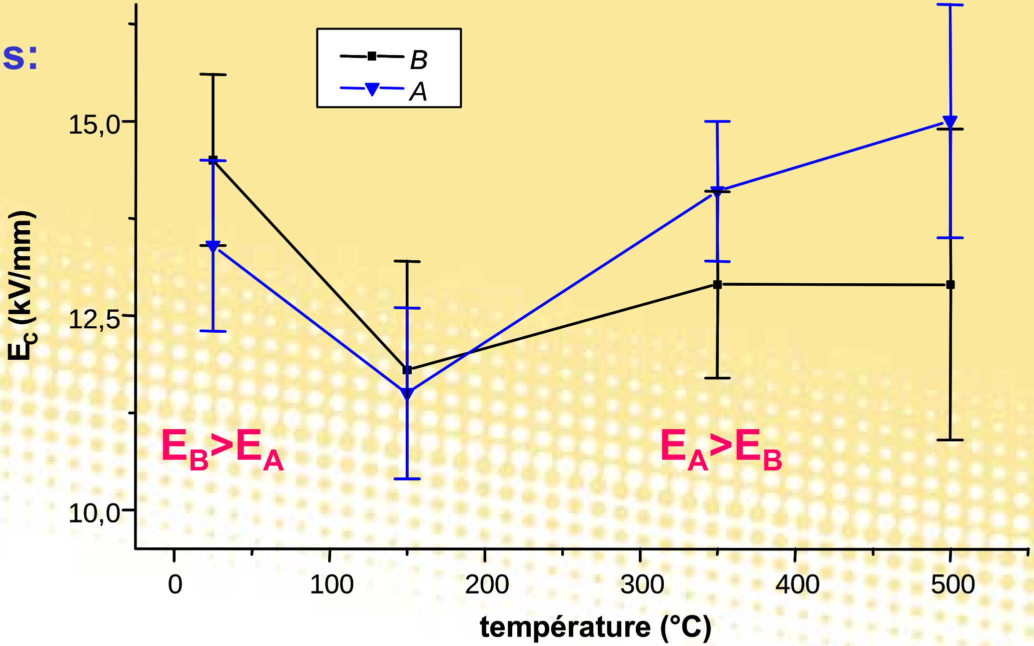


- alumina powder + various sintering aids
- sintering in liquid phase
- example of 2 materials A and B
- ajouts de frittage différents ⇨ joints de grains différents

Material	Vitrous Phase (%)
A : Industrial	15,9
B : Laboratory	4,6

Characterization of the dielectric stifness:





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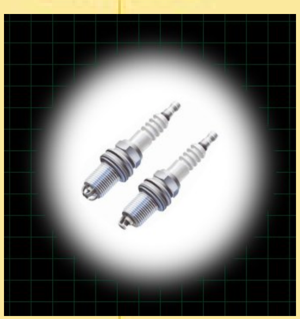
* X. Meyza, Mémoire de Thèse , D. Goeuriot, X. Meyza, M. Touzin, C.Guerret-Piécourt, D. Juvé, D. Tréheux, H.-J. Fitting *Journal of the European Ceramics Society*, (sous presse), Thèse en cours de M. Touzin, St Etienne

III.1. Mirror method and influence current

Characterization of polycrystalline alumina samples*

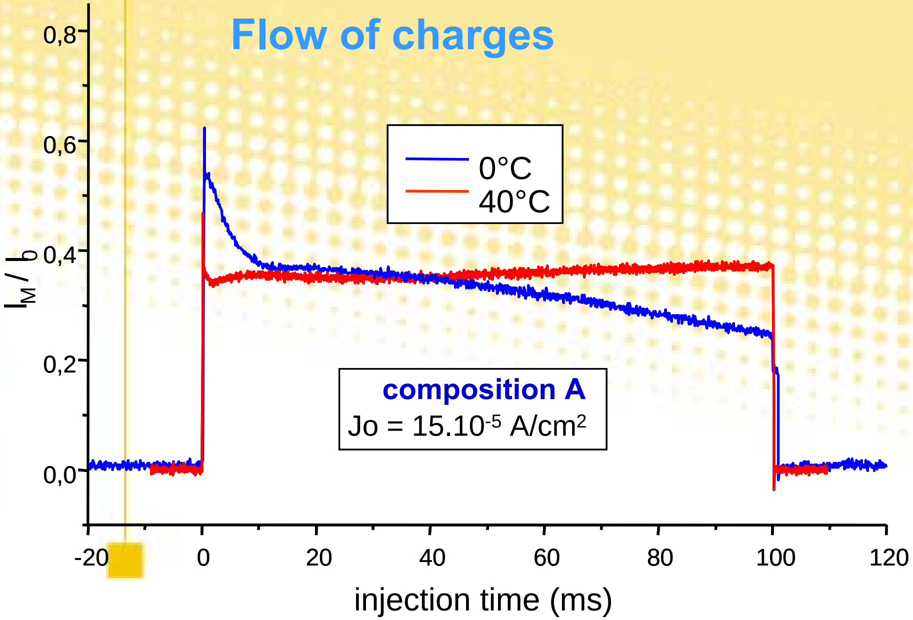


Trapped charge (SEMM)

