Dielectric Barrier and Corona Discharges

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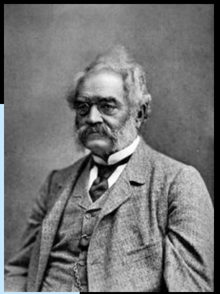
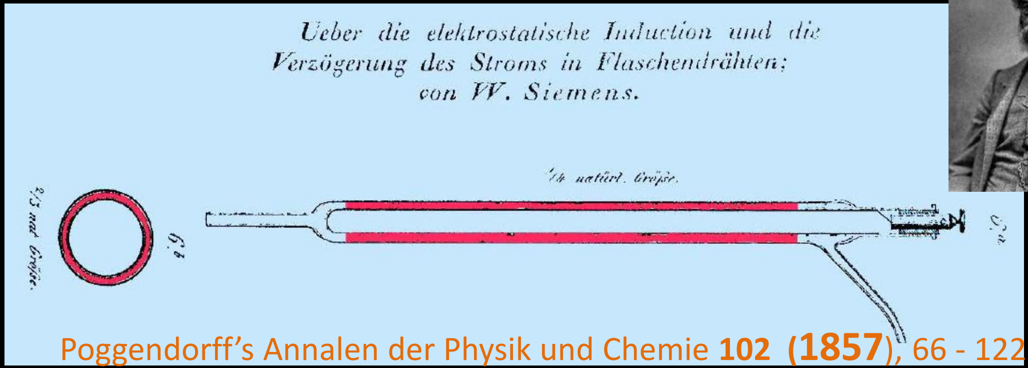
Why using Corona and DBDs?





Poggendorff's Annalen der Physik und Chemie **102** **(1857)**, 66 - 122

Technological motivations

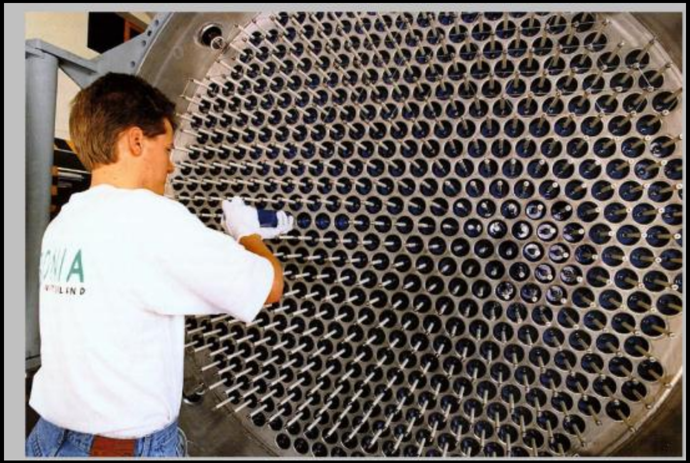
Atmospheric plasma sources:

- Cost reduction
- Works in surrounding air

Corona and DBD

Flexible size

Chemical efficiency

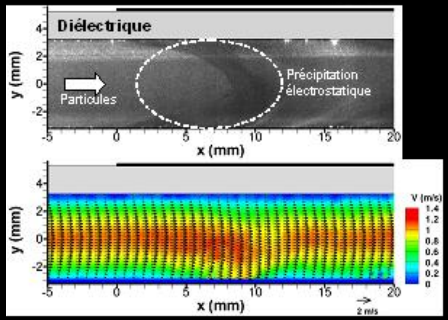


O_3 production

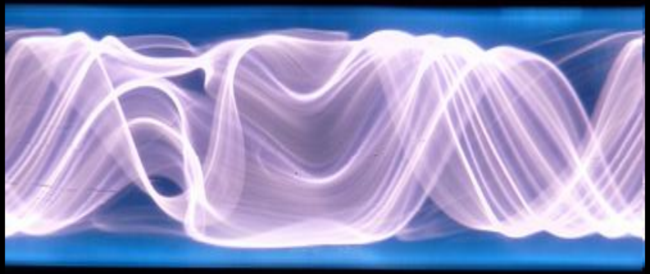
Main applications of Corona and DBD

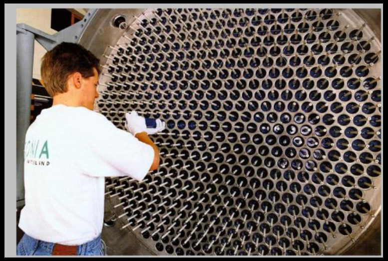
Flow control

Electrostatic precipitation



lighting





O_3 production

Ions wind

UV emission

3 body reactions

Corona and DBD

Very good to prevent gas heating

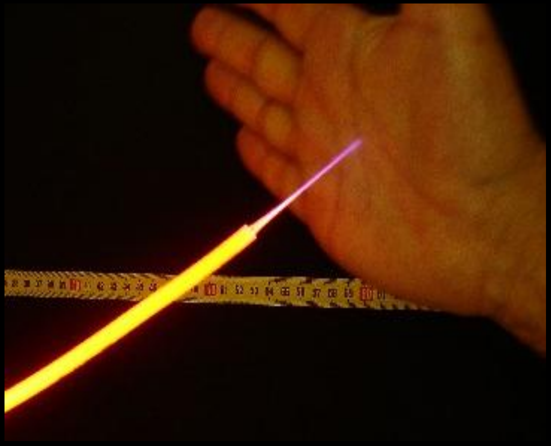
Surface reactivity

Synergy of all

Plasma/catalyst coupling

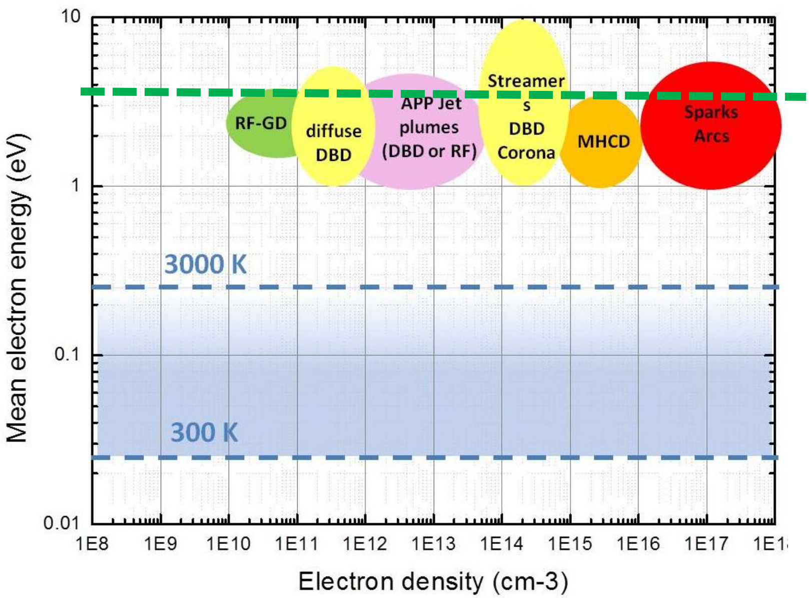
(air treatment, solar fuels)

Surface functionalization



Biomedical applications

Why Atmospheric Pressure Plasmas heat the gas?



Atmospheric pressure: $n_{gas} \approx 2.5 \times 10^{19}\ cm^{-3}$

What is different at higher pressure?

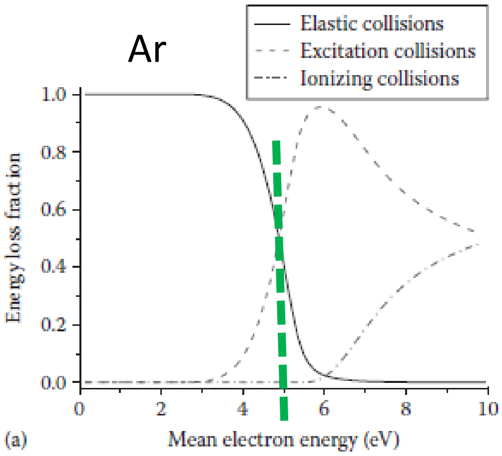
Collision frequency increases

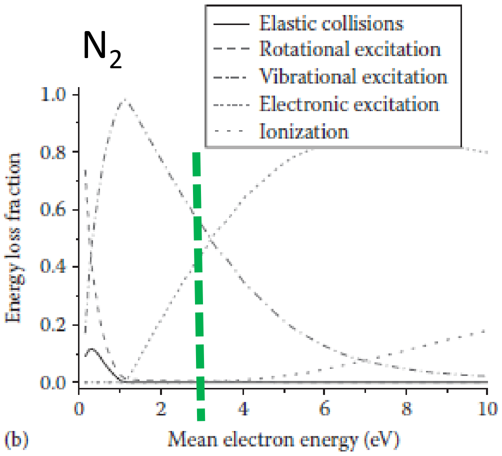
$$\lambda = \frac{\langle \upsilon \rangle}{\nu_n} = \frac{1}{n_n \cdot \sigma_n}$$

e- mean free path ≈ 500 nm

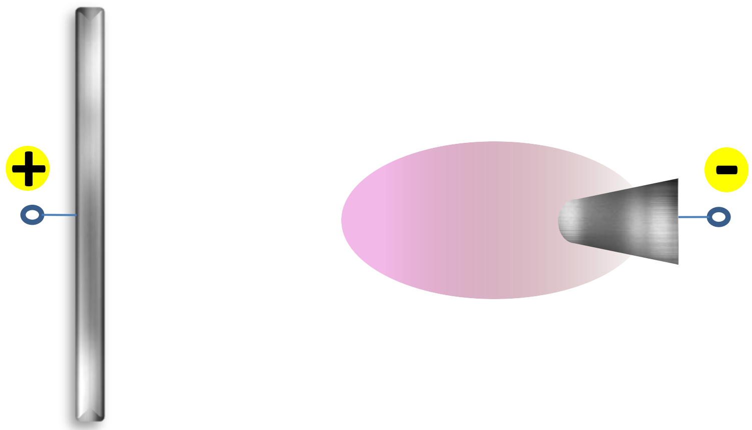
electrons collisions are mostly :

- elastic collisions (atomic gases)
- vibrational excitation (molecular gases





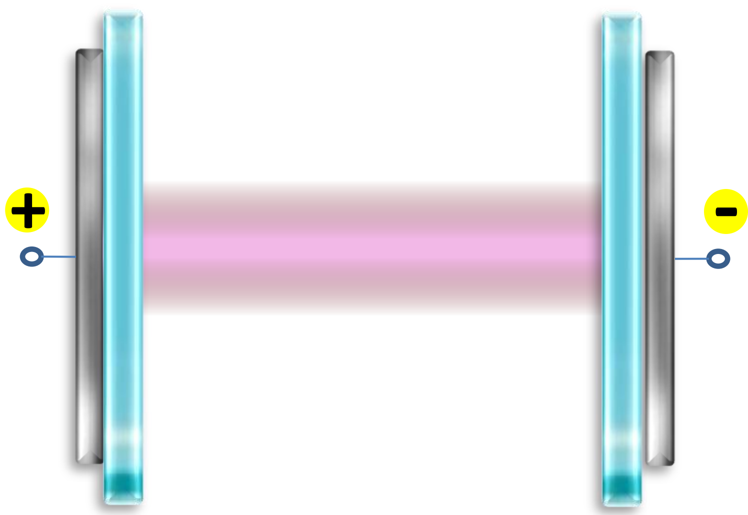
How to avoid gas heating ?



Very quickly, plasma is easier to sustain where it has started

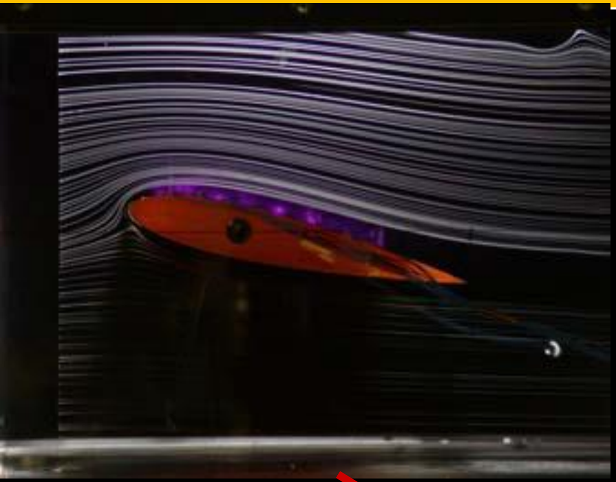
Arcing, high current, strong heating

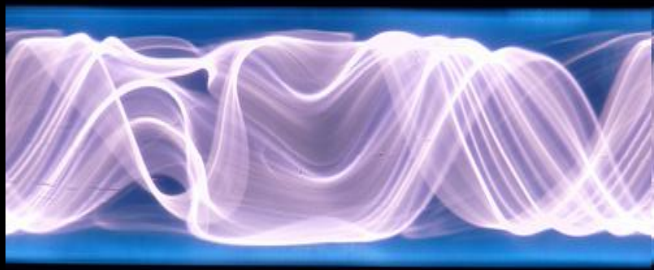
How to prevent Arcing ?



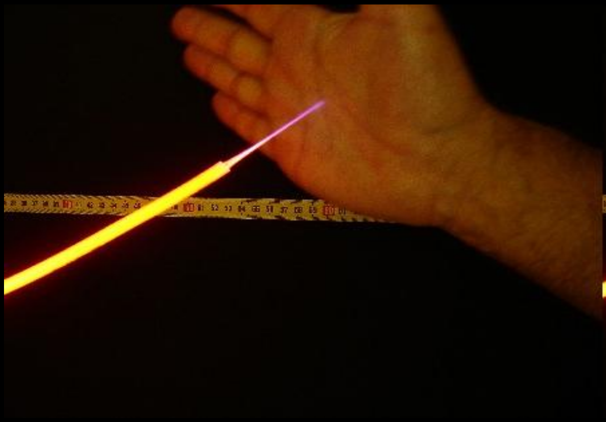
- Limit the current (resistive discharge)
- Voltage pulse shorter than arc development (<100 ns)
- **Strongly non uniform E field (Corona)**
- **Dielectric between the electrode (DBD)**

Coronas and DBDs: Atmospheric pressure plasma sources





Most of the time, filamentary discharges



Semantic confusions…

"Discharge": any flow of electrical current through ionized gas (extension of initial meaning)

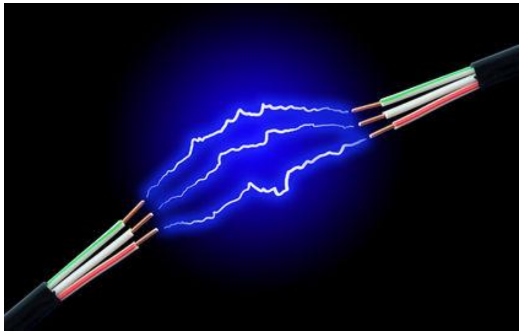
"self-sustained" discharge = produce its own current that does not depends on any external source (UV, radioactivity, etc…)

Coronas and DBDs, are "transient" self-sustained discharges

"breakdown" ≠ "ignition" ≠ "onset"

Corona discharges especially can develop at "onset" voltage lower than "breakdown voltage"

"filament" ≠ "streamer"   streamer = a breakdown mechanism



"Corona" and "DBDs" CONFIGURATIONs are reactor geometries

"DBDs" and Corona DISCHARGEs = more than just 2 types of discharges. Often developing with Townsend breakdown or Streamer breakdown mechanism

Outline

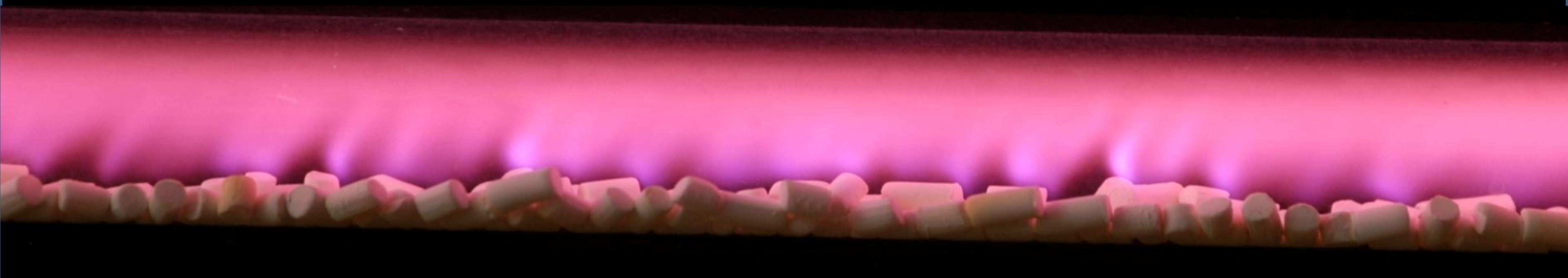
I. **Breakdown mechanisms**
   a) Townsend mechanism
   b) Streamer mechanism

II. **Corona discharges**

III. **What is a Dielectric Barrier Discharge?**
   a) Electrical characteristics
   b) Development of a single filament
   c) Role of the dielectric?

IV. **Role of surface vs gas phase dynamics**
   a) Interaction between filaments
   b) Diffuse discharges

V. **Confinement and gas motion**



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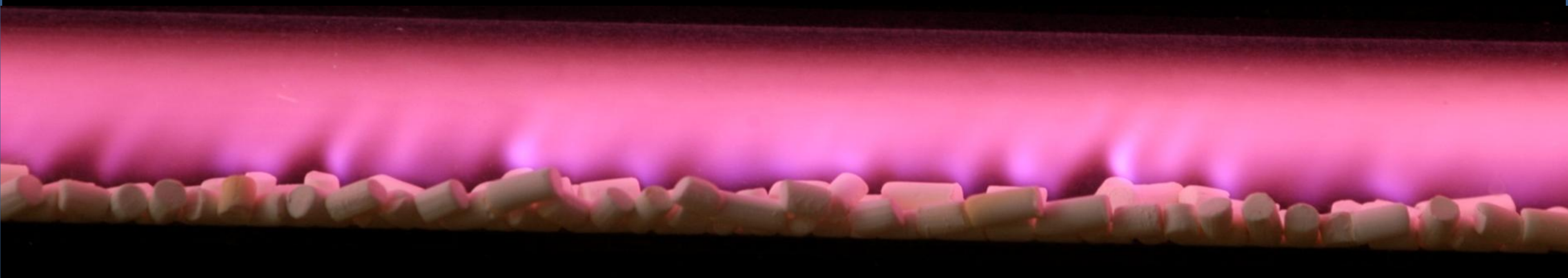
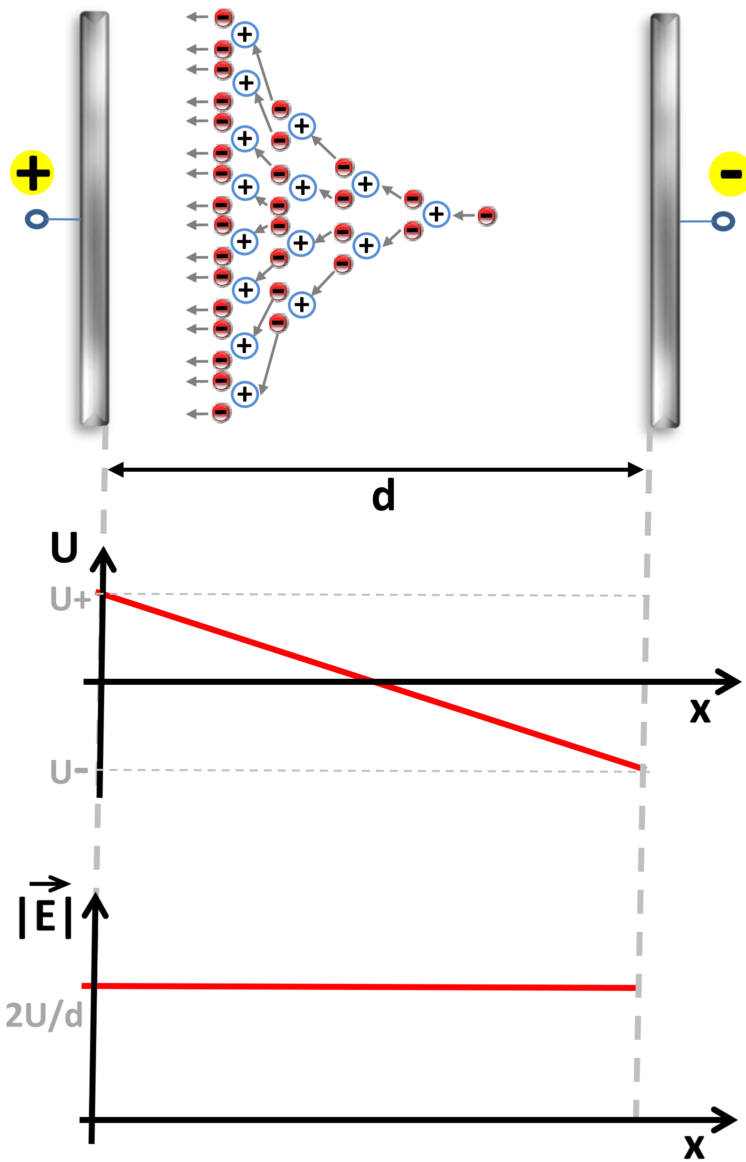


Townsend breakdown mechanism



Naturally $n_e \approx 10^3 cm^{-3}$ (radioactivity, etc...)

$$dn = \alpha n \cdot dx$$

$$n(x) = n_0 \exp(\alpha x)$$

$$j_-(x) = j_-(0) \exp(\alpha x)$$

α – number of ionization acts from 1 e- drifting in E per unit of length

$$\frac{\alpha}{p} = A \exp\left(-B\frac{p}{E}\right)$$

α is a steep function of E/n_g

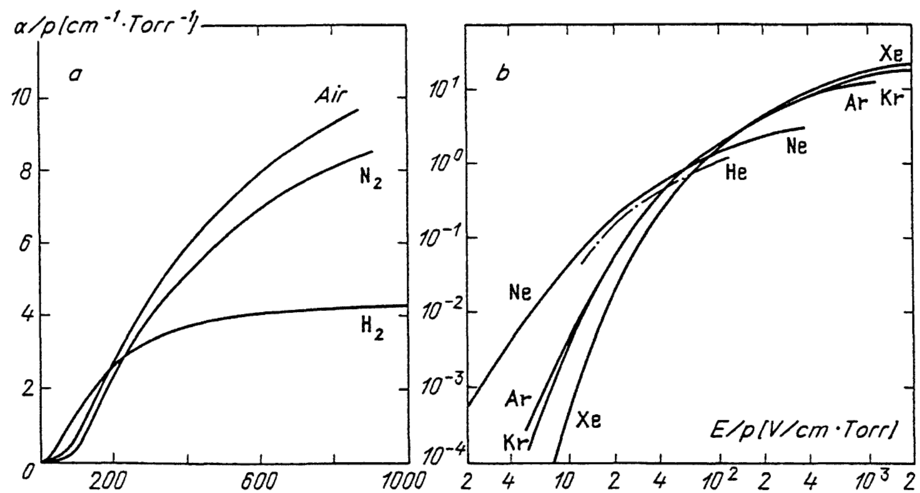
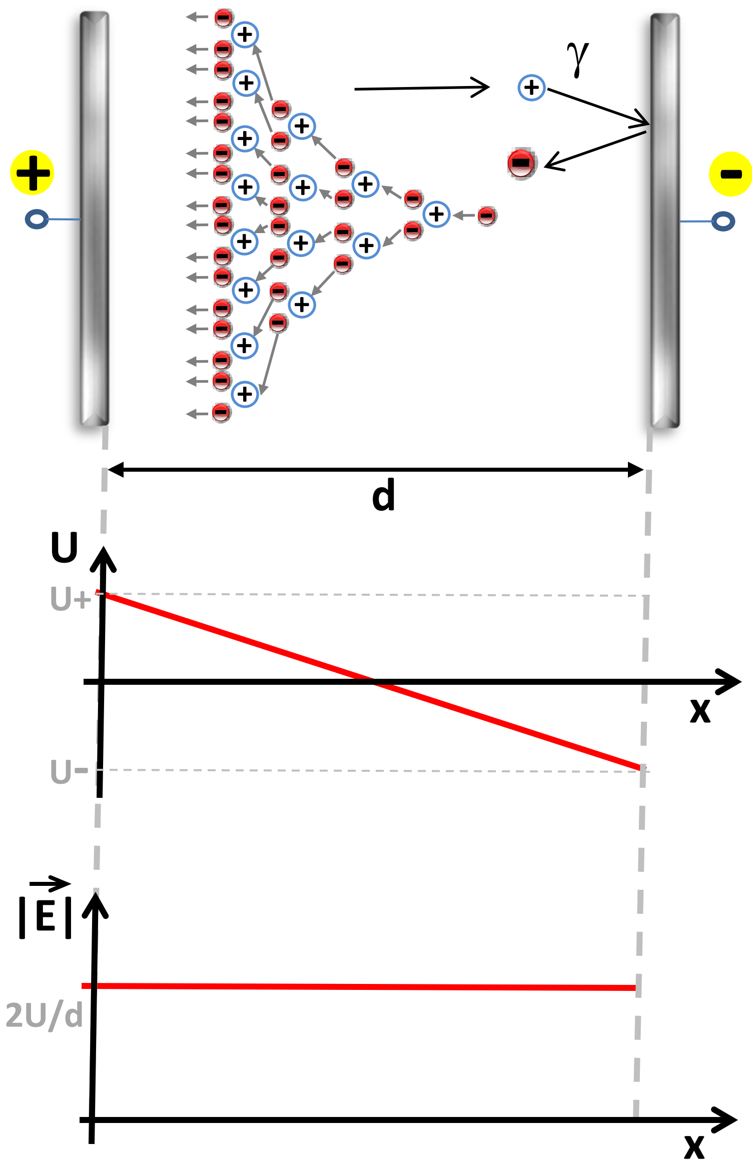


