ECM'08
Electron Cloud Mitigation 2008 (CARE-HHH Mini-Workshop)
20 – 21 November 2008, CERN

MEST

Multipactor Effect Simulation Tool

Work done under ESA AO 4025:
Surface Treatment and Coating for the Reduction of Multipactor
and Passive Intermodulation (PIM) Effects in RF Components

by

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Overview

For detecting multipactor in infinite parallel plate geometry

Determines initial multipactor susceptibility

For studying influence of secondary electron emission properties

Outline

Simplifications and limitations

Complete detailed simulation of electron cloud

Simple detailed realistic Secondary Electron Emission model

Results

Final comments

Electromagnetic field extremely simplified

Infinite parallel plate

$$F_z(t) = e\frac{V_o}{d}\sin(\omega t)$$

Only electric field

Homogeneous every where, only dependent of time

No relativistic effects

No space charge effects

Each electron moves alone in the unperturbed electric field

Each electron trajectory calculated independently

Exact analytical trajectory: emission event ⇒ impact event

event: time, position, velocity

No need to calculate trajectories, series of (time, position)

Initial stage or tendency (susceptibility) of multipactor discharge

All the electrons in the cloud are simulated individually

Detailed discrete branching process of multiplications and absorptions

Electron cloud: impact event queue ordered by time to be processed

Electron: object defined by impact event, can relate to emission event

At impact event, new electrons are generated by Secondary Emission

The simulations discrete event approach

loops along the queue

advance simulation time

generate new events

placing new event orderly in the queue

No resonant conditions are imposed

Simulation procedure

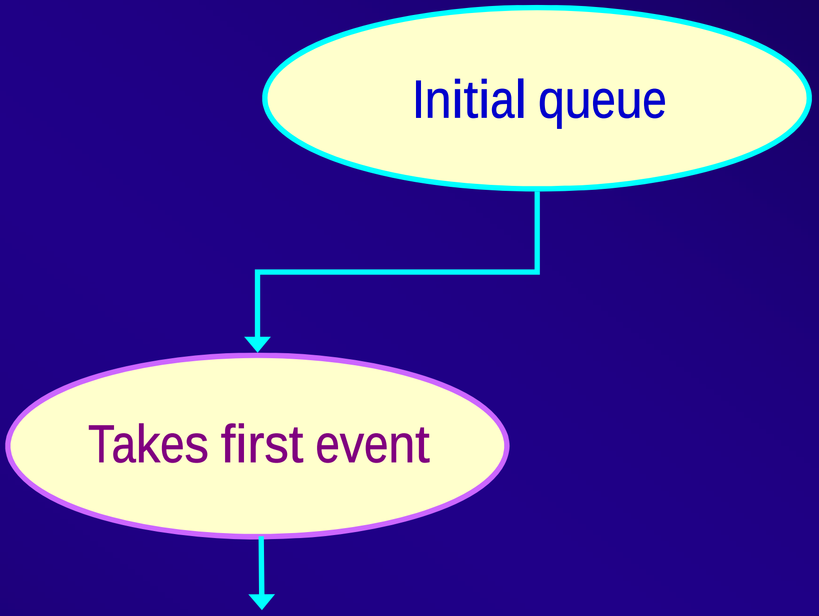
Initial queue: initial electrons, seeding electrons

Random $\mathfrak{D}$istribution (time, position, velocity) number ← user

time $\in$ $\mathfrak{D}$**U**niform(first period)

position $\in$ $\mathfrak{D}$**U**niform(first plate)

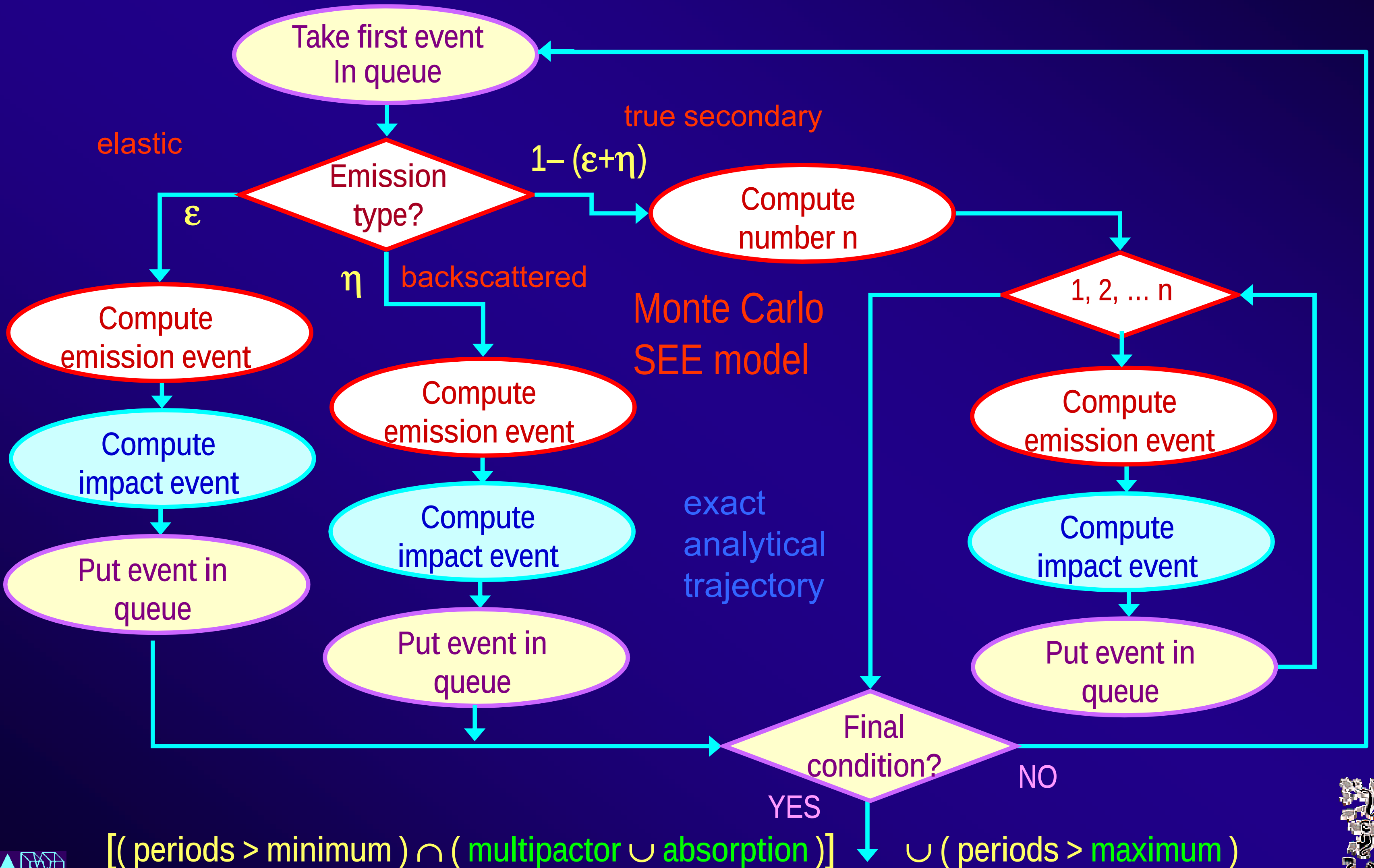
velocity $\in$ $\mathfrak{D}$**N**ormal(initial velocity)



Initial queue

Takes first event

Simulation procedure



Take first event
In queue

Emission type?

elastic

ε

Compute emission event

Compute impact event

Put event in queue

η

backscattered

Compute emission event

Compute impact event

Put event in queue

true secondary

1– (ε+η)

Compute number n

1, 2, … n

Compute emission event

Compute impact event

Put event in queue

Monte Carlo
SEE model

exact
analytical
trajectory

Final condition?

