

# Simulation of Low Temperature, Weakly Ionized Plasmas with Applications to the Electric Power Industry

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**RSE S.p.A.** (Ricerca sul Sistema Energetico) is a company within the **GSE Group**, controlled by the **Ministry of Economy and Finance**. It provides support to the Ministry of the Environment and Energy Security (**MASE**) and to the Regulatory Authority for Energy, Networks and Environment (**ARERA**).

**RSE** finances its research programs through:

- the research system fund (Rds)
- **EU** projects
- contracts with third parties (institutions, companies, ... )

**RSE** has five departments:

- **EUT** - efficient use of energy for end uses and the territory
- **SFE** - sustainable development and energy sources
- **SSE** - development of energy systems
- **TGM** - generation technologies and materials
- **TTD** - transmission and distribution technologies

## TOTALE

personale in forza  
**~380**



età media  
**46 anni**

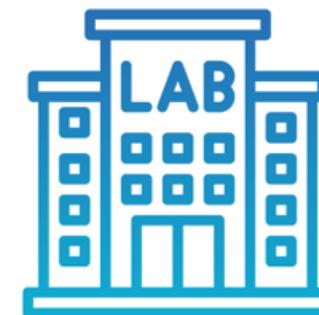
anzianità lavorativa media  
**15 anni**



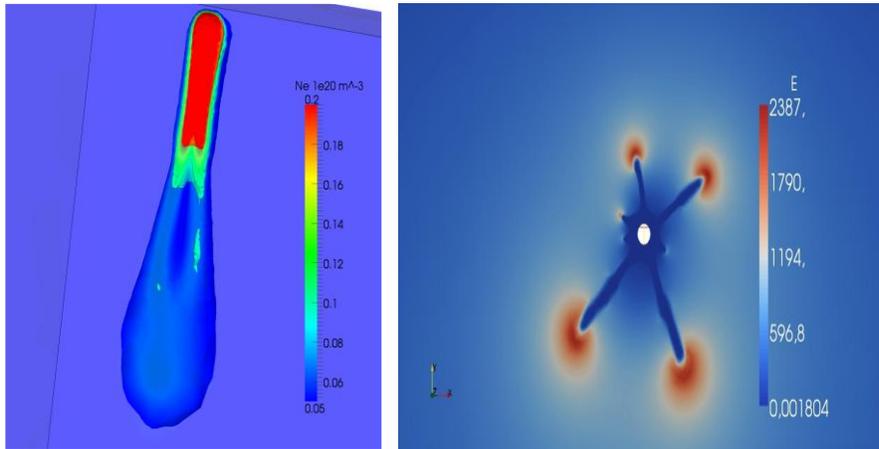
## LABORATORI E SEDI

laboratori  
**50+**

- **Sede e laboratori RSE a Milano**  
Via Rubattino, 54
- **Sede RSE a Roma**  
Viale Maresciallo Pilsudski, 122/124
- **Laboratorio RSE a Roma**  
Via Antonio Bosio, 15
- **Sede e laboratori RSE a Piacenza**  
Via Callegari
- **Laboratori RSE a Brugherio (MB)**  
Via Matteotti, 105



## Cold – Weakly Ionized

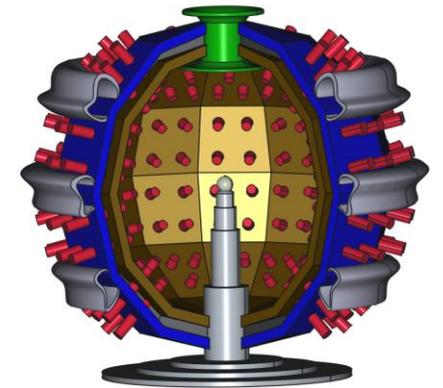


RSE has developed models for the simulation of the initiation and propagation of electrical discharges, with applications to the power system for predicting the onset of the **corona effect** and the **ageing of insulating polymer materials**.

## Inertial fusion

RSE participates in research on inertial confinement fusion, contributing in several areas such as:

- neutronic design
- analysis of new materials
- reaction chamber design
- plasma and plasma - laser interaction



RSE has several research agreements with other partners such as **ENEA** and **CNR-INO** (a joint Ph.D. project has been funded).

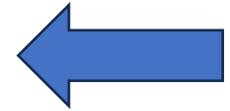


# Blackout

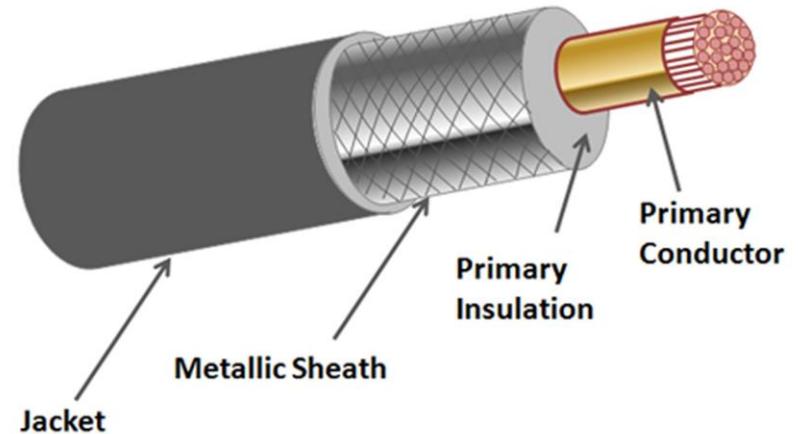


## Why a blackout takes place:

- **Big events**, like Spain (April, 2025)
- **Small localized events** -> insulation fault

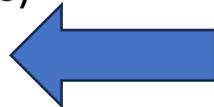


## High Voltage Cable



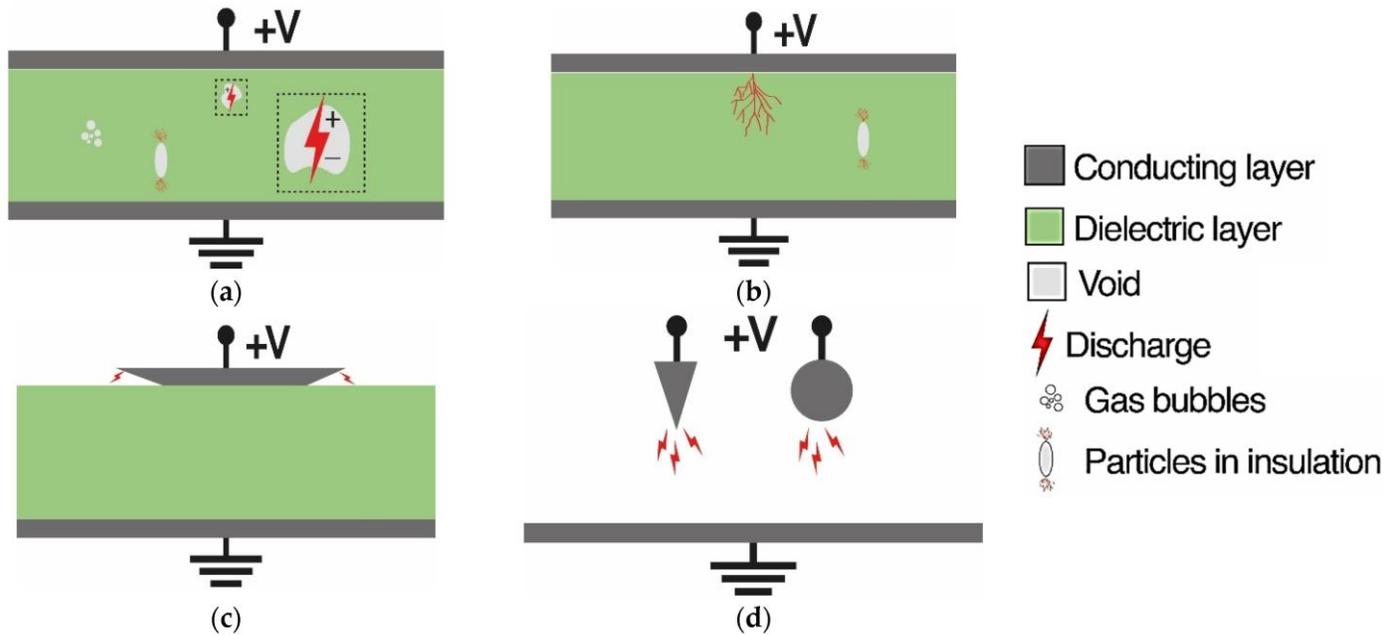
## What are the causes:

- **Space Charge** accumulation (DC)
- **Partial Discharges** (AC)

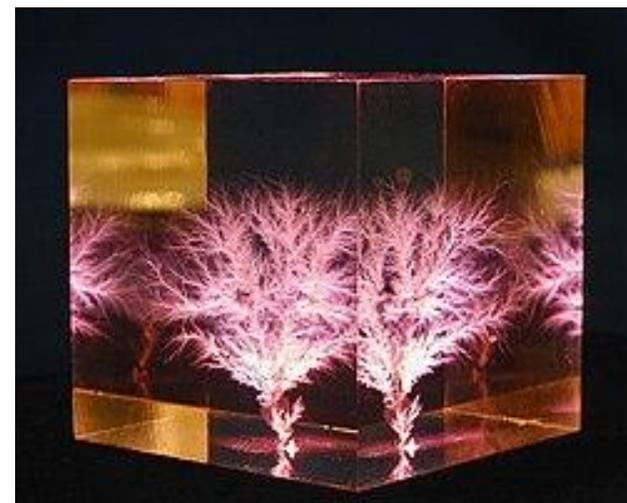




# Partial discharges



- Internal, **gas-filled**, defect;
- High electric field;
- **Partial Discharges** (1-1000) for each period
- Propagation of the defect (**Treeing**)
- **Carbonization** of the branches





## Aim of the research

### PDs measurement devices:

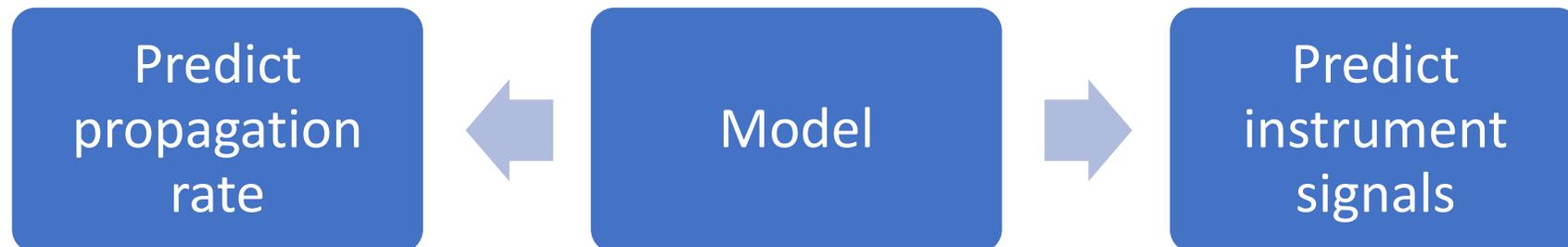
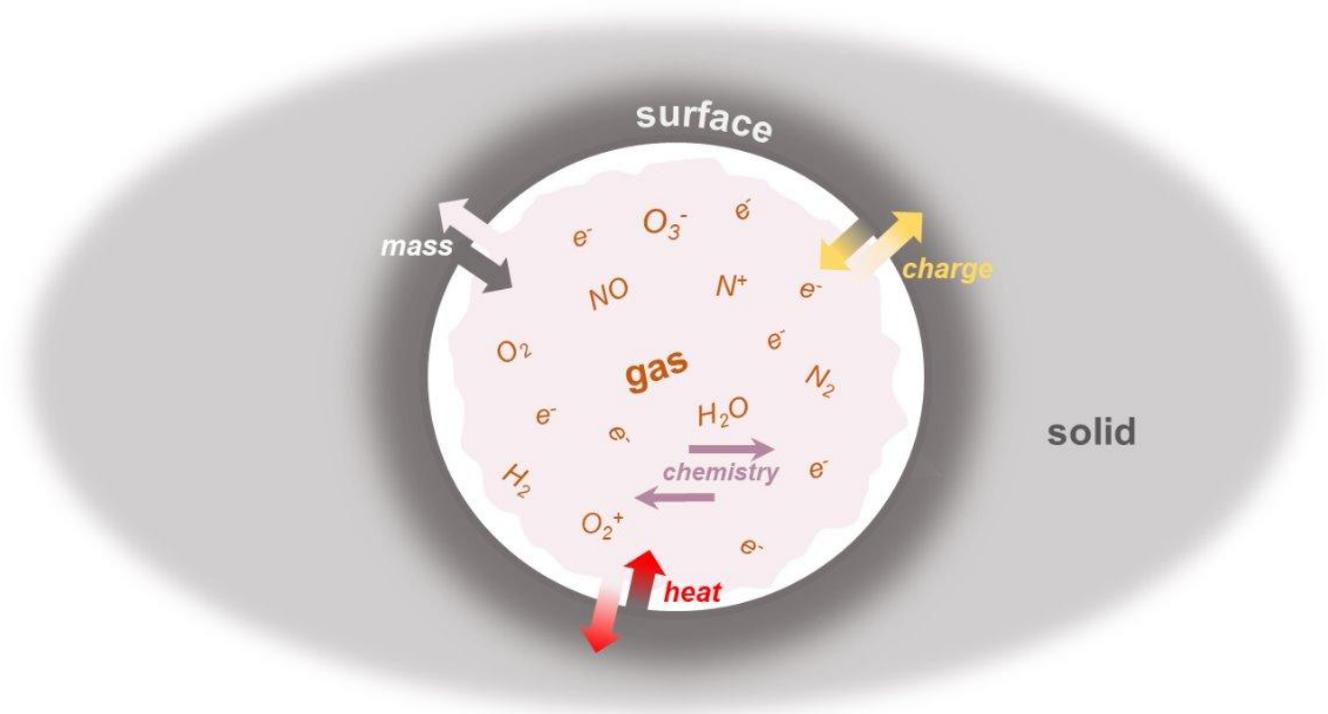
- Amperometers
- Antenna
- Microphones

### Problems:

- correlation between **defects** and **signals**
- plan maintenance

### Targets:

- predict correlation **defect/signals**
- evaluate **evolution** of the **defect**