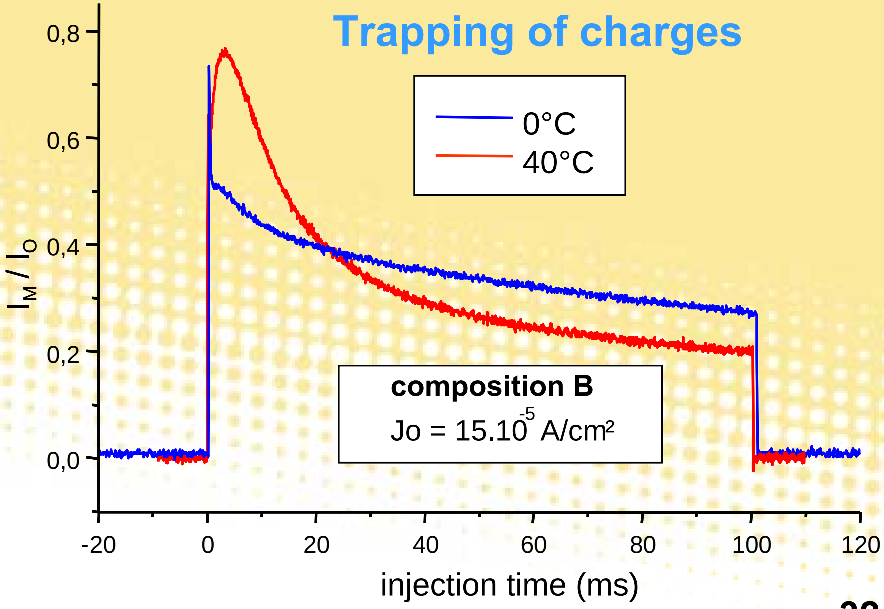
Stabilization Ratio

Injected Charge (ICM)

Matériau Industriel (A)	**0°C**	**40°C**
Q_P (pC)	**94**	**0**
Q_M (pC)	**98**	**108**
R = Q_P / Q_M	**96 %**	**0**
Matériau Laboratoire (B)		
Q_P (pC)	**94,5**	**12,2**
Q_M (pC)	**105**	**102**
R (%) = Q_P / Q_M	**90 %**	**12 %**



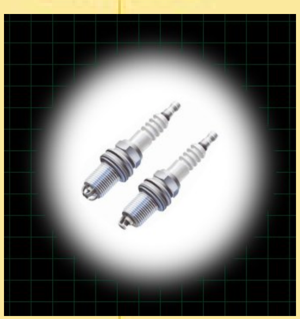
Flow of charges



Trapping of charges

III.1. Mirror method and influence current

Characterization of polycrystalline alumina samples*



Effects of the microstructure on the flow and on the trapping of the charges: favorable cases to optimize the dielectric stiffness

At low temperature:

- crystallized secondary phase (material B): deep traps

"Trapping" insulator

At high température:

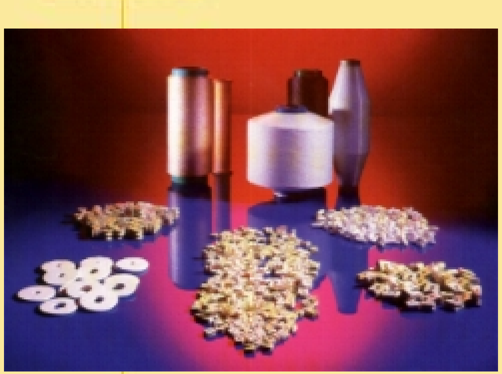
- vitrous secondary phase (material A): traps of weak deepness, favorable to the flow of charges

- weak number of grain joints

"Conductive" Insulator

III.1. Mirror method and influence current

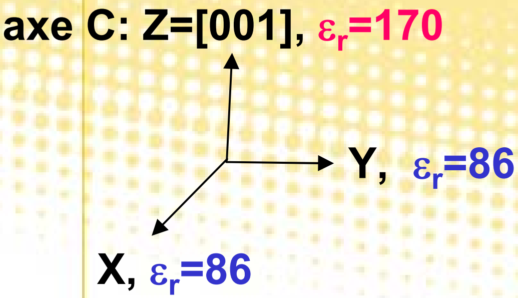
Characterization of a SC with high forbidden gap: TiO_2 rutile*



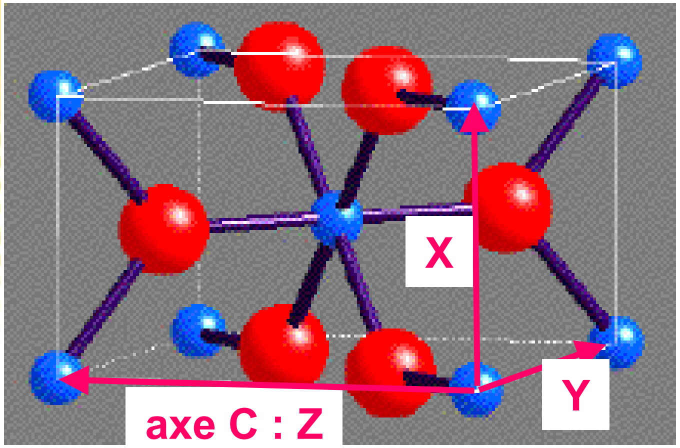
Characteristics of Ti02 rutile:

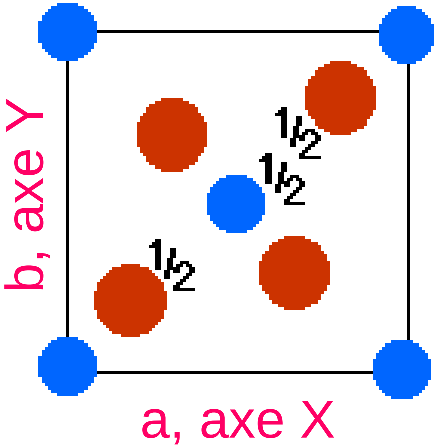
- **SC with high forbidden gap: 3,1 eV**
- **resistivity R> 10^{13} Ωcm (sensibility to oxygen)**
- **anisotropy of the permittivity : ε_r=86 at T_{room} in the X,Y plane**
  axe C: ε_r=170 at T_{room} along Z= [001]

Structure of Ti02 rutile



Unit Cell : Tetragonal (a=b, c)

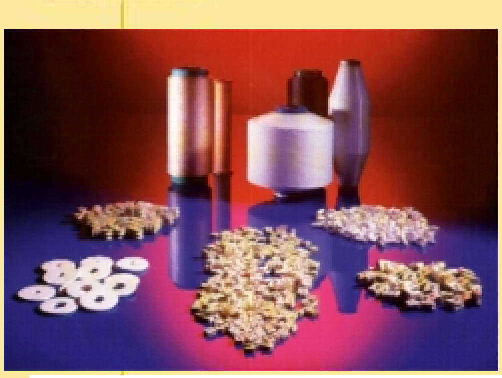




* Temga Temga, Mémoire de Thèse , Lyon, 2004

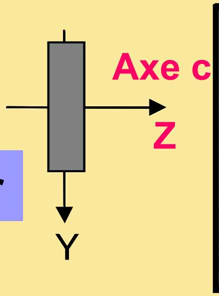
III.1. Mirror method and influence current

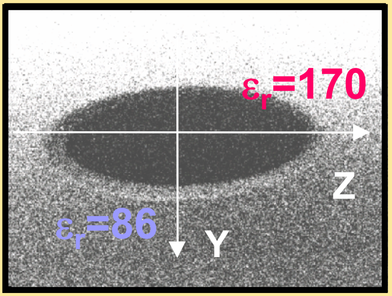
Characterization of a SC with high forbidden gap: TiO_2 rutile*



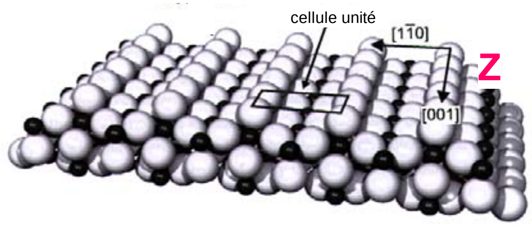
Injection along the axe X= [110]

Anisotropy of the obtained mirror





Trapping of the electrons near the Ti ions

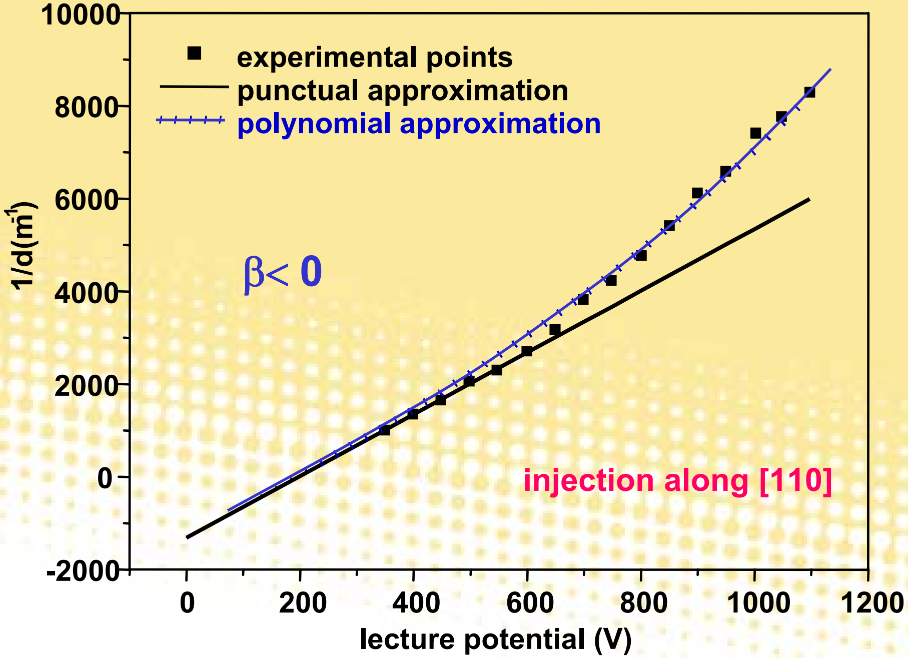


(c)

Deep trapping :

$$\frac{1}{d} = K\left\{ \frac{V}{AQ_p} - 2\beta R_0^2 \left(\frac{V}{AQ_p} \right)^3 \right\}$$

Cylindrical Distribution radius R=2µm
and deepness h=280 µm



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* T. TEMGA, D. JUVE, D. TREHEUX, C. GUERRET-PIECOURT and C. JARDIN soumis à J. Appl. Phys.