NO

YES

[(periods > minimum) ∩ (multipactor ∪ absorption)] ∪ (periods > maximum)

Monte Carlo Secondary Electron Emission Model

Impact event = (time, position, velocity) velocity $\Leftrightarrow (E_p, \varphi)$

emission event = (time, position, velocity) velocity $\Leftrightarrow (E, \theta, \zeta)$

TYPE OF EMISSION EVENT

probability $\Leftarrow$ SEE yield functions

Elastically reflected electron

$$P_e(E_p,\varphi) = \varepsilon(E_p,\varphi)$$

Inelastically backscattered electron

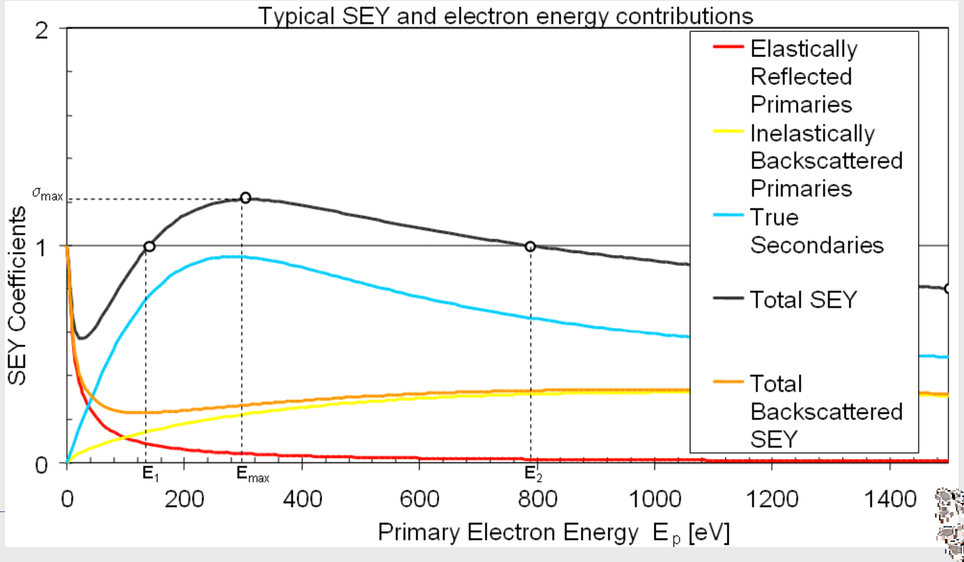
$$P_b(E_p,\varphi) = \eta(E_p,\varphi)$$

True secondary emission of n electrons

$$P_s(E_p,\varphi) = 1 - P_e(E_p,\varphi) - P_b(E_p,\varphi)$$

$n \in \mathfrak{D}$Poisson(impact velocity)

$$\langle n \rangle = \delta(E_p, \varphi) / P_s(E_p, \varphi)$$



Monte Carlo Secondary Electron Emission Model

SEE YIELD FUNCTIONS empirical

$$\varepsilon(E_p,\varphi) = \varepsilon(E_p)^{\cos(\varphi)}.C_2^{\;1-\cos(\varphi)}$$

$$C_2 = \chi\cdot\frac{\varepsilon(E_p)}{\eta(E_p)+\varepsilon(E_p)}$$

$$\varepsilon(E_p) = \frac{\varepsilon_1}{1+\frac{E_p}{E_{e_1}}} + \frac{\varepsilon_2}{1+\frac{E_p}{E_{e_2}}}$$

$\varepsilon(E_p \approx 0) = 0$

$$\eta(E_p,\varphi) = \eta(E_p)^{\cos(\varphi)}.C_1^{\;1-\cos(\varphi)}$$

$$C_1 = \chi\cdot\frac{\eta(E_p)}{\eta(E_p)+\varepsilon(E_p)}$$

$$\eta(E_p) = a\cdot(1-b\cdot E_p)\cdot E_p^{\gamma}\cdot\exp\left(-\left(\frac{E_p}{E_b}\right)^{\mu}\right)$$

$$\delta(E_p,\varphi) = \delta(E_p)\frac{k+1}{k+\cos(\varphi)}$$

$$\delta(E_p) = \delta_m\cdot\frac{s\cdot\frac{E_p}{E_m}}{s-1+\left(\frac{E_p}{E_m}\right)^{s}}$$

constants ⇐ Material properties

Monte Carlo Secondary Electron Emission Model

EMISSION EVENT: EMISSION ENERGY AND ANGLES

Elastically reflected electron $E = E_p\,,\ \theta = \varphi\,,\ \zeta = 0$

Inelastically backscattered electron

$E = E_p \cdot G_b(u)$ where $u = \in \mathfrak{D}\text{Uniform}[0, 1]$

$$G_b(u) = \alpha^{-1/n_b} \cdot (\arccos(1 - \beta \cdot u))^{1/n_b} \qquad \beta = 1 - \cos(\alpha) \qquad \alpha = \pi \cdot X_{cb}^{n_b}$$

inverse cumulative probability function, empirical

$X = G(u) \in \mathfrak{D}$istribution(probability $f(X)$)$[0, 1]$

where $f(X) = \dfrac{dF}{dX}$ $F \equiv G^{-1}$

$\theta = \varphi\,,\ \zeta = 0$

constants ⇐ Material properties

Monte Carlo Secondary Electron Emission Model

EMISSION EVENT: EMISSION ENERGY AND ANGLES

True secondary emission of n electrons

$$E = E_{remain} \cdot G_b(u) \qquad G_s(u) = \left(\frac{2}{\pi} \cdot \arctan\left(\sqrt{\tan(\frac{\pi}{2} \cdot X_{cs}) \cdot \tan(\frac{\pi}{2} \cdot u)} \right) \right)^{\frac{1}{n_s}}$$

$$E_{remain}(\text{initial}) = E_p$$

$$E_{remain}(\text{next}) = E_{remain} - E$$ ensures conservation of energy, realistic

