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LabCAF

# Aging and conductivity of electrodes for high rate tRPCs from an ion conductivity approach

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INFN, Frascati, 2012, miguel.morales@usc.es

# Outline

- Outlook of electric high rate RPCs plate requirements
- Dielectric constant measurements
- Conductivity types on insulators
- Processes activated by temperature
- Ionic current model
- Ionic aging model

# Plate impedance effects for high rate RPCs

- DC Model : Disregard perturbation effects, so observables are just function of the **primary rate** ($\phi_p$) and **the column resistivity** ($\rho d$).

- **Resistivity:** Low $\rho d$ values improves rate capability (k) :

$$k = \frac{\rho_0 d_0}{\rho d}$$

- **Permittivity:** Characteristic dielectric perturbation time should be checked:

$$\tau \sim RC$$

# Plate resistivity limits

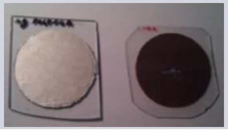
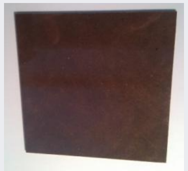
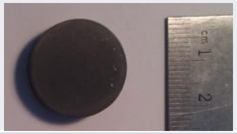
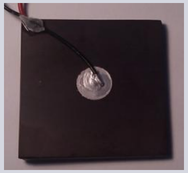
- **Higher the resistivity** higher the loose of effective E field in the gap, therefore less efficency at high rates.

$$V_{gap} = I\, R_{plate} - \phi_p\, \rho\, d$$

**But**

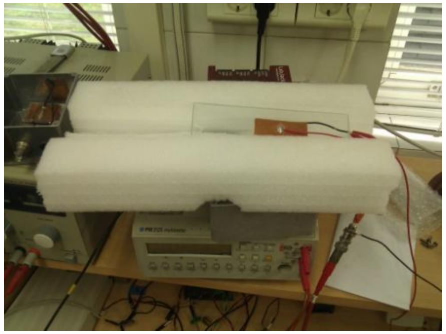
- **Low resistivity**: Greater current paths and more death time as PPC limit is approached.

# Materials Under Test

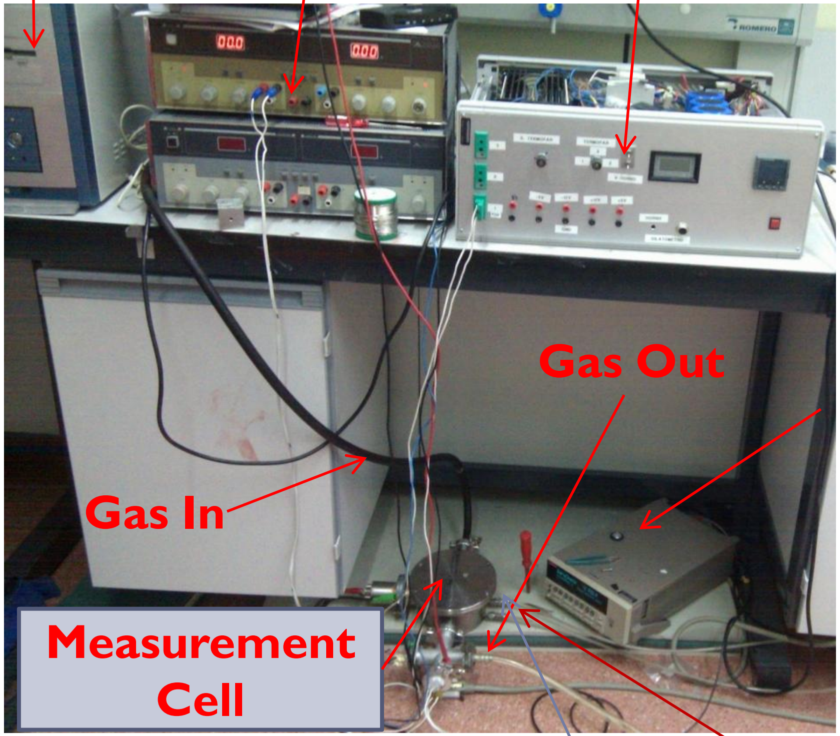
| | | Materials | Provider |
|---|---|---|---|
| **GLASSES** | | | |
| |  | Soda Lime Silicate Glasss (**SLS Glass**) | Hades |
| |  | Low Resistive Silicate Glass (**LRS Glass**) | Tsinghua University |
| **POLYMERs** | | | |
| |  | **Bakelite** | CMS |
| **CERAMICs** | | | |
| |  | **Mullite/Mo** | Developed in colaboration with ICMM/CSIC |
| |  | **Ferrite Ceramic** | Developed in colaboration with ICMM/CSIC |

