

Theory and modeling of limiting factors in high-gradient accelerating structures

**Gregory Nusinovich, Rami Kishek and
Victor Granatstein**

*IREAP, University of Maryland,
College Park, MD*

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MOTIVATION

The theory and modeling of the phenomena which limit accelerating gradients is not a new topic but recent experimental results have modified the picture of which factors are most important.

We propose a comprehensive program of theoretical studies of all the corresponding phenomena.

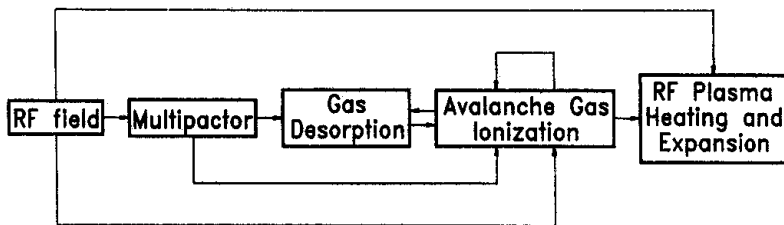
We plan to develop a predictive model, which will allow one to design surfaces and structures immune to the RF breakdown

One expected outcome will be the development of new codes that will be made available to CLIC, SLAC and other research teams for comparison with experimental and theoretical results

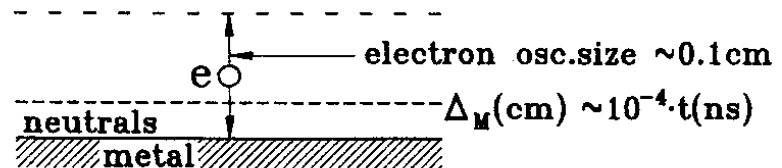
Possible scenario of pulse shortening

A number of experimental data indicate that the following scenario of the RF breakdown is possible:

- occurrence of the multipactor near the metallic surface,
- multipactor bombardment and the RF heating of the walls stimulates desorption of gas molecules and atoms from the metallic surface,
- the gas undergoes an avalanche RF breakdown,
- resultant plasma terminates the RF pulse.



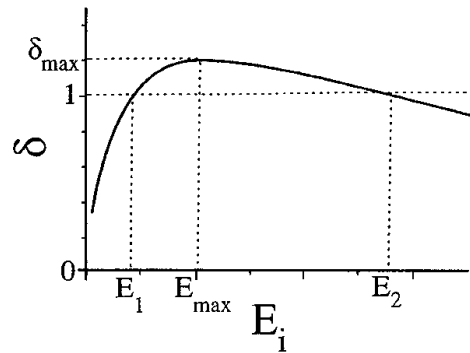
plasma boundary - ↑ $-\Delta_p(\text{cm}) \sim 3 \cdot 10^{-2} \cdot t(\text{ns})$



Multipactor

Multipactor depends on many variables:

- Geometry
- Surface material and finish
- Surface coating and conditioning
- Surface charging
- Vacuum conditions.



single-surface MP

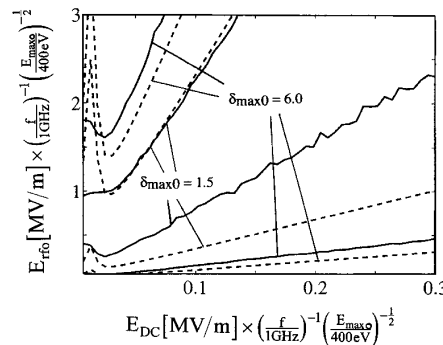
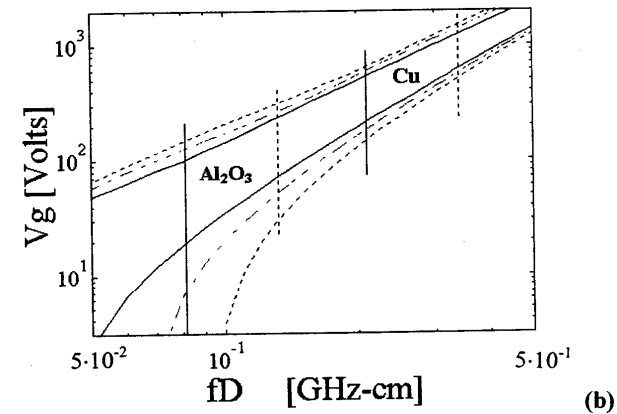


FIG. 5. Multipactor regions derived analytically (dashed) compared with the ones obtained through Monte Carlo simulations (solid) for $\delta_{\max 0} = 1.5$ and $\delta_{\max 0} = 6.0$. Here, $E_{0m}/E_{\max 0} = 0.005$.

double-surface MP



(a) Susceptibility curve showing the regions of (V_{g0}, fD) space prone to 1st and 3rd order multipactors, for BiCs_3 , C (diamond), Fe, and Pt. The secondary electrons are assumed to be emitted with zero velocities.

(b) Susceptibility curve for OHFC Cu and Al_2O_3 (1st order) assuming monoenergetic non-zero emission energy: $E_0 = 2$ eV (—); 5 eV (---) and 10 eV (...).