$$X_{cs}(E_{remain}, \text{material})$$

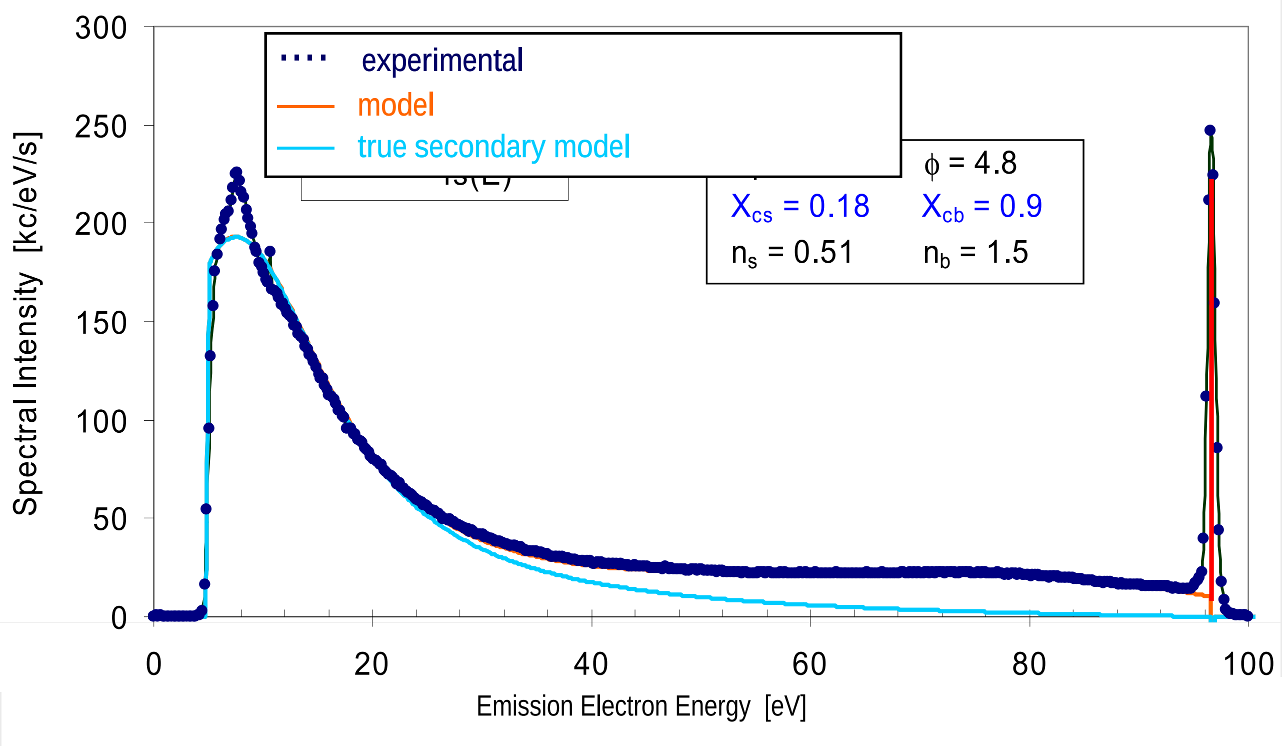
$$\theta = \arcsin\left(\sqrt{x^2 + y^2}\right) \quad \zeta = \arctan\left(y/x\right) \quad (x, y) = \in \mathfrak{D}\text{Uniform}(\text{Circle } x^2 + y^2 \leq 1)$$

constants ⇐ Material properties

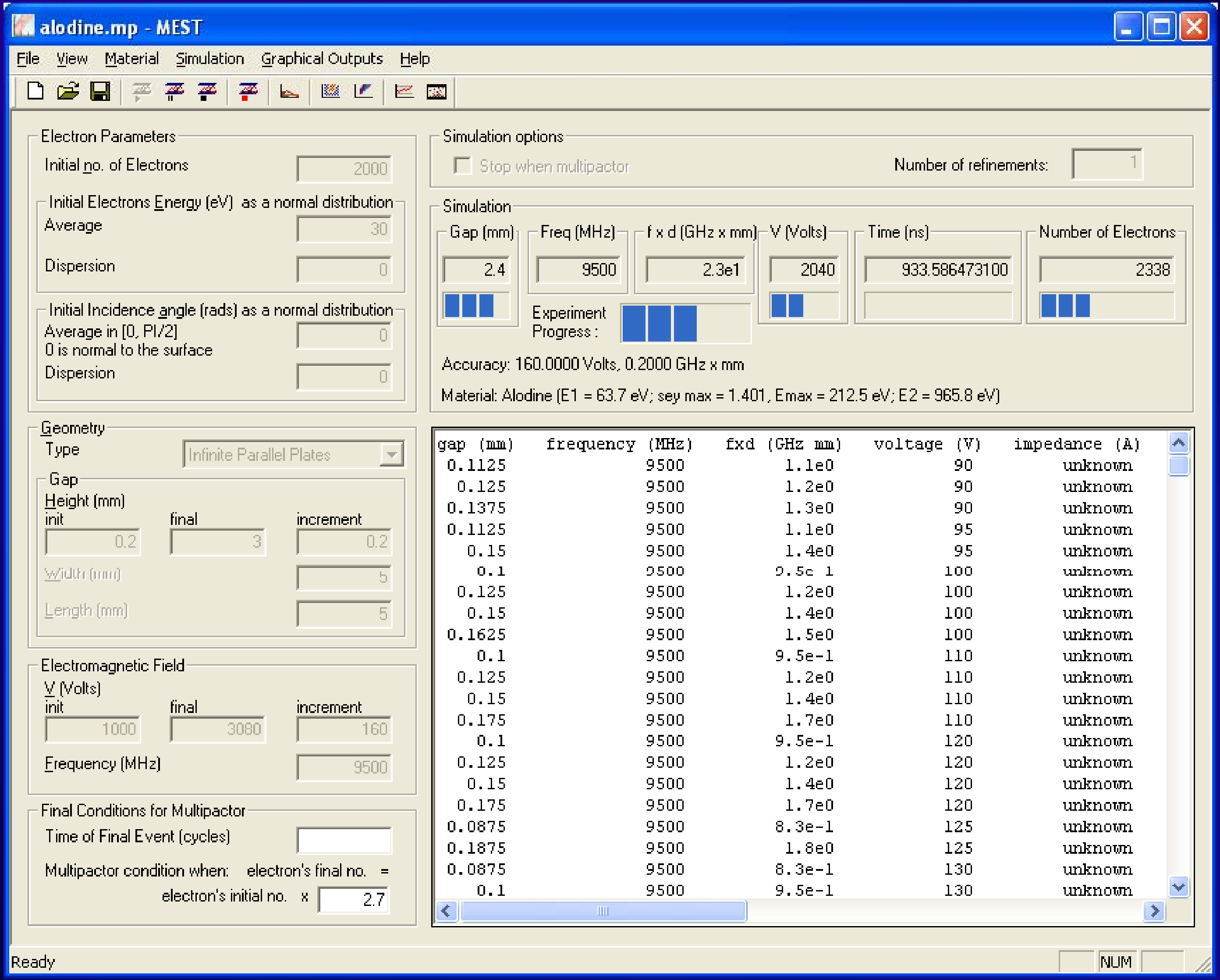
Monte Carlo Secondary Electron Emission Model