# Measurement Setups

**From the simplest one:**



**LCR HP4284A 1MHz**



**Computer**

**DC Power Supply**

**Temperature DAQ system**

Control:
**Peltier power**

Read:
**PT100**

**Gas Out**

**Electrometer Keithley 6517A**

*(Up to 1KV Voltage src.)*

**Gas In**

**Measurement Cell**

**Peltier Heat Transfer:** **Water In** **Water Out**

# Dielectric Constant

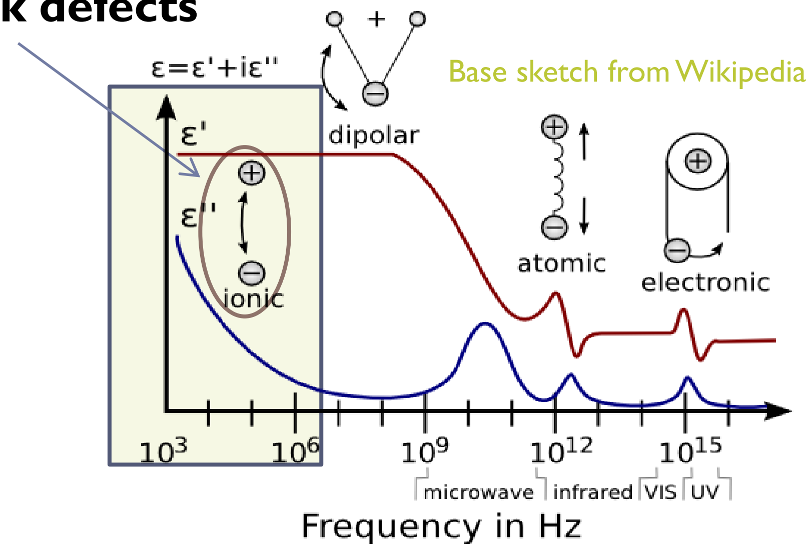
Parallel plate capacitor:

$$C = \varepsilon_r \frac{A}{d}$$

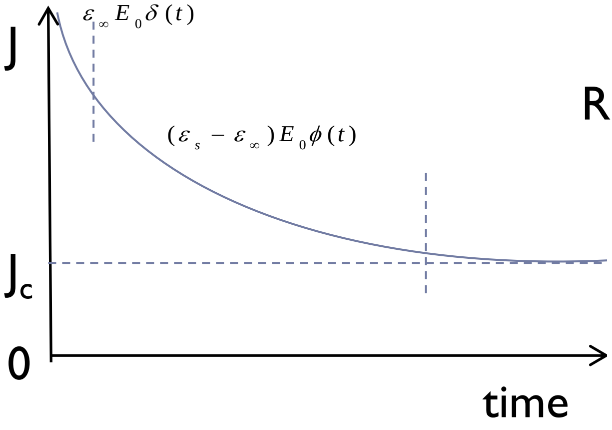
Energy stored in the plate:

$$W = \frac{A}{2d} \varepsilon_r V^2$$

Could damage the FEE or even cause material breakdown.