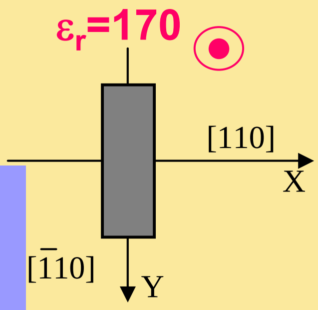
III.1. Mirror method and influence current

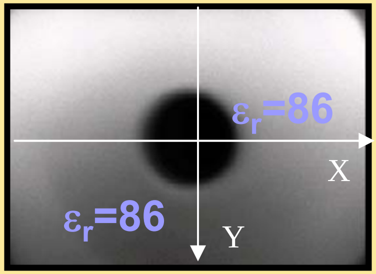
Characterization of a SC with high forbidden gap: TiO$_2$ rutile*

Injection along axe Z= [001]

circular mirror, analytical model taking into account the anisotropy of ε_r*

$$\xcancel{\frac{1}{d}=\left(\frac{4\cdot L}{d'}\cdot\frac{2\pi\varepsilon_0(\varepsilon_r+1)}{Q_p}\right)\cdot V_i}$$



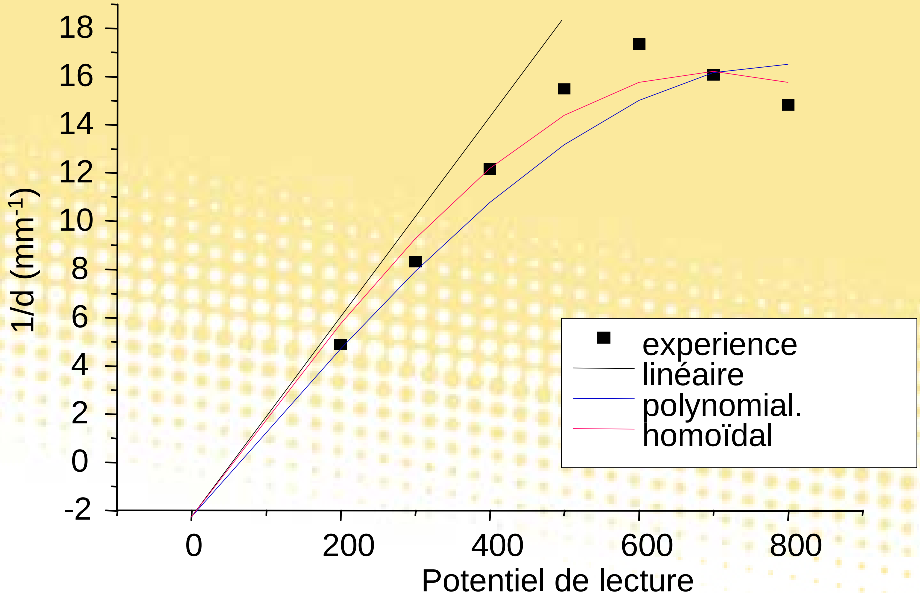


Transversal Isotropic Material: punctual charge

$$\frac{1}{d}=\left(\frac{4\cdot L}{d'}\cdot\frac{2\pi\varepsilon_0(\boxed{\sqrt{\varepsilon_X}\sqrt{\varepsilon_Z}}+1)}{Q_p}\right)\cdot V_i$$

Transversal Isotropic Material: homoïdal distribution

$$\frac{2c}{d}=\frac{4H}{\phi}\left\{\begin{matrix}\sin\\ \mathrm{sh}\end{matrix}\right\}\left(\frac{2c.8\pi\varepsilon_0 E_{cin}}{Q}\right)$$



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* developed by G DAMAMME, PHDthesis T TEMGA, publication in preparation

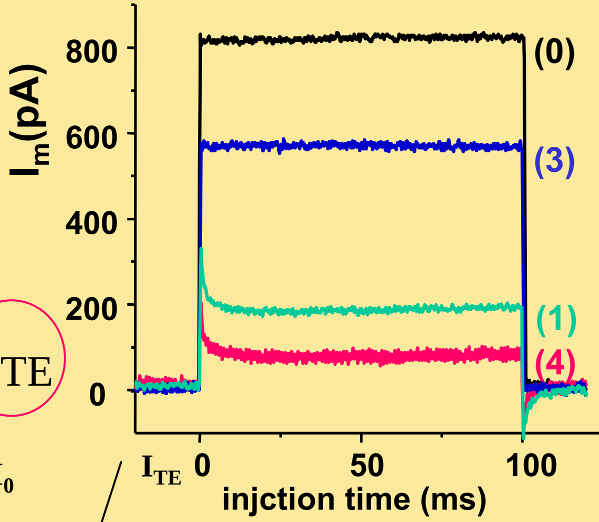
III.1. Mirror method and influence current