EMISSION PROBABILITY FUNCTIONS AND EXPERIMENTAL EDC

Clean Cu



MEST main window



Electron Parameters
Initial no. of Electrons: 2000
Initial Electrons Energy (eV) as a normal distribution
Average: 30
Dispersion: 0
Initial Incidence angle (rads) as a normal distribution
Average in [0, PI/2]
0 is normal to the surface: 0
Dispersion: 0

Geometry
Type: Infinite Parallel Plates
Gap
Height (mm)
init: 0.2 final: 3 increment: 0.2
Width (mm): 5
Length (mm): 5

Electromagnetic Field
V (Volts)
init: 1000 final: 3080 increment: 160
Frequency (MHz): 9500

Final Conditions for Multipactor
Time of Final Event (cycles):
Multipactor condition when: electron's final no. = electron's initial no. x 2.7

Simulation options
☐ Stop when multipactor
Number of refinements: 1

Simulation
Gap (mm): 2.4
Freq (MHz): 9500
f x d (GHz x mm): 2.3e1
V (Volts): 2040
Time (ns): 933.586473100
Number of Electrons: 2338
Experiment Progress :

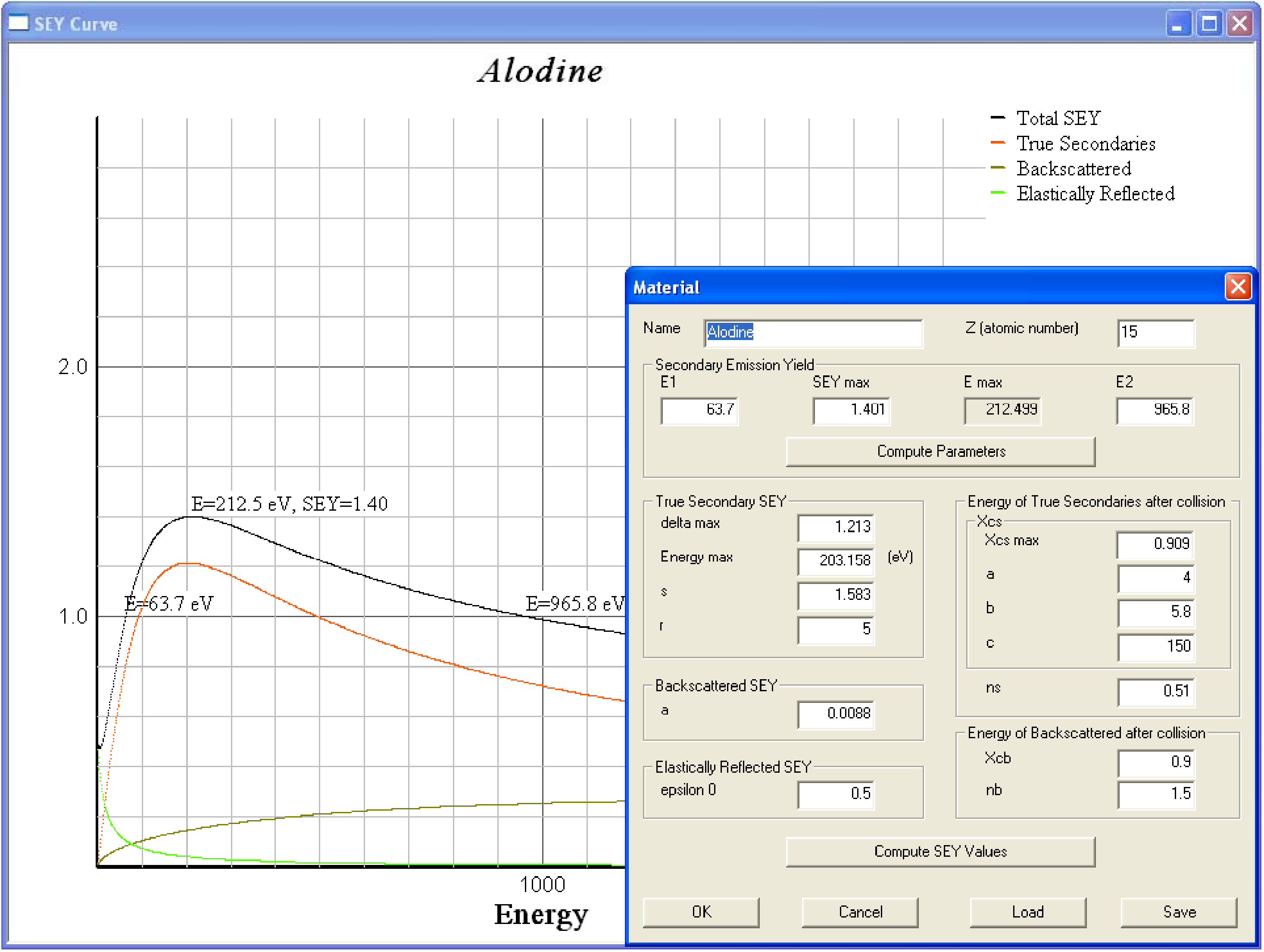
Accuracy: 160.0000 Volts, 0.2000 GHz x mm

Material: Alodine (E1 = 63.7 eV; sey max = 1.401, Emax = 212.5 eV; E2 = 965.8 eV)

```
gap (mm)    frequency (MHz)    fxd (GHz mm)    voltage (V)    impedance (A)
 0.1125               9500           1.1e0             90          unknown
  0.125               9500           1.2e0             90          unknown
 0.1375               9500           1.3e0             90          unknown
 0.1125               9500           1.1e0             95          unknown
   0.15               9500           1.4e0             95          unknown
    0.1               9500          9.5e-1            100          unknown
  0.125               9500           1.2e0            100          unknown
   0.15               9500           1.4e0            100          unknown
 0.1625               9500           1.5e0            100          unknown
    0.1               9500          9.5e-1            110          unknown
  0.125               9500           1.2e0            110          unknown
   0.15               9500           1.4e0            110          unknown
  0.175               9500           1.7e0            110          unknown
    0.1               9500          9.5e-1            120          unknown
  0.125               9500           1.2e0            120          unknown
   0.15               9500           1.4e0            120          unknown
  0.175               9500           1.7e0            120          unknown
 0.0875               9500          8.3e-1            125          unknown
 0.1875               9500           1.8e0            125          unknown
 0.0875               9500          8.3e-1            130          unknown
    0.1               9500          9.5e-1            130          unknown
```