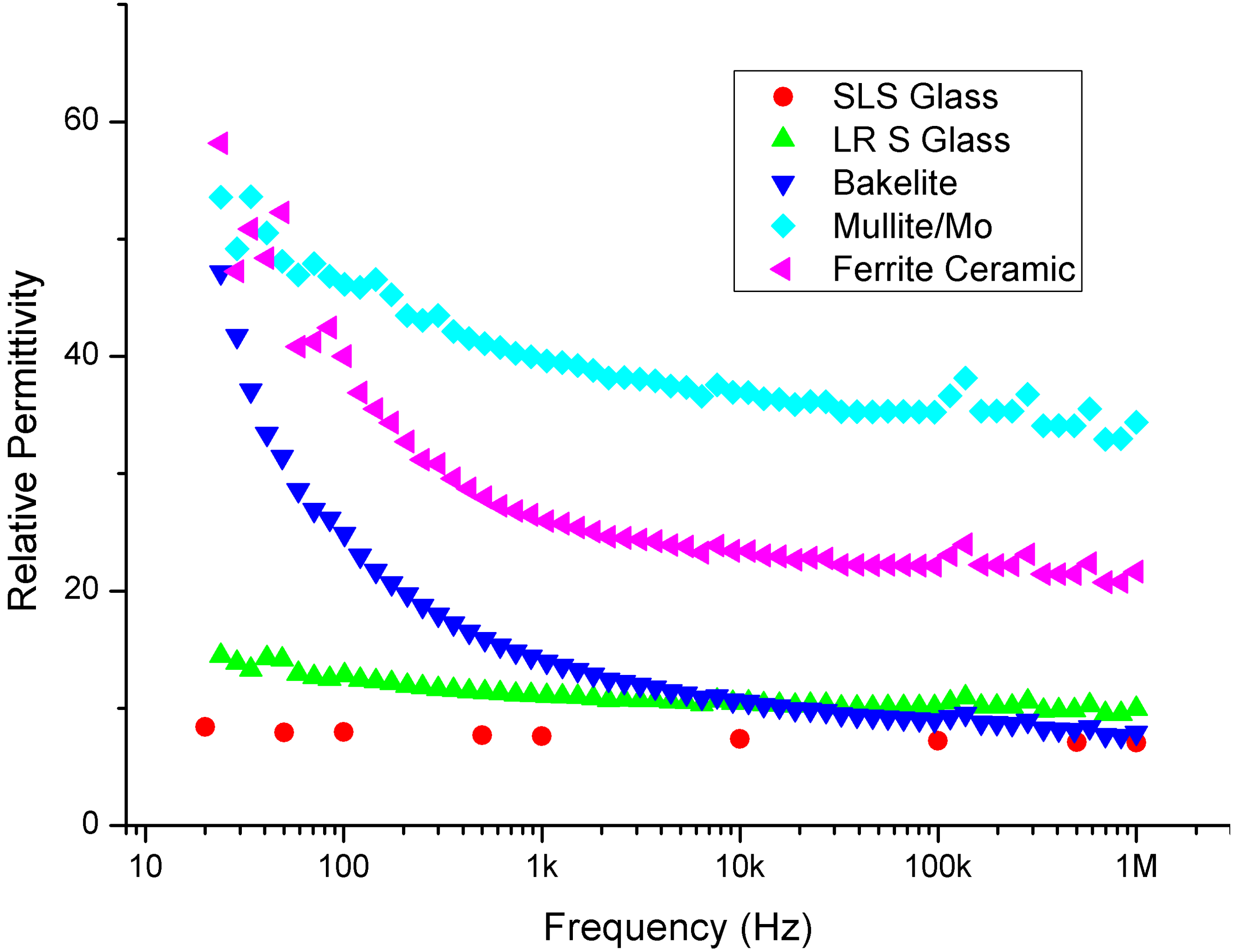

**Network defects**

Base sketch from Wikipedia.org



Relax time:
τ ~ RC

# Materials Dielectric Constant



# Insulator Conductivity Types

| **Controlled by the Insulator** | | |
|---|---|---|
| | **J(V)** | **J(T)** |
| **Ohmmic** | $J \sim V$ | $\log(J/E) \sim 1/T$ |
| **Poole-Frenkel** | $\log(J/V) \sim V^{1/2}$ | $\log(J) \sim 1/T$ |
| **Space Charge Limit** | $J \sim V^2$ | T add carriers |
| **Ionic** | $J \sim V$ | $\log(J/E) \sim 1/T$ |

| **Controlled by the electrode** | | |
|---|---|---|
| | **J(V)** | **J(T)** |
| **Tunelling** | Strong rising with V | Almost independent |
| **Field Emission** | $J \sim V^2 \exp(-b/V)$ | Almost independent |
| **Schottky** | $\log(J/V) \sim V^{1/2}$ | $\log(J/T^2) \sim 1/T$ |

Física de dieléctricos – J. M. Albella ,1984

# Conductivity Types Identification Issues

- Usually **more than one conductivity** type is involved.
- **Relaxation times** longer than we would like.
- Keep in the **right range of electric field and temperature** to identify the conductivity type.
- **Not homogeneus** effective **electric field** inside the material due to phases of different conductivities.
- Different conductivity types could arise changing the **gas environment**.
- Interference from the resistence or the capacities of the **measurement devices**.
- … …

