Overview of Tutorial – Low Temperature Plasmas (LTP)

LTP I
Monday, August 10 -
1:00 PM to 2:00 PM
Open Discussion –
2:00 PM to 2:30 PM

Jose L. Lopez

- Fundamentals of Low Temperature Plasmas
- Plasma Generation & Chemistry
- Low-Pressure vs. High-Pressure Plasmas

LTP II
Tuesday, August 11 -
11:30 AM to 12:30 PM
Open Discussion –
12:30 PM to 1:00 PM

Igor Kaganovich

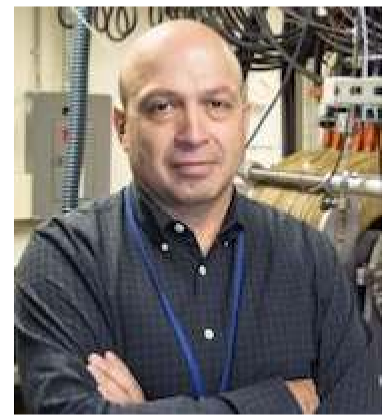
- Computational, Modelling, and Simulations of Low Temperature Plasmas

LTP III
Wednesday, August 12 -
4:00 PM to 5:00 PM
Open Discussion –
5:00 PM to 5:30 PM

Arthur Dogariu

- Optical Diagnostics of Low Temperature Plasmas
- Laser spectroscopy

LTP IV
Friday, August 14 –
2:30 PM to 3:30 PM
Open Discussion –
3:30 PM to 4:00 PM



Yevgeny Raitses

- Low Temperature Plasma applications & technologies
- Low Temperature Plasma enabled technologies

PPPL PRINCETON PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY

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Low Temperature Plasmas :

Fundamentals

Jose L. Lopez, Ph.D.

SETON HALL UNIVERSITY

Department of Physics
Laboratory of Electrophysics & Atmospheric Plasmas (LEAP)
South Orange, New Jersey (USA)
&
PPPL PRINCETON PLASMA PHYSICS LABORATORY
Plasma Science & Technology Department
Princeton, New Jersey (USA)

PPPL Graduate Summer School 2020

The Plasma State – New Jersey

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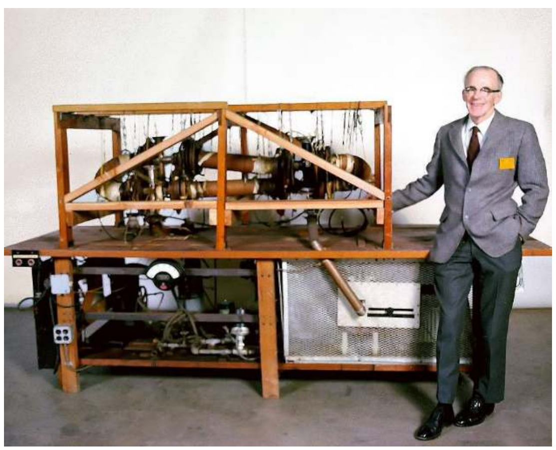
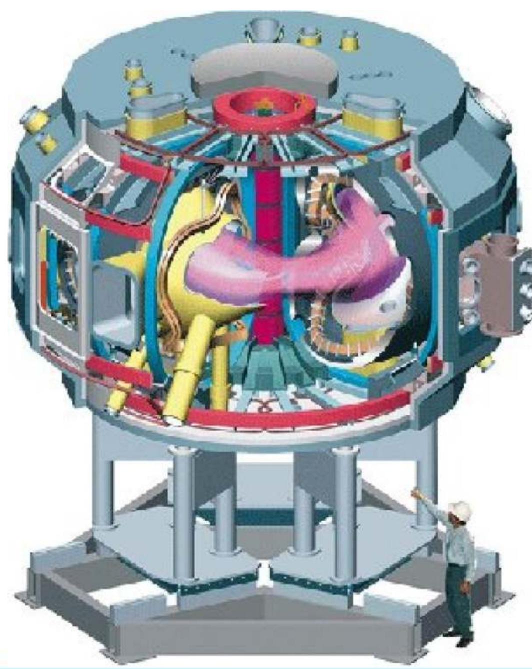
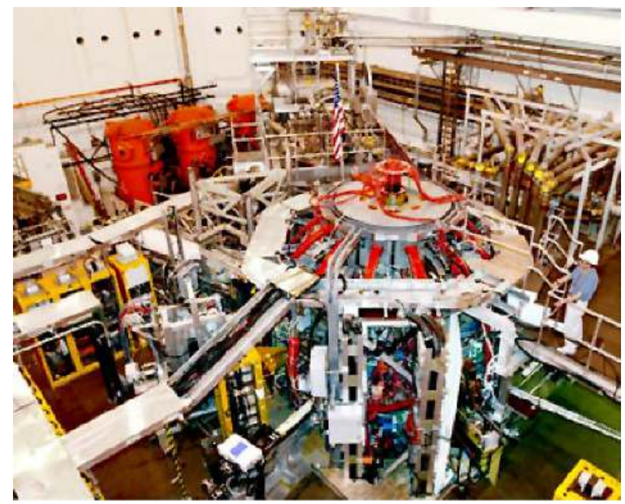
The U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) is a collaborative national center for plasma and fusion science. Its primary mission is to develop the scientific understanding and the key innovations which will lead to an attractive fusion energy source. Associated missions include conducting world-class research along the broad frontier of plasma science and technology, and providing the highest quality of scientific education.