Ready

MEST material SEE properties



Name: Alodine
Z (atomic number): 15

Secondary Emission Yield
E1: 63.7
SEY max: 1.401
E max: 212.499
E2: 965.8

True Secondary SEY
delta max: 1.213
Energy max: 203.158 (eV)
s: 1.583
r: 5

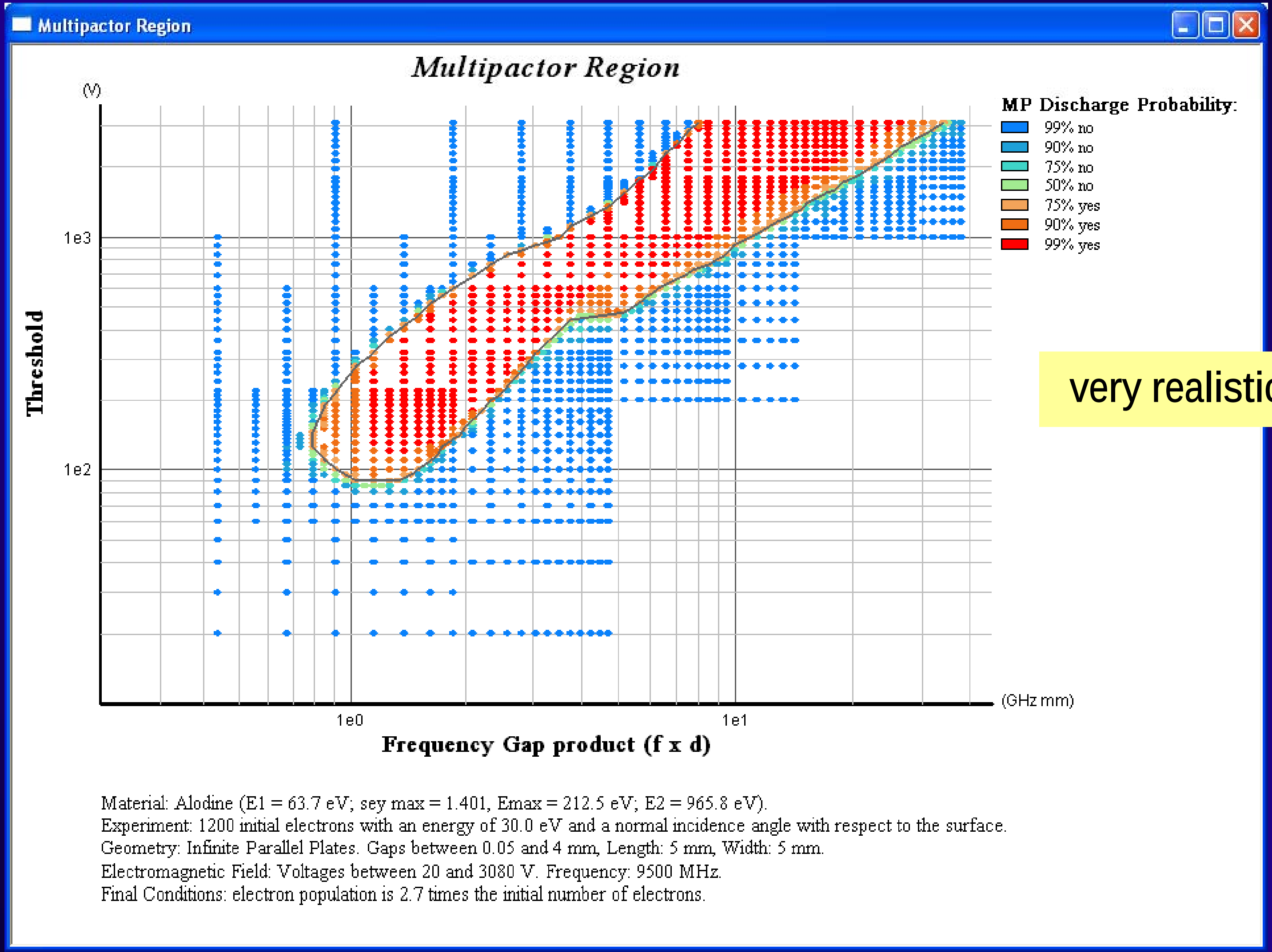
Energy of True Secondaries after collision
Xcs
Xcs max: 0.909
a: 4
b: 5.8
c: 150
ns: 0.51