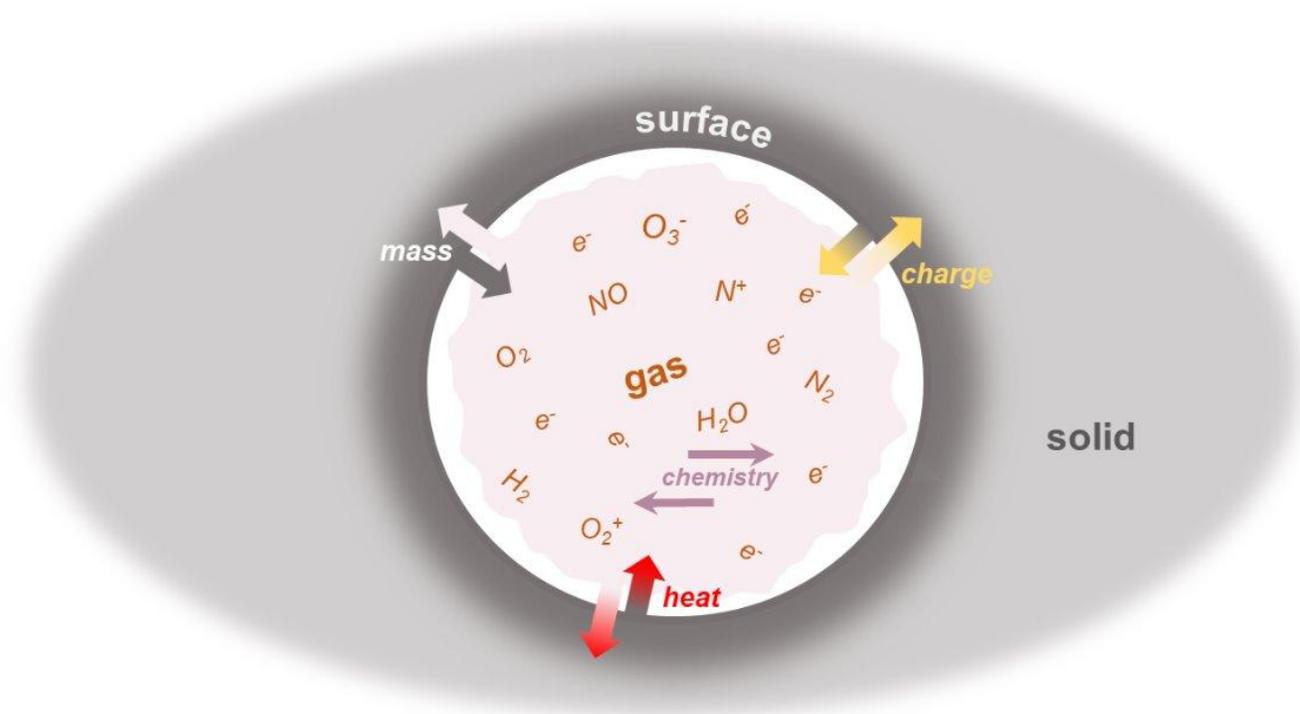
$$\frac{\partial}{\partial t} (n_{p,q}) + \vec{\nabla} \cdot \left( \left( \omega_p \mu_p \vec{E} + \vec{v} \right) n_{p,q} \right) - \vec{\nabla} \cdot \left( \nu_p \vec{\nabla} n_{p,q} \right) = C_{p,q} + S_{p,q}^{ph},$$

$$\frac{\partial}{\partial t} (\rho \vec{v}) + \vec{\nabla} \cdot (\rho \vec{v} \vec{v} + P) = - \sum_{p=1}^3 \vec{\nabla} (\Delta P_p) + \vec{g} + q \vec{E},$$

$$\begin{aligned} & \frac{\partial}{\partial t} (\rho e^t) + \vec{\nabla} \cdot (\rho e^t \vec{v}) + \vec{\nabla} \cdot (\nu^t \vec{\nabla} T) \\ &= - \sum_{p=1}^3 \left( \frac{\partial}{\partial t} (\rho_p \Delta e_p^t) + \vec{\nabla} \cdot \left( \rho_p \Delta e_p^t \left( \mu_p \vec{E} + \vec{v} \right) \right) \right) \\ &+ W_J (1 - \chi^v) - L^v + \vec{g} \cdot \vec{v}, \end{aligned}$$

## Groups:

- Electrons
- Negative ions
- Positive ions
- Neutral particles





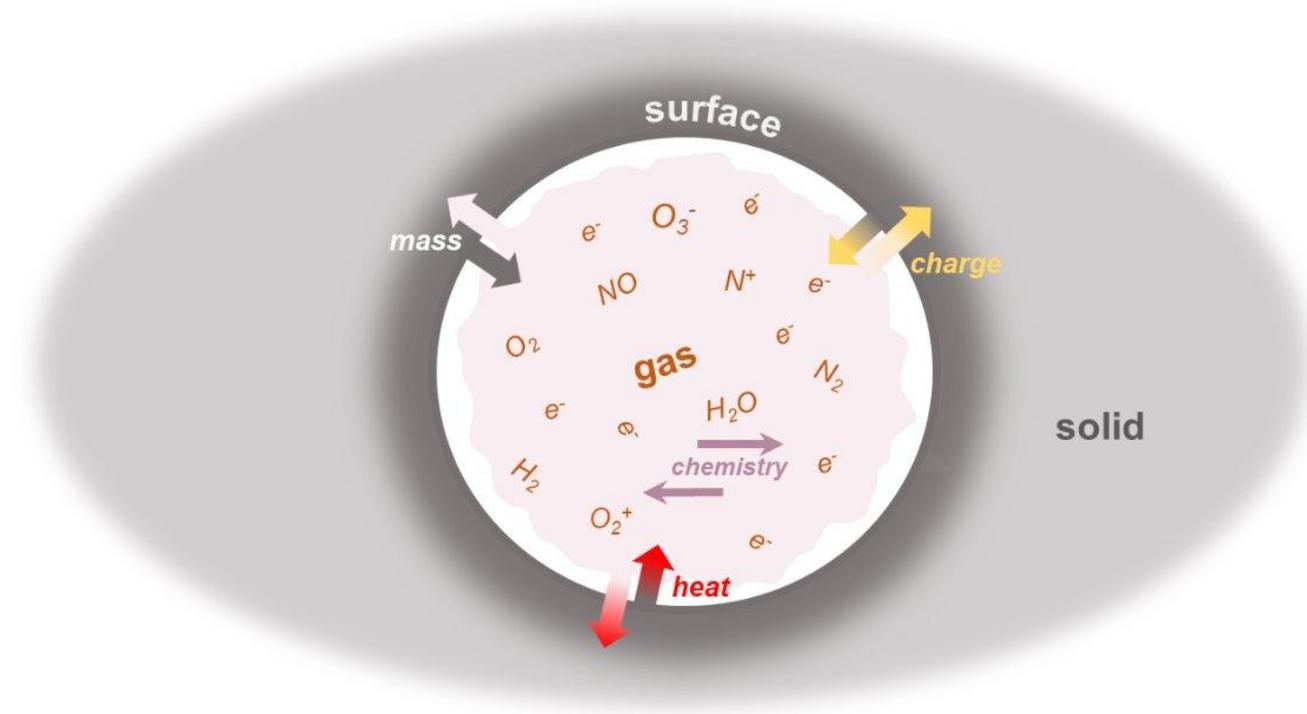
# Gas-Solid Interface

## Charge transfer:

- Electron trapping
- Ion neutralization
- Schottky emission
- Secondary electron emission

## Mass transfer:

- Adsorption
- Abstraction
- Sputtering
- Dissociative electron attachment
- Localized breakdown



# Electric field

$$\vec{\nabla} \cdot \vec{E}_g = \frac{e}{\epsilon_0} \left( \sum_{p=1}^4 \omega_p n_p \right),$$