# Arrhenius process: Activation Energies

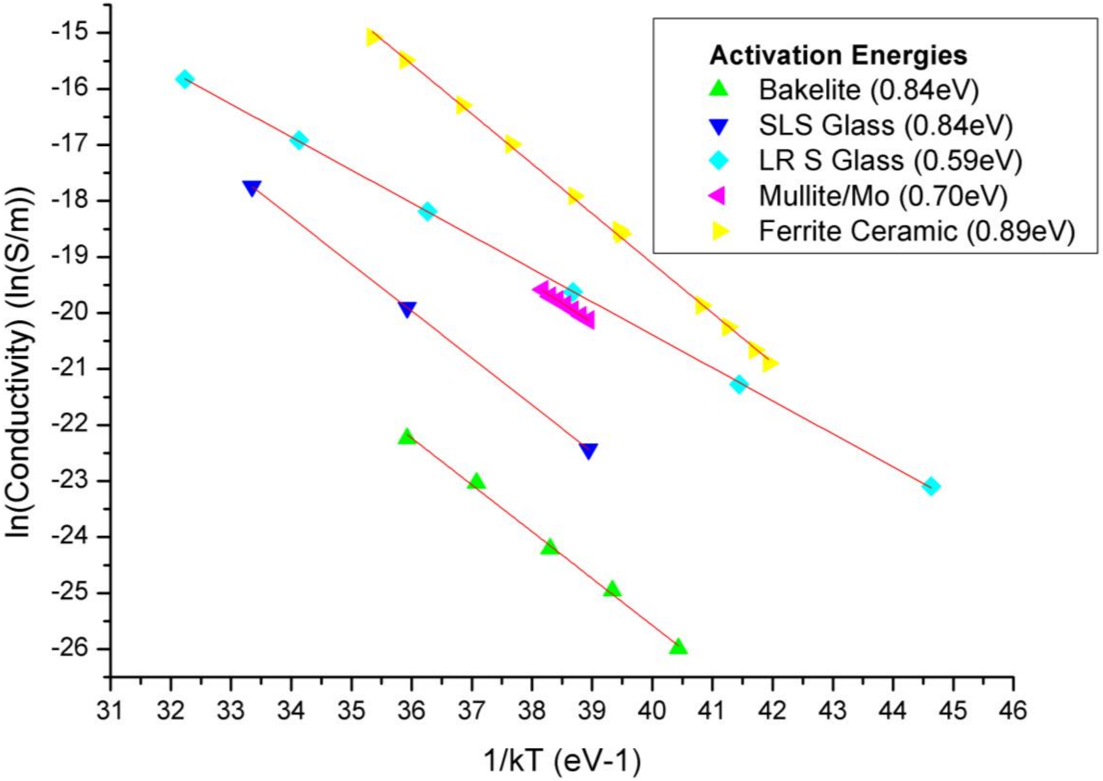
**Conductivity** (σ):

$$\sigma = \sigma_0 e^{-\frac{E_a}{kT}}$$

**Ea**: Activation energy
**K:** Boltzman constant
**T**: Temperature

**Ea** related with the activation energies for **deffects generation** and **ion migration**

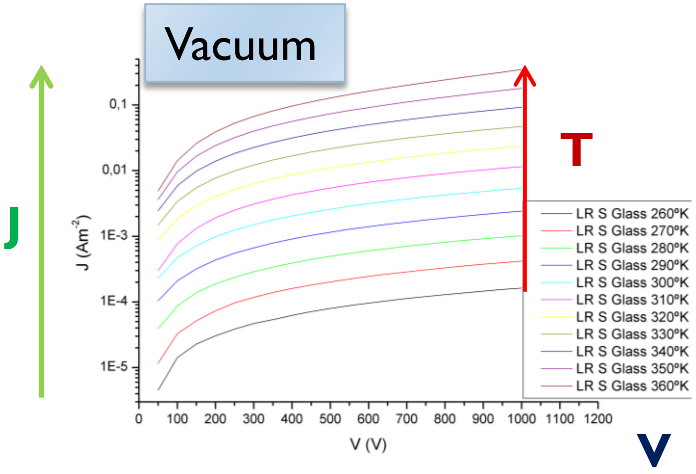
| Material | Ea(eV) |
|---|---|
| LR S Glass | 0.59 |
| Mullite/Mo | 0.70 |
| Bakelite | 0.84 |
| SLS Glass | 0.84 |
| Ferrite Ceramic | 0.89 |