Fig. 4.3. Ionization coefficients for a wide range of E/p values (a) in molecular gases, (b) in inert gases. From [4.3]

Y.P. Raizer, Gas Discharge Physics, Springer Verlag

Townsend breakdown mechanism



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$$dn = \alpha n \cdot dx$$
$$n(x) = n_0 \exp(\alpha x)$$
$$j_-(x) = j_-(0)\exp(\alpha x)$$

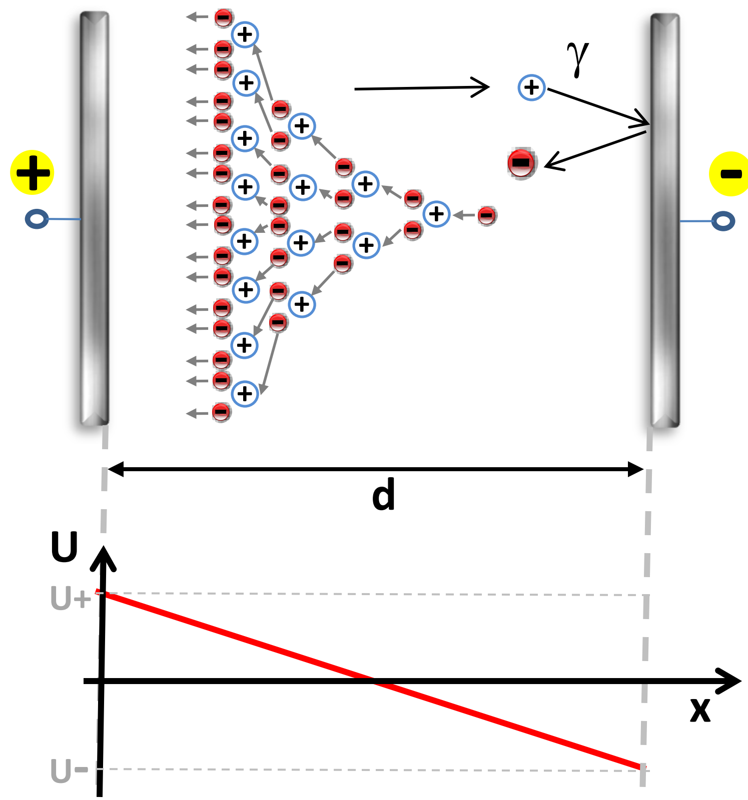
α – number of ionization acts from 1 e- drifting in E along 1 cm

$$\frac{\alpha}{p} = A\exp\left(-B\frac{p}{E}\right)$$

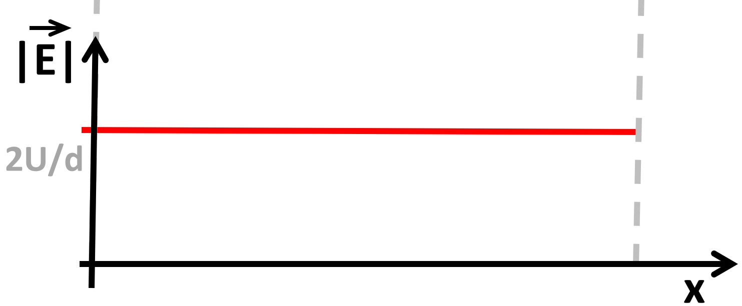
γ– number of secondary e⁻ produced per ion hitting the cathode surface per second

in electronegative gases, loss of e⁻ from attachment have to be taken into account: α –> $\alpha_{eff} = \alpha - \eta$

Townsend breakdown mechanism



No significant potential distortion



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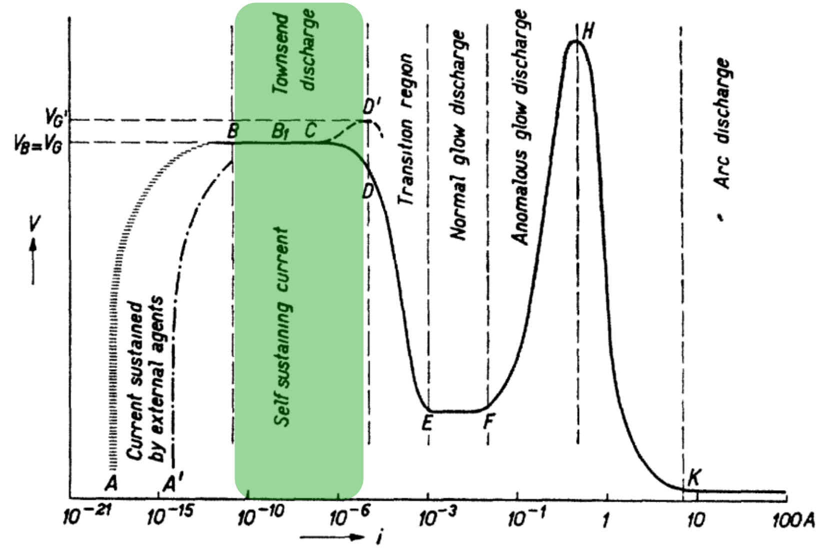
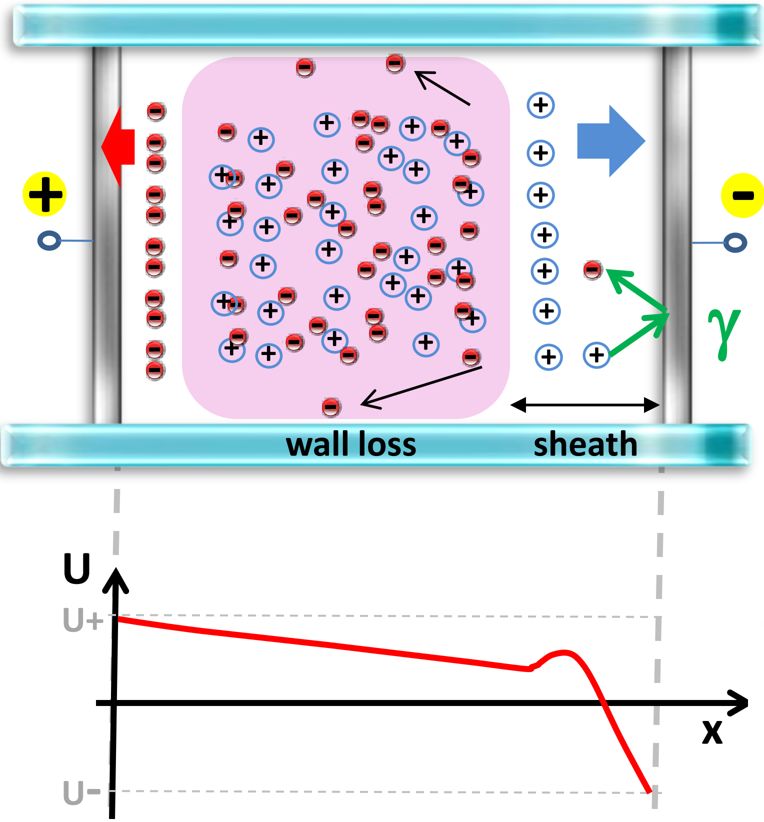
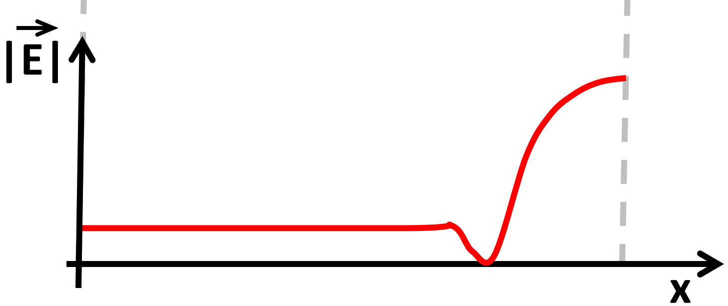
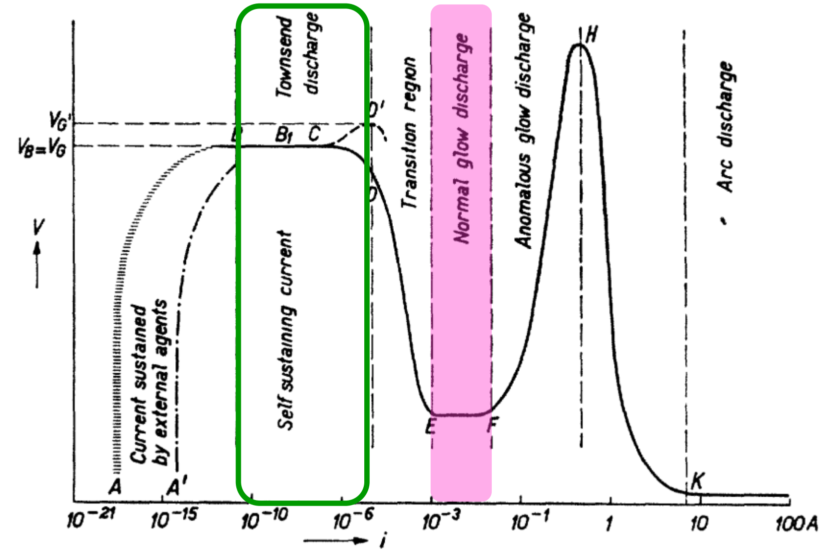


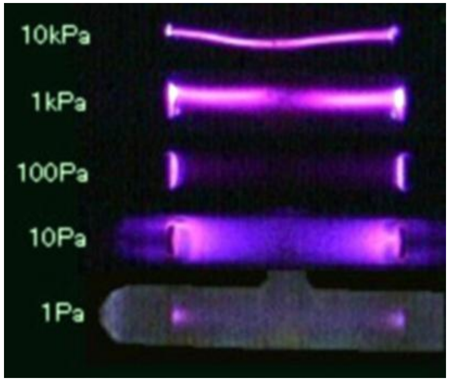
Avalanche to glow transition

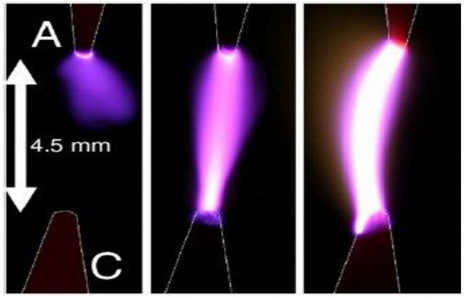


Space charge at the cathode









Difficult to stabilize at atmospheric pressure because of constriction and heating

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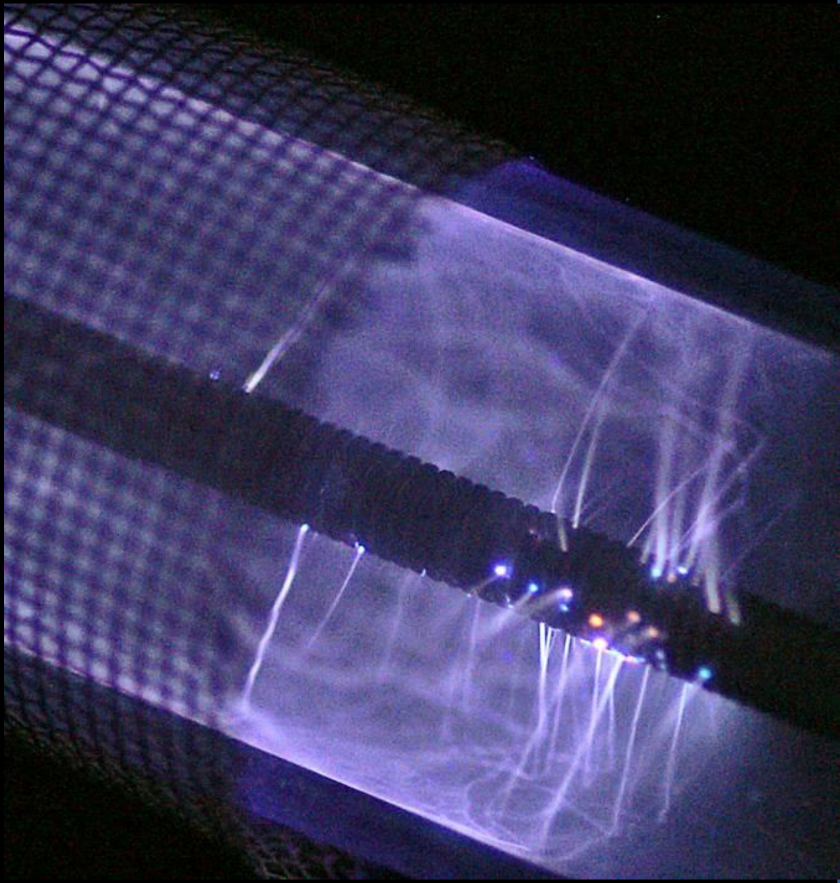
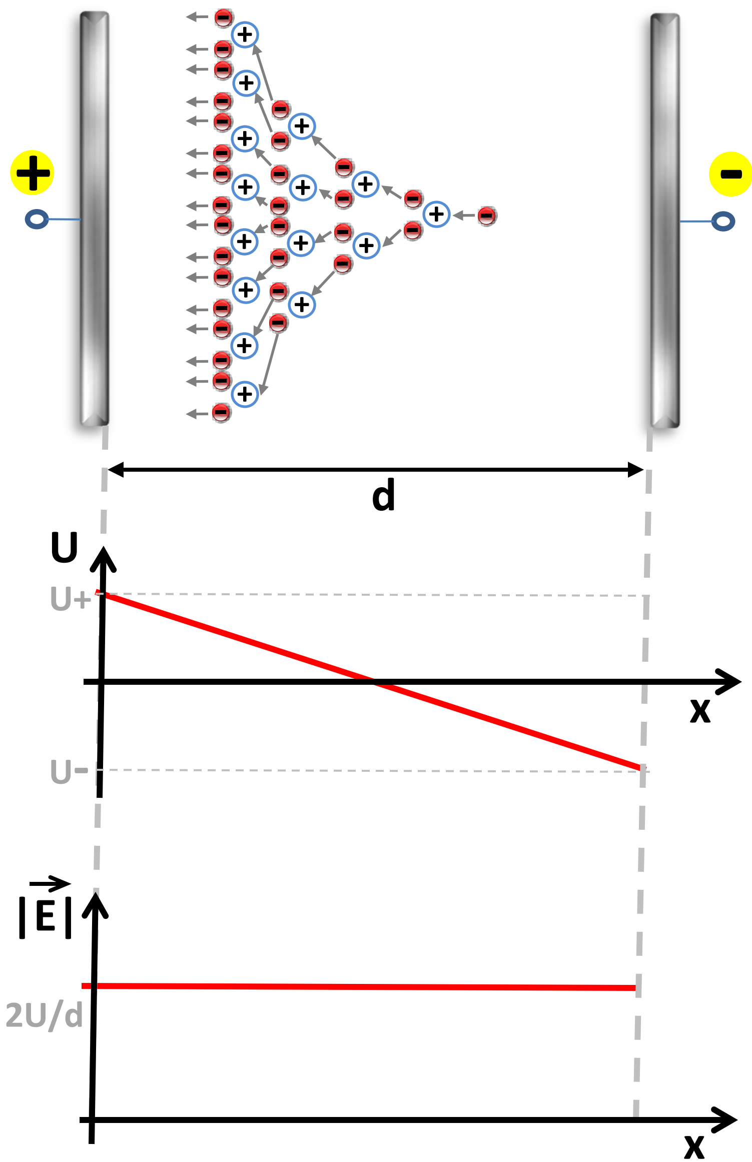


Streamer growth mechanism

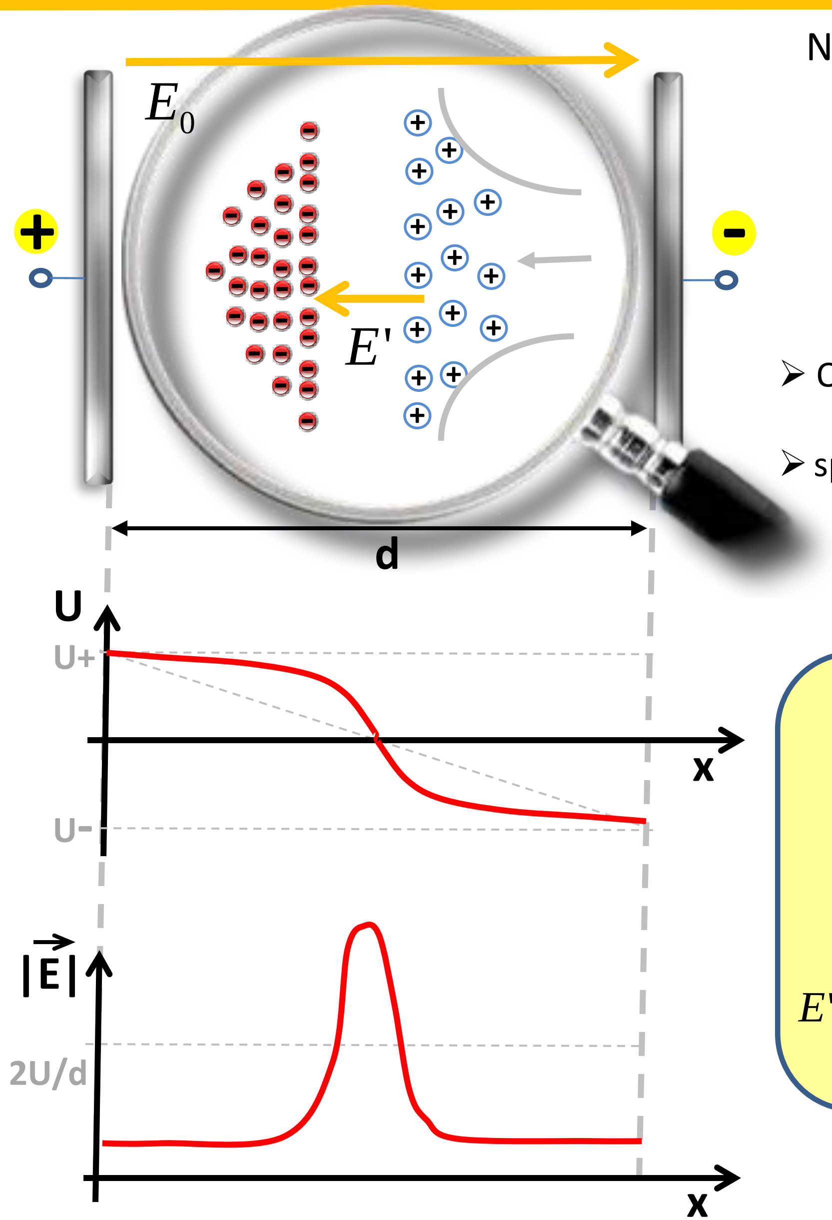
Naturally $n_e \approx 10^3 cm^{-3}$ (radioactivity, etc...)

$$n(x) = n_0 \exp(\alpha_{eff}\, x)$$



What happens if the amplification is very efficient (large α) ?

Streamer growth mechanism



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What happens is the amplification is very efficient?

- On short time scale e- drift away from ions (higher mobility)
- space charge → field distortion

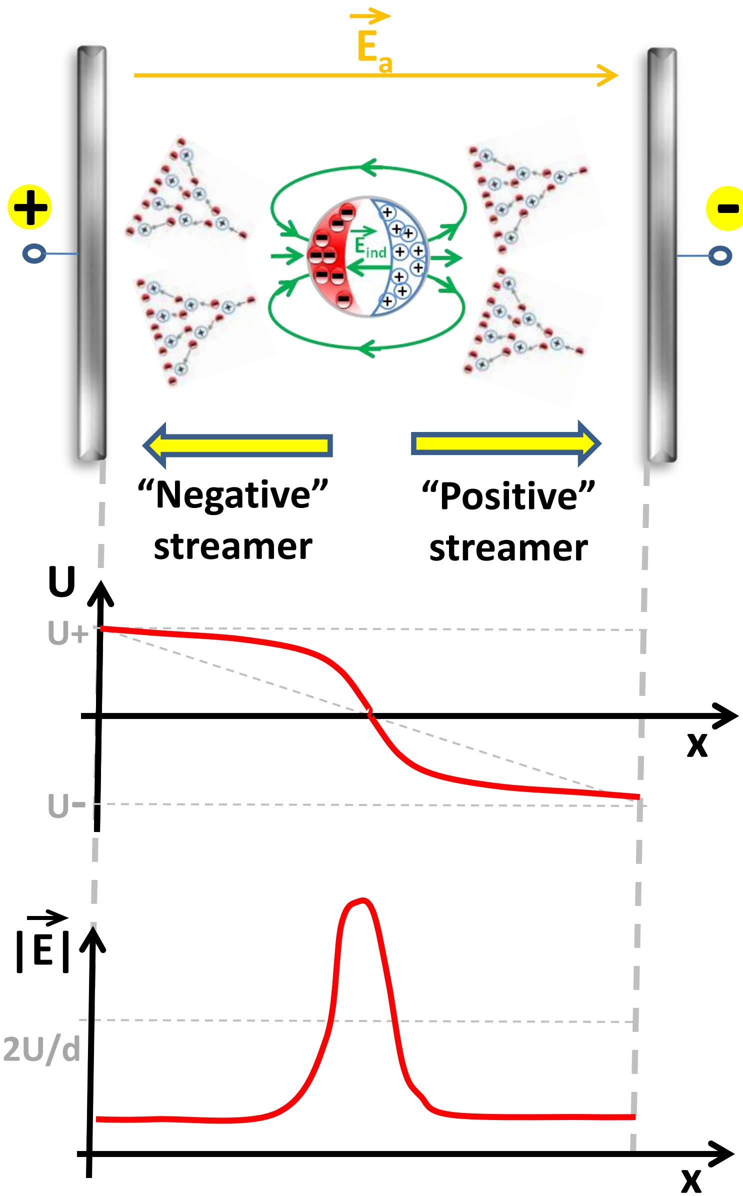
How much charge for disturbing E_0 ?

Breakdown field in air ≈ 30 kV/cm
Mean free path ≈ 0.5µm
ionization length (α^{-1}) ≈ 50µm (α^{-1})

In order to have $E_0 \approx E'$: **Meek criterion**

$$E' \approx \frac{e \cdot N_e}{4\pi\varepsilon_0 R^2} \quad \rightarrow \quad N_e \approx \frac{4\pi\varepsilon_0 (\alpha^{-1})^2 \cdot E_0}{e} \approx 5 \cdot 10^8\ cm^{-3}$$

Streamer growth mechanism



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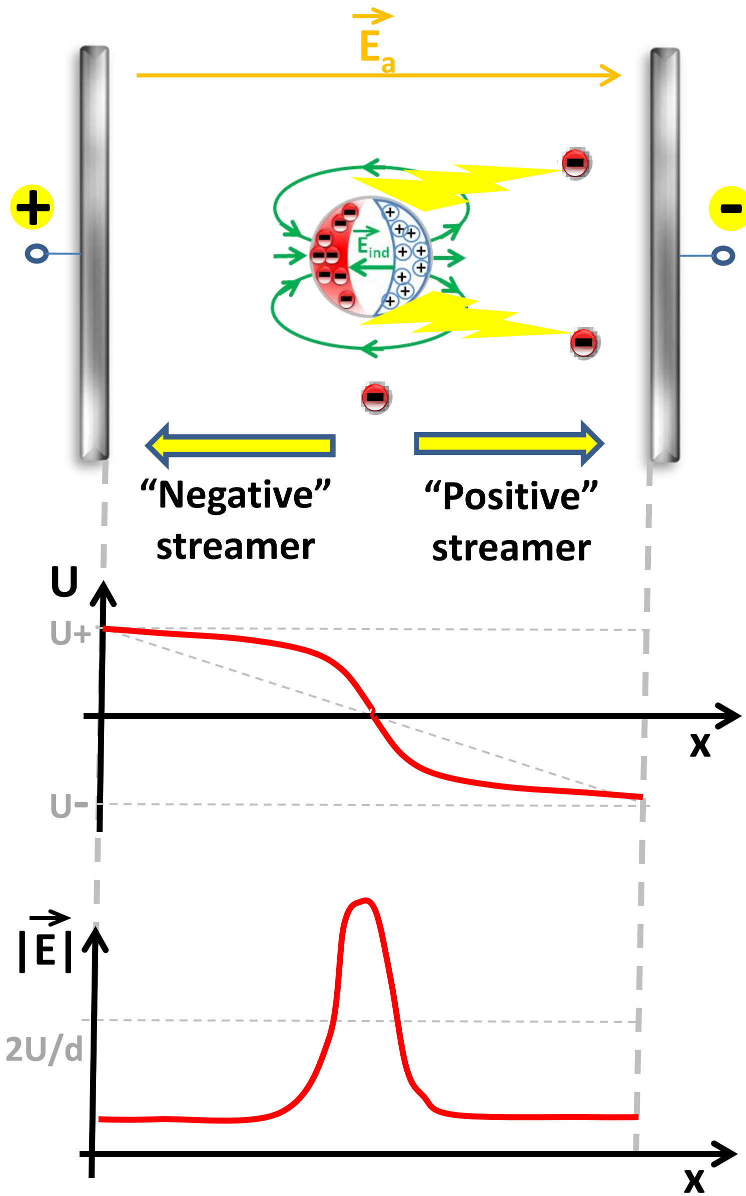
- when $1e^- \rightarrow N_e \approx 10^8$ (Meek creeterion) $\left|\vec{E}_{ind}\right| \approx \left|\vec{E}_a\right|$
- α increases very fast with E -> secondary avalanches are very efficient

Streamer growth mechanism



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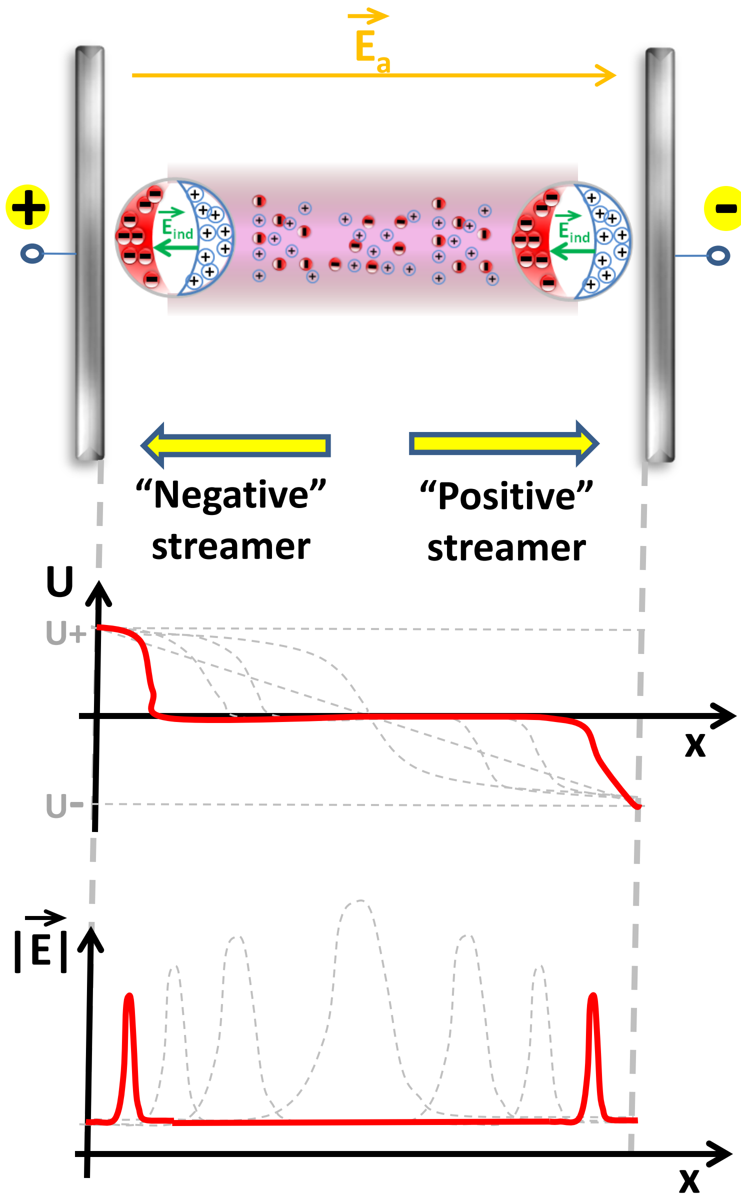
- when $1e^- \rightarrow N_e \approx 10^8$ (Meek creeterion) $|\vec{E}_{ind}| \approx |\vec{E}_a|$
- α steep function of E -> secondary avalanches are very efficient
- "positive" streamer: need for electrons in front of streamer head... photoionization?