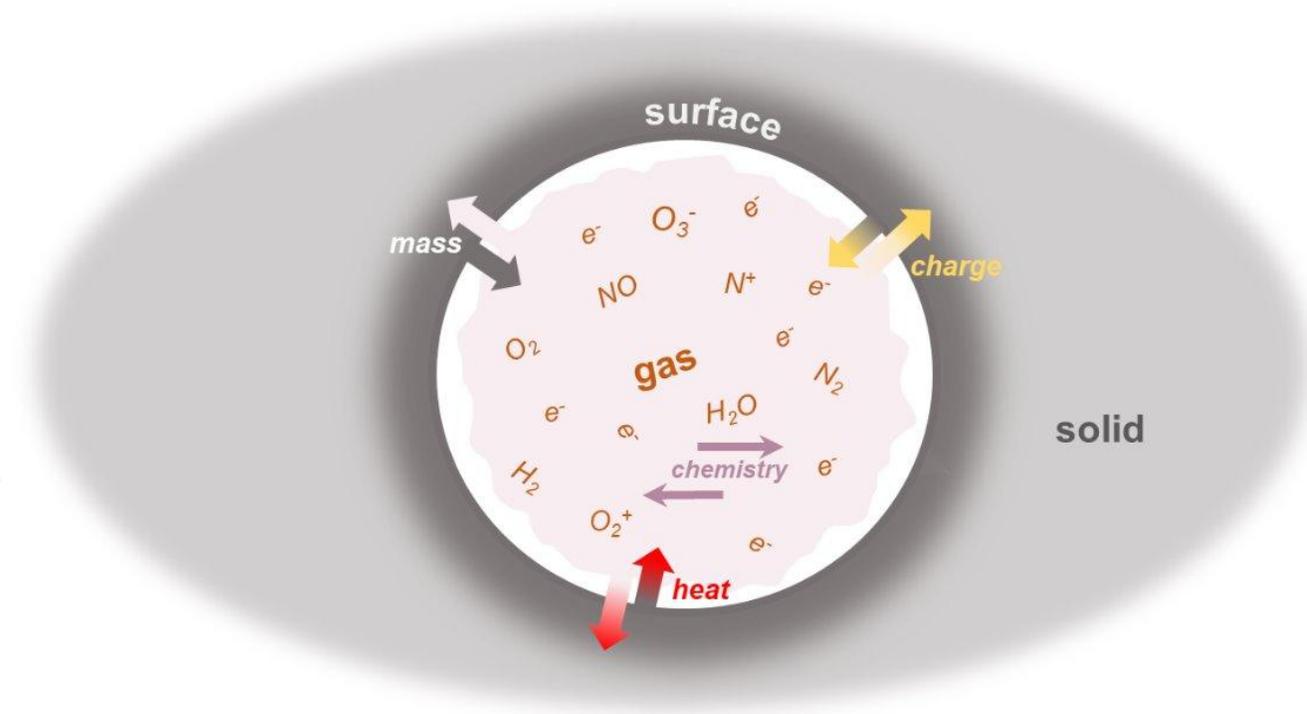
$$\vec{\nabla} \cdot (\epsilon_s \vec{E}_s) = 0,$$

$$\vec{E} = -\vec{\nabla} \phi,$$

$$\epsilon_s \vec{E}_s \cdot \vec{n}_s + \vec{E}_g \cdot \vec{n}_g = -\frac{e}{\epsilon_0} (n_{\Gamma,h} - n_{\Gamma,e}),$$

$$\frac{\partial n_{\Gamma,e}}{\partial t} - \vec{\nabla}_t \cdot (n_{\Gamma,e} \mu_{\Gamma,e} \vec{E}_\Gamma) = \sum_{p=1}^2 n_p \mu_p \vec{E}_g \cdot \vec{n}_g - \nu_1 \vec{\nabla} n_1 \cdot$$

$$\frac{\partial n_{\Gamma,h}}{\partial t} + \vec{\nabla}_t \cdot (n_{\Gamma,h} \mu_{\Gamma,h} \vec{E}_\Gamma) = n_3 \mu_3 \vec{E}_g \cdot \vec{n}_g,$$

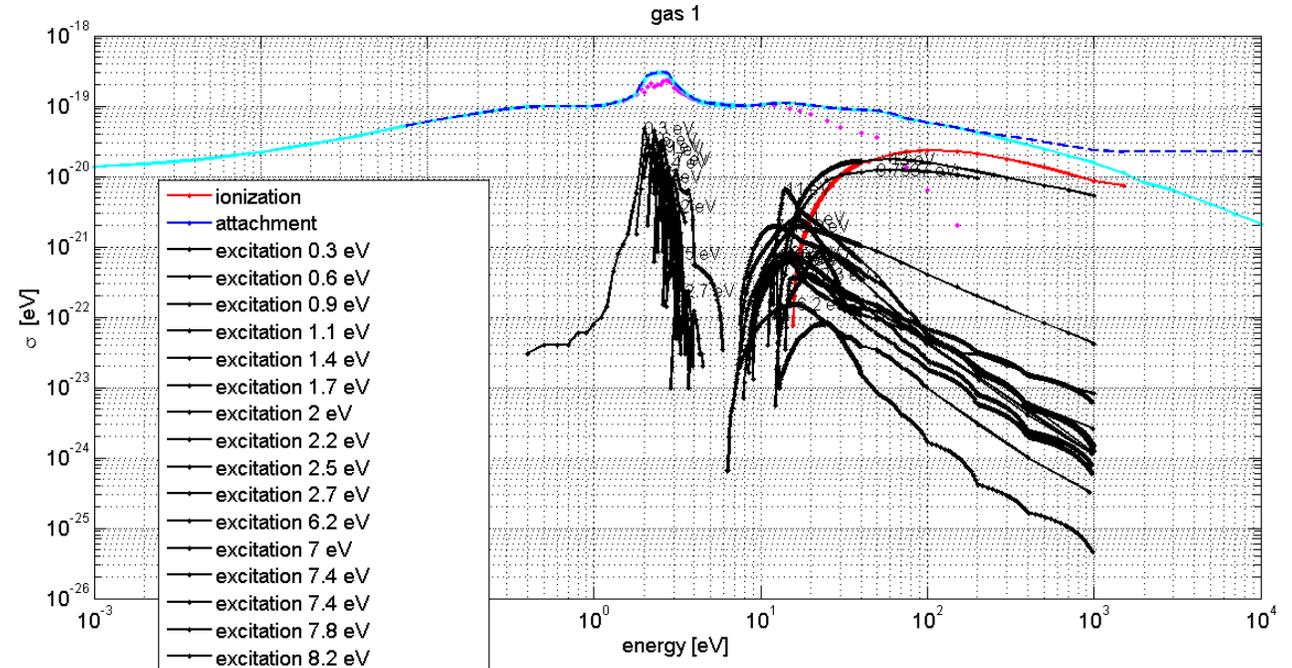
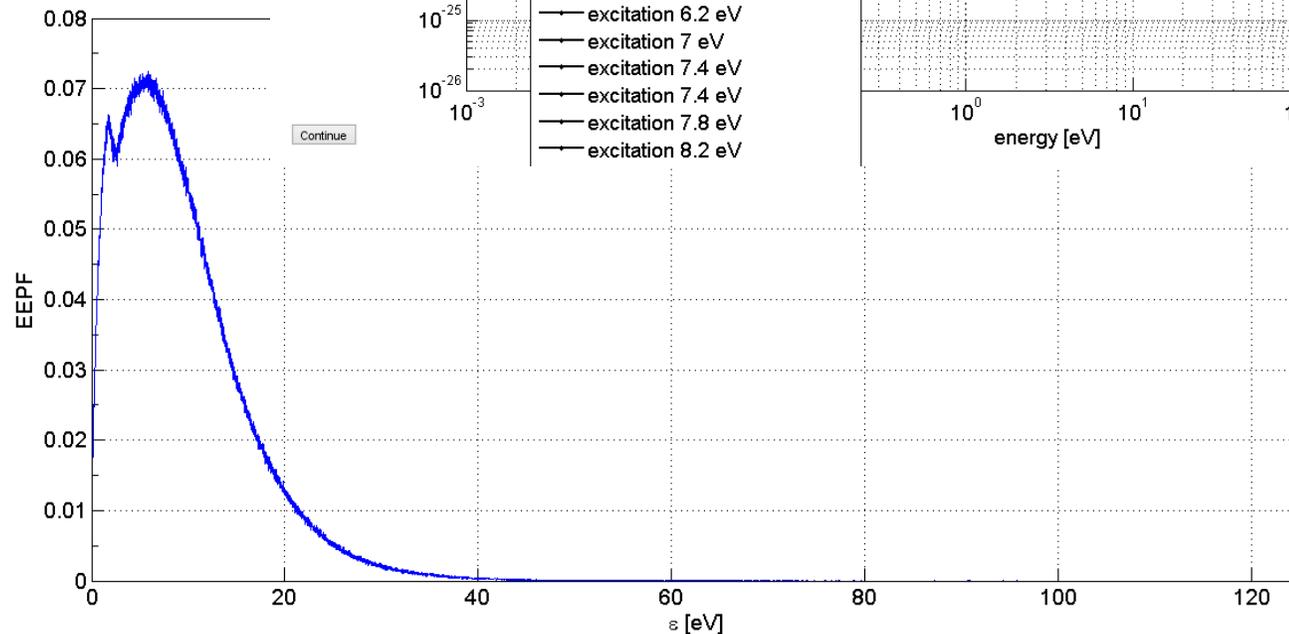