Reference: R. A. Kishek, Y. Y. Lau et al., “*Multipactor Discharge on Metals and Dielectrics: Historical Review and Recent Theories*”, Physics of Plasmas, vol. 5, 2120 (1998);

R. A. Kishek and Y. Y. Lau, “*Multipactor Discharge on a Dielectric*”, PRL, vol. 80, 193 (1998)

Multipactor (cont.)

Our plans:

- With the use of available code to extend theoretical studies of multipactor to more realistic (CLIC related) situations,**
- To analyze the dependence of multipactor phenomenon on the frequency, power level, and vacuum conditions**

Note: collaboration with other groups working in this field (SLAC, Tech-X, ANL, NRL) is desirable.

Surface physics

Surface roughness (macro- and micro-scales) and molecular absorption enhance the field emission. This process can be treated using available code.

- **Thermal, field, and photoemission components treated to evaluate total current (not simply current density): Model accounts for non-uniformity in geometry, temperature, and work function over the emitter surface.**
- **Work function modification by sub-monolayer coating.**
- **Environmental change due to absorption/desorption.**
- **Code has been used to model gated field emitter arrays laser-illuminated tungsten wires, photo-dispenser cathodes and illuminated Cesium surfaces:**
- **Agreement between emitted current and quantum efficiency experimental data and theoretical predictions for variety of cathodes**

References:

- K. L. Jensen, D. W. Feldman, P. G. O'Shea, "Time dependent models of field-assisted photoemission", J. Vac. Sci. Technol. B23, 621 (2005).
- K. L. Jensen, D. W. Feldman DW, P. G. O'Shea, "The quantum efficiency of dispenser photocathodes: Comparison of theory to experiment", Appl. Phys Lett. 85, 5448 (2004).
- K. L. Jensen, "On the application of quantum transport theory to electron sources," Ultramicroscopy 95, 29 (2003).
- K. L. Jensen, C. M. Marrese-Reading, "Emission statistics and the characterization of array current", J. Vac. Sci. Technol. B21, 412 (2003).

Desorption and ionization

Desorption of molecules from a metallic wall and the gas ionization can be studied with the use of available Fokker-Planck kinetic code.

This code includes electron energization by the RF field in the presence of inelastic electron-neutral collisions with molecules.

It has been a useful tool in producing a fully kinetic description of air breakdown and has been successfully benchmarked against some experimental data.

References:

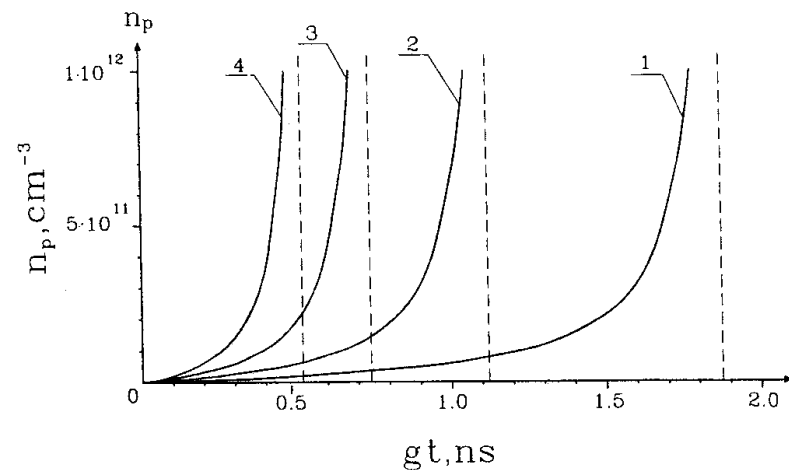
K. Papadopoulos, G. Milikh, A. V. Gurevich et al., “*Triggering the HF breakdown of the atmosphere by barium release*”, J. Geophys. Res., vol. 98, 17, 593 (1993),

G. Nusinovich, G. Milikh and B. Levush, “*Removal of halocarbons from air with high-power microwaves*”, J. Appl. Phys., vol. 80, 7, 4189 (1996).

Avalanche RF breakdown as a result of explosive instability

It seems possible that the plasma density in the breakdown grows in the explosive manner, i.e. as

$$n_p \propto \frac{1}{t - t_e}$$



Our goal will be:

- 1) To verify the validity of this model of explosive instability,
- 2) To study the effect of various conditions (surface material, RF field gradient and distribution, ionization potential and ionization cross-section, vacuum vs electro-negative gas filling etc) on this explosion time.

Plans:

**a) to form a multi-disciplinary team consisting of
R. Kishek – multipactor,
G. Milikh – physics and chemistry of RF breakdown,
K. Jensen – surface physics,**

**b) to solve the multi-disciplinary problem of
RF breakdown by developing a predictive model,
which allows us to design surfaces and structures
that are immune to breakdown.**

REQUEST: \$250K/YEAR for 3 years

**Note: collaboration with SLAC people (V. Dolgashev) working on
this problem is highly desirable**