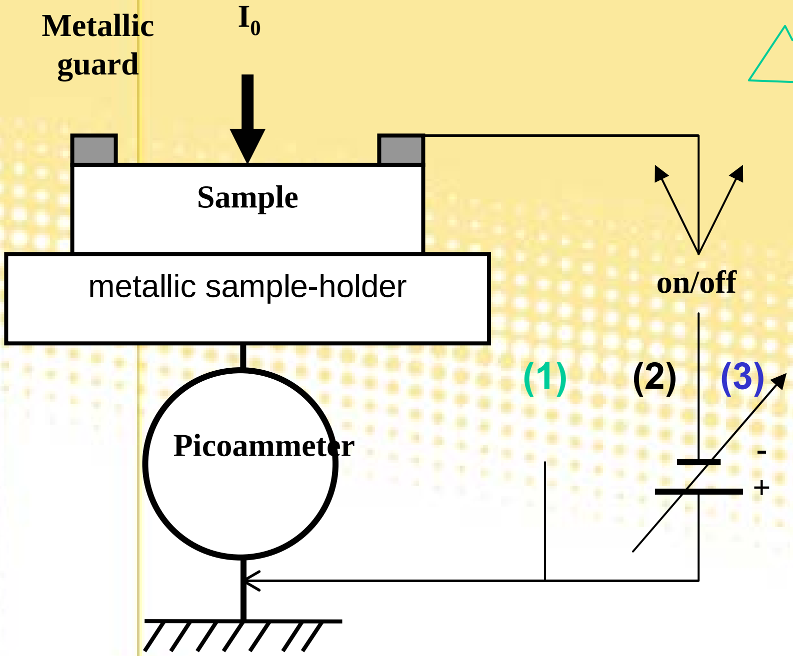
Characterization of a SC with high forbidden gap: TiO_2 rutile*

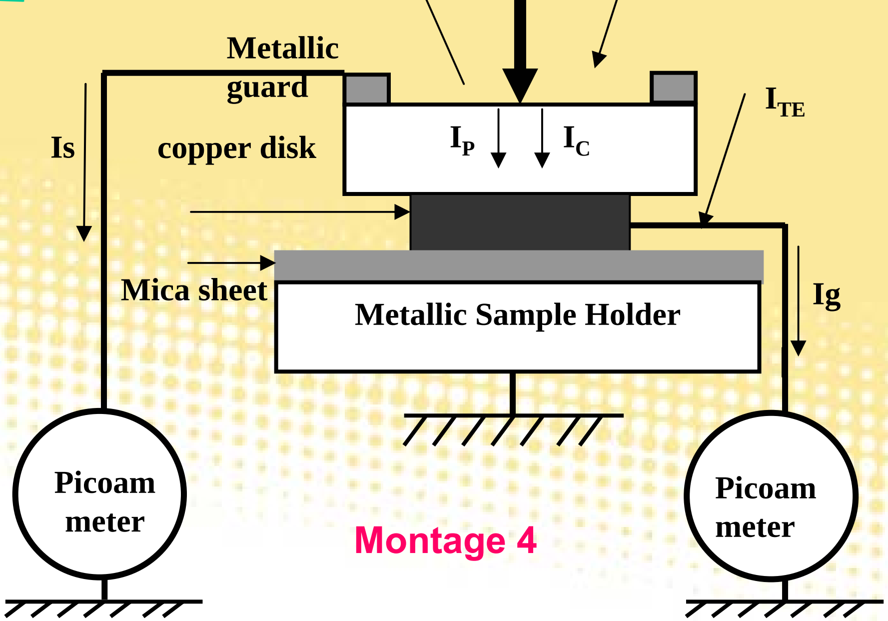
Importance of leakage current

Modification of the ICM method*

$$I_M = (1-\sigma_{EES})\cdot I_0 + I_S + I_V + I_{TE}$$







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* T. Temga, C. Guerret-Piécourt, D. Juvé, D. Trégeux, C. Jardin, (2003) An. Rep. CEIDP, Albuquerque, p 221-224

** proposition HJ Fitting,

OUTLINE

III. **Characterization of the properties of charges flow and of charges trapping : SEMM method and simulations**

1. **"Miror" method and influence current**
2. **Simulation of the injection of electrons**

III.2. Simulation of the injection of electrons*

Self-consistent model

Injection of high energetic electrons in an insulator:**

- **backscattered electrons η**
- **penetration in the bulk PE**
- **generation of e-h pairs (secondary e)**
- **secondary emission**
- **e-h recombination**
- **trapping, effect of the electric field**

Principle of the simulation:

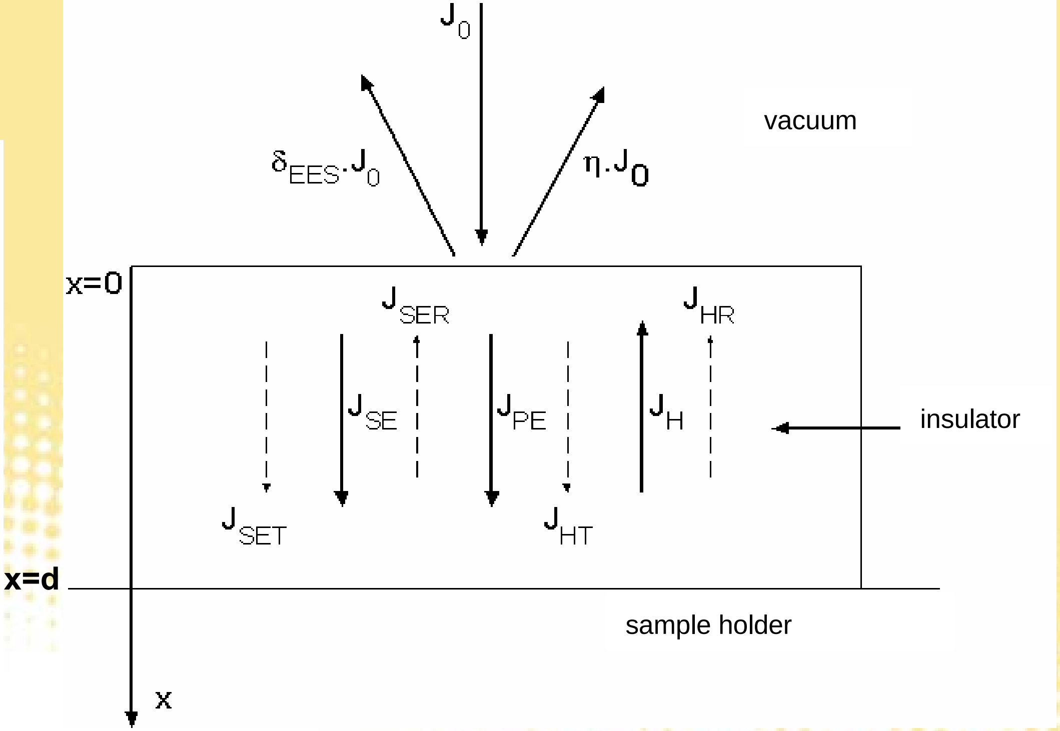
- **model with 1 dimension**
- **determination for each time and for each position x in the sample of the quantity of charges**

$$j_{PE}(x,E) = j_0(1-\eta)\ \exp\left[-4.605\left(\frac{x}{R(E,z)}\right)^{p(z)}\right]$$

$$g_i/\mathring{A} = 0.146\cdot(E_0/keV)^{-0.3}\exp\left[-7.5\left(\frac{x}{R}-0.3\right)^2\right]$$

$$j_T^R(x) = \left[j_T^R(x\pm\Delta x) + \frac{1}{2}j_0 g_i(x)\Delta x\right]\cdot W(x)$$

$$j(x) = -j_{PE}(x) - j_{ET}(x) + j_{ER}(x) + j_{HT}(x) - j_{HR}(x)$$



* Collaboration with Pr HJ Fitting, University of Rostock, PHDThesis X Meyza, C Dutriez, and M Touzin

** H.J. Fitting, Phys. Status solid (a), 1974. 26 . I.A..Glavatskikh , V.S. Kortov, H.-J. Fitting, J. Appl. Phys., 2001. 89(2)

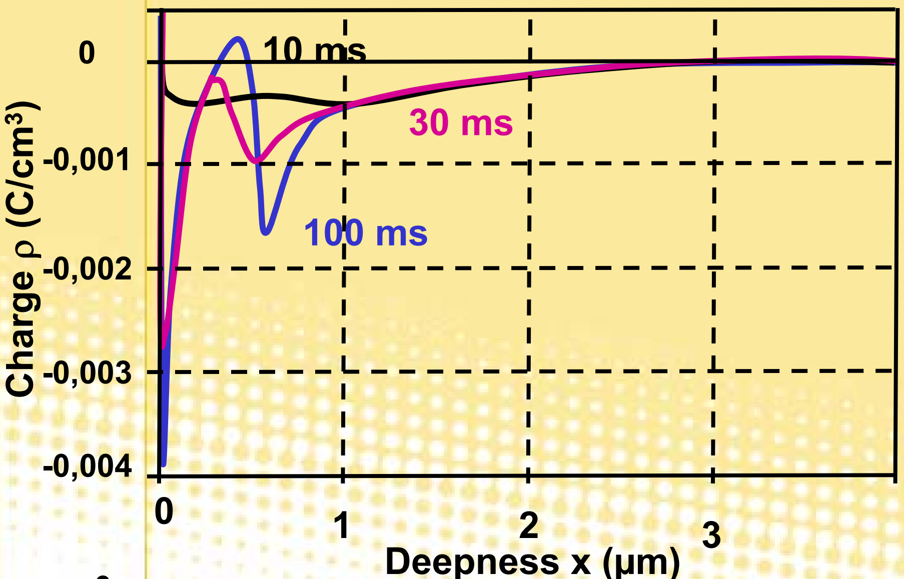
III.2. Simulation of the injection of electrons*