## Physical parameters:

- Electronic mobility
- Electronic diffusion
- Ionic mobility

## Chemical reactions:

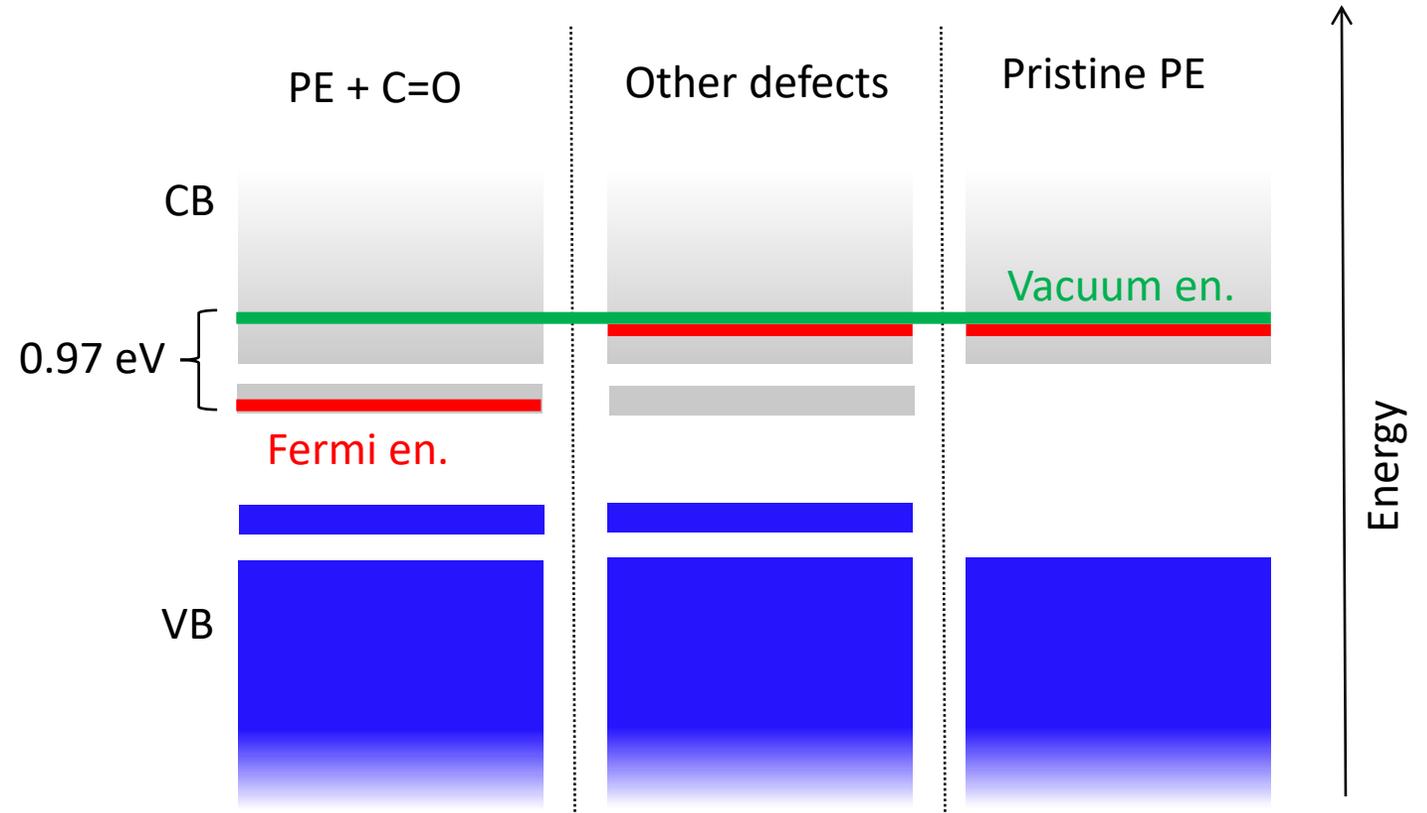
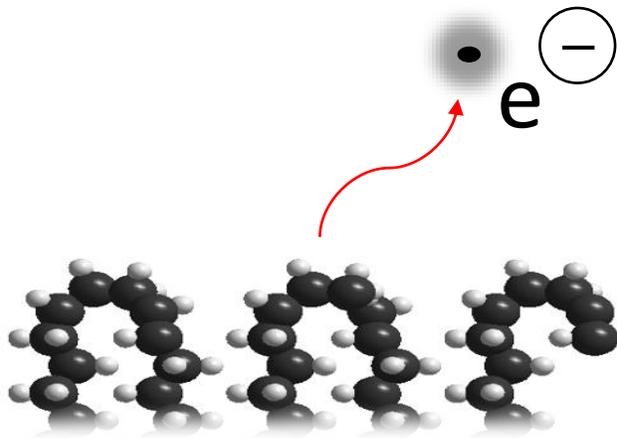
- Attachment
- Vibration excitation
- Electronic excitation
- Dissociation
- Ionization
- Quenching
- Charge transfer
- Recombination
- Neutral reactions





## Schottky emission:

- Evaluation of the **work function**
- Experimental evidences  **$W=1.3$  eV**
- **DFT** -> chemical defects, surplus charge (1 electron every  $10^5$  sites)