Streamer growth mechanism



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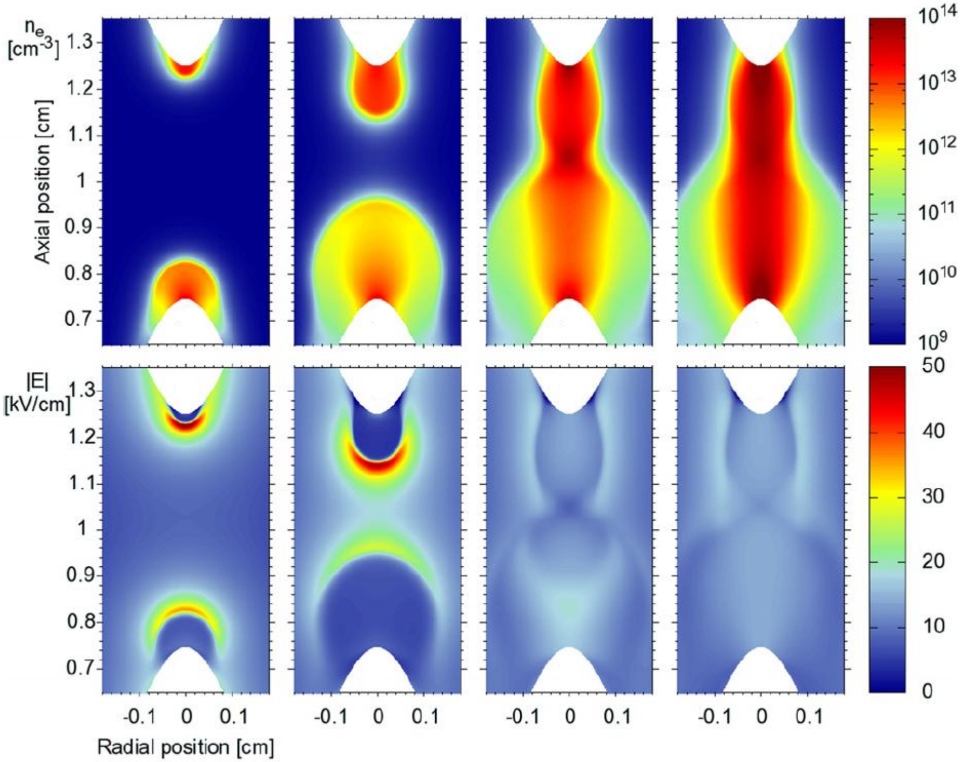
- α increases very fast with E -> secondary avalanches are very efficient
- for "positive" streamer: need for upfront electrons... photoionization?
- quasi neutral column is growing, space charge is moving further
- streamer growth is much faster than e$^-$ drift velocity

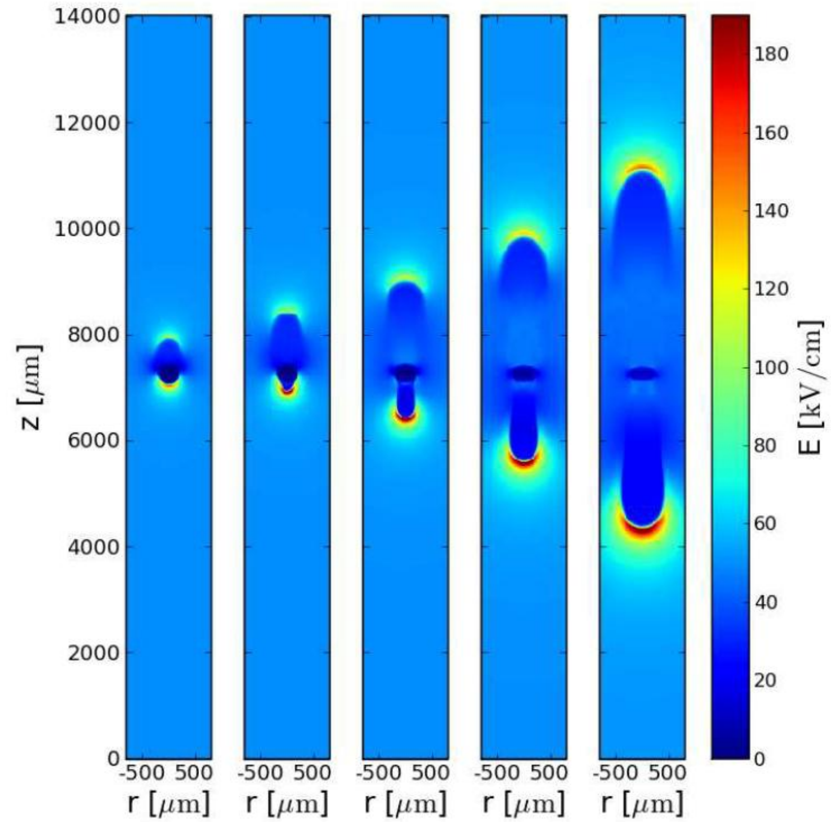
A streamer is not "propagating", it's "growing"

Positive and negative streamer

where are positive and negative electrodes?



Bourdon et al, *Plasma Sources Sci. Technol.* **19** (2010) 034012

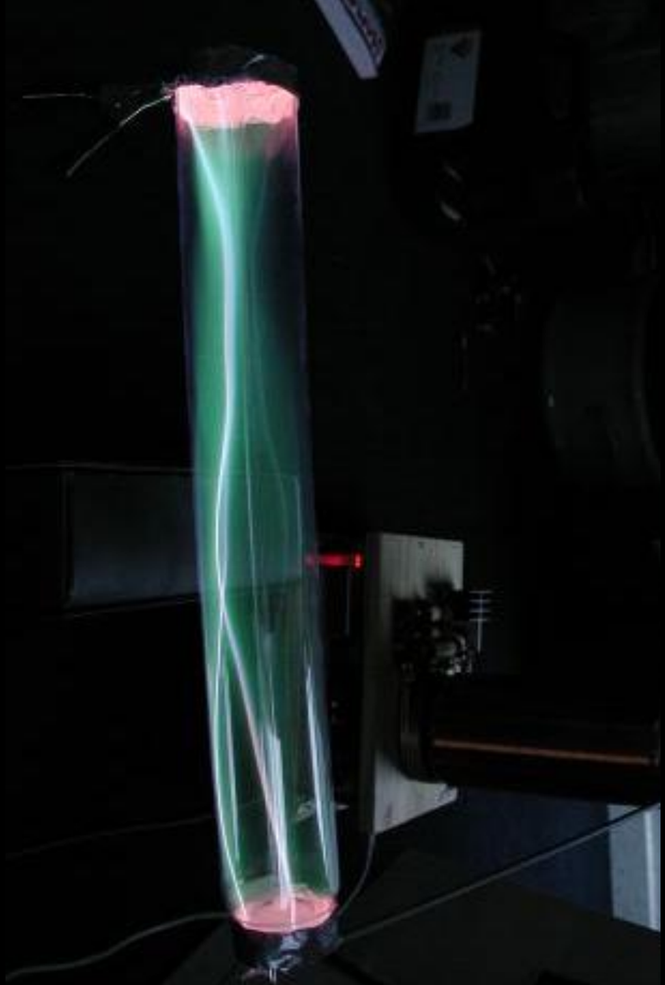


Luque et al, *J. Phys. D: Appl. Phys.* **41**, 234005 (2008)

Streamers in nature : sprites

sprites…

Streamer in a lab…



Main difference: contact with electrodes and/or dielectric

About Streamer breakdown…

✓ Growth duration	1-10 ns
✓ radius	100-200 µm
✓ Current density	100-1000 $A.cm^{-2}$
✓ Electron density	10^{14}-10^{15} cm^{-3}
✓ Mean Electron Energy	1-10 eV

✓ negative streamer wider and slower than positive ones

✓ initial charge density?
✓ necessity for photo-ionization?
✓ branching mechanism?
✓ …

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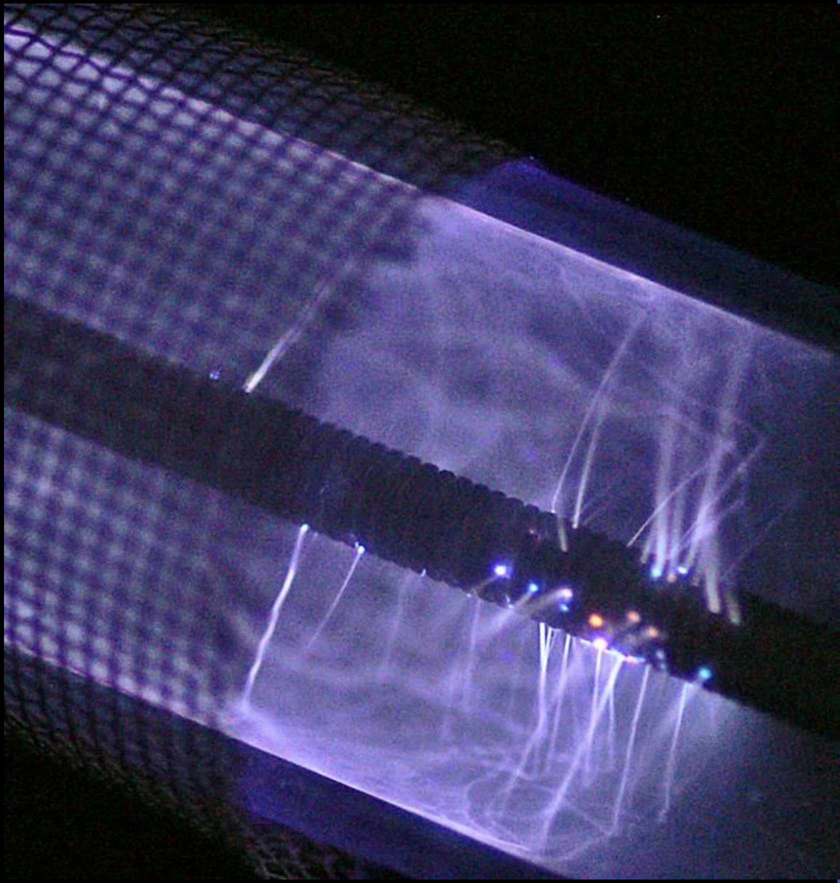
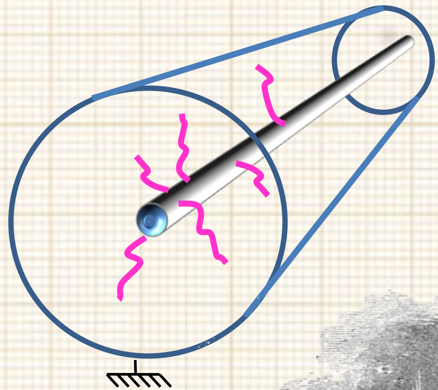
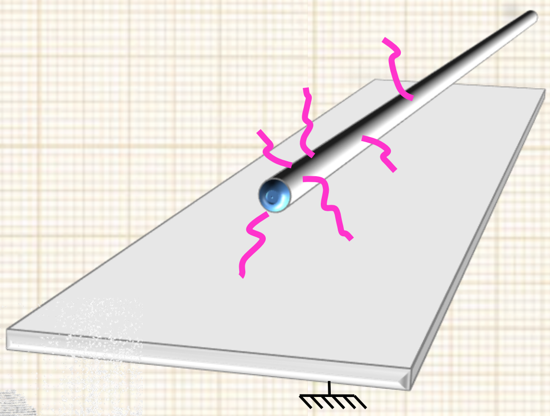


Various geometries for producing Corona discharges

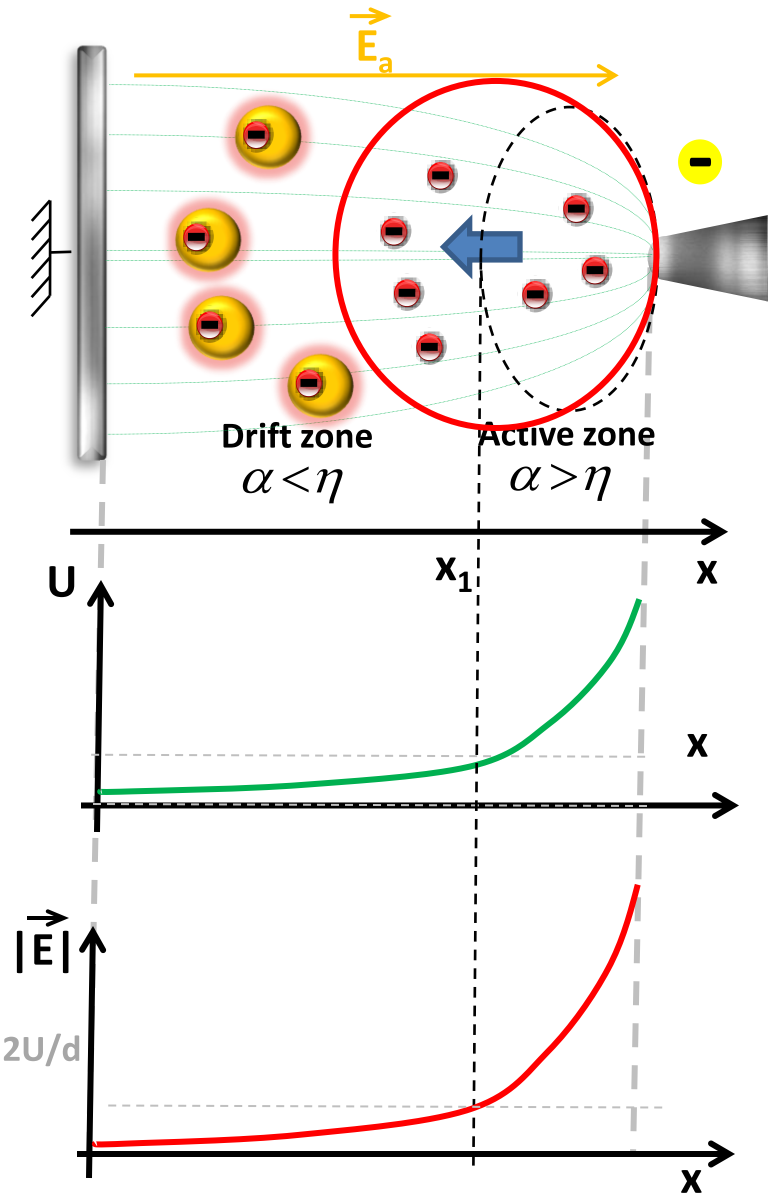
Strongly Non –uniformed applied electric Field…





***The Aerial World*, by Dr. G. Hartwig, London, 1886. P. 310**

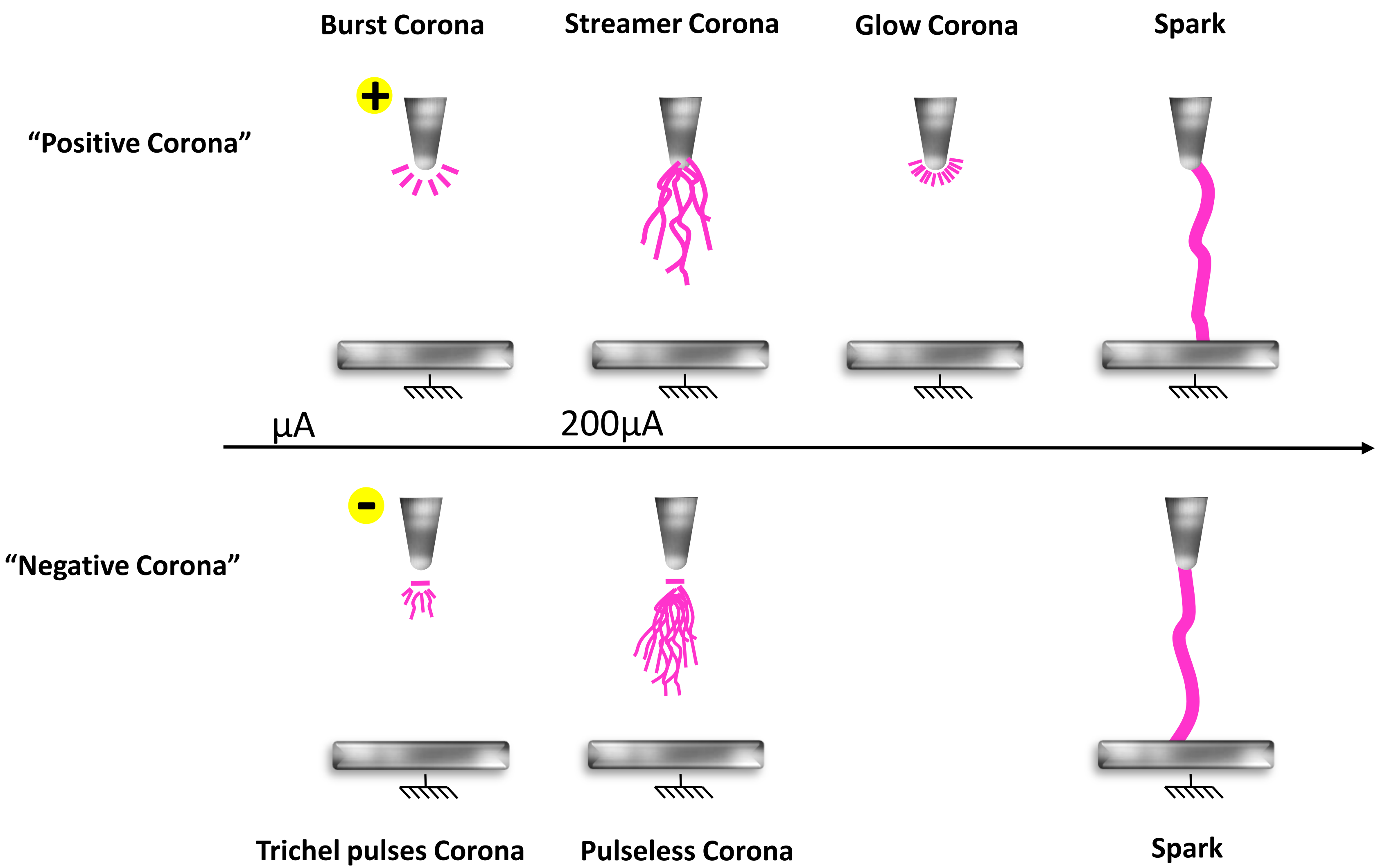
Corona discharges: principle



$$\int_0^{x_1}(\alpha(x)-\eta(x))dx=\ln(1+1/\gamma)$$

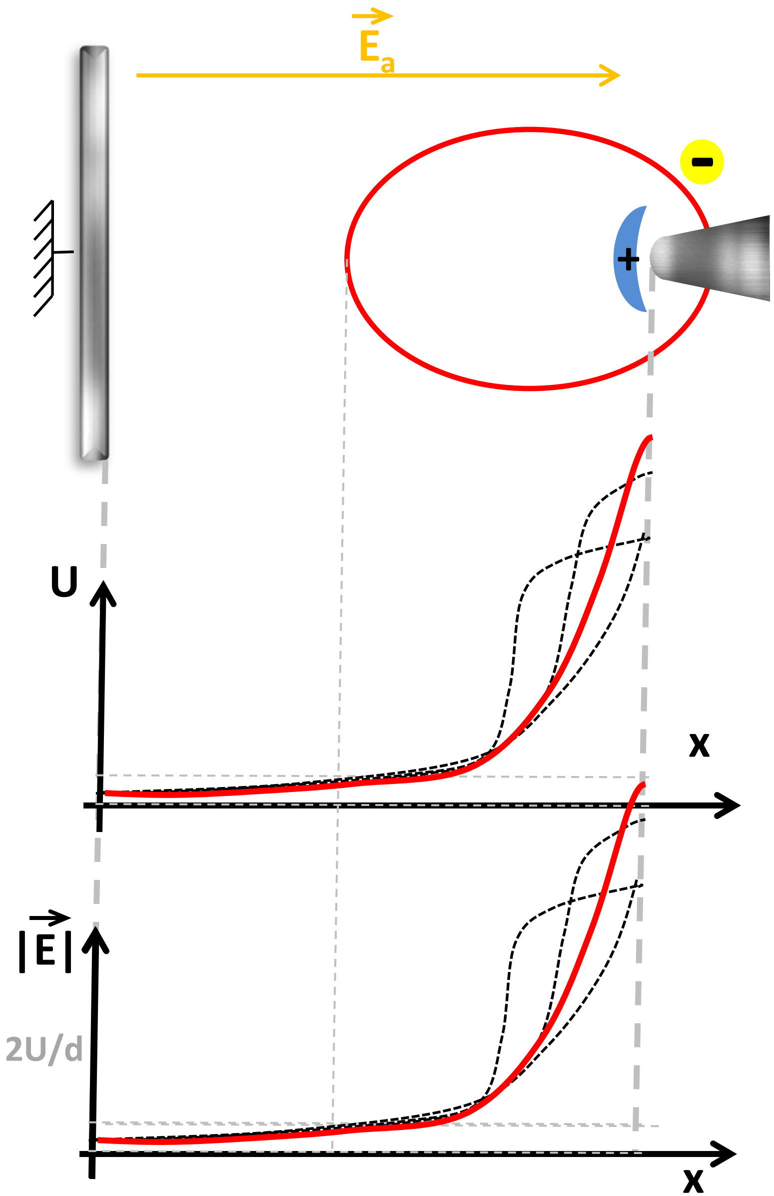
- Ionization occurs only in the active zone
- The current is collected at the ground via ion drift only $I = k \cdot U(U - U_0)$
- The potential between the electrode is very weakly disturbed by the plasma ignition in the active zone
- Active zone increases with U