Backscattered SEY
a: 0.0088

Energy of Backscattered after collision
Xcb: 0.9
nb: 1.5

Elastically Reflected SEY
epsilon 0: 0.5

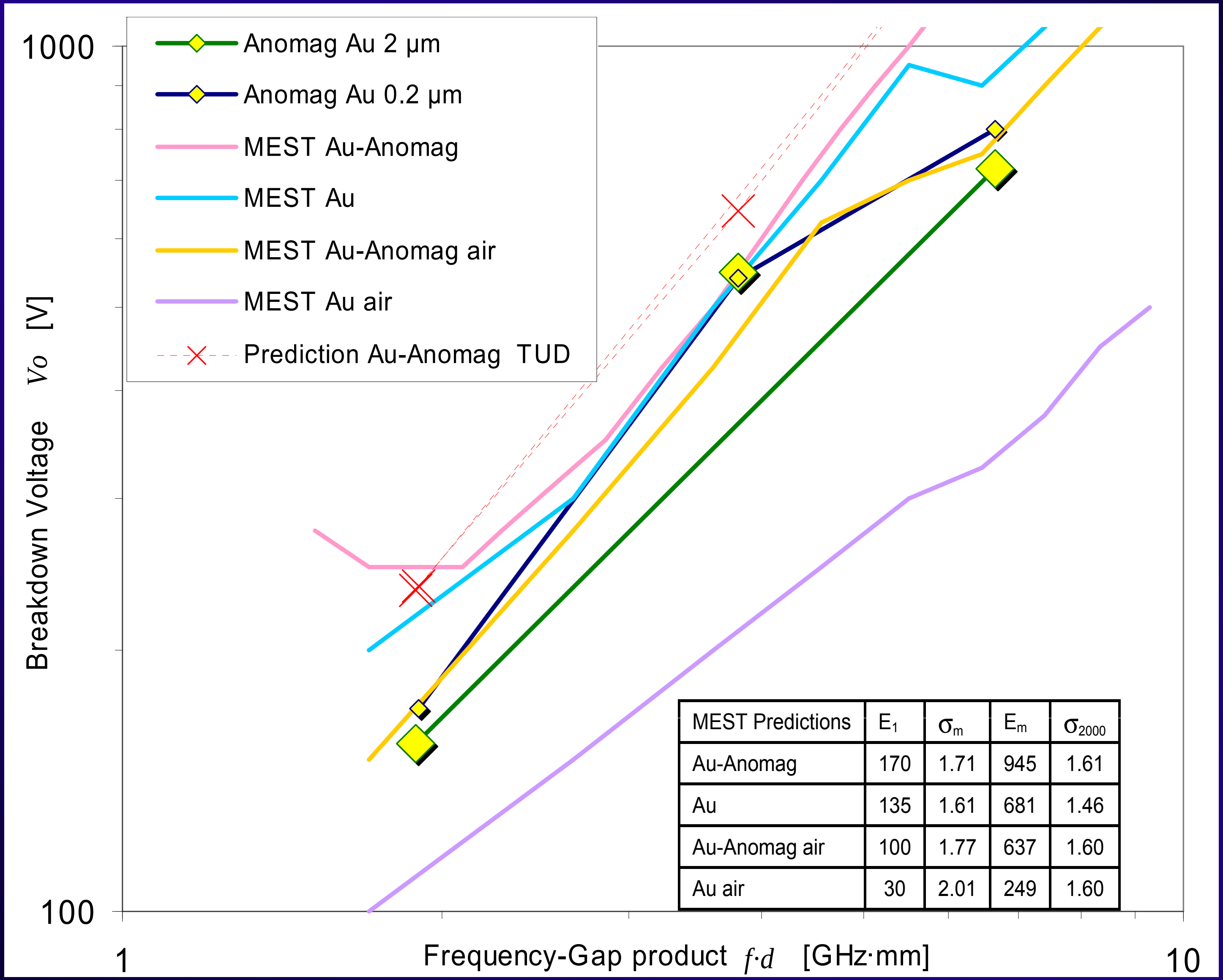
MEST results: multipactor region



Material: Alodine (E1 = 63.7 eV; sey max = 1.401, Emax = 212.5 eV; E2 = 965.8 eV).
Experiment: 1200 initial electrons with an energy of 30.0 eV and a normal incidence angle with respect to the surface.
Geometry: Infinite Parallel Plates. Gaps between 0.05 and 4 mm, Length: 5 mm, Width: 5 mm.
Electromagnetic Field: Voltages between 20 and 3080 V. Frequency: 9500 MHz.
Final Conditions: electron population is 2.7 times the initial number of electrons.