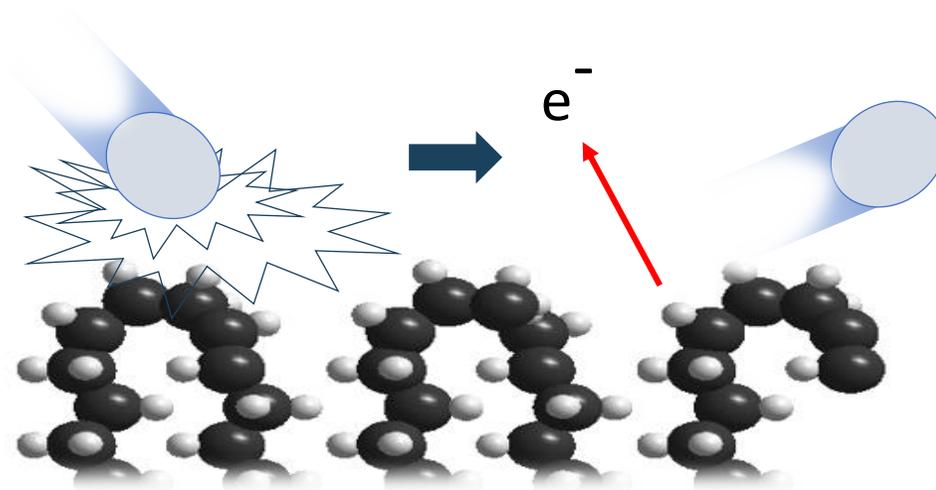


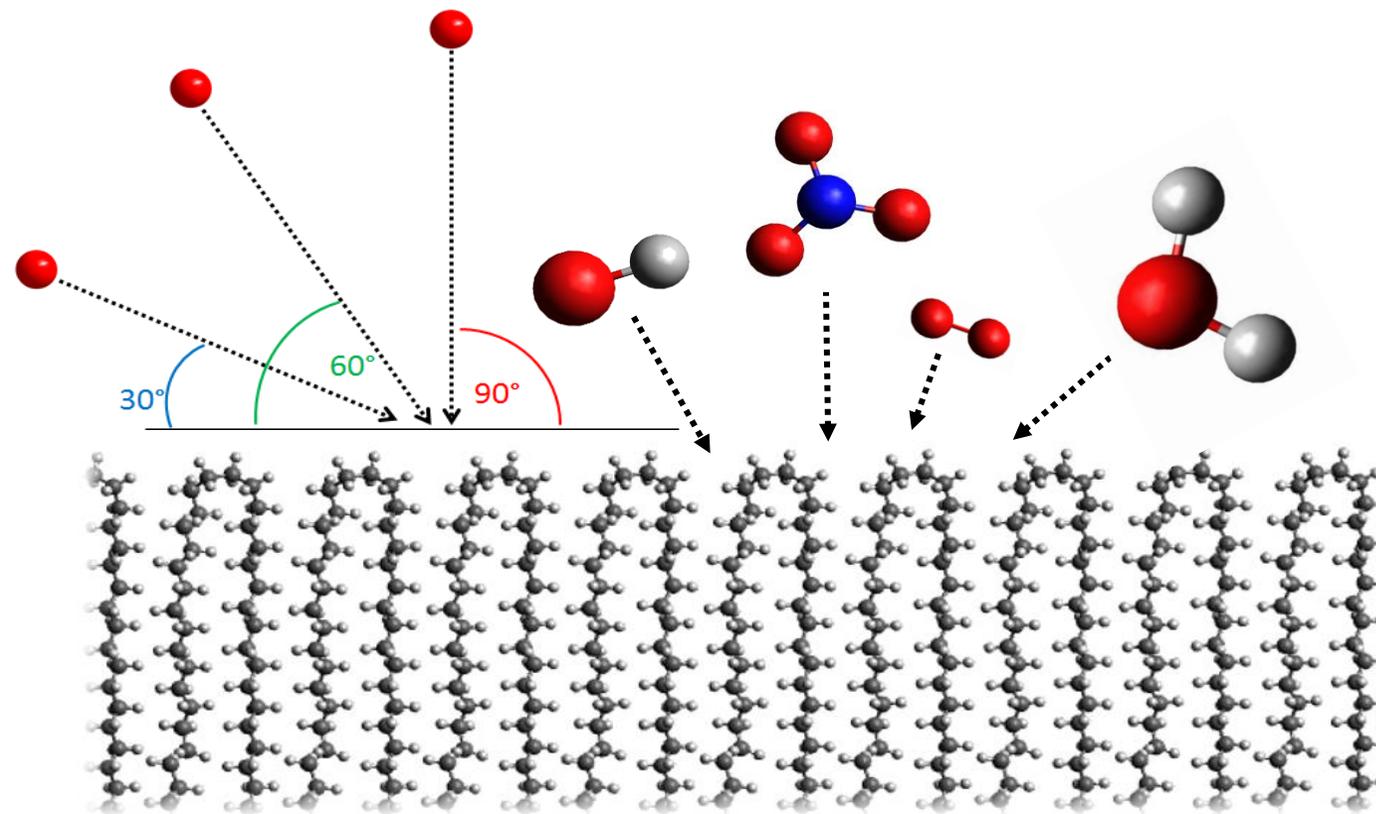
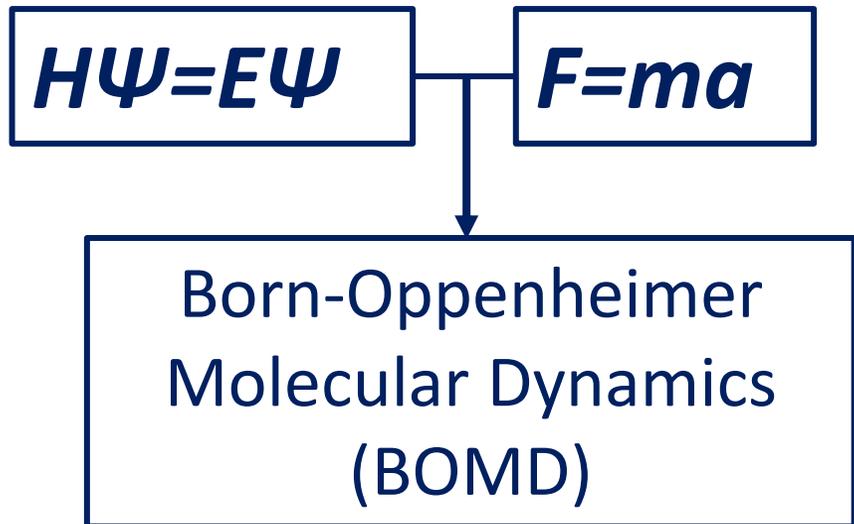
## Secondary electron emission:

- Auger neutralization
- Experimental evidence **0.01**
- Theoretical estimations are **uncertain**

$$\gamma = \frac{J_e^{2\text{nd}}}{J_{\text{imp}}} \rightarrow \begin{array}{l} \text{Secondary electrons' current} \\ \text{Impinging species' current} \end{array}$$

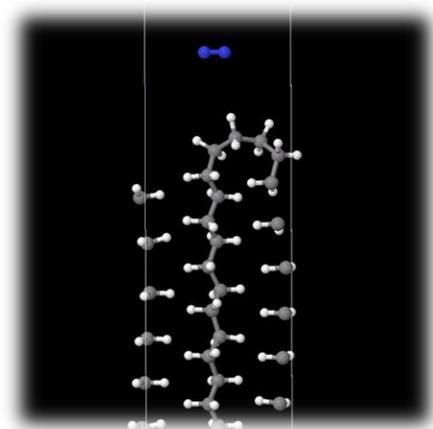
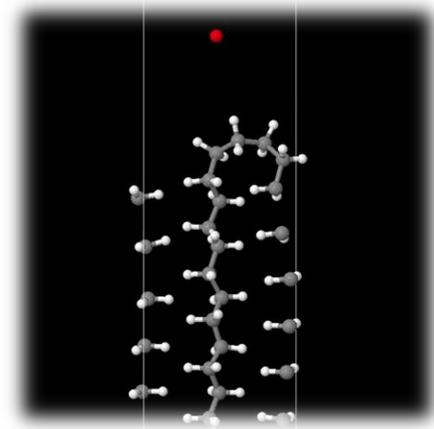
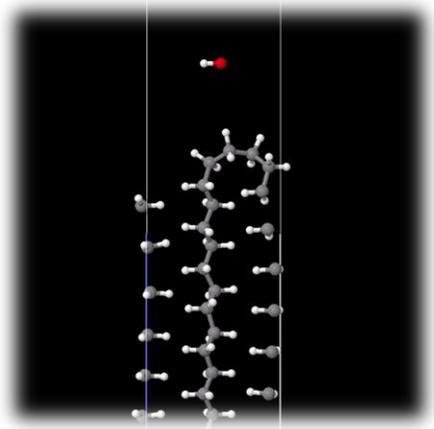
$$\gamma_N = \frac{\int_{\max\{\varepsilon_b, \varepsilon_{fe}\}}^{\varepsilon_i - 2W + \varepsilon_{fe}} P_e(\varepsilon) D_c(\varepsilon) \times T\left[\frac{\varepsilon + \varepsilon_{fe} - E_i}{2}\right] d\varepsilon}{\int_{\max\{\varepsilon_b, \varepsilon_c\}}^{\varepsilon_i - 2W + \varepsilon_{fe}} D_c(\varepsilon) \times T\left[\frac{\varepsilon + \varepsilon_{fe} - E_i}{2}\right] d\varepsilon}$$