Corona discharges



Adapted from Chang et al, *IEEE Trans. Plasma Sci.* **19** (1991) 1102-1166

Corona discharges: Trichel pulses



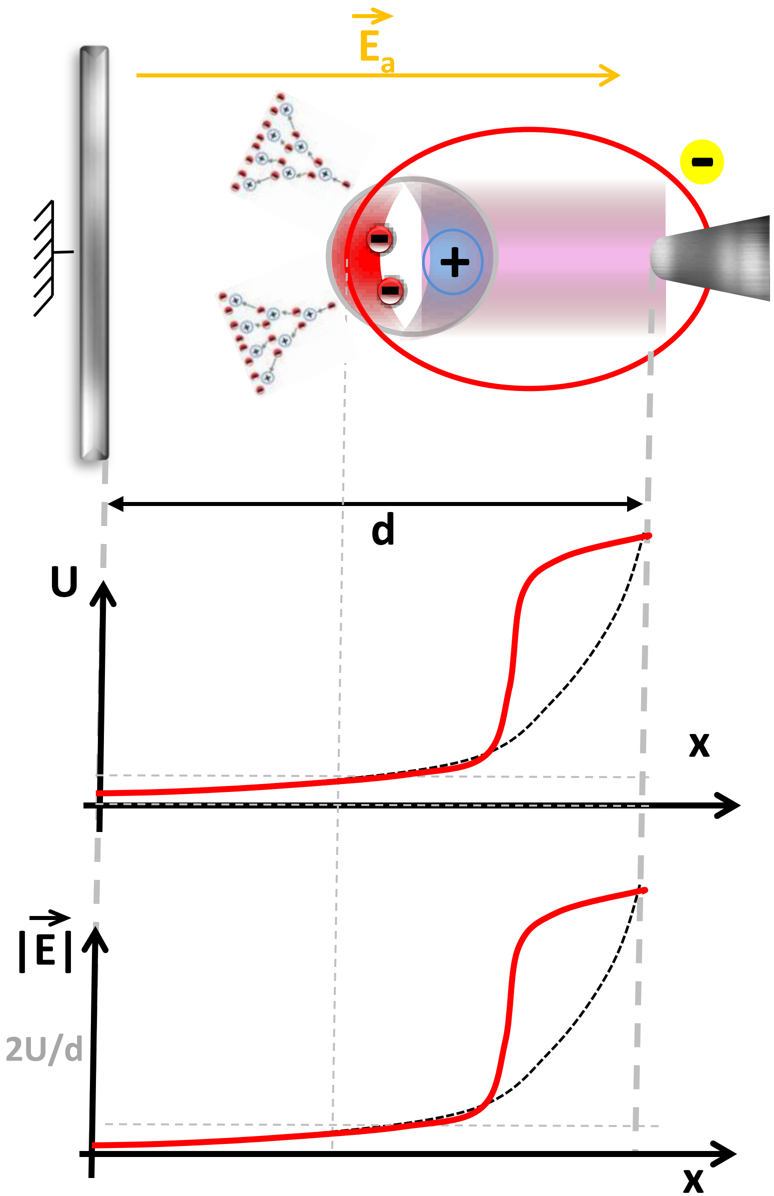
•Ionization can occur only in the active zone

1. A space charge starts to build up
2. However charge density is too low and E_a is not shielded
3. The positive cloud collapses

• the process restarts to produce the next "Trichel pulse"

• frequency is proportional to the current

Corona discharges: Streamer corona



• If the space charge is strong enough (ie charge density high enough)

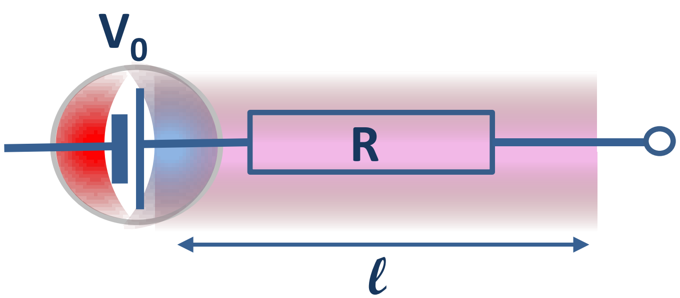
↓

E_o shielded at the tip, streamer growth starts

↓

Streamer corona

Why is the streamer stopping in the drift zone?



$$R = \frac{\rho \cdot \ell}{S}$$

- Streamer is not an ideal conductor
- Potential in the head decreases with distance

About Corona discharges…

- ✓ Partial breakdown discharges in non uniform field
- ✓ Different discharges simply by adjusting the current
- ✓ ions drift in the weak field zone
- ✓ streamer stops because of its own resistivity
- ✓ risk of spark at low voltage (leader mechanism)

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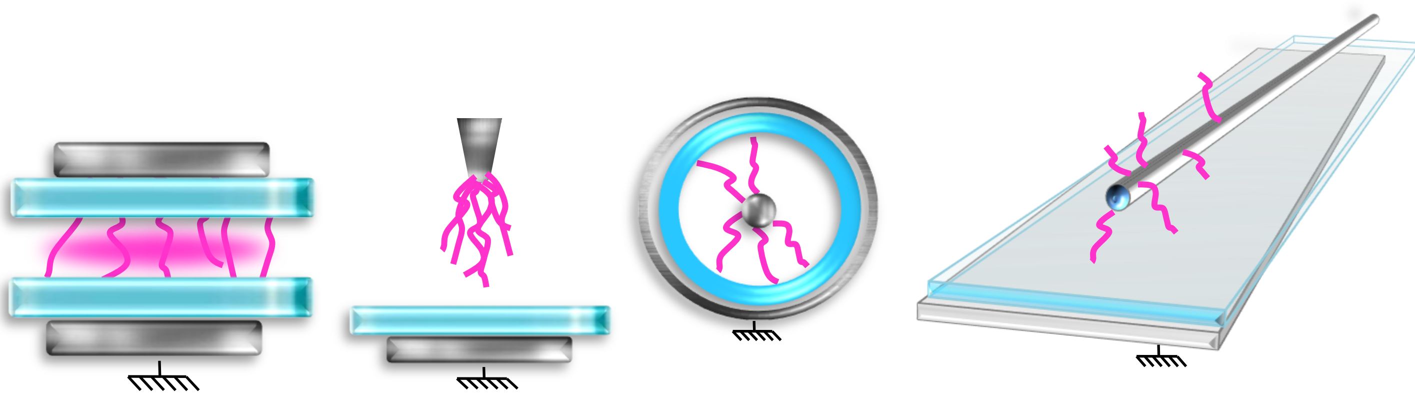
Many different geometries of DBDs

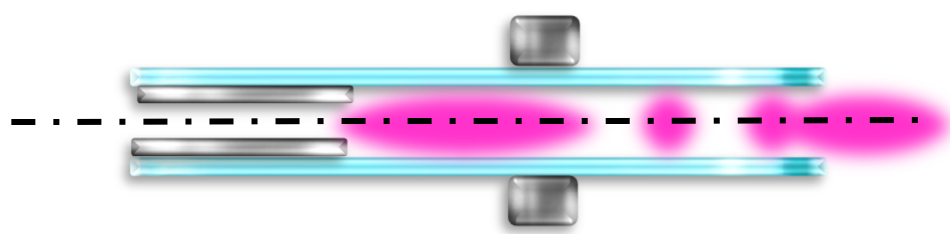
Any geometry, but at least 1 dielectric between the electrodes

“Volume” DBD

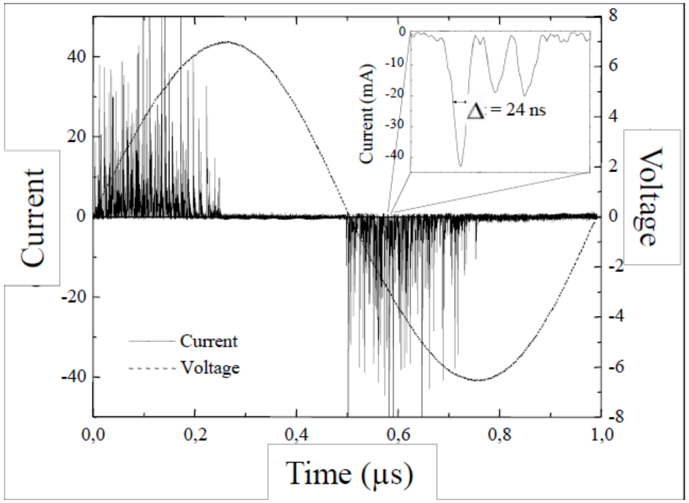


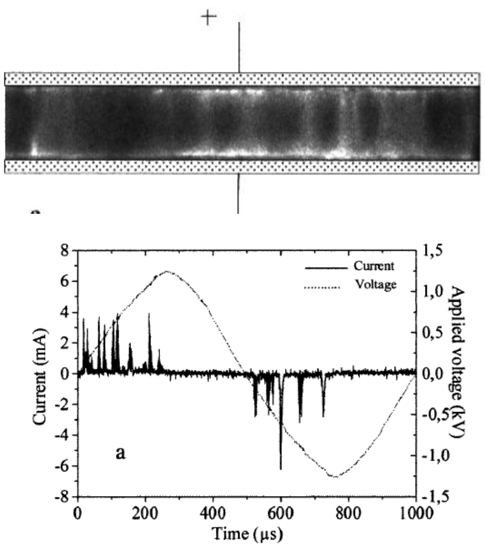
“Surface” DBD

“jet” DBD

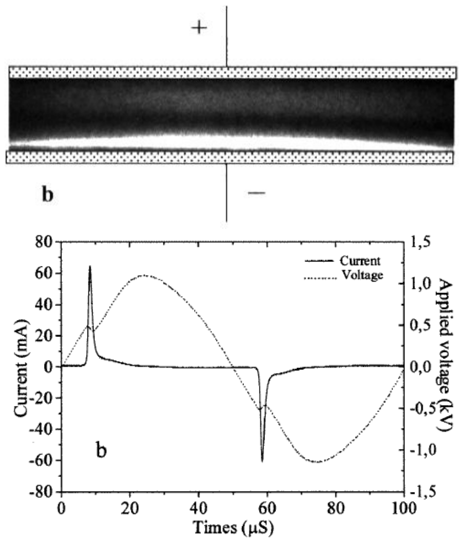


Dielectric Barrier Discharges: different regimes





(a)



(b)

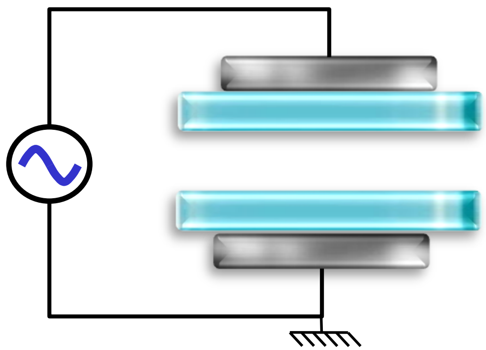
- ➢Most commonly DBD develops into filaments crossing the whole gap
- ➢ under peculiar conditions: diffuse Townsend or even glow discharge

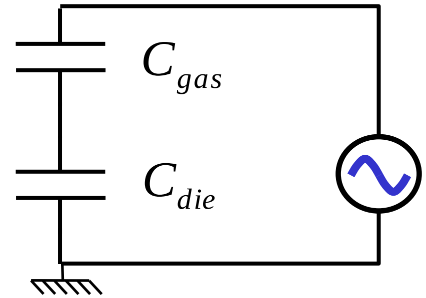
Massines et al, *J. Phys. D: Appl. Phys.* **31** (1998) 3411–3420

Electrical scheme of DBDs

DBD geometry is a capacitance

Plasma "OFF"





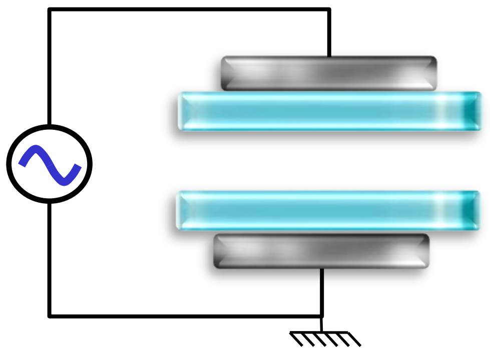
DBD = capacitive limitation of the current

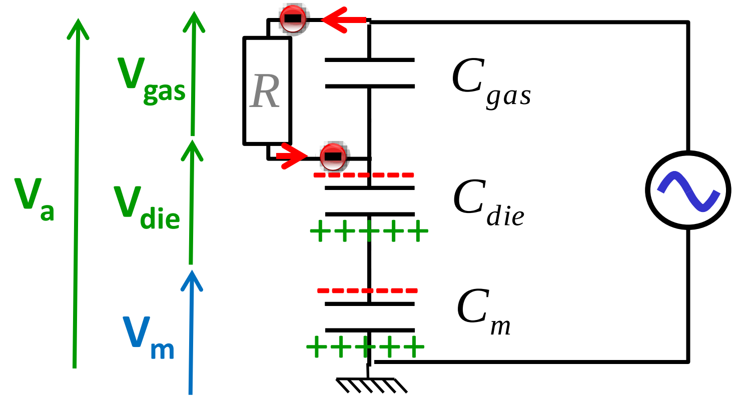
resistive limitation → Joule heating
Inductive limitation → current rise time limited

Electrical scheme of DBDs

DBD geometry is a capacitance

Plasma "ON"





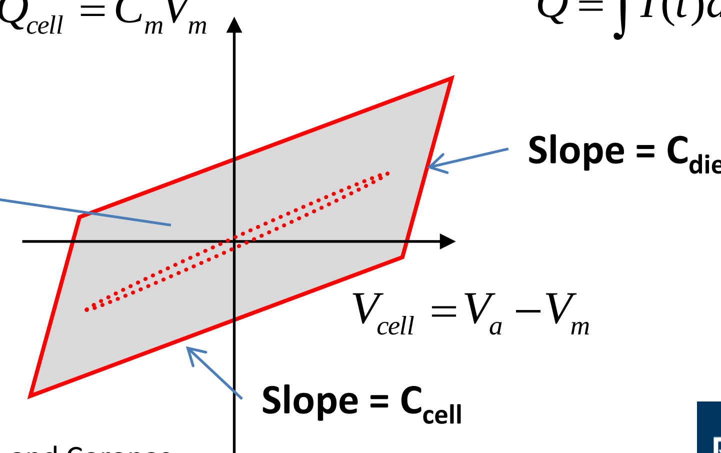
$$C_{gas} < C_{die} << C_m$$

Measure of power dissipated into the plasma

Manley, *Trans. Electrochem. Soc.* (1943) 83-96

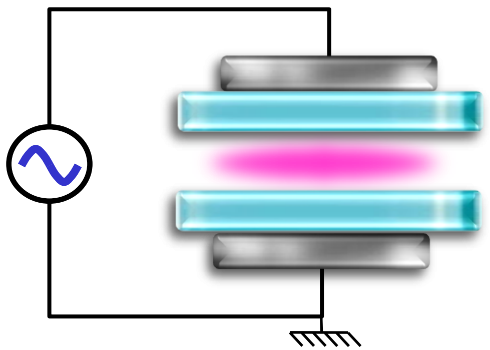
$$Q = \int I(t)dt = CV$$

$$P = 4f \cdot U_b C_{die}\left[U_{peak} - \frac{C_{die}+C_{gas}}{C_{die}} \cdot U_b\right]$$

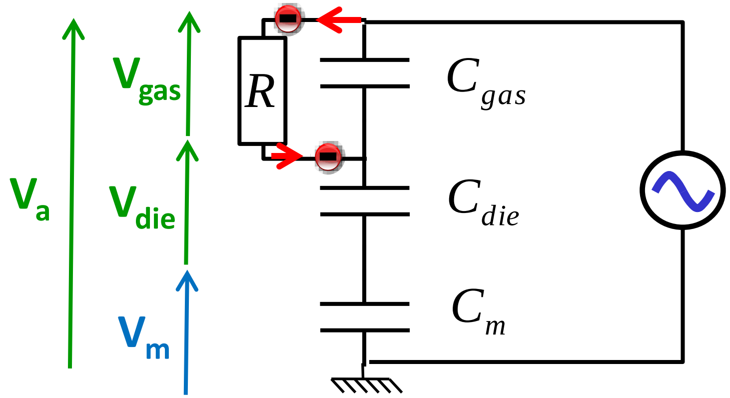


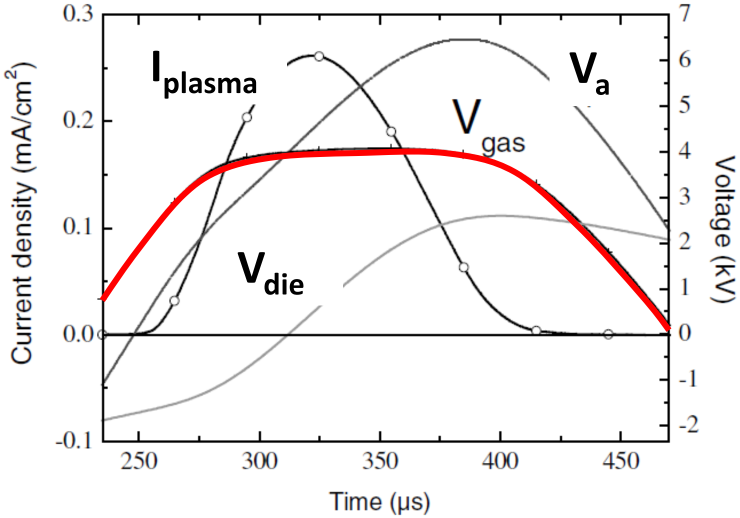
Electrical scheme of DBDs

DBD geometry is a capacitance



Plasma "ON"





$$I = I_{plasma} + I_{gas}$$

$$V_{gas} = V_a - \frac{1}{C_{die}} \int I(t)dt$$

Voltage across the gas gap remains constant at breakdown voltage

Massines et al, *Plasma Phys. Control. Fusion* **47** (2005) B577–B588

Outline

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   a) Townsend mechanism
   b) Streamer mechanism

II. **Corona discharges**

III. **What is a Dielectric Barrier Discharge?**
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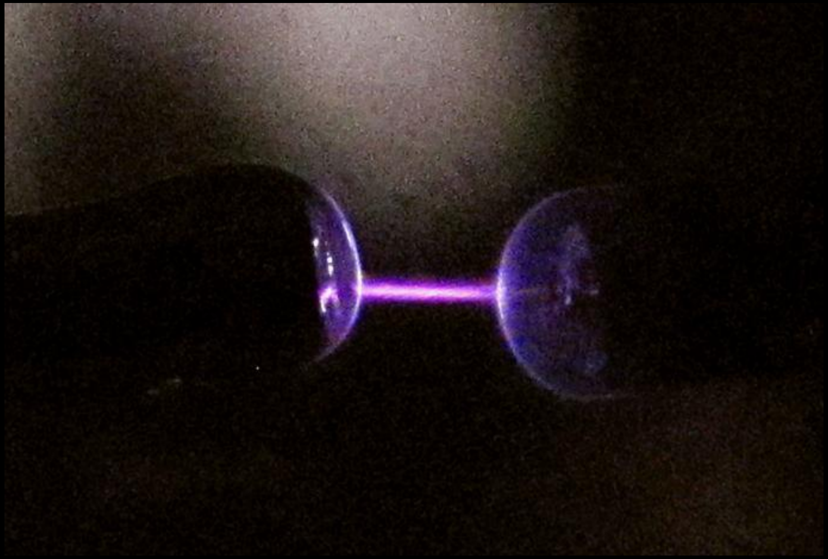
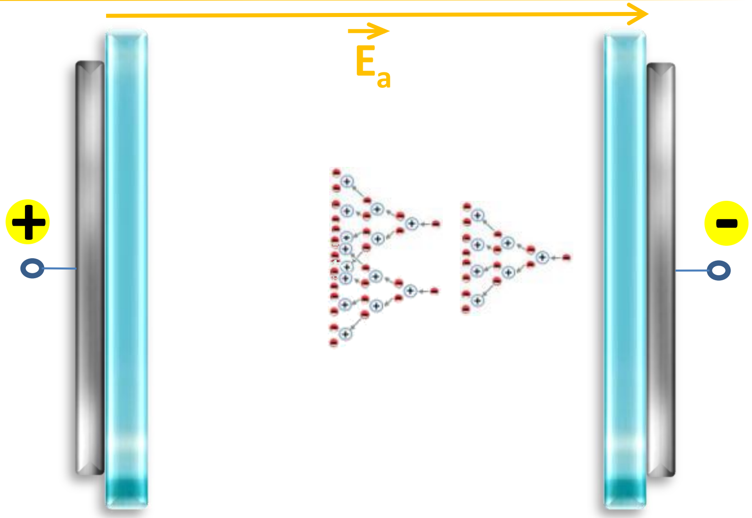
V. **Confinement and gas motion**

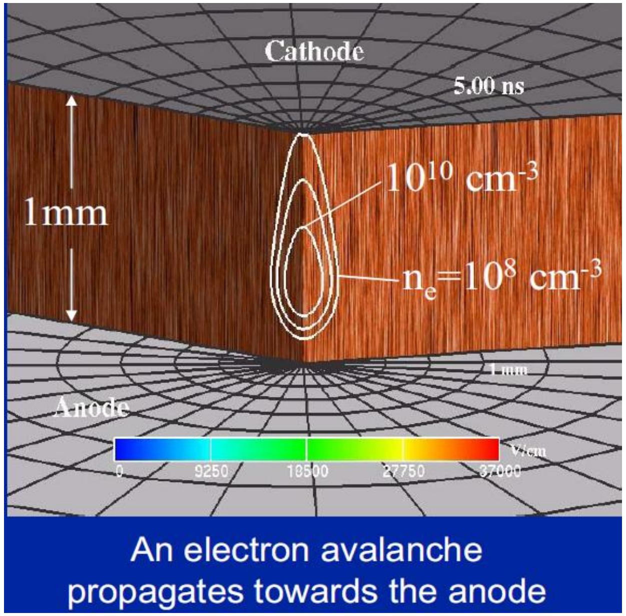


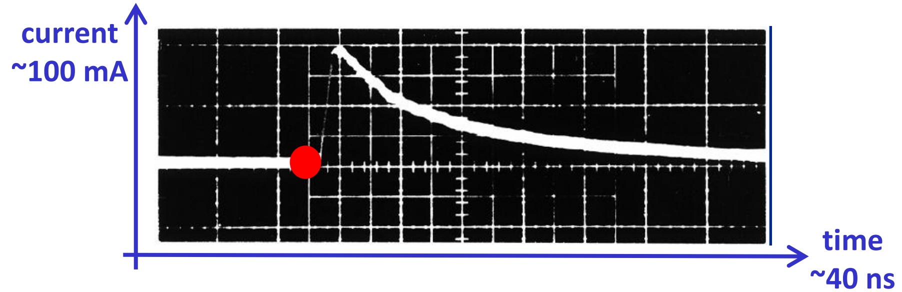
DBDs: micro-discharge regime (filamentary mode)



- Avalanches are leaving the cathode

- streamer growth





Kogelschatz et al, *IEEE Trans. Plasma Sci.* **30** (2002), 4, 1400–1408

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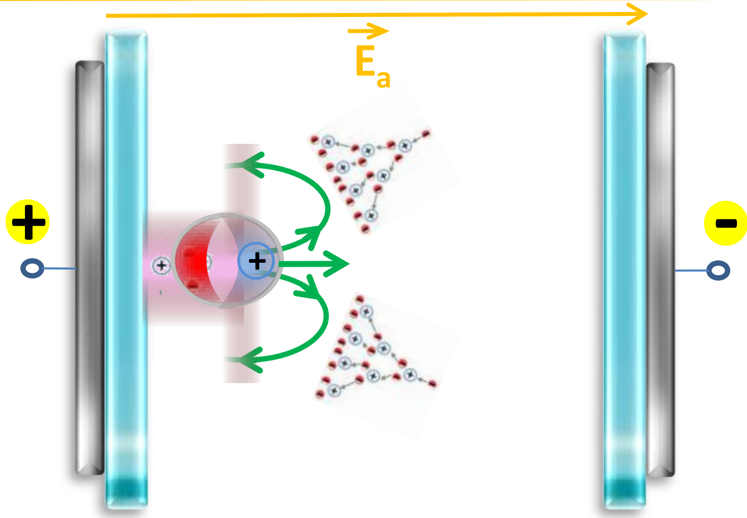
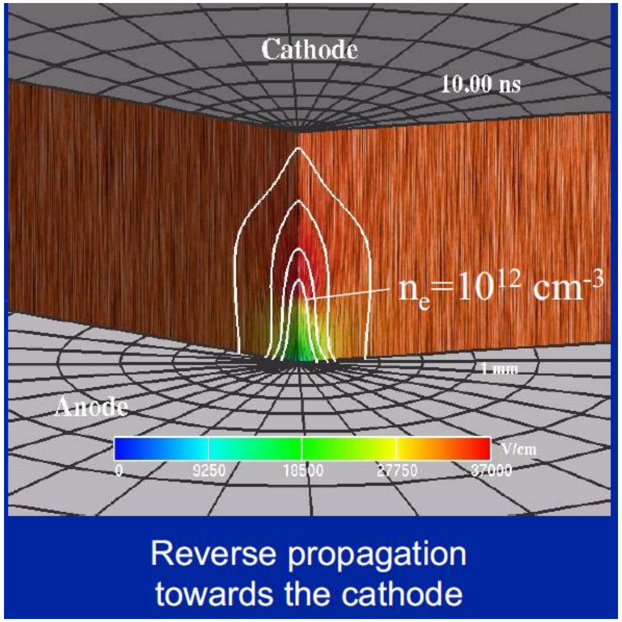
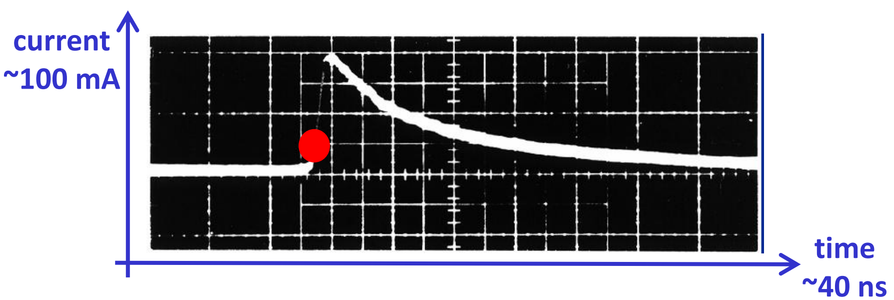