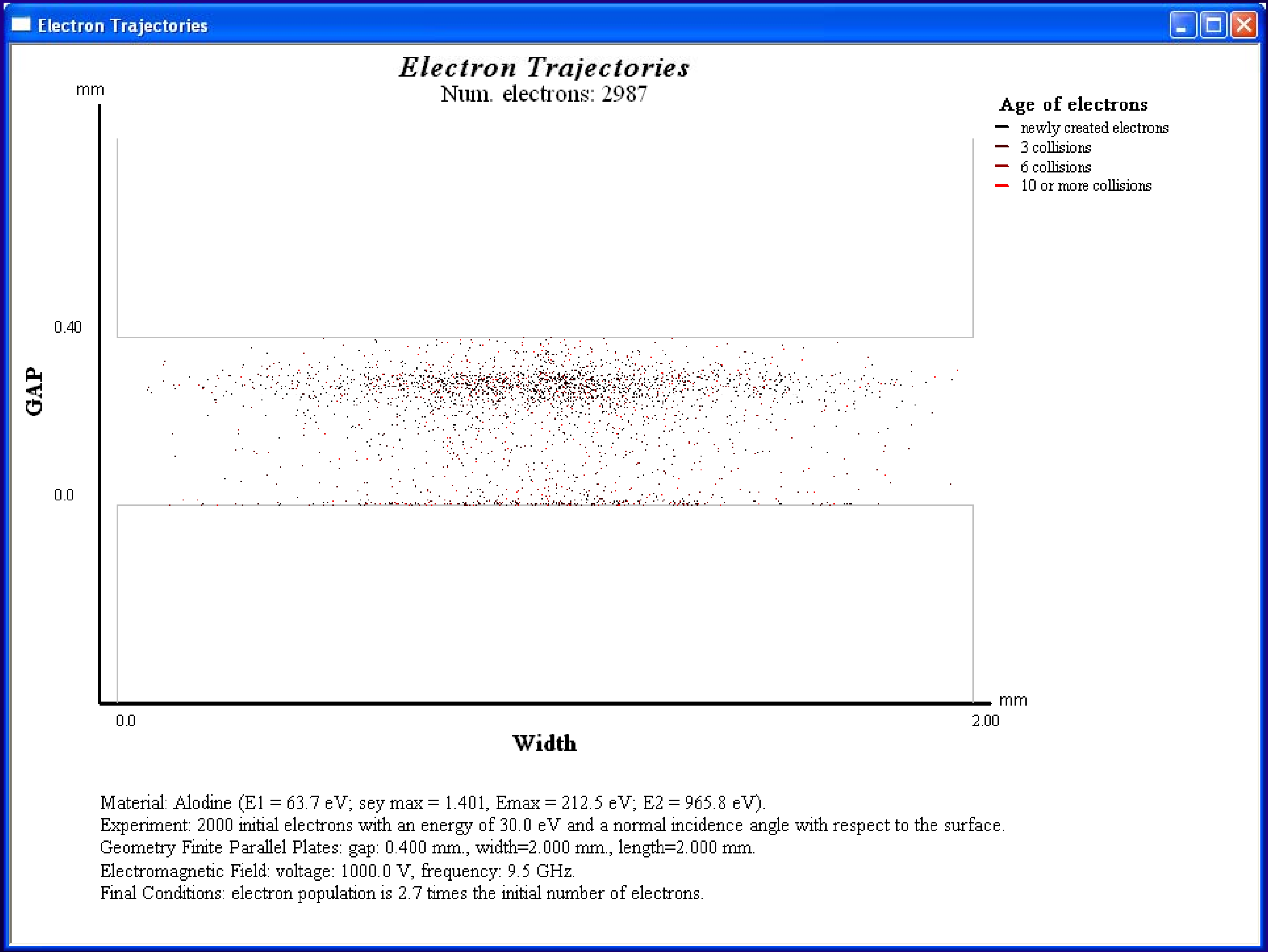
very realistic

MEST results: multipactor region



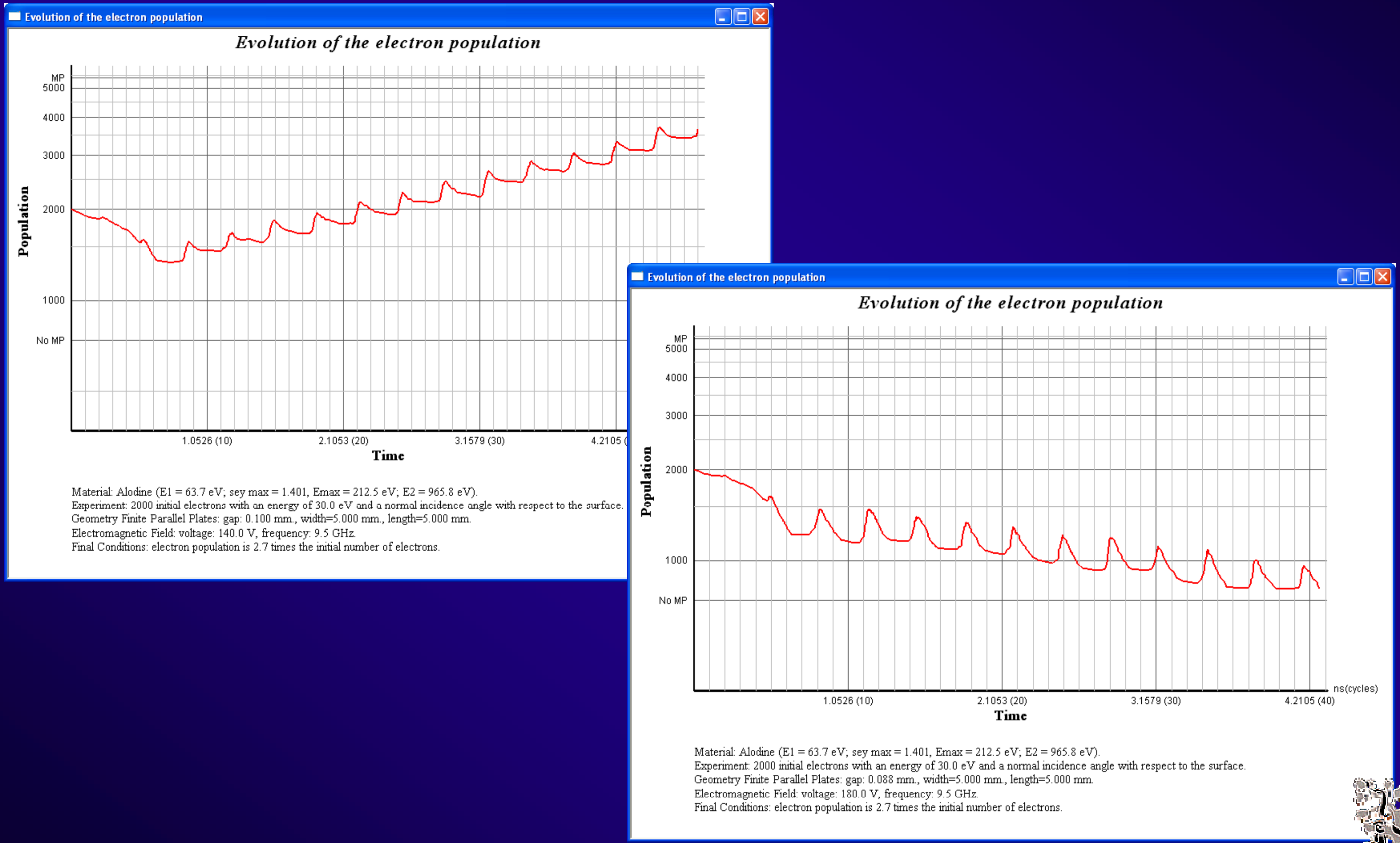
MEST Predictions	E_1	σ_m	E_m	σ_{2000}
Au-Anomag	170	1.71	945	1.61
Au	135	1.61	681	1.46
Au-Anomag air	100	1.77	637	1.60
Au air	30	2.01	249	1.60

MEST results: electron cloud evolution



Material: Alodine (E1 = 63.7 eV; sey max = 1.401, Emax = 212.5 eV; E2 = 965.8 eV).
Experiment: 2000 initial electrons with an energy of 30.0 eV and a normal incidence angle with respect to the surface.
Geometry Finite Parallel Plates: gap: 0.400 mm., width=2.000 mm., length=2.000 mm.
Electromagnetic Field: voltage: 1000.0 V, frequency: 9.5 GHz.
Final Conditions: electron population is 2.7 times the initial number of electrons.

MEST results: electron population evolution

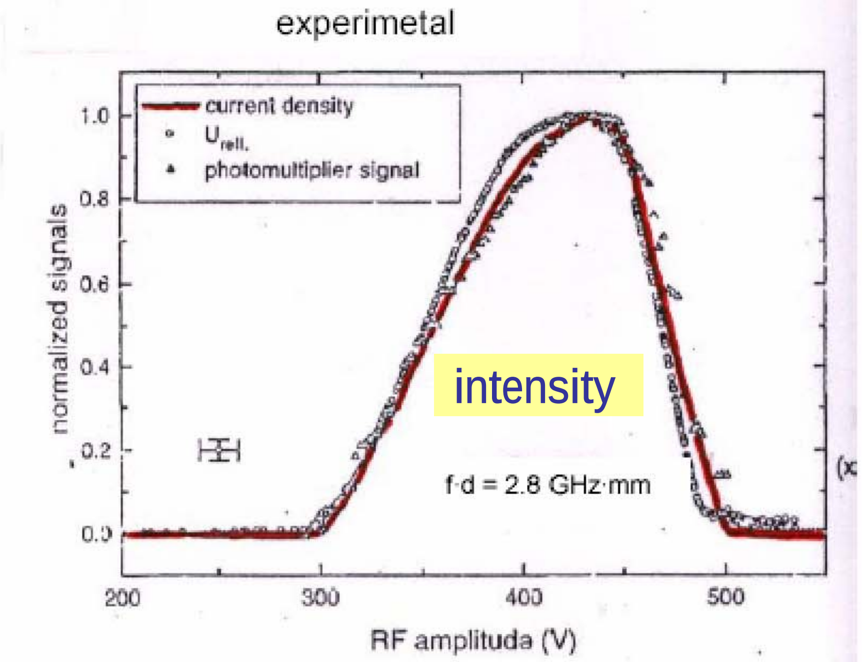


Material: Alodine (E1 = 63.7 eV; sey max = 1.401, Emax = 212.5 eV; E2 = 965.8 eV).
Experiment: 2000 initial electrons with an energy of 30.0 eV and a normal incidence angle with respect to the surface.
Geometry Finite Parallel Plates: gap: 0.100 mm., width=5.000 mm., length=5.000 mm.
Electromagnetic Field: voltage: 140.0 V, frequency: 9.5 GHz.
Final Conditions: electron population is 2.7 times the initial number of electrons.