# Multiscale-Surface



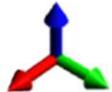
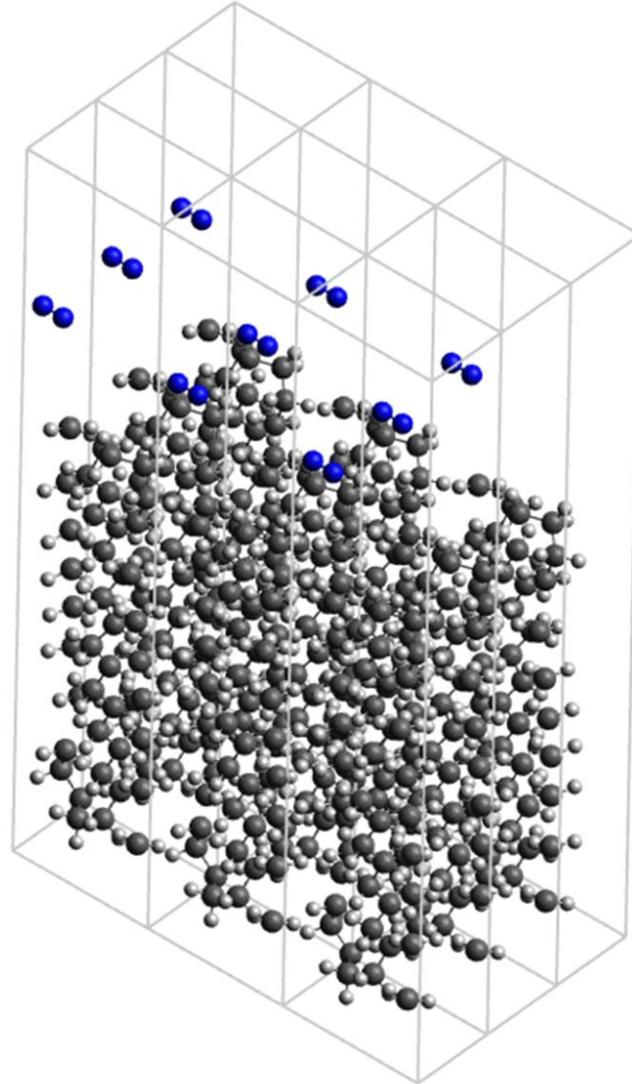
Possible chemical reactions

Sputtering



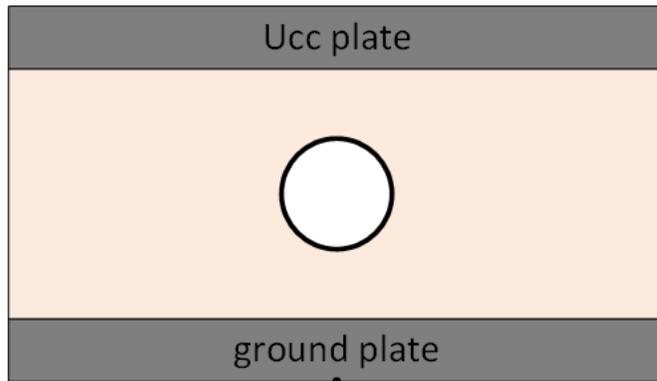


# Multiscale-Surface

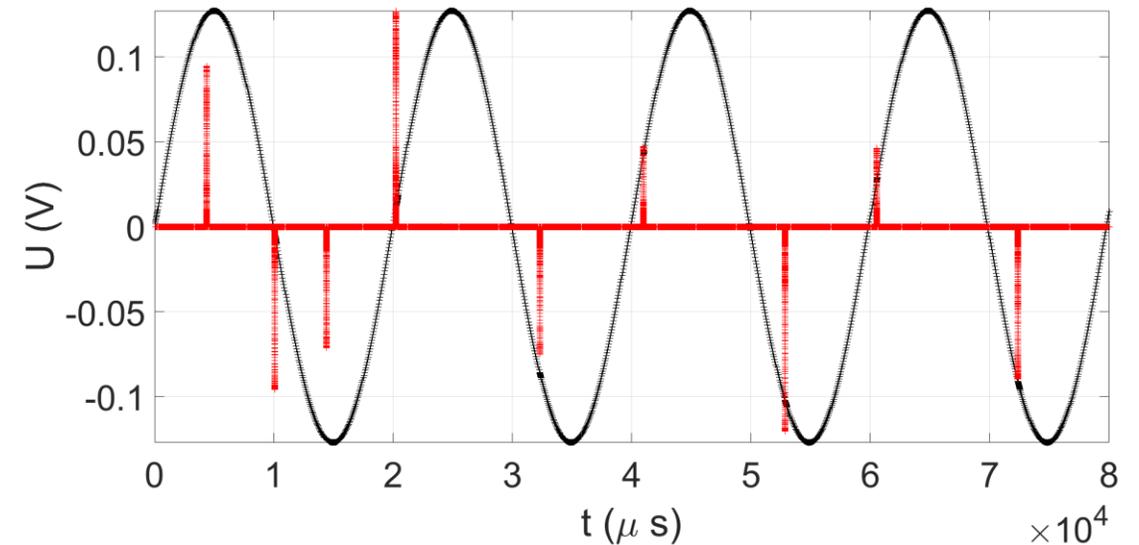
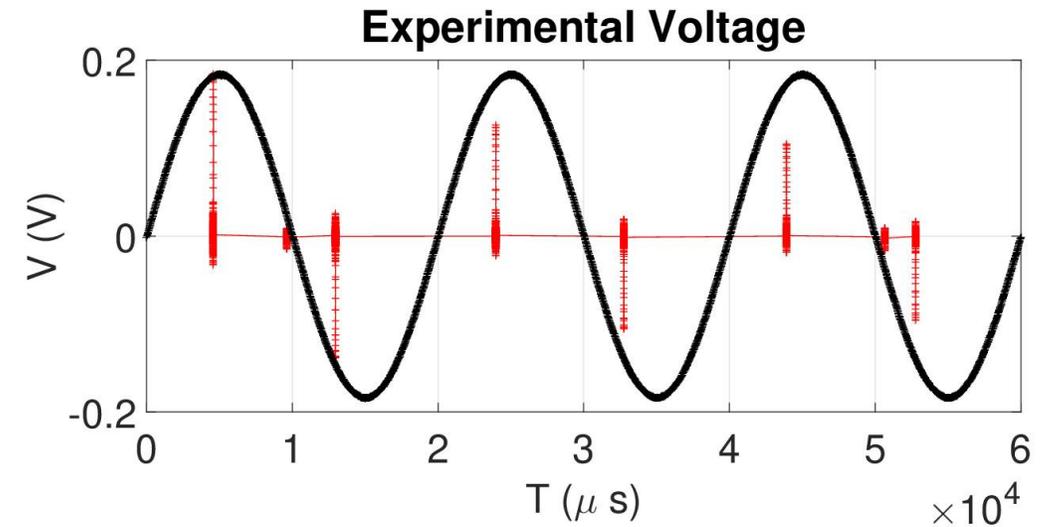




## Validation-Void



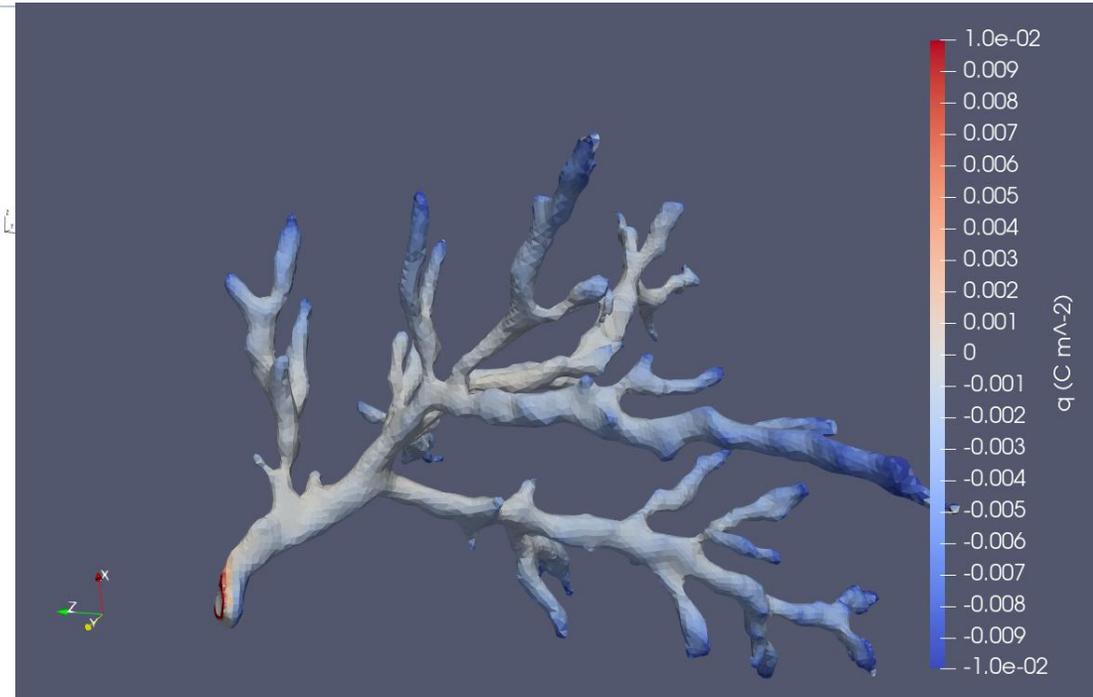
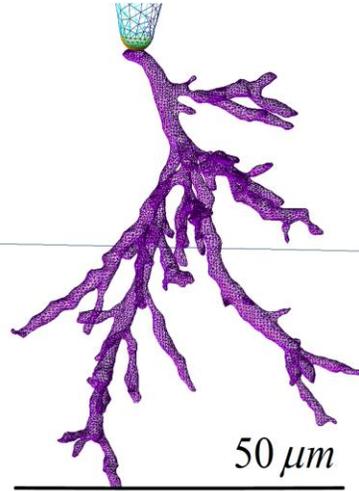
- 2 mm **insulating layer**
- 1 mm **sphere**
- R = 100 ohm
- V = 4.41 kV (AC)
- A PDE-based partial discharge simulator – A. Villa, L. Barbieri, M. Gondola, A.R. Leon-Garzon, R.Malgiesini – JCP 345, 687-705