- Avalanches are leaving the cathode
- space charge is formed at the anode

- streamer growth





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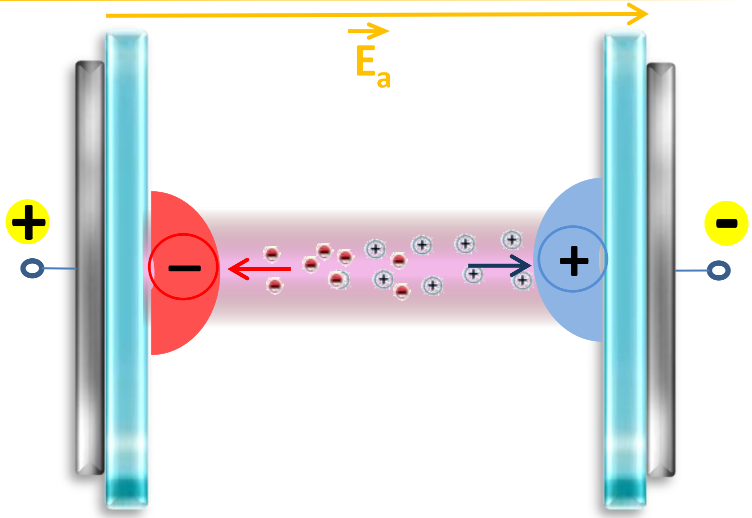
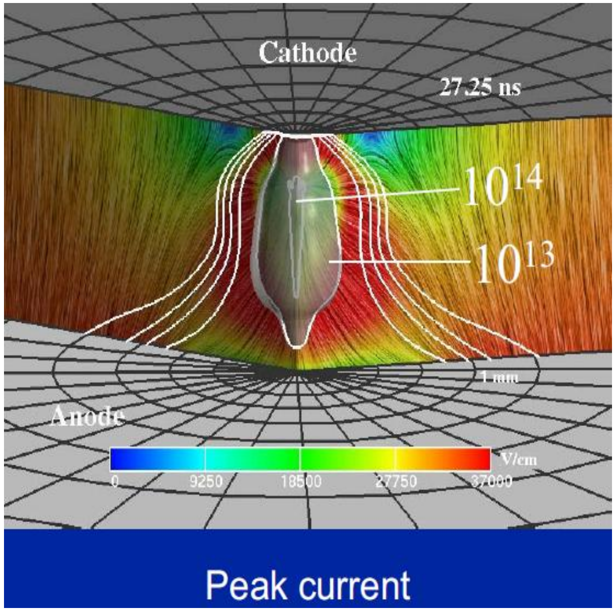
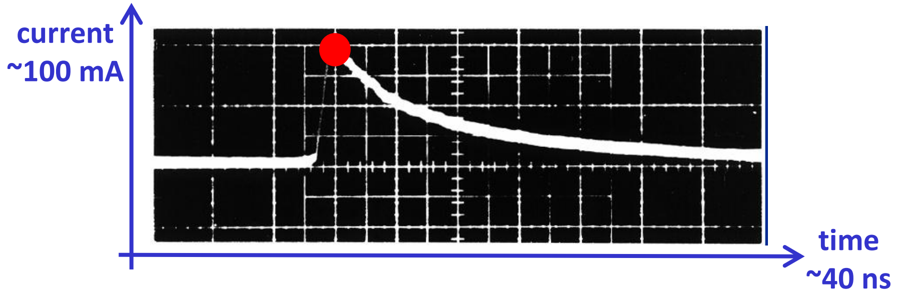


- streamer growth

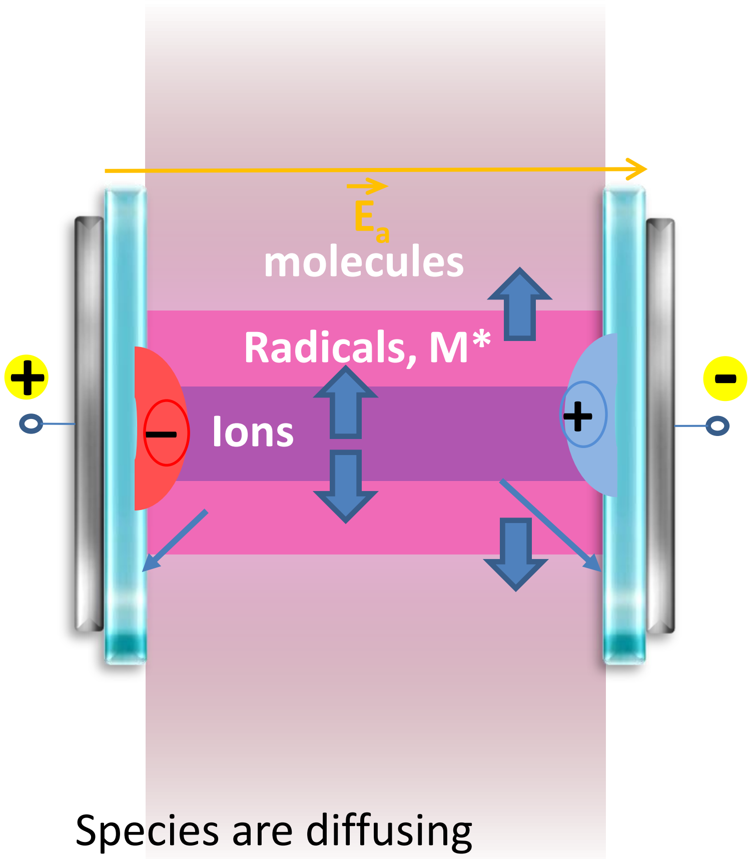


- Avalanches are leaving the cathode
- space charge is formed at the anode
- “positive” streamer is growing
- charge deposition on the dielectric shield the field

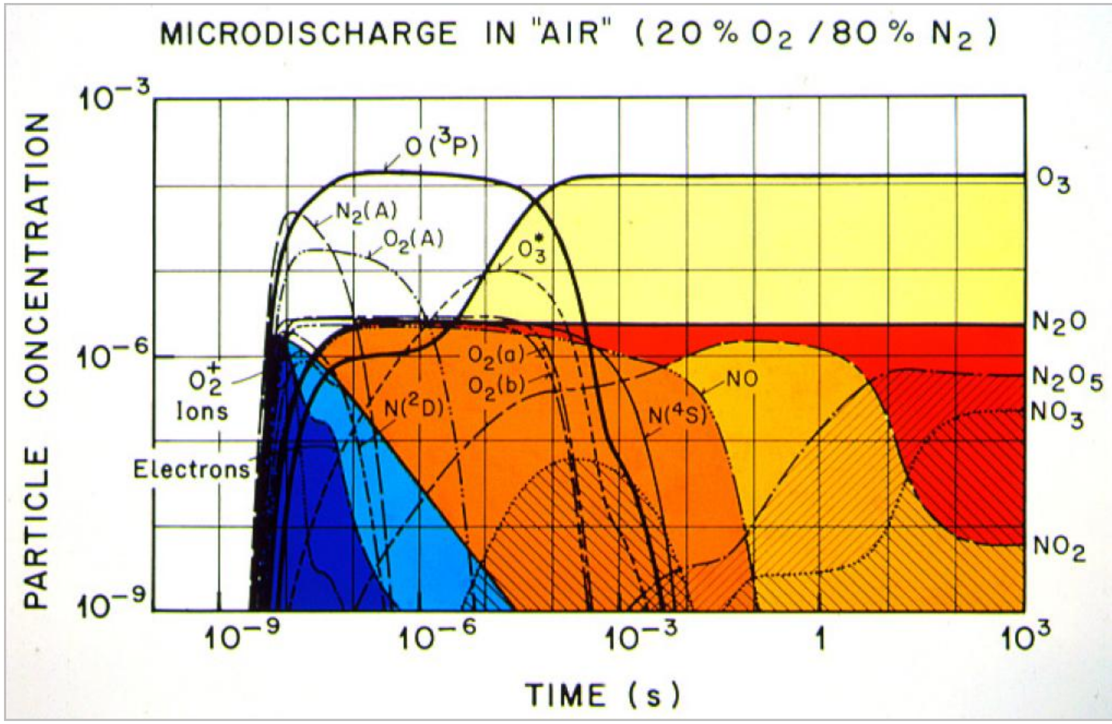


Kogelschatz et al, *IEEE Trans. Plasma Sci.* **30** (2002), 4, 1400–1408

Each filament = micro-chemical reactor



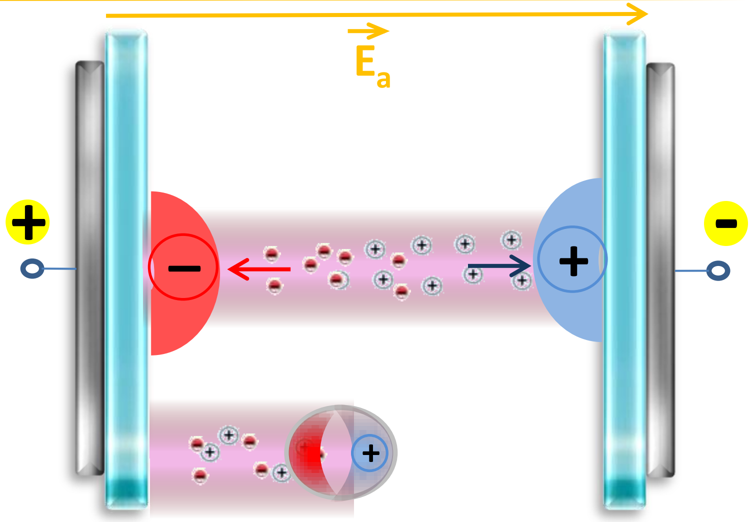
Species are diffusing accordingly to their life time

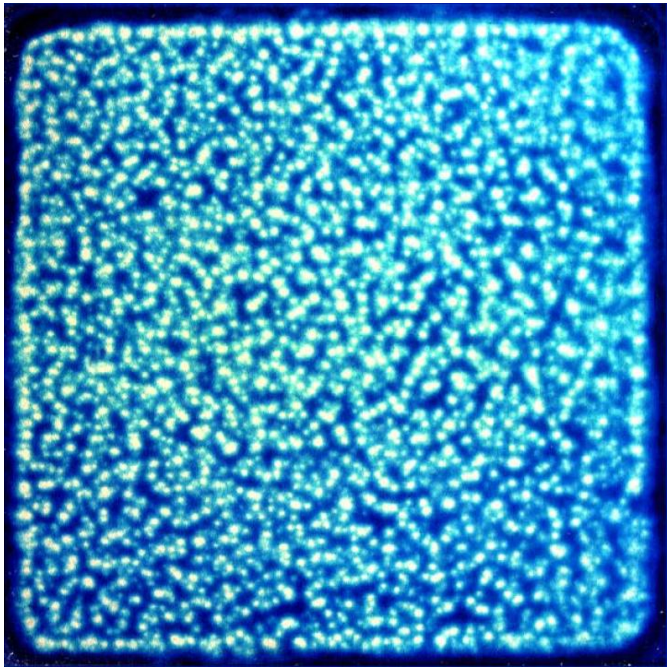


Modeling the chemistry of 1 filament:

- **Need to take into account radial diffusion**
- **Calculation on time scale from 1 ns to 1h !!!**

DBDs: micro-discharge regime (filamentary mode)





Kogelschatz et al, *IEEE Trans. Plasma Sci.* **30** (2002), 4, 1400–1408

Plate Ozonizer
Size: 6 cm x 6 cm
Exposure Time: 20 ms

How to ignite another filaments ?

a) At another place on the dielectric (field not shielded yet)

b) At the same place if the voltage is increased enough

c) at the same place by reversing the polarity
DBD is never powered by DC voltage

About micro-discharges in DBD…

✓Development through positive streamer mechanism (~ 10 ns)

✓ plasma column weakly ionized, similar to a transient high pressure glow discharge

✓ The dielectric is stopping the growth (need for periodic power supply)

- How are charges “adsorbed”?
- Are they only stopping the filament?

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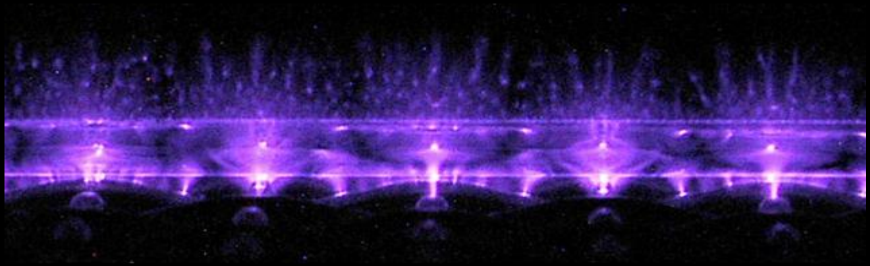
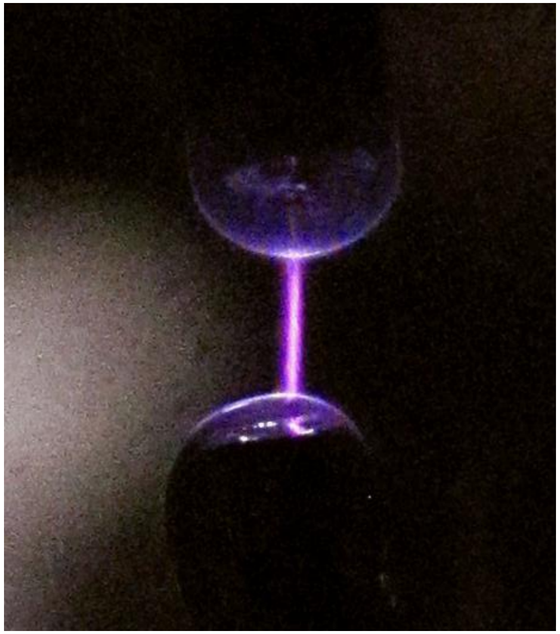
Al_2O_3



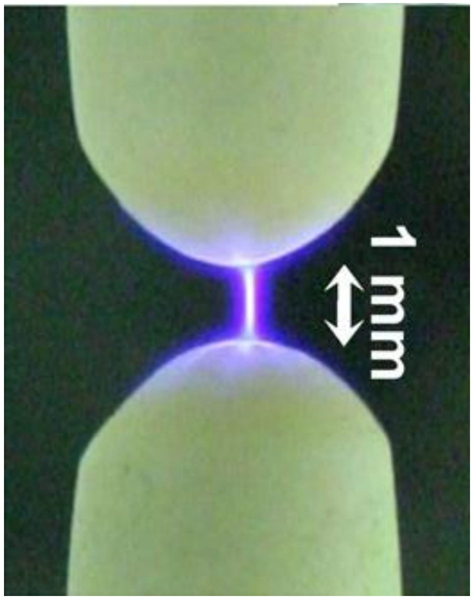
glass

Role of the dielectric in filament ignition

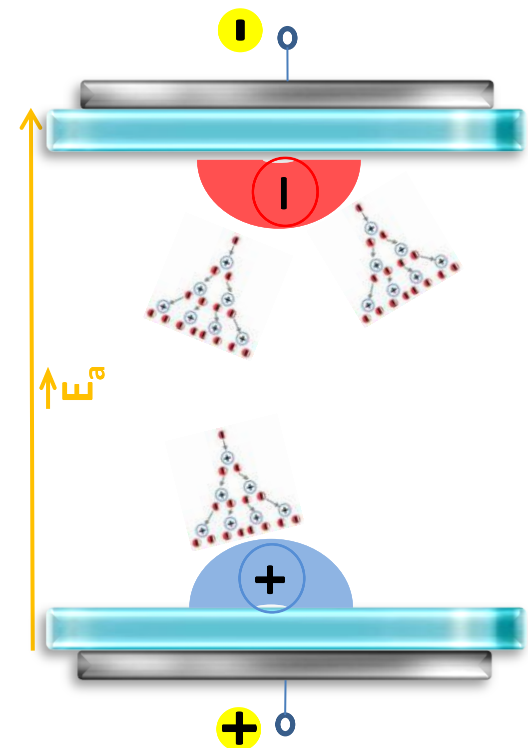


Why a filament in a DBD is never starting in the middle of the gap?

Why is it developing most of the time through a positive streamer?

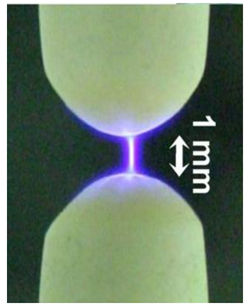


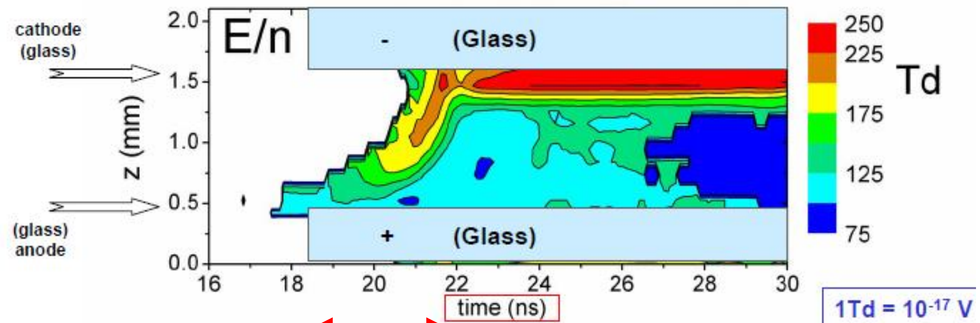
Role of adsorbed charges in pre-breadown phase?



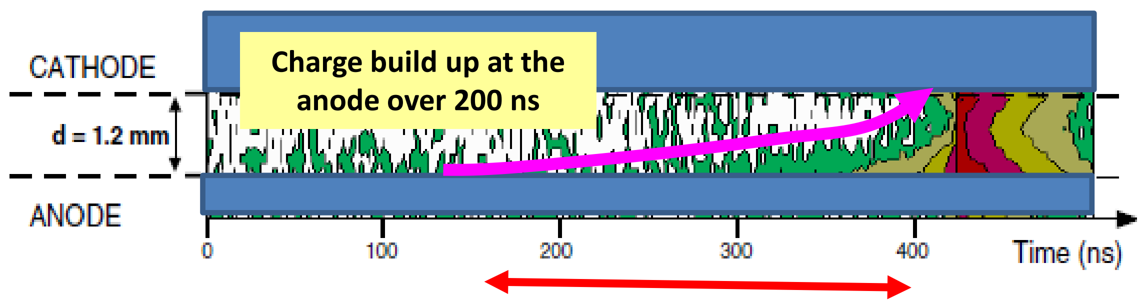
Microdischarges development measured by Cross-Correlation Spectroscopy

K.V. Kozlov et al. *J. Phys. D: Appl. Phys.*, **34** (2001)





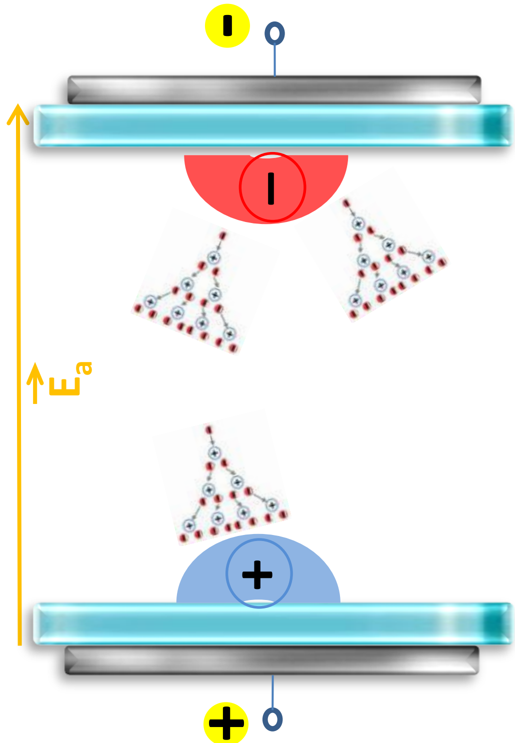
4 ns



250 ns

Charge build-up in front of the anode (>200 ns!) before streamer starts ("pre-breakdown" phase)

Role of adsorbed charges in pre-breadown phase?



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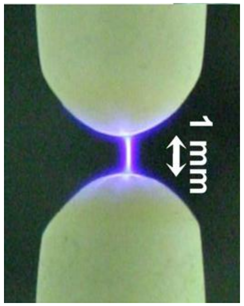
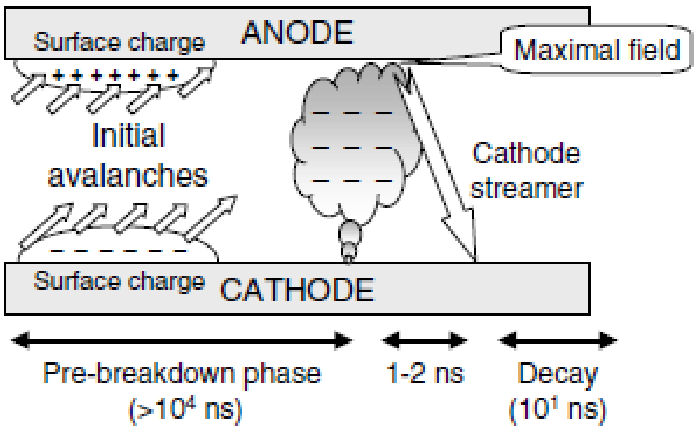
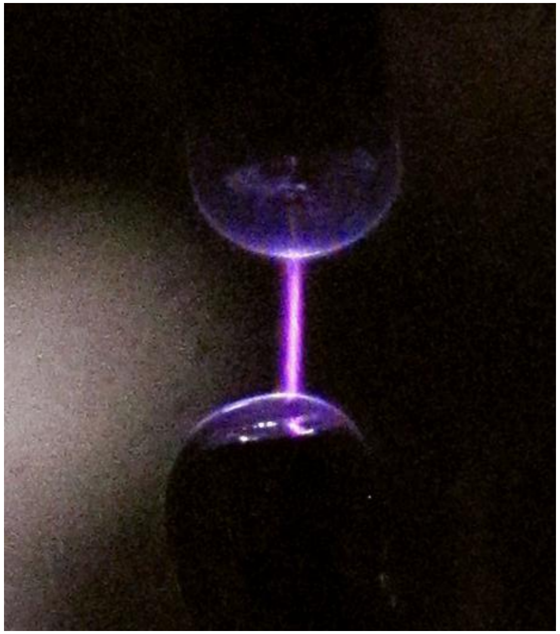


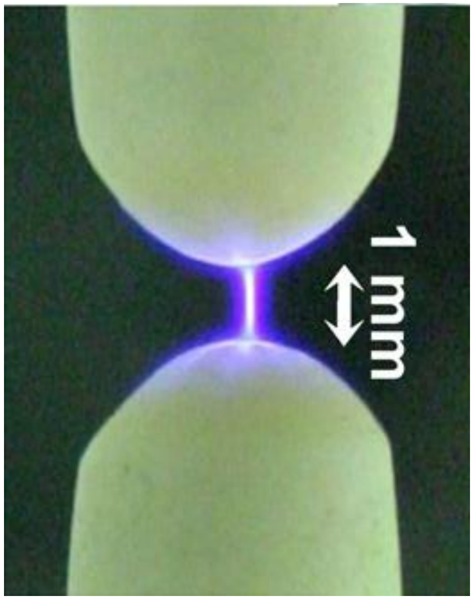


- **Charge build-up in front of the anode (>200 ns!) before streamer starts ("pre-breakdown" phase)**
- **Accumulation of many avalanches**
- **Avalanches become efficient only where the field if enhanced by the adsorbed charge**

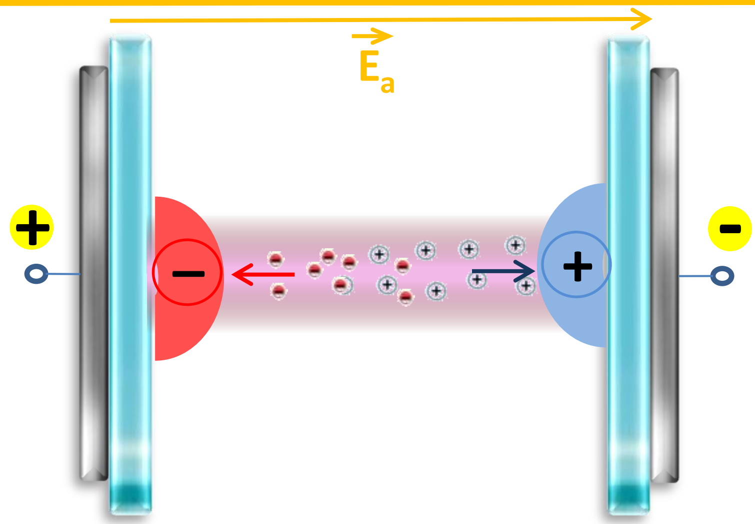
Role of the dielectric in filament ignition



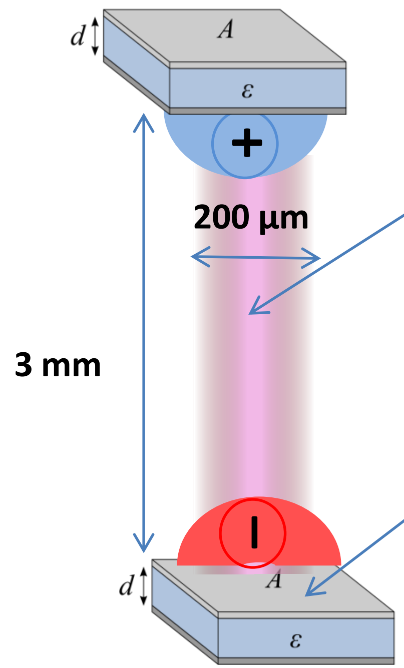
How the dielectric is stopping the filament?