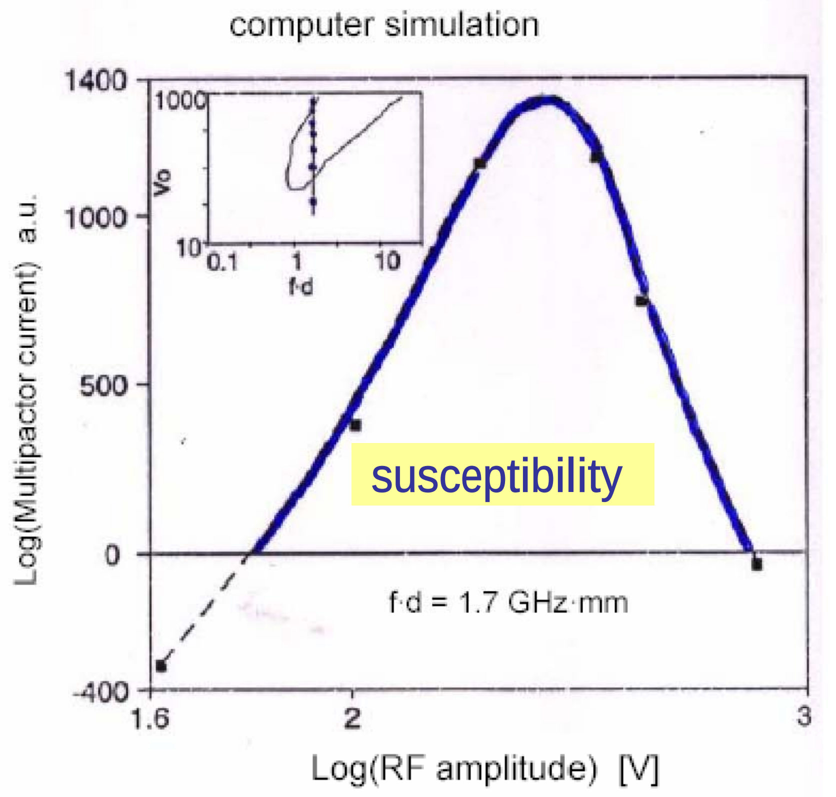
Material: Alodine (E1 = 63.7 eV; sey max = 1.401, Emax = 212.5 eV; E2 = 965.8 eV).
Experiment: 2000 initial electrons with an energy of 30.0 eV and a normal incidence angle with respect to the surface.
Geometry Finite Parallel Plates: gap: 0.088 mm., width=5.000 mm., length=5.000 mm.
Electromagnetic Field: voltage: 180.0 V, frequency: 9.5 GHz.
Final Conditions: electron population is 2.7 times the initial number of electrons.

MEST results: electron cloud internal parameters

Precursor of MEST



Dependence of the current density, amplitude of the reflected wave and emitted light on the rf amplitude at a pressure of 1×10^{-4} Pa. The error bar represents the absolute error. Relative errors are comparable to the symbol size.



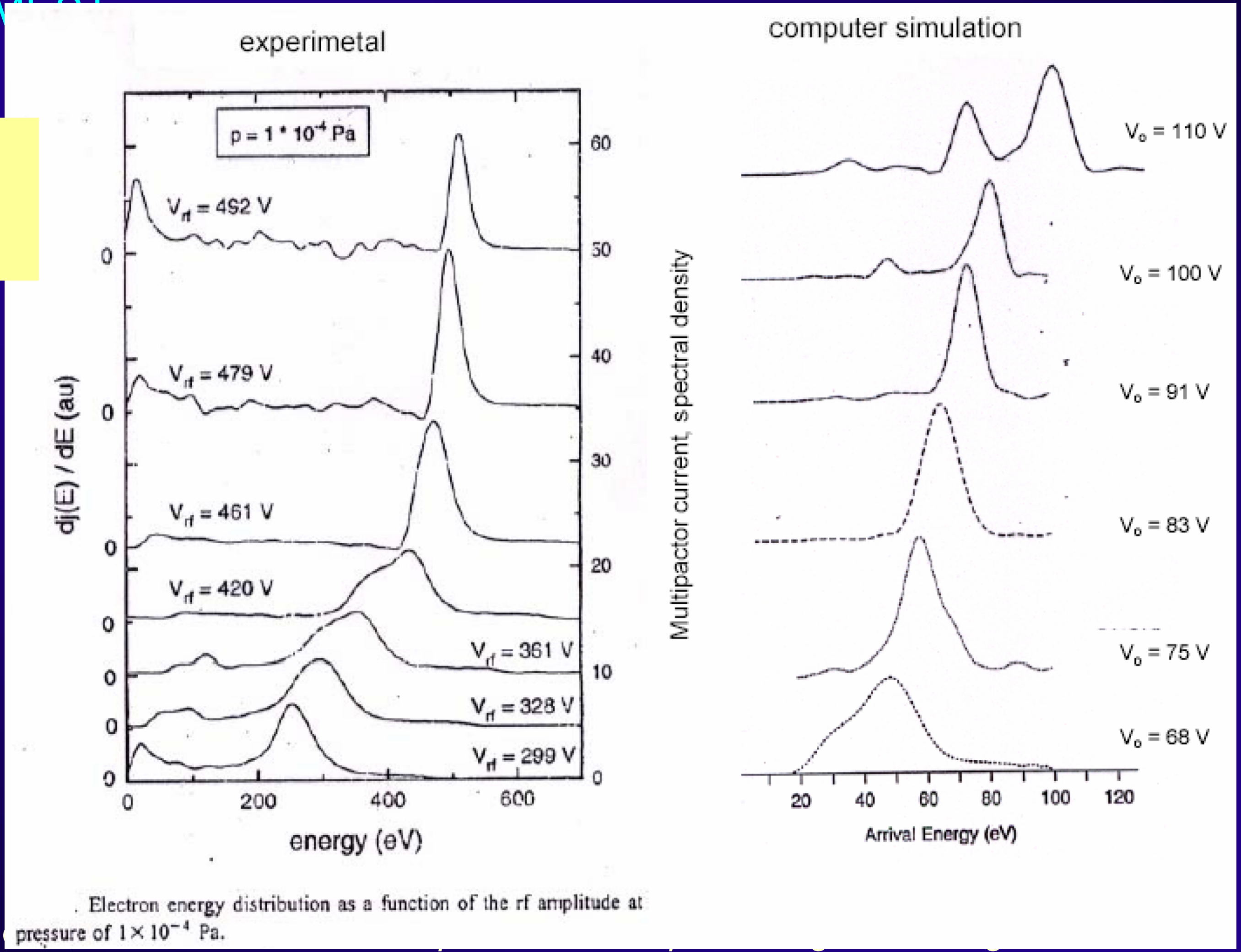
F. Höhn et al, *The transition of a multipactor to a low pressure gas discharge.*

Phys. Of Plasmas **4**, (10), pp. 940947 (1997)

MEST results: electron cloud internal parameters

Precursor of M

Bunching of electron energies



. Electron energy distribution as a function of the rf amplitude at pressure of 1×10^{-4} Pa.

F. Höhn

Phys. Of Plasmas **4**, (10), pp. 940947 (1997)

FINAL COMMENTS

- Multipactor predictions very realistic in spite of strong simplifications in RF field
- Encouragement for using as a tool for testing SEE models and the influence of SEE parameters
- It is still a question how precise should be the SEE model for multipactor predictions
- Are experimental BSE curves important for multipactor prediction?
- Many SEE material parameters are not well known
- which are “universal”?
- which are only dependent on Z?
- which need experimental measurement?
- Is there a need for a materials SEE data base with more than SEY curves?
- Can SEE models explain abnormal SEY curves of rough surfaces?