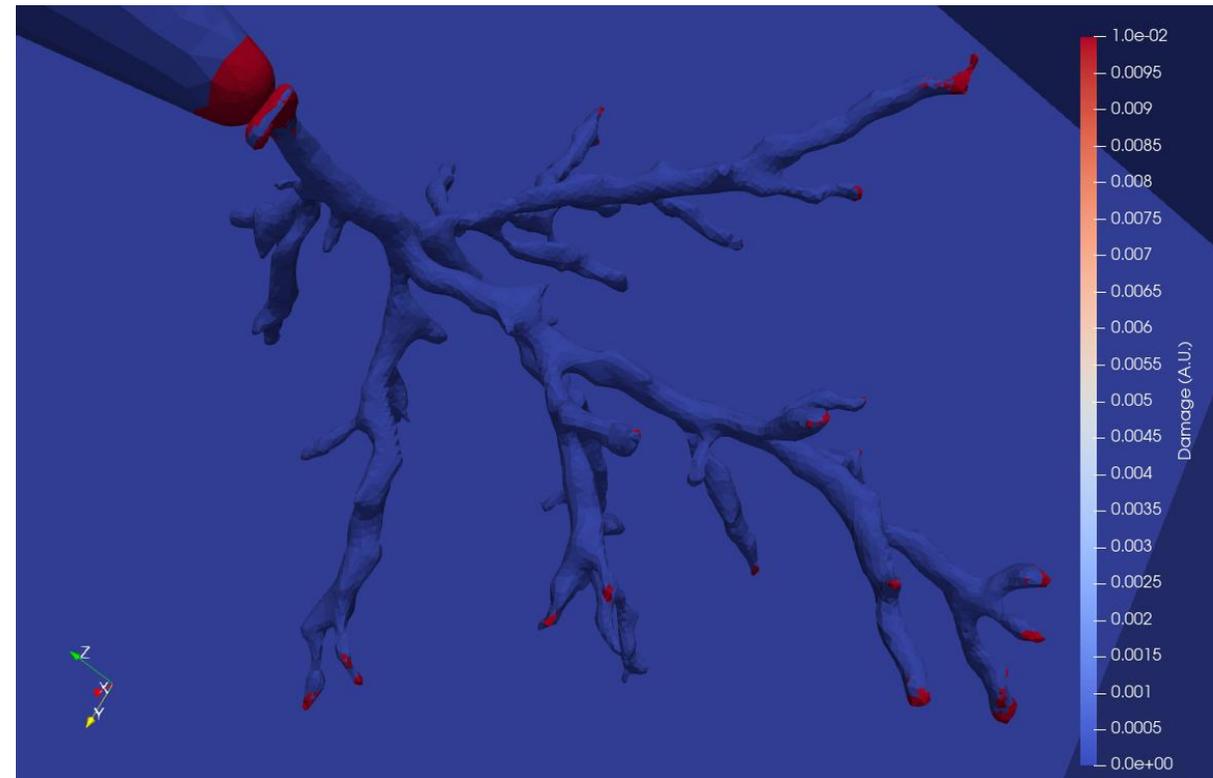
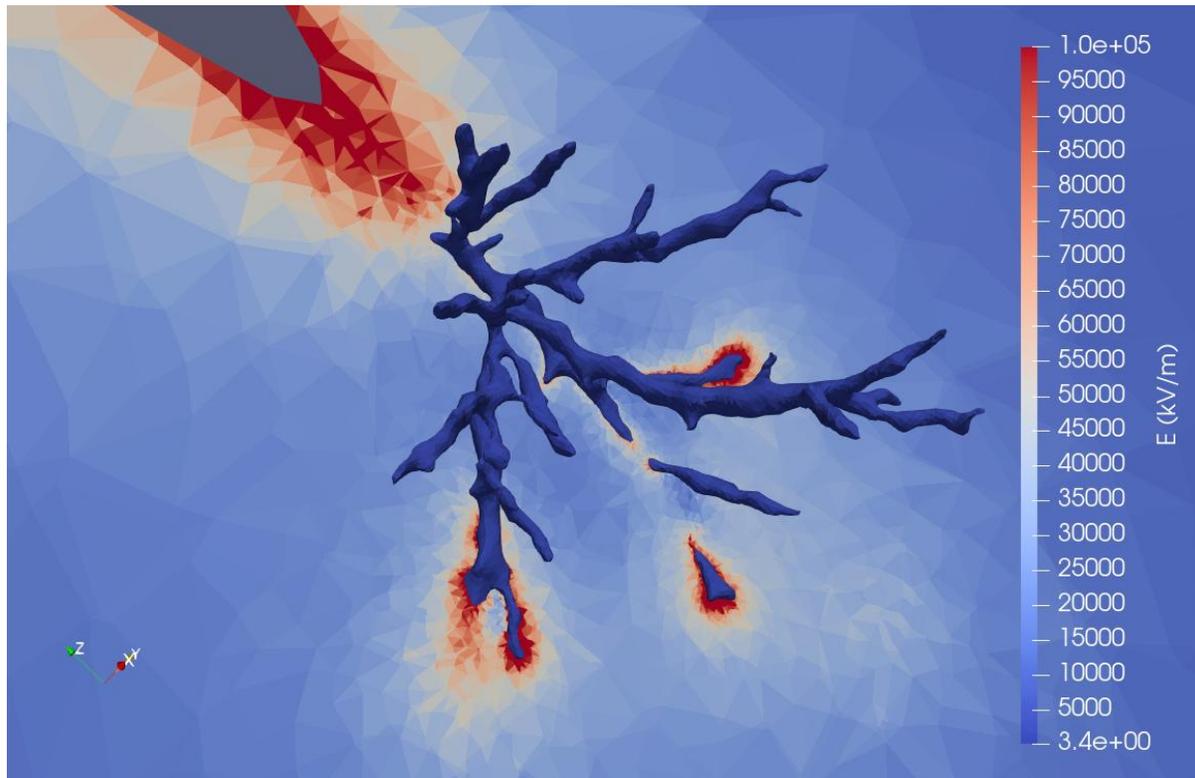
# Treeing

- 1.2 ms
- Point-Needle configuration
- **Gap 2 mm**
- 10 kV r.m.s
- Geometry obtained with a **CAT** scanner
- **Treeing inception phase**





# Treeing





Rimani sempre aggiornato con RSE perché

# #wemoversearch

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