influence of the dielectric in filamentary DBDs



What happens when the streamer reach the dielectric?



$$U_{applied} \approx 10^4 V$$

$$n_e = 3 \cdot 10^{13} cm^{-3}$$

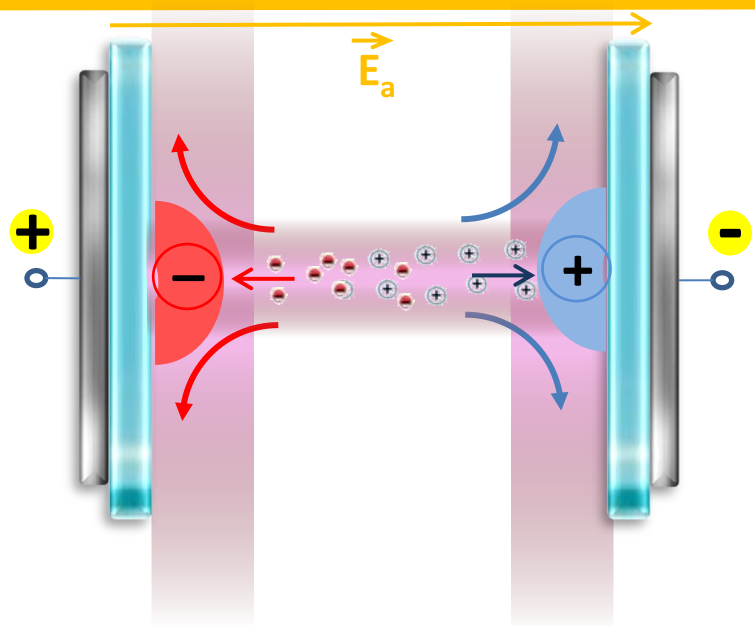
$$Q \approx 0.5 nC$$

$$C_d = \varepsilon_0 \varepsilon_r \frac{A}{d} \approx 10^{-3} pF$$

$$U = \frac{Q}{C} \approx 10^6 V!!!$$

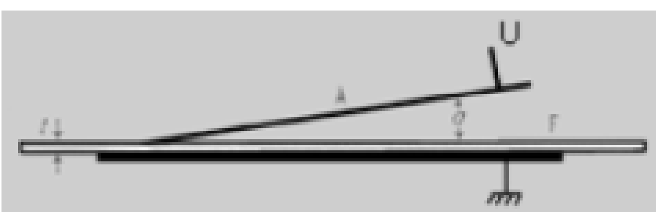
The filament must spread over the dielectric

DBD: streamer spreading over the dielectric

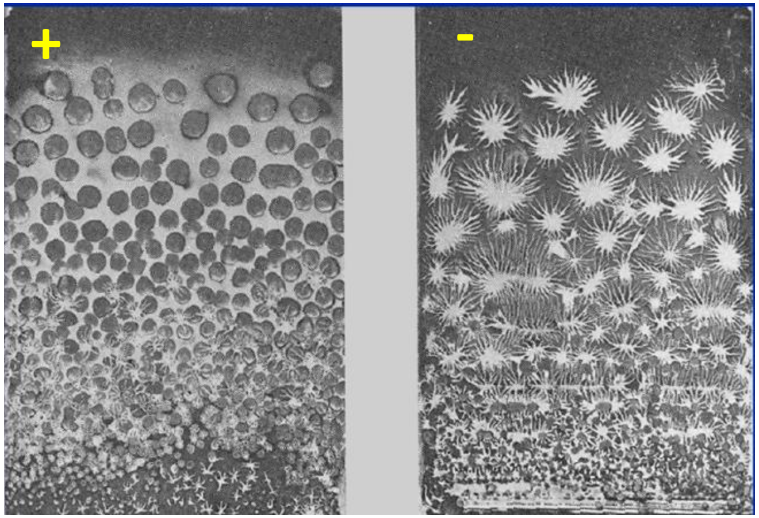


What happens when the streamer reach the dielectric?

H. Bertein, *J. Phys. D: Appl. Phys.* **6** (1973), 1910



Electrography with red lead
and lycopodium powder

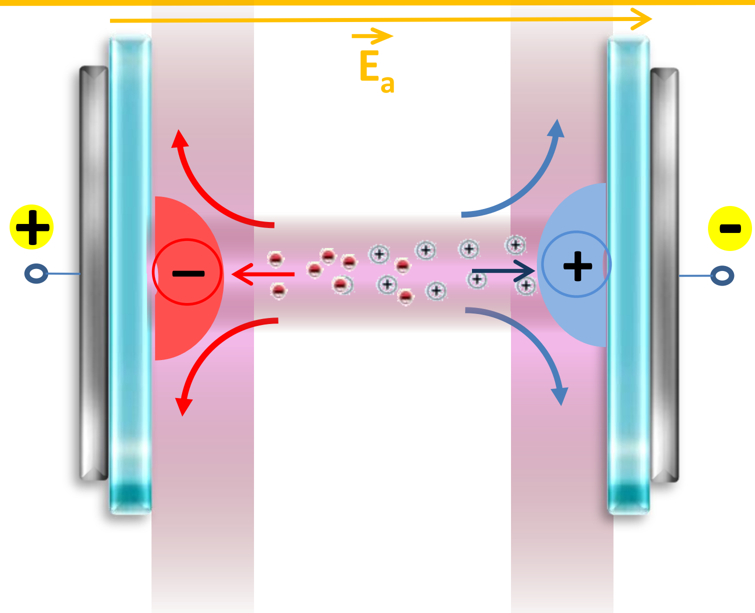


A longer filament carries more charge

⇓

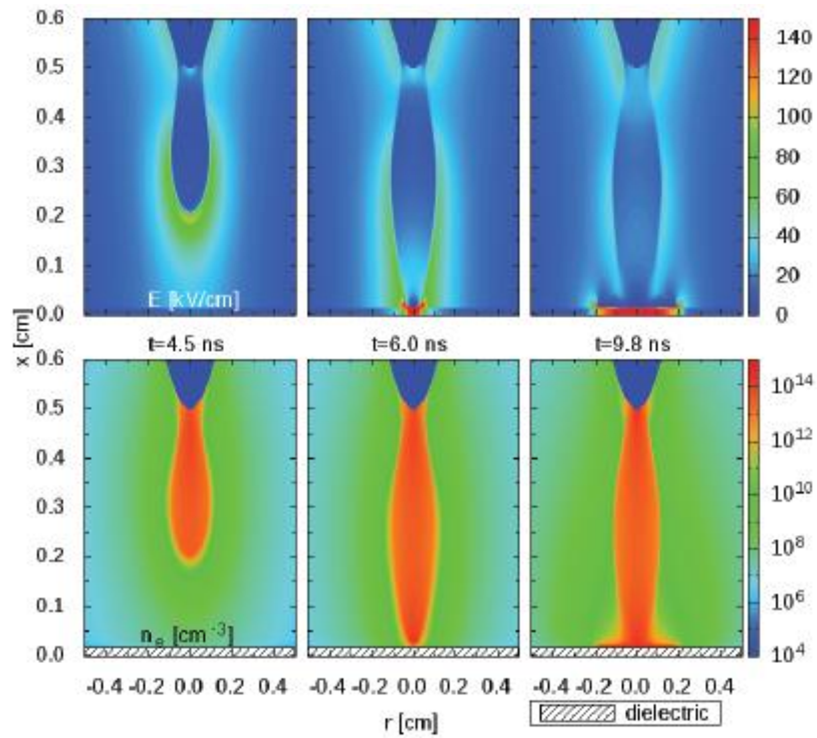
Larger spreading on the dielectric

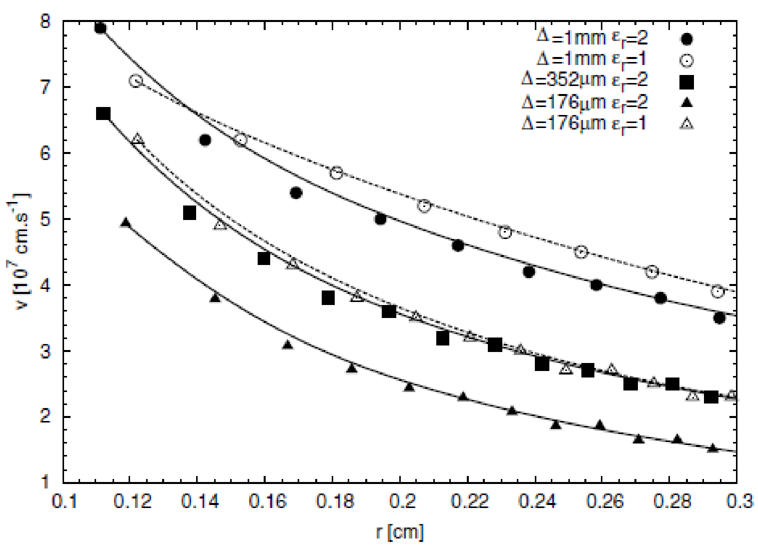
DBD: streamer spreading over the dielectric



What happens when the streamer reach the dielectric?

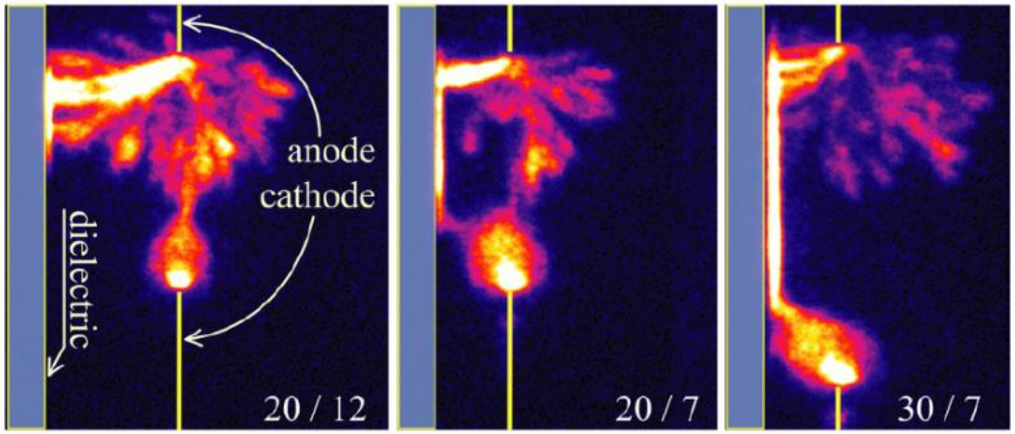
Pechereau et al, *Plasma Sources Sci. Technol.* **21** (2012) 055011



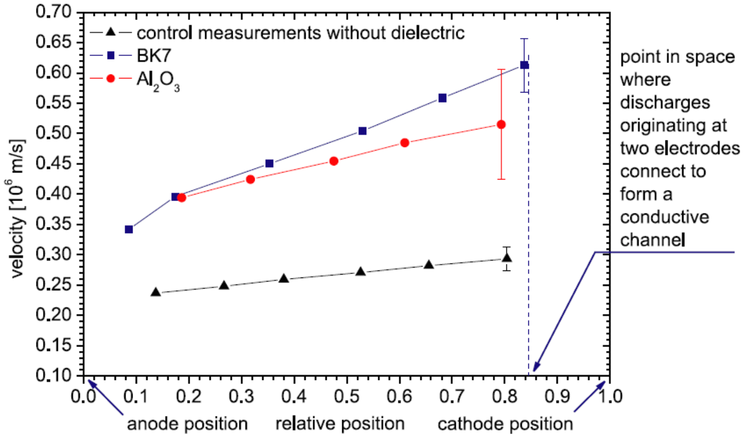


- ➢ The capacitance of the dielectric is driving the filament spreading
- ➢ higher capacitance, slower discharge

speeding up over surface (lighting, flashover, actuator)



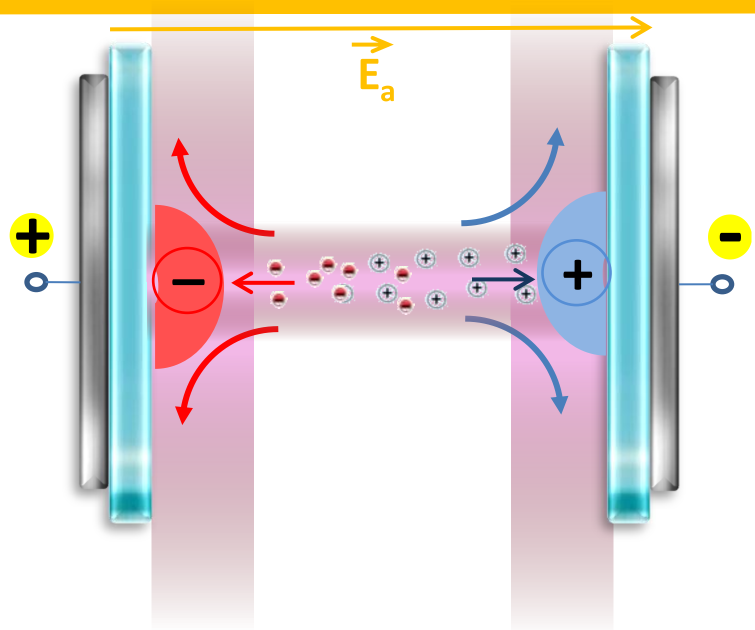
A Sobota et al, J. Phys. D: Appl. Phys. **42** (2009) 015211



Role of permittivity of the dielectric material is different depending on the direction of E field with respect to the surface:

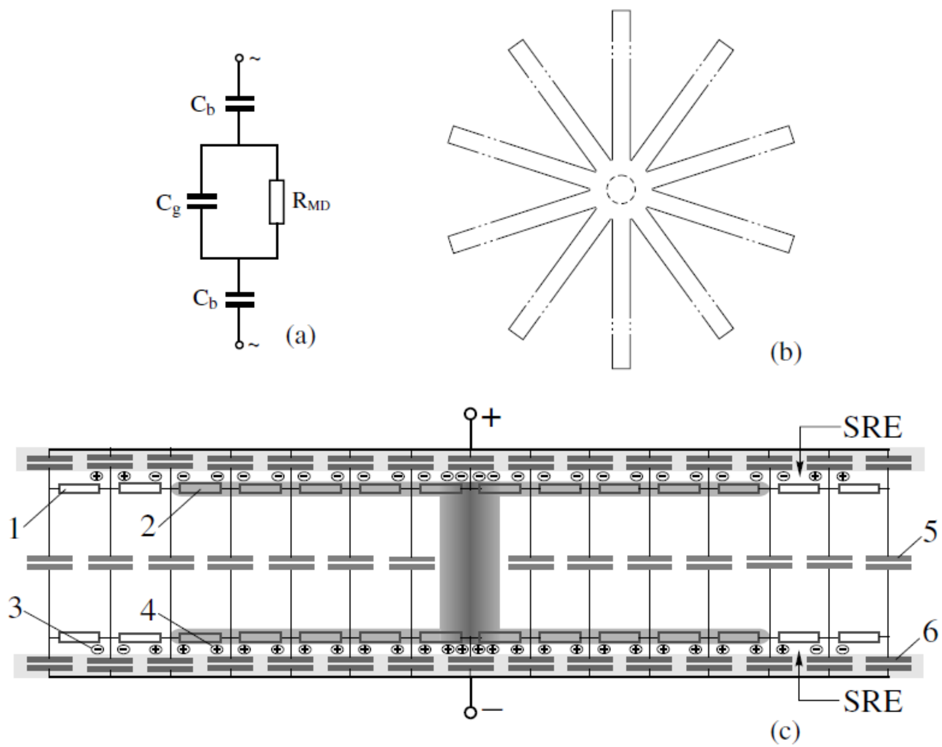
- E perpendicular: Charging of the capacitance make the discharge slowing down
- E parallel: desorption of charges and reinforcement of local field
  Adsorbed negative ions are desorbed and give back electron by detachment

DBD: streamer spreading over the dielectric



model for describing “n” filaments over the surface

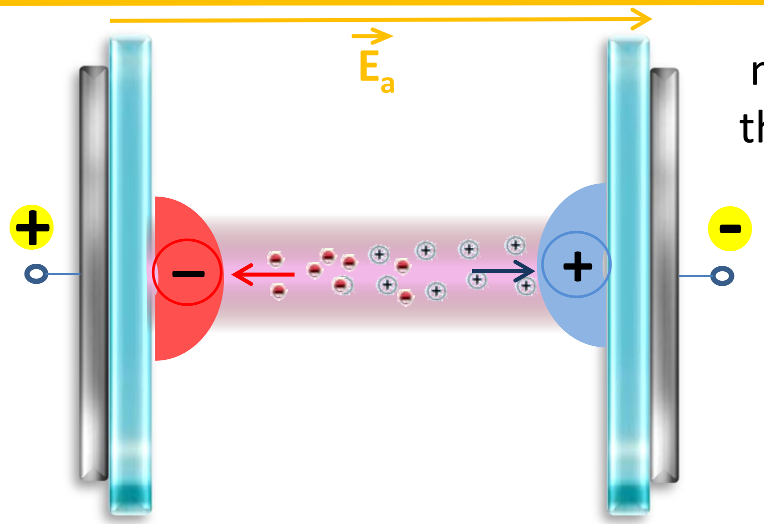
Akishev et al, *Plasma Sources Sci. Technol.* **20** (2011) 024005



Streamer over a dielectric
= resistor and capacitances in series

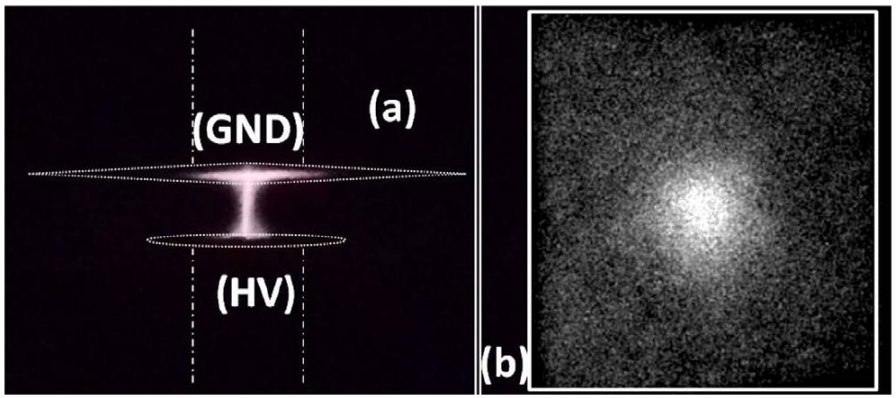
- **About 1/3 of energy dissipated by a streamer, is dissipated over the dielectric surface**
- A “volume” micro-discharge is also a “surface” one…

How charge is "adsorbed" on the dielectric ?



measurement of trapped electron on Al_2O_3 by thermoluminescence technic

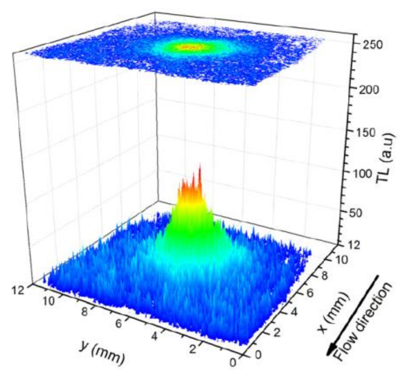
Ambrico et al, *J. Phys. D: Appl. Phys.* **47** (2014) 305201



• Electrons trapped in lattice default of the material with energy about **1eV**

• negative ions physisorbed? Chemisorbed?

•In any case γ is strongly enhanced by charges "adsorbed" on the dielectric



About micro-discharges in DBD...

- ✓Adsorbed charges → Stop the micro-discharges
  AND
  Initiate the micro-discharges

- ✓ "pre-breadown" phase can be 0.1-1 µs !

- ✓ adsorbed charges are e- trapped, or negative ions ?

- ✓charges adsorbtion energy is weak (~ 1 eV)

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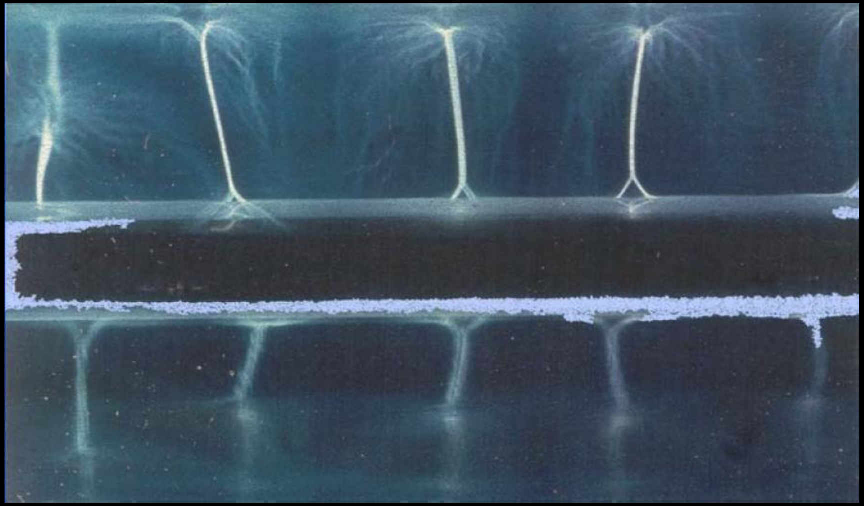

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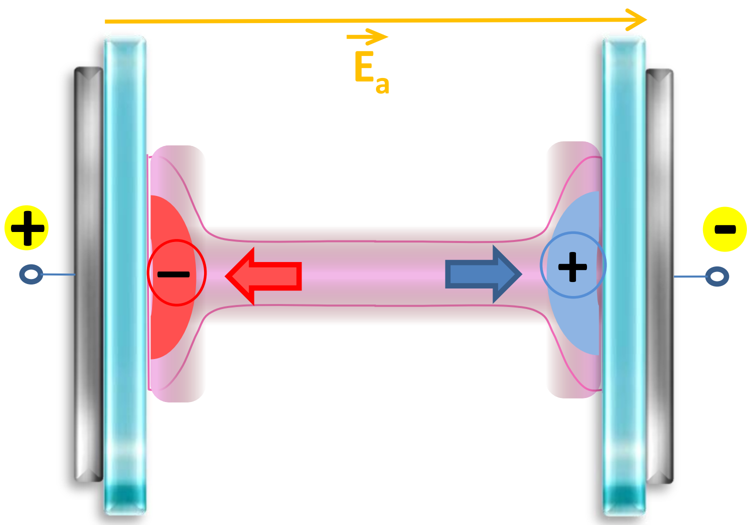
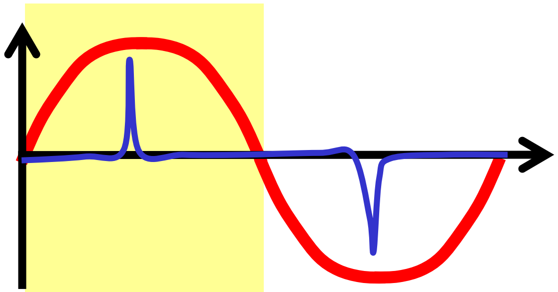
   b) Diffuse discharges