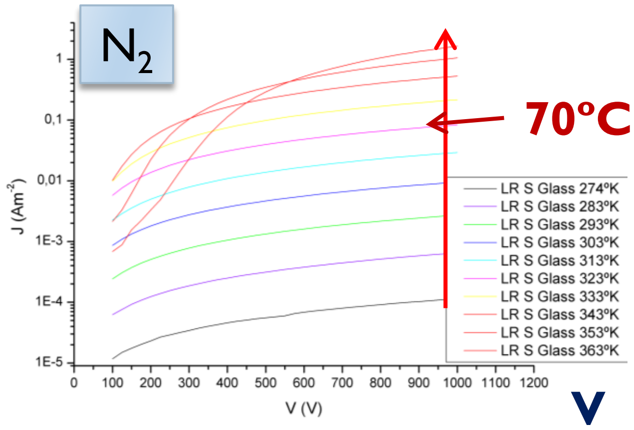


# Activation Energies: gas and temperature effects

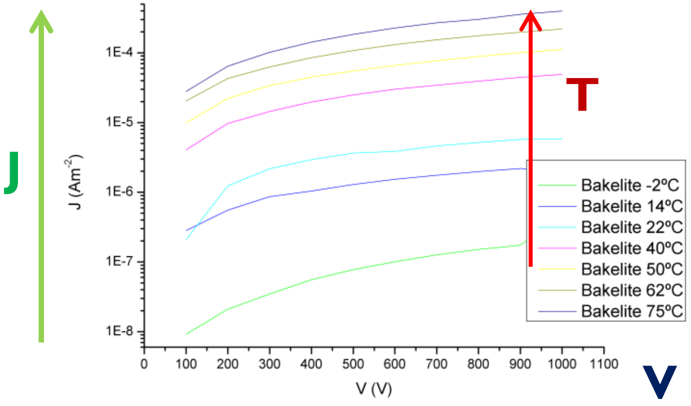
## LR S Glass T>70°C and Bakelite T>50°C, Ea shift

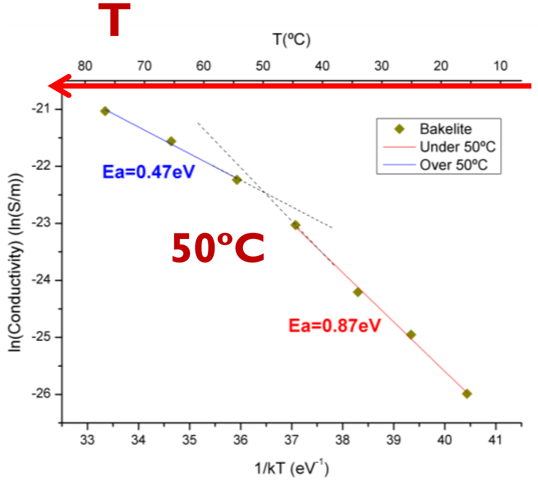
**LR S Glass**





**Bakelite**





# Ionic Current

$$J = nq \quad \mu$$

[Hyde and Tomozawa, 1986]

$$J = nq \left\{ 2 l \nu_0 e^{-\frac{W}{kT}} \sinh\left( \frac{qEl}{2kT} \right) \right\}$$

Mobilitiy

***J***: *Current density*
***n***: *Number of charge carriers*
***q***: *Ion charge*
***μ***: *carrier movility*
***l***: *Mean free path*
***$\nu_0$***: *natural frequency in the well ($10^{13}$HZ)*
***W***: *barrier potential*
***E***: *Electric Field*
***K***: *Boltzman constant*
***T***: *Temperature*