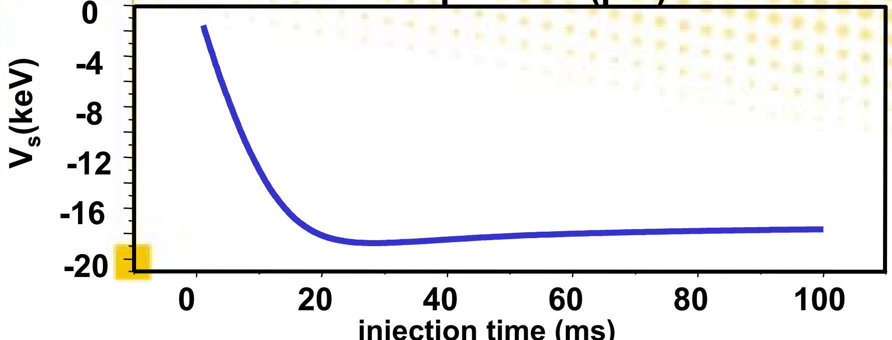
Self-consistent model

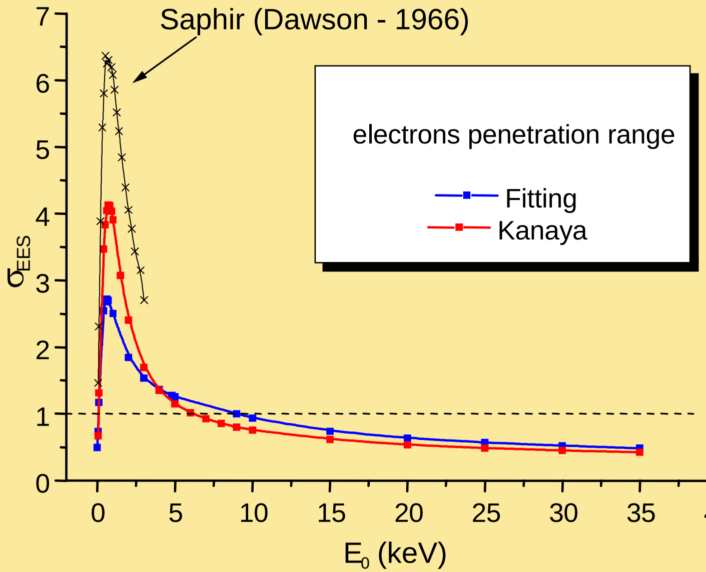
Very short injection:

- determination of the instantaneous secondary emission curve (negligible V_s)

- validation of the model





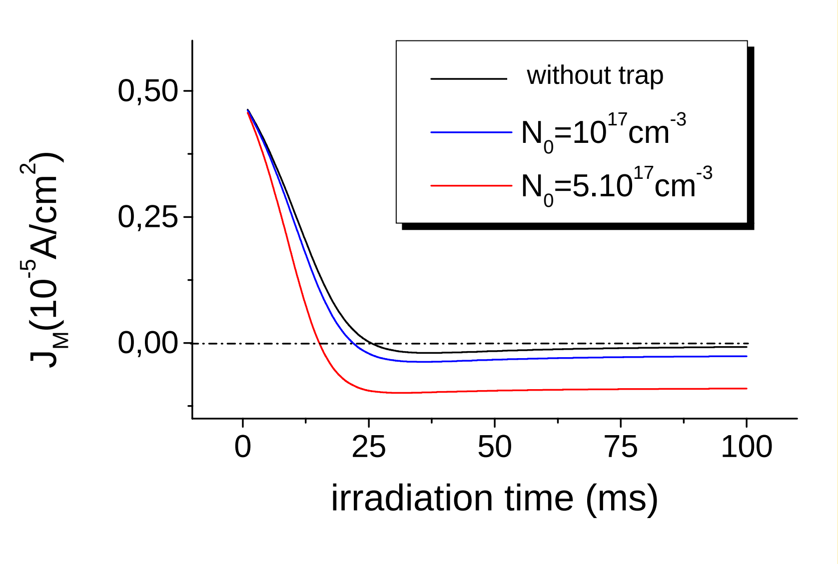


Self-regulated Phenomenon:

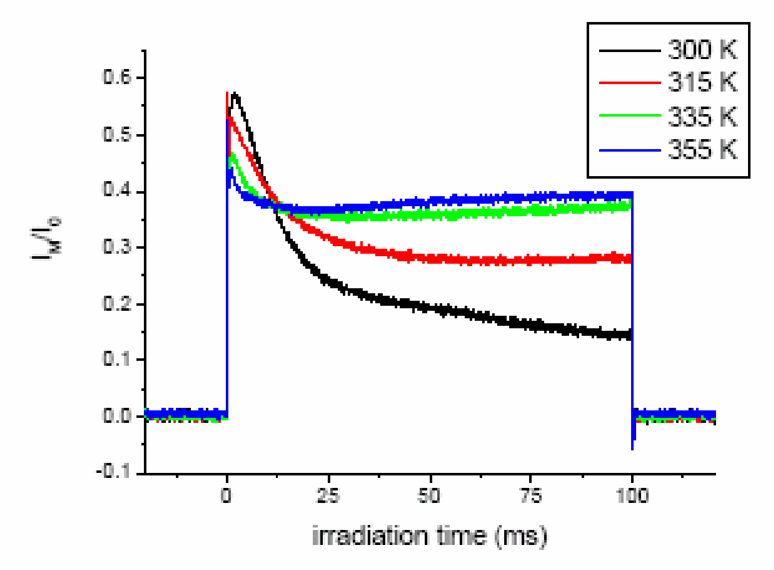
negatives charges are injected in the depth of the sample leading to the creation of a high negative potential and increase de secondary emission incoming charges are slow down less and less charges are injected, surface potential and secondary emission become stable

III.2. Simulation of the injection of electrons*

Self-consistent Model



Example of simulation:
effect of the electronic traps number on the decrease of the influence current



Development of a new model* :

- to take into account the effect of the temperature through the Poole-Frenkel effect