V. **Confinement and gas motion**

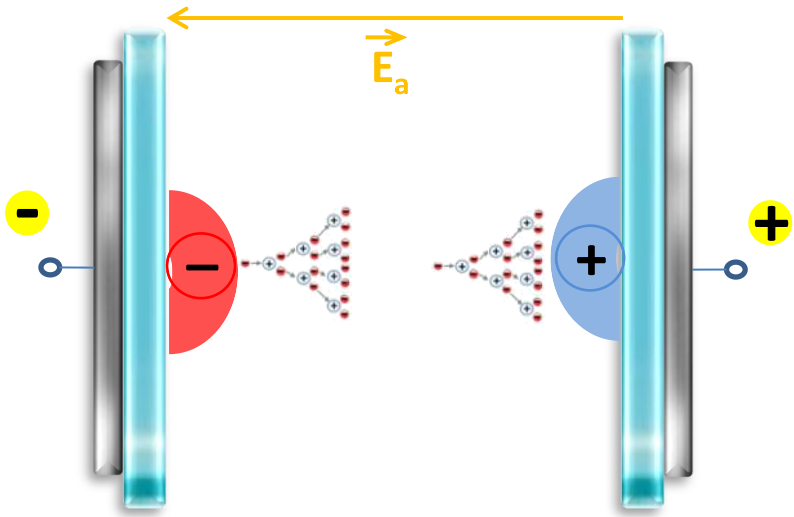
Self organization: field shielding



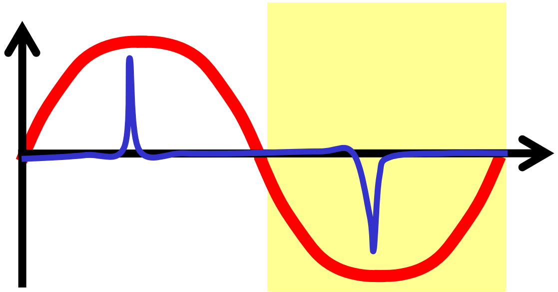


J. Guikema et al., Phys. Rev. Lett. **85 (2000) 3817**

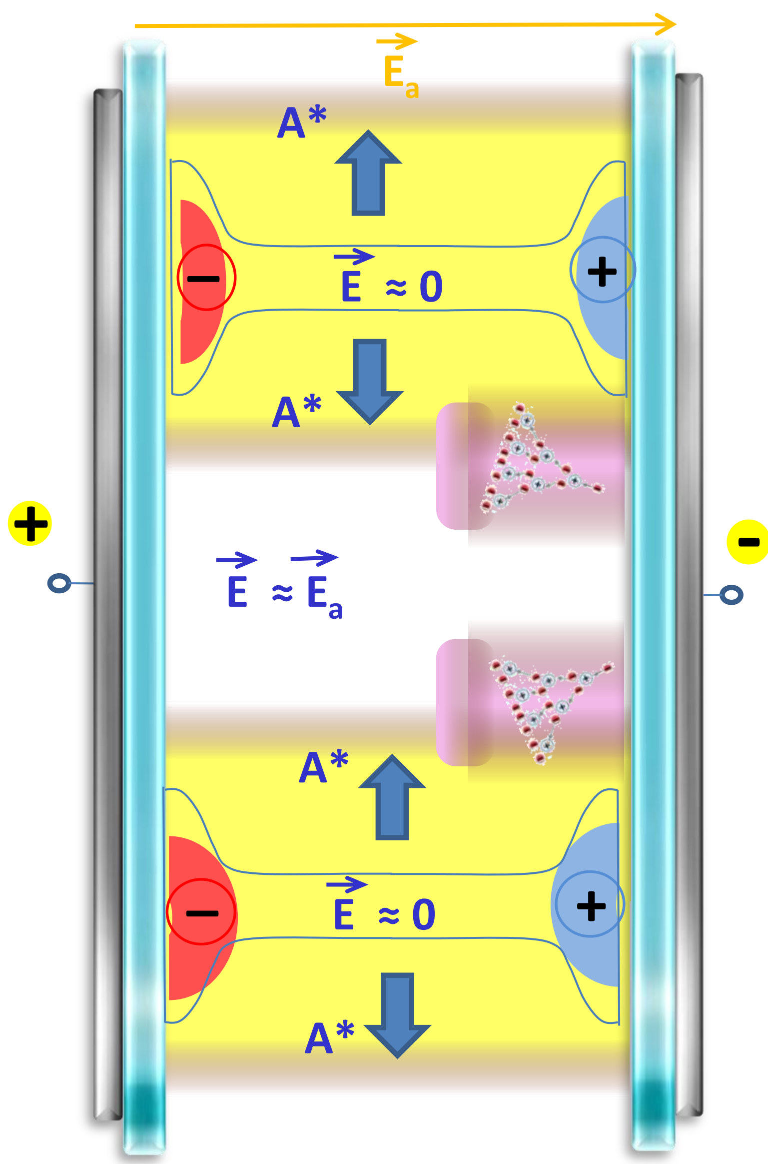
Low voltage

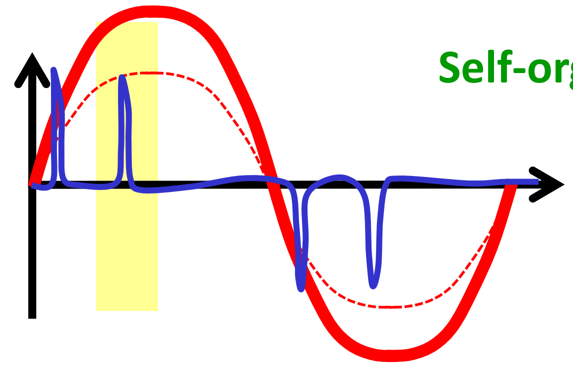


- Adsorbed charge fix the position of the filaments
- Distance between filaments depends on spreading



Self organization: gas phase contribution





Self-organization in 1D

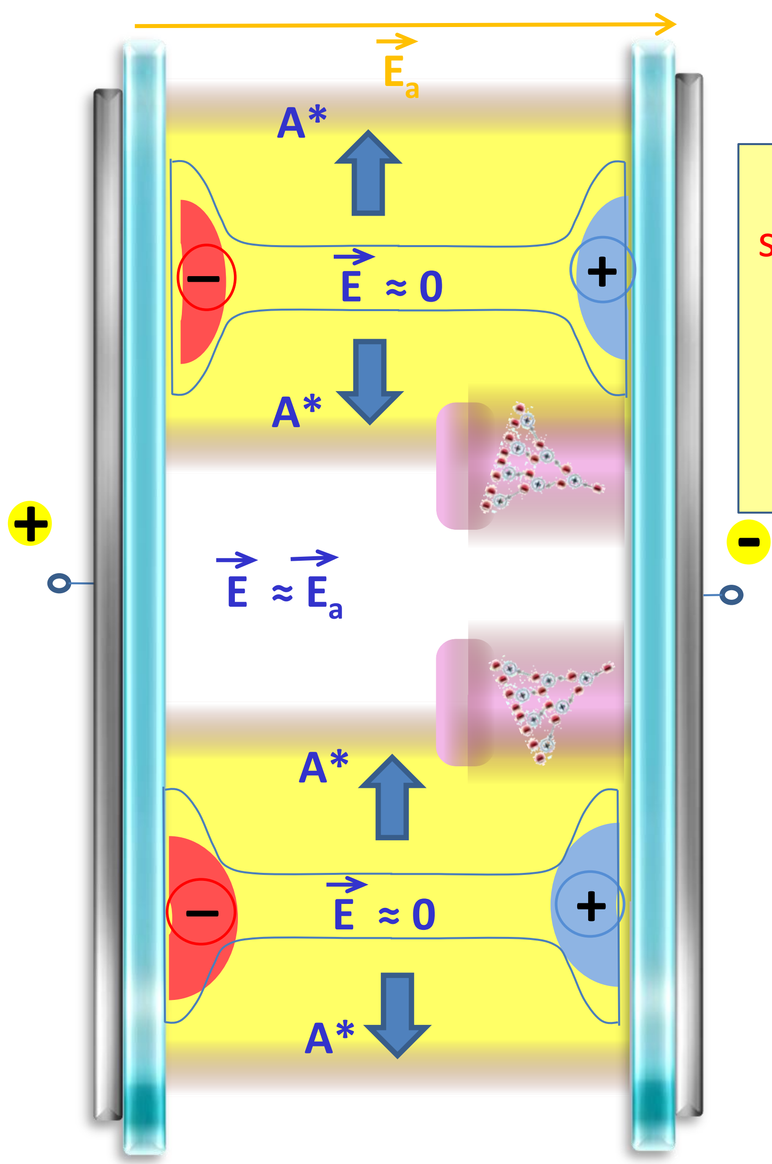
J. Guikema et al., Phys. Rev. Lett. **85 (2000) 3817**

2nd filament unstable

Instability of 2nd filament: gas phase vs surface

Field is higher between the 1st filaments
But
Gas is "pre-excited" close to 1st filaments

Adsorbed charge vs "pre-excited" channel



Behavior of a DBD is driven by this question:

Where will occurs the most efficient avalanches?

surface charges distribution → **shield the field during the same half-period**

→ **Provide first e- when polarity is reversed**

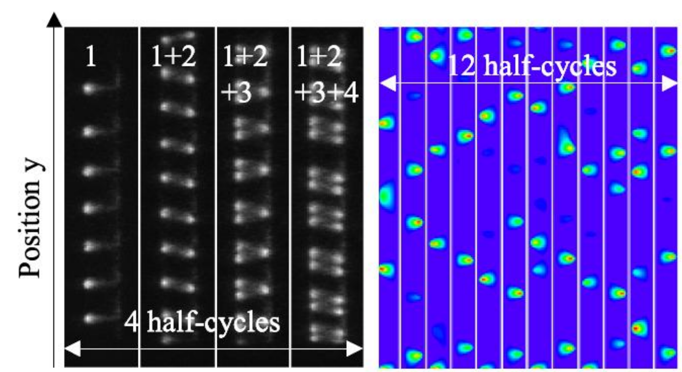
Vs

diffusion of excited species in the gas phase

Equations for describing such system:
activator-inhibitor equations

$$\frac{da}{dt} = \frac{pa^2}{h} - \mu a + D_a \frac{d^2 a}{dx^2}$$

$$\frac{dh}{dt} = p' a^2 - \nu h + D_h \frac{d^2 h}{dx^2}$$



Bœuf et al, *Appl. Phys. Lett.* **100** (2012) 244108

About filaments interactions

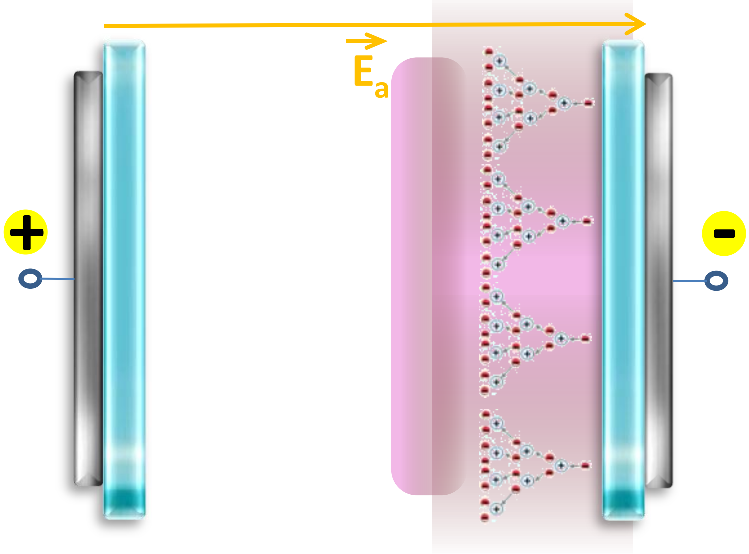
✓Filaments can be self-synchronized and/or spatially organized

✓ Filaments can interact through:

- field of the streamer itself
- emitted light
- field shielding
- excited species diffusion

How the surface and gas phase contribution can lead to diffuse discharge?

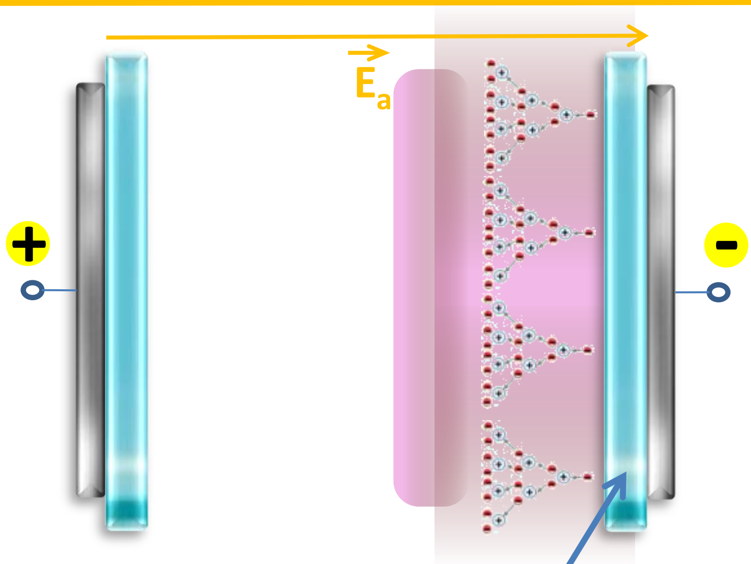
diffuse discharge: electron emission from the surface

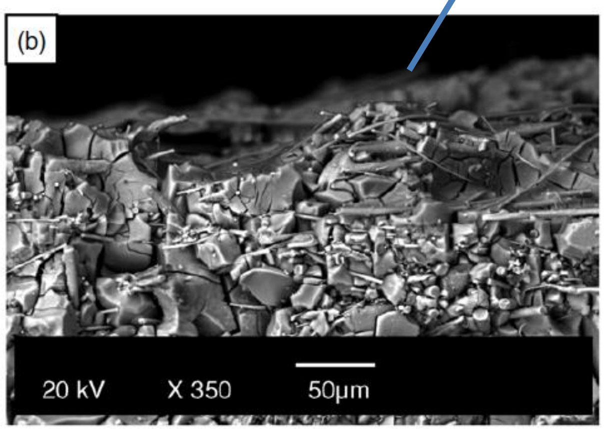


How to get a diffuse discharge at atmospheric pressure ?

1) e- emission from the surface over a large area

diffuse discharge: electron emission from the surface





How to get a diffuse discharge at atmospheric pressure ?

1) e- emission from the surface over a large area

a) Increasing γ_{eff}

Okazaki et al, J. Phys. D Appl. Phys. **26** (1993)

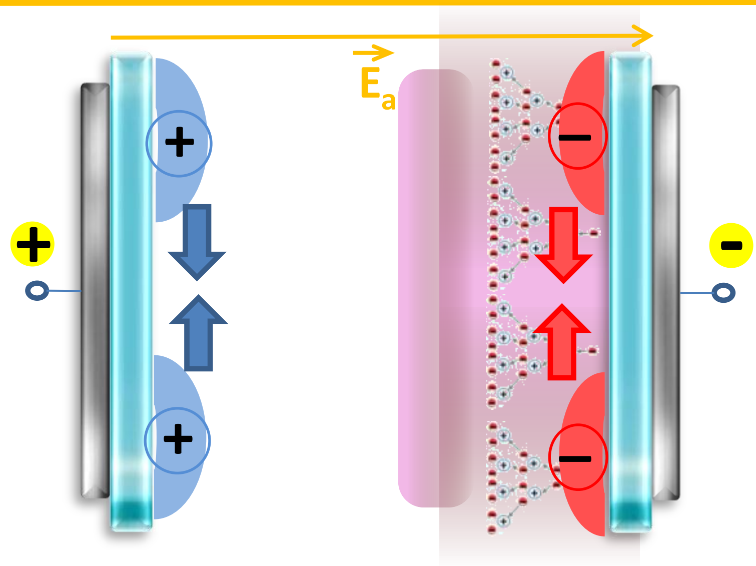
Adsorbed aceton release e^- in Ar discharge

Garamoon et al, Plasma Sources Sci. Technol. **18** (2009) 045006

High γ material: Al_2O_3, MgO

Warning: it is an effective γ that include desorption of electron…

diffuse discharge: electron emission from the surface

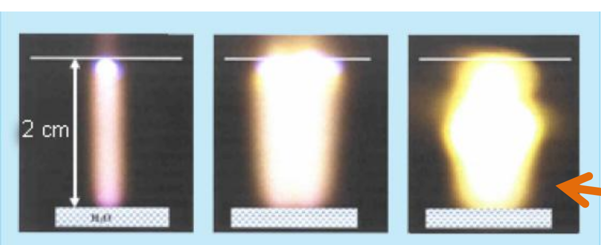


How to get a diffuse discharge at atmospheric pressure ?

1) e- emission from the surface over a large area

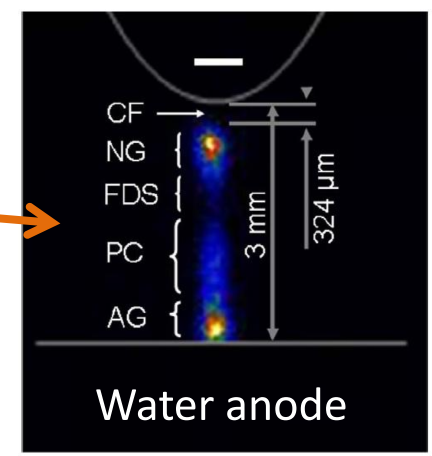
a) Increasing γ
b) lower surface resistivity

- Use of semi-conductor as “barrier”
- similar idea with discharges above water surface

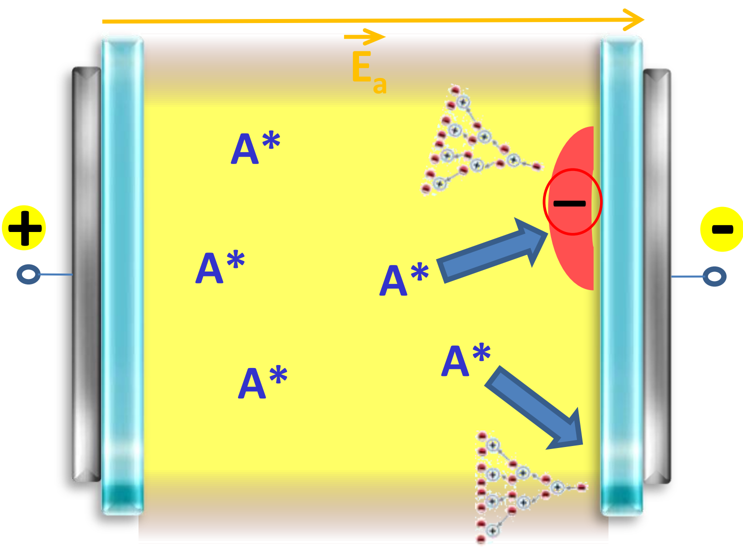


Bruggeman et al, *J. Phys. D: Appl. Phys.* **41** (2008) 215201

M. Laroussi et. al., 2002 Int. Power Modulator Conf



diffuse discharge: electron emission from the surface



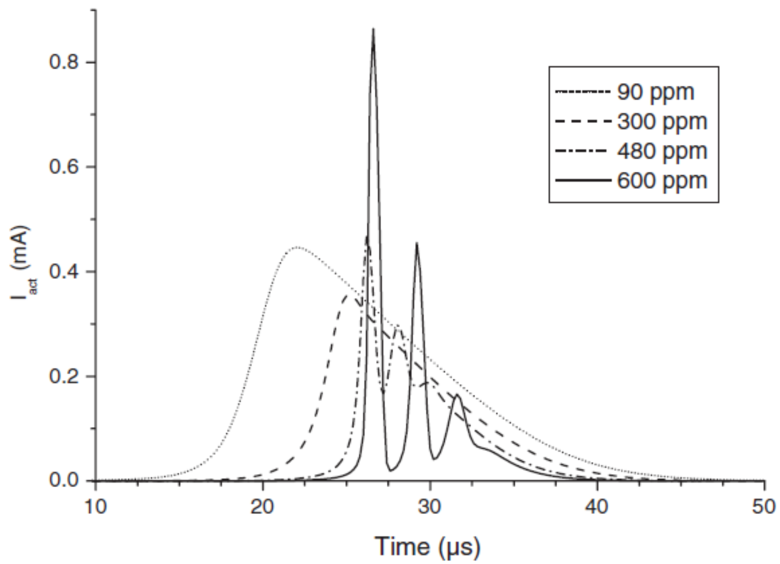
How to get a diffuse discharge at atmospheric pressure ?

1) e- emission from the surface over a large area

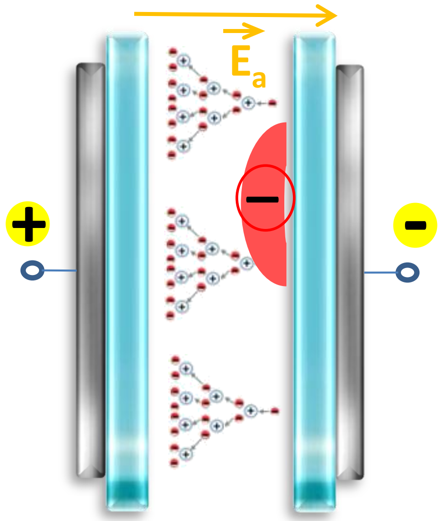
a) Increasing γ
b) lower surface resistivity
c) High flux of energetic particles to enhance γ_{eff} (ions, metastables…)

Brandenburg et al, *J. Phys. D: Appl. Phys.* **38** (2005) 2187–2197

ex: **Diffuse Townsend N_2 discharge**:
secondary electron emission from metastable $N_2(A\ ^3\Sigma_u)$ impact
Admixture of O_2 quenches $N_2(A\ ^3\Sigma_u)$ (+ attachment)



diffuse discharge: gas phase conditions

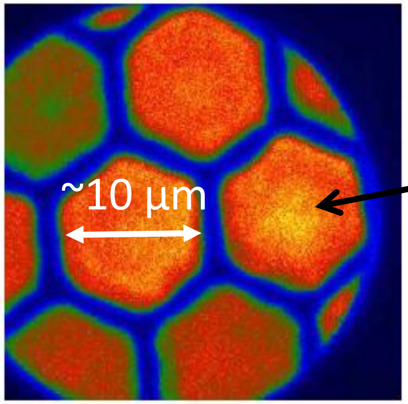


How to get a diffuse discharge at atmospheric pressure ?

1) **e- emission from the surface over a large area**

2) **gas phase homogenisation**

   a) Very short gap

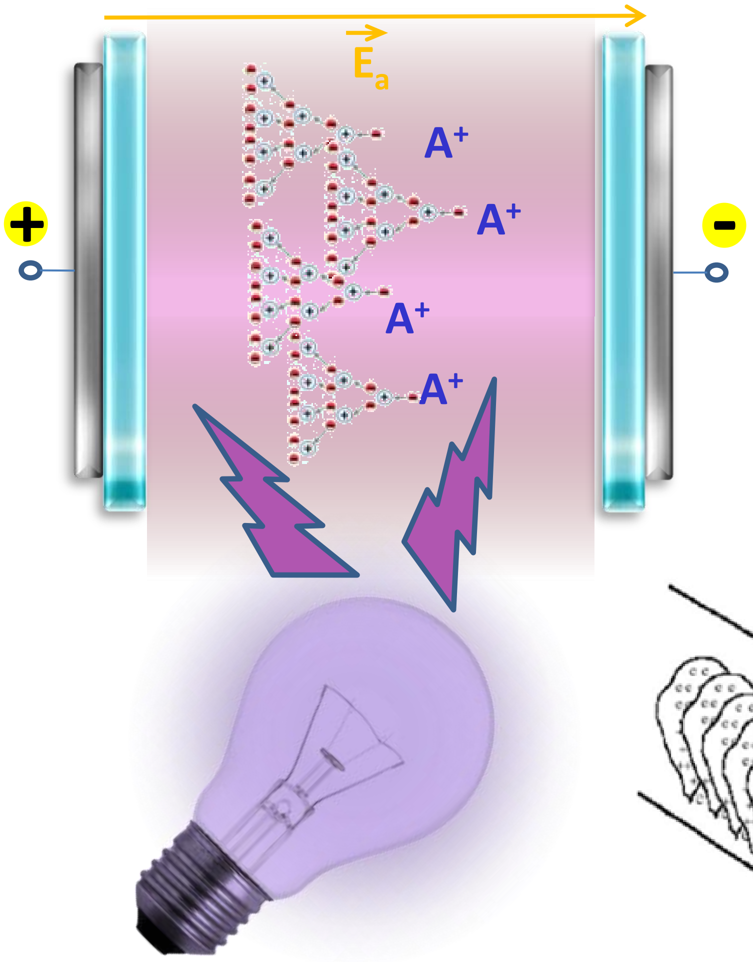


Qiu et al, IEEE Trans. Diel. Elec. Ins. **18** (2011) 1

Townsend discharge in air inside polymer voids

Important topic for plasma/catalyst coupling and insulator damaging

diffuse discharge: gas phase conditions

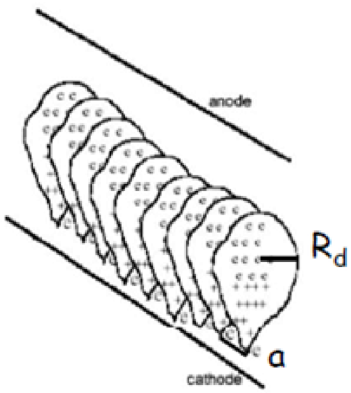


How to get a diffuse discharge at atmospheric pressure ?

1) e- emission from the surface over a large area

2) gas phase homogenisation

   a) Very short gap
   b) Pre-ionize the gas



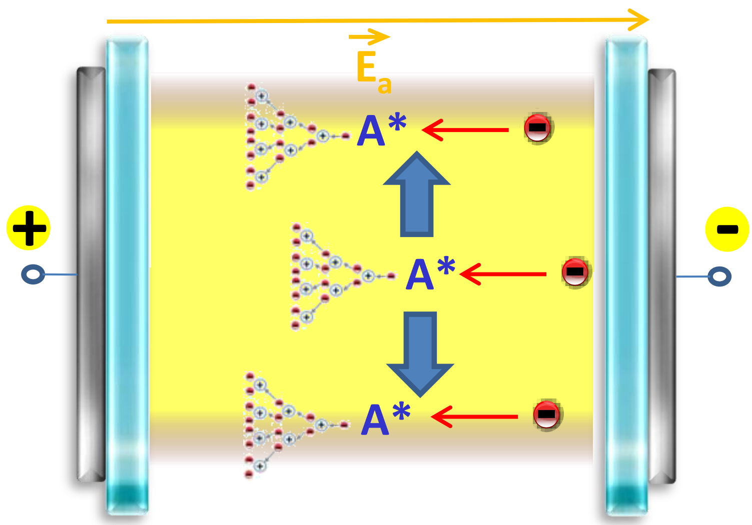
Numerous simultaneous avalanches

Require pre-ionization with $n_{e0} \approx \cdot 10^6 cm^{-3}$

Palmer et al, J. *Appl. Phys. Lett.* **25** (1974) 3-138

Example: photo-triggered discharge

diffuse discharge: gas phase conditions



How to get a diffuse discharge at atmospheric pressure ?