**Fitting variables:**

$$J = C_1 \sinh(C_2 \ E) \Longrightarrow$$

$$C_1 = 2 \ l \ q \ \nu_0 n \ e^{-\frac{W}{kT}}$$

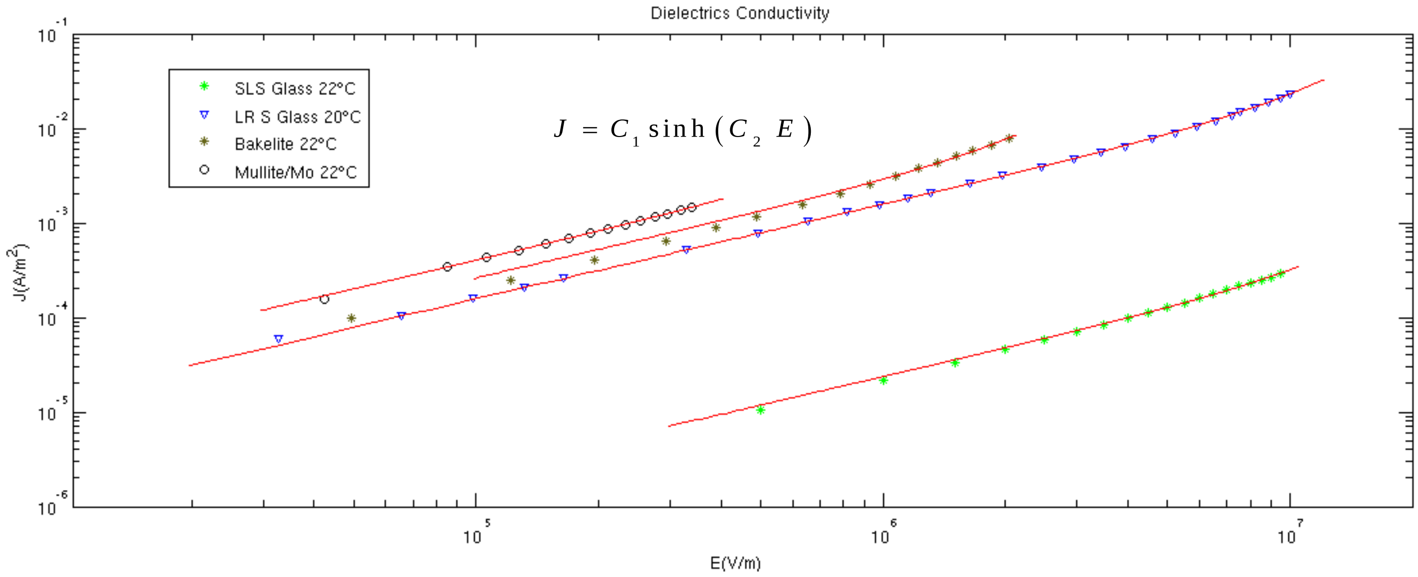
$$C_2 = \frac{q l}{2 k T}$$

$$\Longrightarrow$$

$$\rho = \frac{1}{C_1 C_2}$$ **Resistivity**

$$l = \frac{2kT}{q} C_2$$ **Mean Free Path**

# Ionic Current Fitting



| | $C_1$(A m-$^2$) | $C_2$(m V$^{-1}$) | Rho(Ohm m) | l (m) |
|---|---|---|---|---|
| SLS Glass | 1.7±0.2 ·10$^{-4}$ | 1.4±0.1 ·10$^{-7}$ | 4.2 ±0.7 ·10$^{10}$ | 7.0 ±0.6 ·10$^{-9}$ |
| LR S Glass | 1.00±0.01 ·10$^{-2}$ | 1.57±0.01 ·10$^{-7}$ | 6.4 ±0.1 ·10$^{8}$ | 7.9 ±0.2 ·10$^{-9}$ |
| Bakelite | 3.3±0.4 ·10$^{-3}$ | 7.8±0.7 ·10$^{-7}$ | 3.8±0.8 ·10$^{8}$ | 4.0±0.4x ·10$^{-9}$ |
| Mullite/Mo | 2.0±0.1 ·10$^{-3}$ | 2.0±0.1 ·10$^{-6}$ | 2.5 ±0.3 ·10$^{8}$ | 1.01±0.08 ·10$^{-7}$ |

# Simple Ionic Ageing Model

Carrier density loss:

$$\frac{dn}{dt} = -\frac{J}{qd}$$

Low or moderate field **aproximation**: $qEl \ll kT$

$$J(t) = l^2(t)\, n(t) \frac{E v_0 q^2}{kT} e^{-\frac{W}{kT}}$$

$$n(t) = \frac{J(t)}{l^2(t)} \cdot \frac{kT}{E v_0 q^2} e^{\frac{W}{kT}}$$

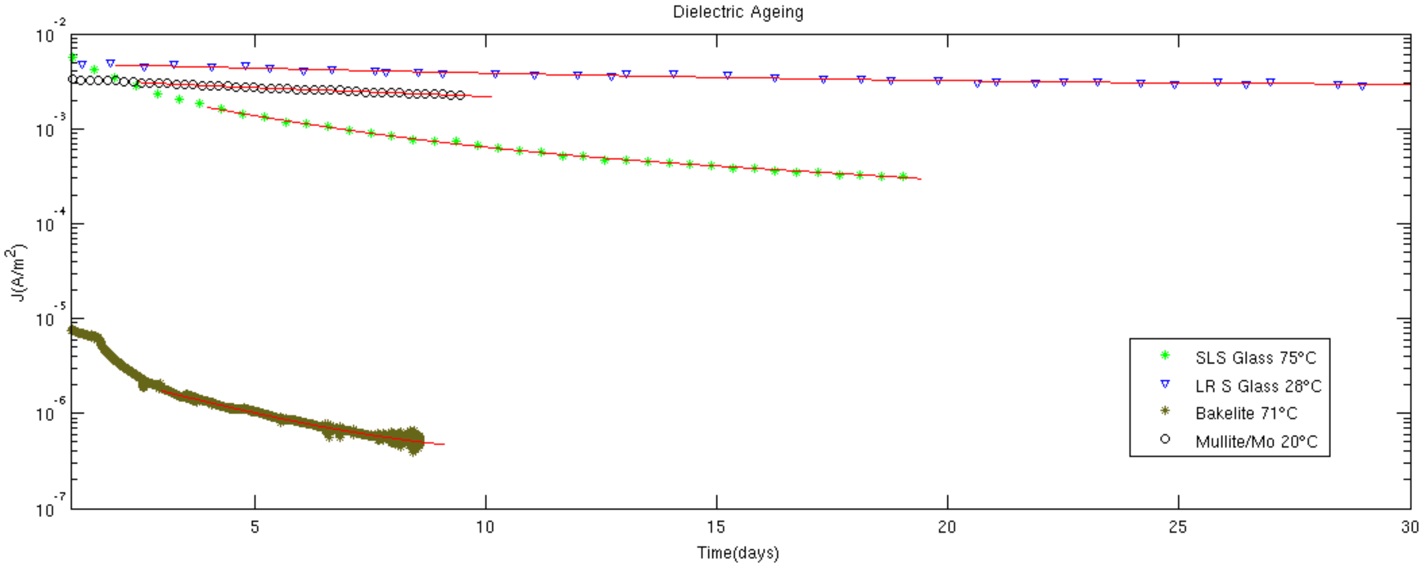
Let the **mean free path** be:

$$l(t) = l_0 \left(1 - \frac{t}{\tau_1} + \frac{t^2}{\tau_2^2}\right)$$

Final current time function from the model:

$$J(t) = J_0 \left[1 - 2\frac{t}{\tau_1} + t\left(\frac{1}{\tau_1^2} + \frac{1}{\tau_2^2}\right)\right] e^{\frac{t}{\tau_n}\left[1 - \frac{t}{\tau_1} + \frac{t^2}{3}\left(\frac{1}{\tau_1^2} + \frac{1}{\tau_2^2}\right)\right]}$$

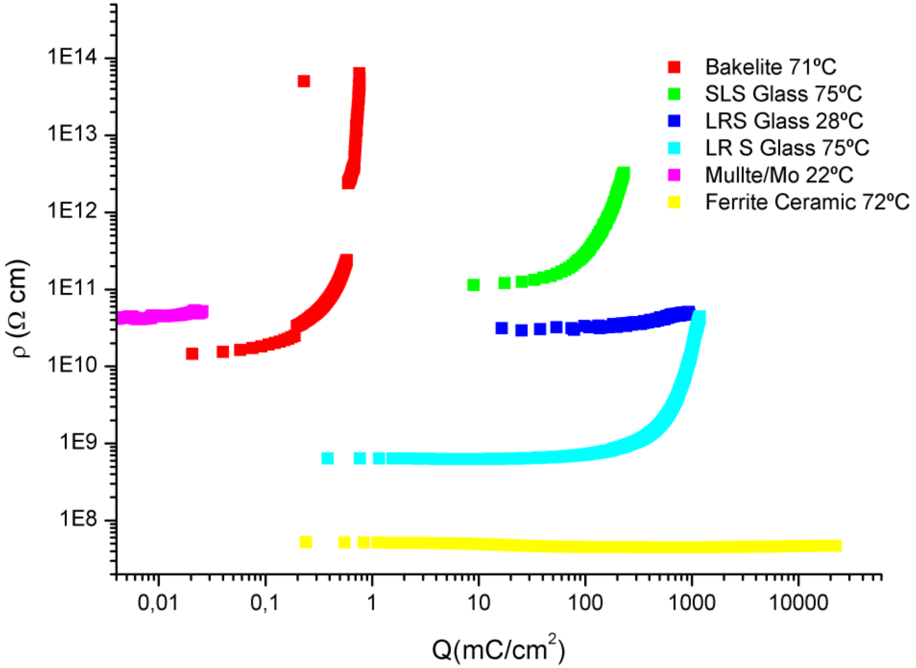
# Fitting to the ionic aging model



$$f_i = \frac{1}{\tau_i}$$

| | $J_0$ (A m$^{-2}$) | $f_1$(Hz) | $f_2$(Hz) | $f_n$(Hz) |
|---|---|---|---|---|
| SLS Glass | $4.2\pm0.6\ \cdot10^{-3}$ | $3.8\pm0.6\cdot10^{-2}$ | $3.1\pm0.8\ \cdot10^{-2}$ | $1.8\pm0.3\cdot10^{-1}$ |
| LR S Glass | $4.9\pm0.3\ \cdot10^{-3}$ | $1\pm1\cdot10^{-2}$ | $1.1\pm0.3\ \cdot10^{-2}$ | $1\pm4\cdot10^{-2}$ |
| Bakelite | $4.45\pm0.06\ \cdot10^{-6}$ | $6.8\pm0.3\cdot10^{-2}$ | $3.20\pm0.05\ \cdot10^{-2}$ | $2.1\pm0.1\cdot10^{-2}$ |
| Mullite/Mo | $3.7\pm0.2\ \cdot10^{-3}$ | $3\pm6\cdot10^{-3}$ | $5\pm1\ \cdot10^{-2}$ | $8\pm1\cdot10^{-2}$ |