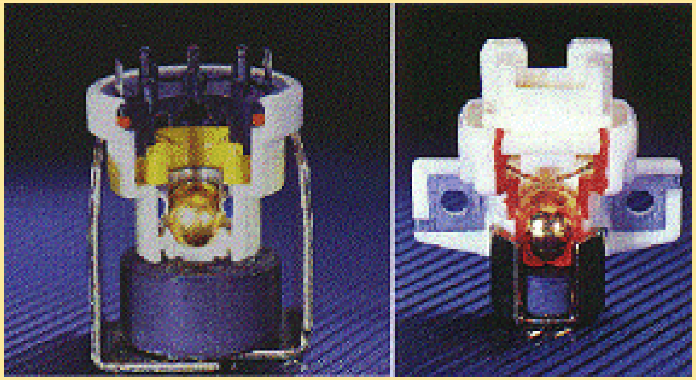
- to take into account the anisotropy of the diffusion and drift due to the field

* Collaboration with Pr HJ Fitting, University of Rostock, PHDThesis C Dutriez, and M Touzin

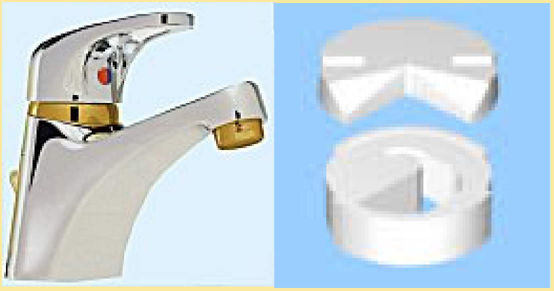
OUTLINE

IV. **Conclusions and Prospects**

Importance of the triboelectrification



Electromechanical sensor of acceleration for airbag

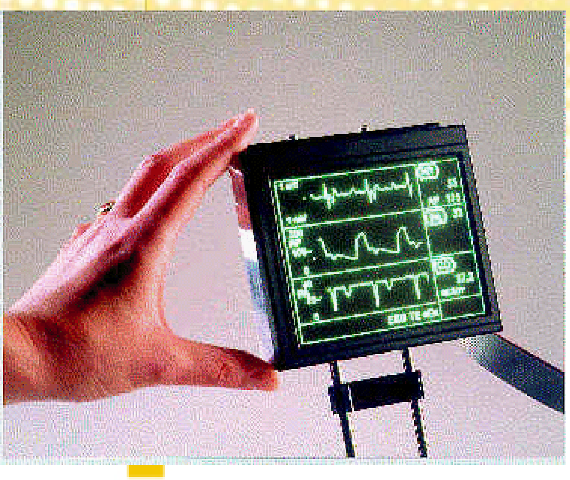


Pieces for mitigation tap

yarn-guide

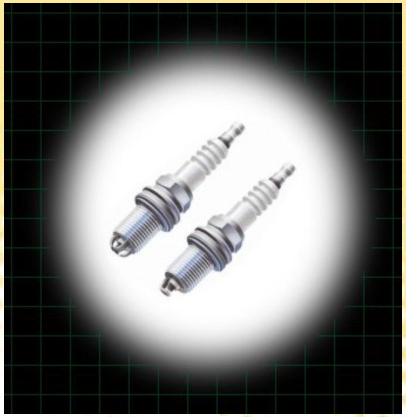
Evidencing of the importance of the electrical charges for the properties of friction and adhesion

Understanding of the mechanisms of injection and trapping of the electrical charges :
- experiments
- simulation



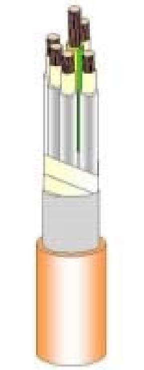
FEG screen

Improvement of the dielectric strength by determination of the structural parameters leading to a better accommodation of the injected charges depending on the temperature of use : "trapping" insulators or "conductive" insulators



Sparking plug

IV.2. Prospects : The polymers insulators



- Study of the trapping and flow of electrical charges in the polymers*

- Link between triboelectrification of the melt and emergence of defects during the extrusion of molten polymers**

- Utilization of ICM and SEMM methods to characterize the nanostructured materials

- Study of polymers/ conductive charges composites: CNT-Elastomers, PANI- BuA...***

* Thèse Cédric Dutriez, C. Dutriez, X. Meyza, C. Guerret-Piécourt, D. Tréheux, H.J. Fitting (2003) Annual Report Conf. on Elect. Insul.Dielect. Phenomena, Albuquerque, 2003, p 530-533

** Thèse F. Flores, S. Tonon, A. Lavernhe-Gerbier, F. Flores, A. Allal, C. Guerret-Piécourt J. of Non-Newtonian Fluid Mechanics, (accepté, sous presse)

*** 1 brevet déposé, V. Datsyuk, C. Guerret-Piécourt, S. Dagréou, L. Billon, J.-C. Dupin, E. Flahaut, A. Peigney, C. Laurent *Carbon* (sous presse)

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Hans-Joachim FITTING, Fabrice FLORES, Dominique GOEURIOT,

Denyse JUVÉ, Xavier MEYZA, Olivier GUERRET, Fabrice SEGAULT, Temga TEMGA,

André TONCK, Sébastien TONON, Matthieu TOUZIN , Daniel TRÉHEUX .../...

...

- **Laboratoire des Solides Irradiés (SESI) à l'Ecole Polytechnique**
- **Laboratoire d'Analyse et d'Architecture des Systèmes à Toulouse**
- **Laboratoire de Tribologie et de Dynamique des Systèmes de l'ECLyon**
- **Laboratoire d' Ingénierie et Fonctionnalisation des Surfaces de l'ECLyon**
- **Laboratoire de Physico-Chimie des Polymères de Pau**