1) e- emission from the surface over a large area

2) gas phase homogenisation

a) Very short gap
b) Pre-ionize the gas
c) Multi-steps ionization
d) diffusion of excited species

Ionization of excited species having life time long enough to diffuse
"self-pre-excitation" of the gas

$$1)\quad e^- + A \rightarrow A^* + e^-$$

$$2)\quad A^* + B \rightarrow B^+ + e^-$$

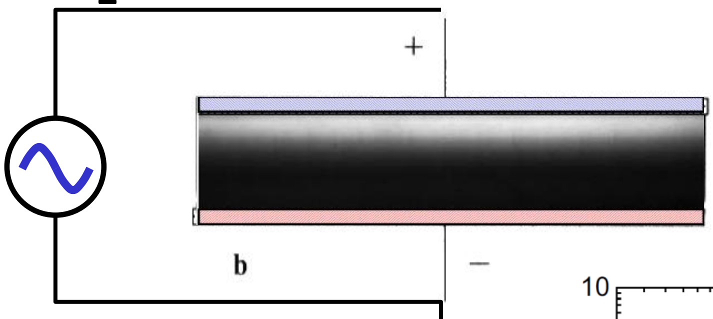
Examples:

- penning ionization in Ar/NH_3 — Bazinette et al, *Plasma Sources Sci. Technol.* **23** (2014) 035008
- ionization of He metastables — F. Massines et al, *J. Phys. D: Appl. Phys.* **31** (1998) 24; Golubovskii et al, *J. Phys. D: Appl. Phys.* **36** (2003) 39

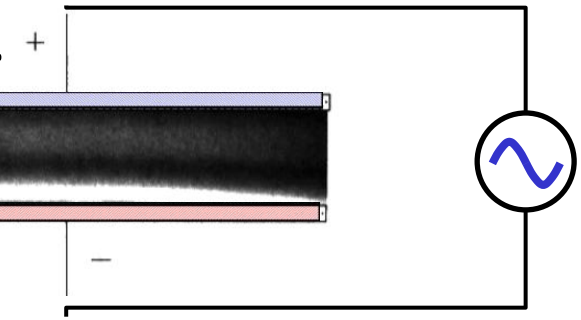
DBD: homogeneous discharges

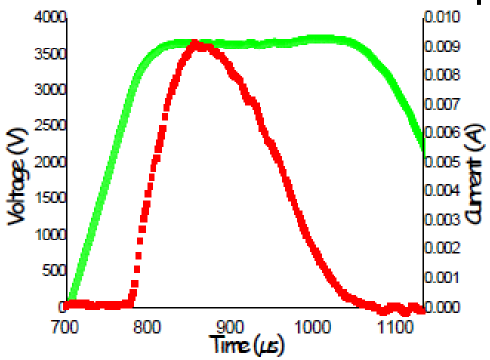
N_2 Townsend , $n_e \approx 10^8$ cm^{-3}

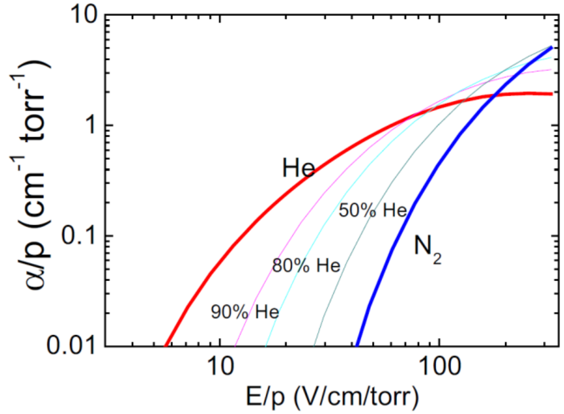
He Glow , $n_e \approx 10^{11}$ cm^{-3}

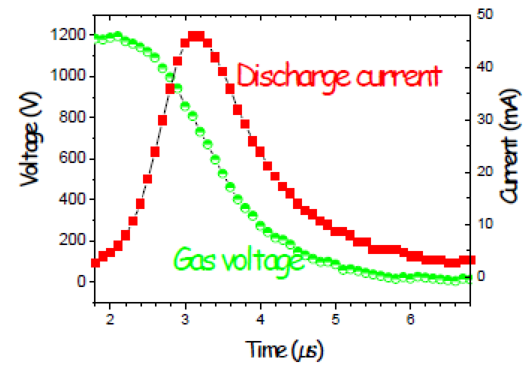


Glow disch.









In Nitrogen:

- High γ
- Increased by metastable $N_2(A\ ^3\Sigma_u)$ impact
- ➢ Surface emission favorable

In Helium:

- α slowly varying with E field
- 2 steps ionization (metastables over large volume)
- Penning ionization if impurities
- ➢ Surface AND gas phase favorable

Massines et al, *Plasma Phys. Control. Fusion* **47** (2005) B577–B588

See also : Golubovskii et al, *J. Phys. D: Appl. Phys.* **36** (2003) 39–49

About filaments interactions

diffuse DBD discharge can be obtained at atmospheric pressure with:

- ✓ **Enhanced electron emission from the surface**
- ✓ **pre-excited species over the whole gas volume**

Outline

I. Breakdown mechanisms
- a) Townsend mechanism
- b) Streamer mechanism

II. Corona discharges

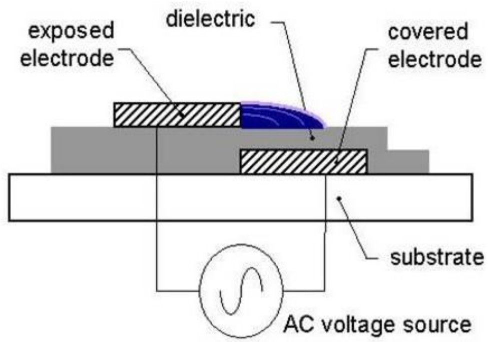
III. What is a Dielectric Barrier Discharge?
- a) Electrical characteristics
- b) Development of a single filament
- c) Role of the dielectric ?

IV. Role of surface vs gas phase dynamics
- a) Interaction between filaments
- b) Diffuse discharges

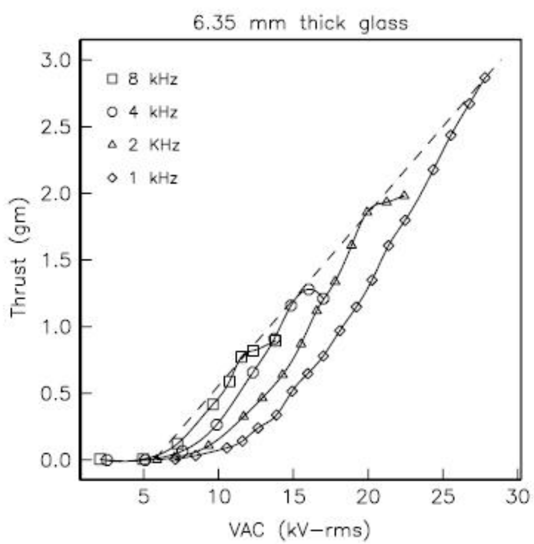
V. Confinement and gas motion

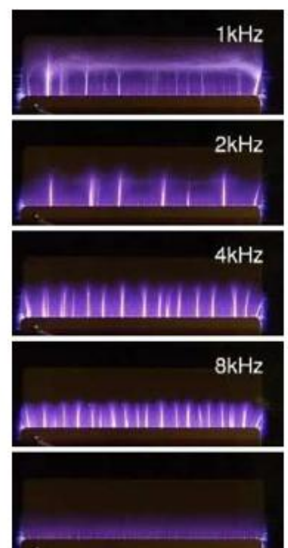
Gas motion induced by filaments: ion wind

Using plasma for limiting turbulences



Corke et al, Exp Fluids **46** (2009) 1–26





Gas motion induced by filaments: ion wind

The force per unit volume transmitted by positive ions to the neutral molecules = ion momentum loss per unit volume per unit time

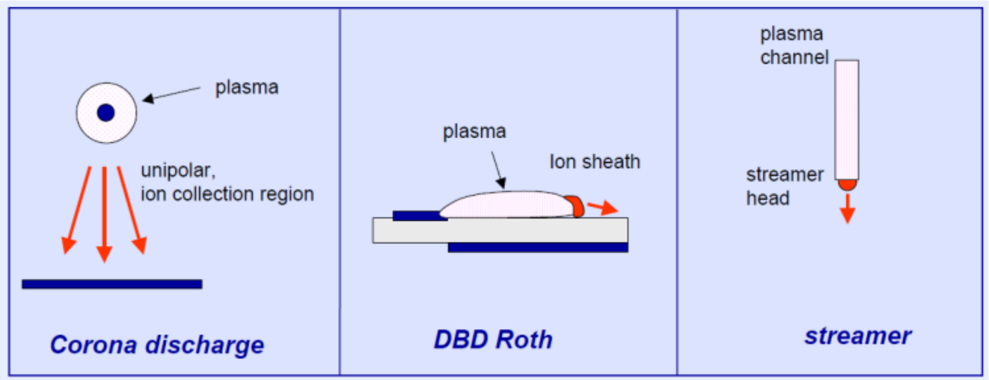
$$f_i = m_i n_i v_{im} v_i = \frac{m_i v_{im}}{e} e n_i v_i = \frac{j_i}{\mu_i}$$

The same for electrons

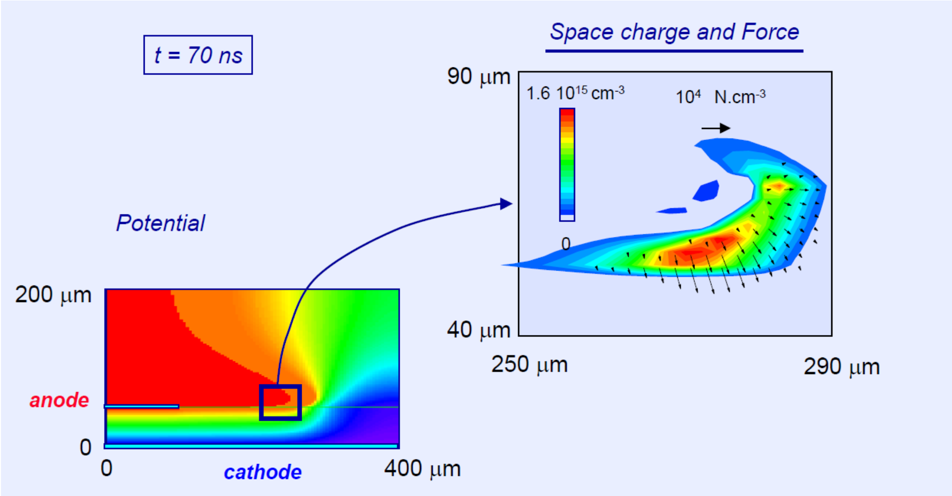
$$f_e = \frac{j_e}{\mu_e}$$

The total force

$$f = \frac{j_i}{\mu_i} - \frac{j_e}{\mu_e} = e(n_i - n_e)E - kT_i \nabla n_i - kT_e \nabla n_e$$

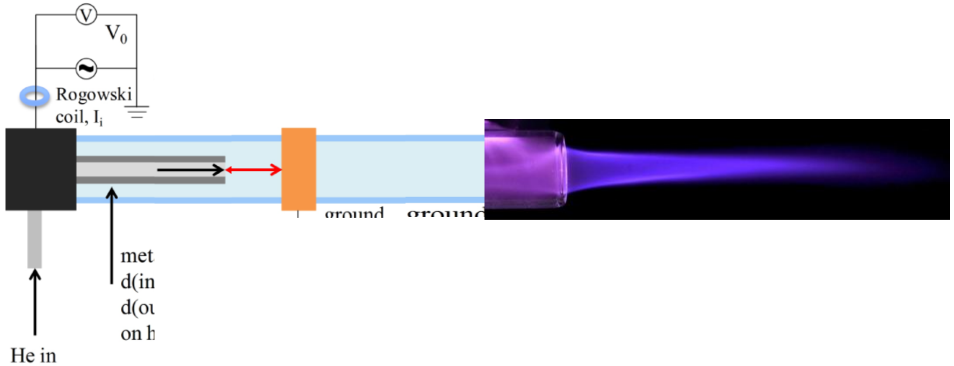


The force is important only in non neutral zone

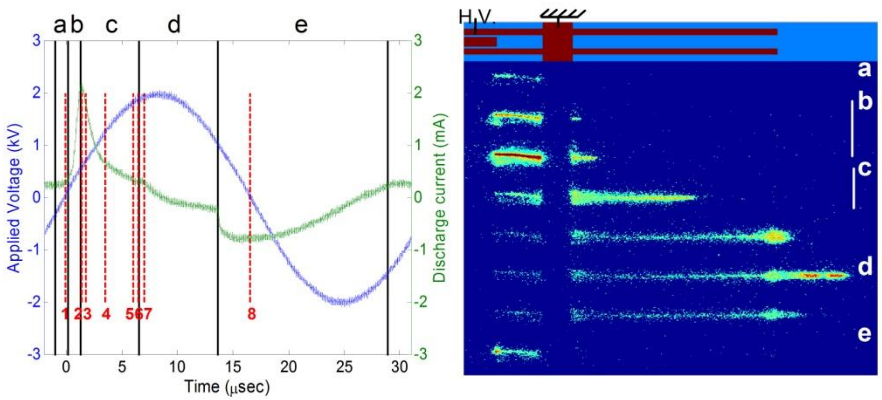


Boeuf et al, *J. Phys. D: Appl. Phys.* **40** (2007) 652–662

DBD Plasma jet in kHz range : a synthesis of atmospheric pressure discharges

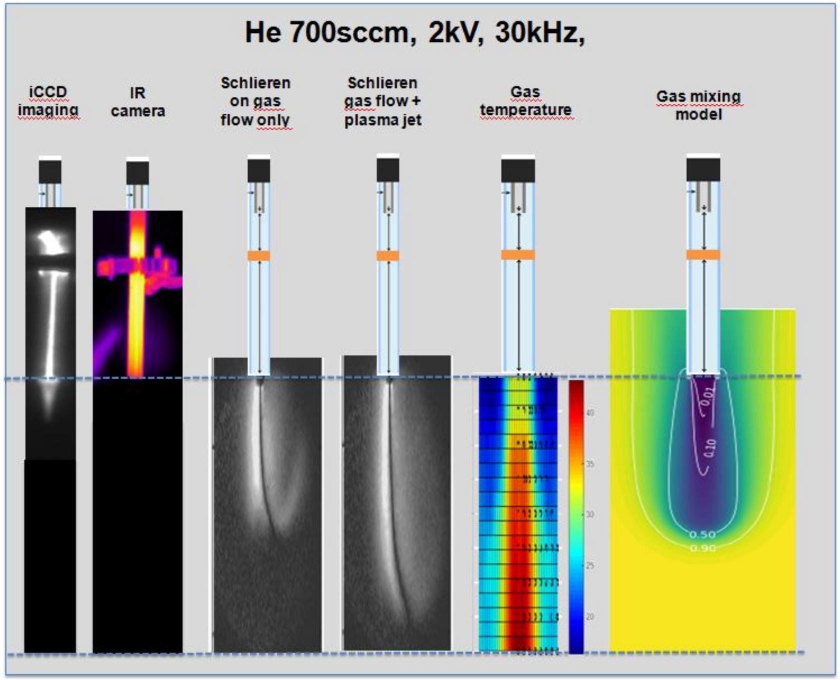


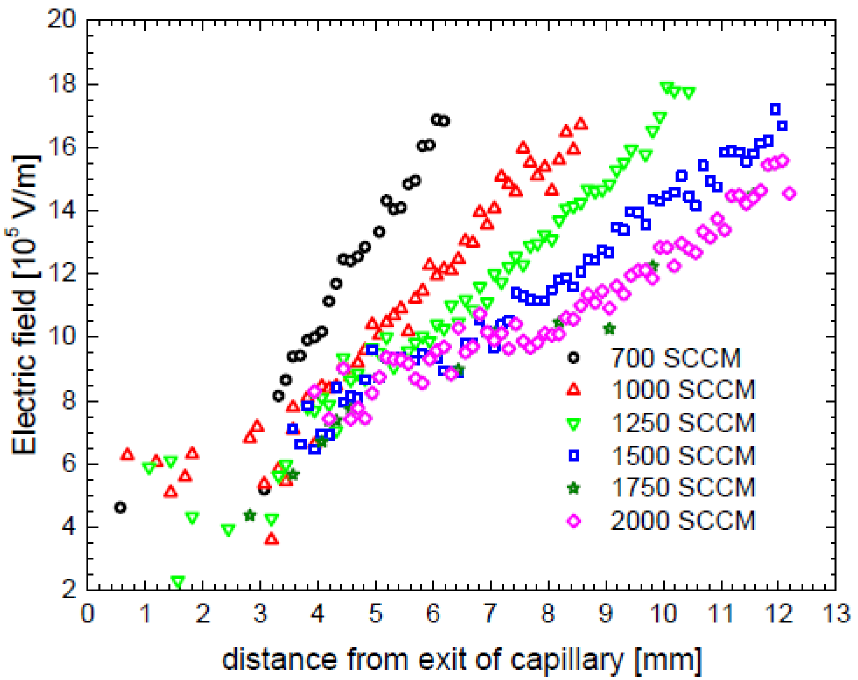
- Capillary discharges in noble gases: "overflowding" of an homogeneous discharge!
- plasma bullet propagation is possible because of confinement of charges
- it is slowed down by the capacitance of the tube
- when it exit in the surrounding atmosphere it is following the flow of He



A Sobota, *Plasma Sources Sci. Technol.* **23** (2014) 025016

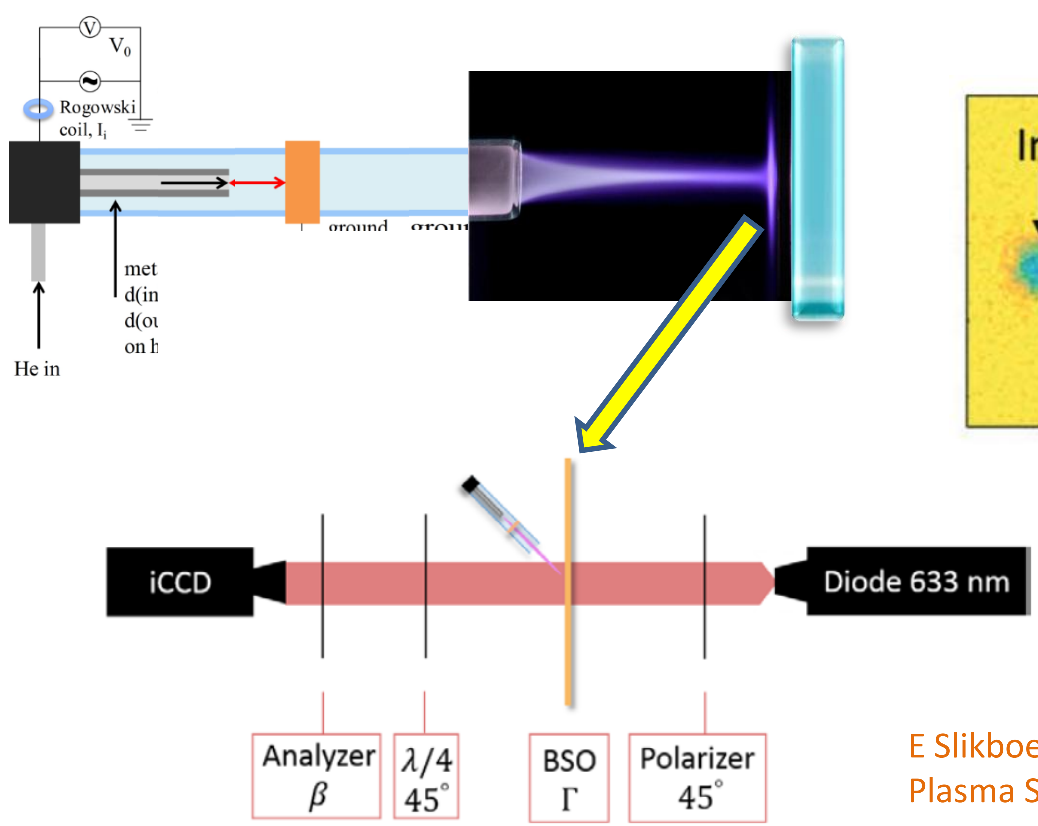
DBD Plasma jet in kHz range: a model ionization wave

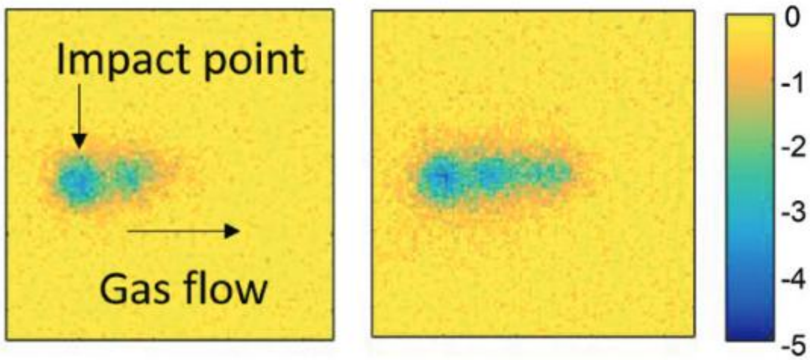




Basic plasma parameters can be measured -> begining of good comparison with models

Electric eld measurements in a kHz-driven He jet - the inuence of the gas ow speed , A Sobota et al Plasma Sources Science and Technology (2016) accepted





Surface
E field
(kV/cm)

E Slikboer, O Guaitella, A Sobota
Plasma Sources Science and Technology 25 (3), 03LT04

Model for ionisation waves interaction with surfaces

conlusions

DBDs and Corona develop different discharges

Building up of a localized space charge determine the discharge behavior

Balance between charge adsorption/emission from the surface and remaining excited species in gas phase is essential for DBD

Chemistry very complex but also very efficient

Books

-**Yu. P. Raizer « Gas Discharge Physics » (Springer)**

- **Nasser E., Fundamental of gazeous ionization and plasma electronics,** Wiley interscience, New-York, 1971

- J. Reece Roth « Industrial Plasma Engineering » (IOP)- Nato ASI Series
"Electrical breakdown and discharges in gases:
"Non Thermal Plasma Technologies for Pollution Control" 1993

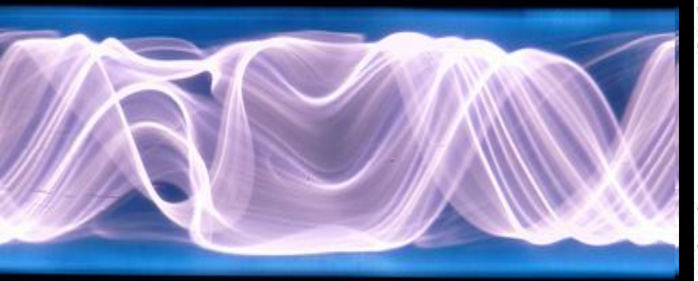
-**Ch. K. Rhodes « Excimer Lasers » (Springer-Verlag)**

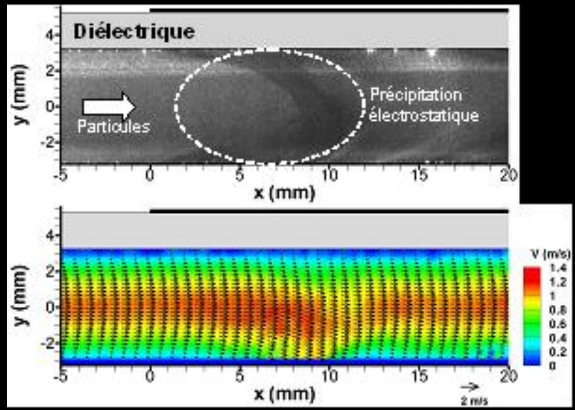
- **K.H. Becker, U. Kogelschatz, K.H. Schoenbarch, B. J. Barker** "Non equilibrium air plasmas at atmospheric pressure", IoP,2005

- **A. Fridman** "Plasma chemistry", 2008, Cambridge

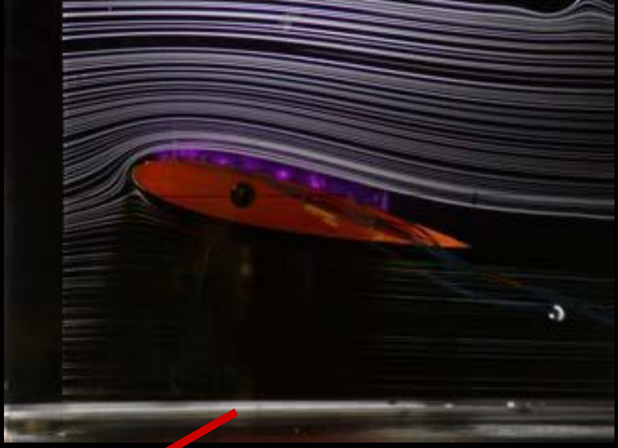
Filamentary discharges at atmospheric pressure

Lighting: surface interaction for regular breakdown and salt evaporation





Electrostatic precipitation and flow control: ion wind

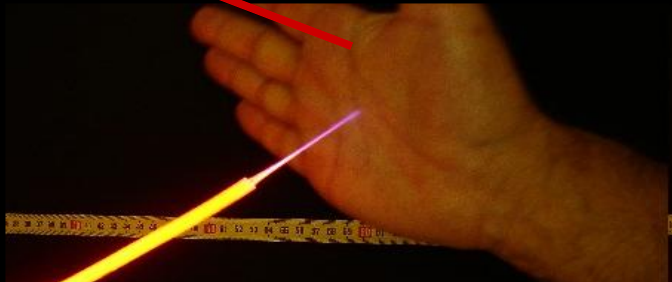


large variety of reseach topics !!

Assisted combustion and air treatment:

Breadown in voids and high pressure complex chemistry

Surface reactivity



Biomedical applications:

Heating processes, complex chemistry, surface interaction