# Resistivity chage aging



| Drifted charge | | |
|---|---|---|
| Material | T(°C) | Q(mC/cm²) |
| SLS Glass | 75 | 230 |
| LR S Glass | 28 | 900 |
| | 75 | 1190 |
| Bakelite | 72 | 0.8 |
| Mullite/Mo | 22 | 0.025 |
| Ferrite Ceramic | 72 | 22 000 |

Note: Expected Charge transfered by the CBM RPCs

$Q/A = 5y \times 0.5 \times 20\ KHz/cm^2 \times 1.5pC/gap = 2C/cm^2$

# Summary

- Methods from Material Science have been introduced to test some RPCs plates and other materials.
- Dielectric constant up to 1MHz have been measured
- Activation energies have been used to set the temperature limit for testing material ageings.
- An Ionic approach model for the J(E) and J(t) has been proposed to match Ionic conductivity involved in the current.
- **TODO**:
- Add other effects more than the charges carries depletion to the ageing model, as space charge or electrode pasivation.
- Test other mean free path functions.
- Measure bakelite ageing with a fair setup, lower temperature.
- Put at least one ceramic used for high rate RPCs under test.
- Test impedances up to GHz.

# Thanks

- **LIP- Coimbra**:
  - Paulo Fonte
  - Alberto Blanco
  - Luis Lopes
- **GSI:**
  - Diego González Díaz
- **CMS Experiment**:
  - Dr.Stefano Bianco / Laboratori Nazionali di Frascati dell'INFN
  - Dr. Paolo Vitulo / Univ. Pavia- INFN
  - Dr. Paulo Montagna / Univ. Pavia-INFN
- Institute of Materials Science Research of Madrid (**ICMM /CSIC**)
- Nanomaterials and Nanotechnology Research Center of Asturias (**CINN/CSIC**)

# Thank you for your attention!!

# References

[Hyde and Tomozawa, 1986] Hyde, J.M. and M. Tomozawa, The Relationship Between The Dielectric Relaxation And The High-Field Conduction Of Glasses. Physics and Chemistry of Glasses, 1986. 27(4): p. 147-151.

# Backup Slides

values for $\tau_n$ and $\tau_l$ are:

| | $J_0$ ($Am^{-2}$) | $\tau_n$ (days) | $\tau_l$ (days) | t (days) | $E$ (V/m) | C·cm$^{-2}$ |
|---|---|---|---|---|---|---|
| Mu/Mo (r.t.) | 0.0066 | 19.76 | 112.24 | 10 | $2.2\cdot10^5$ | 0.44 |
| Glass (50ºC) | 0.0027 | 18.85 | 184.34 | 36 | $9.6\cdot10^6$ | 0.22 |

|  | $C_1$ (Am$^2$) | $C_2$ | $\rho$ ($\Omega\cdot$m) | $l$ (nm) |
|---|---|---|---|---|
| 11% Mu/Mo | $(2.05\pm0.2)\cdot10^{-3}$ | $(1.9\pm0.1)\cdot10^{-6}$ | $2.6\cdot10^{8}$ | 98 |
| 12% Mu/Mo | $(2.18\pm0.1)\cdot10^{-3}$ | $(1.86\pm0.09)\cdot10^{-6}$ | $2.5\cdot10^{8}$ | 93 |
| 13% Mu/Mo | $(1.47\pm0.2)\cdot10^{-3}$ | $(5.0\pm0.2)\cdot10^{-6}$ | $1.3\cdot10^{8}$ | 260 |
| Fresh Float glass | $(2.0\pm0.1)\cdot10^{-4}$ | $(1.23\pm0.05)\cdot10^{-7}$ | $4.1\cdot10^{10}$ | 6 |
| Aged Float glass | $(1.6\pm0.3)\cdot10^{-5}$ | $(1.5\pm0.1)\cdot10^{-7}$ | $4.1\cdot10^{11}$ | 8 |

# Cuts

$$\ln \sigma = \ln \sigma_0 - \frac{Ea}{kT}$$

In band theory:

$$\boxed{Ea = \frac{E_g}{2}}$$

**E**g: Gap band energy

Ionic ageing model simplification:

*If* $t_l >> t_n$ *then the solution:*

$$J = J_0 \, e^{-\frac{t}{\tau_n}\left(1 - \frac{t}{\tau_l}\right)} \qquad \tau_n = \frac{d \; kT \; e^{\frac{W}{kT}}}{l_0^2 \nu_0 q E}$$