National Spherical Torus Experiment (NSTX)

Seton Hall University

Newark, NJ

Nutley, NJ

South Orange, New Jersey

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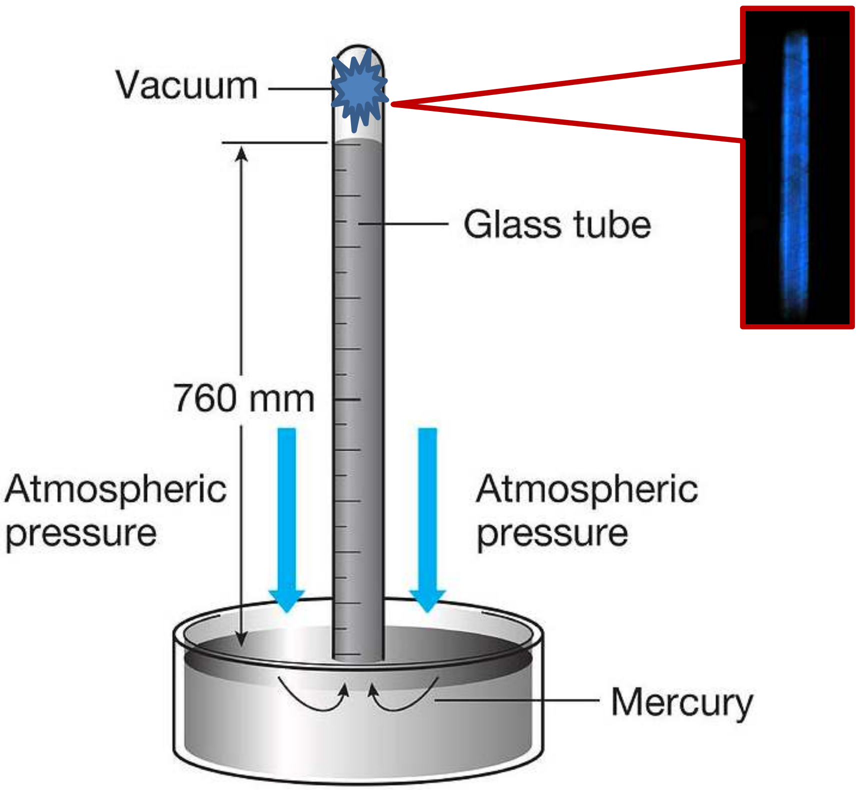
LEAP

LABORATORY OF ELECTROPHYSICS & ATMOSPHERIC PLASMAS (**LEAP**)

The first observation of Low Temperature Plasma by Jean Felix Piccard

Jean (Félix) Picard (July 21, 1620 –July 12, 1682) was a French astronomer and Catholic priest.
The first person to accurately measure the circumference of the earth. Around 1670!

Observed in 1676 that his barometer tube had glowing light that although he didn't know was produced when mercury atoms rubbed against the barometer's glass wall. This was the first documented observation of a *low temperature plasma.*



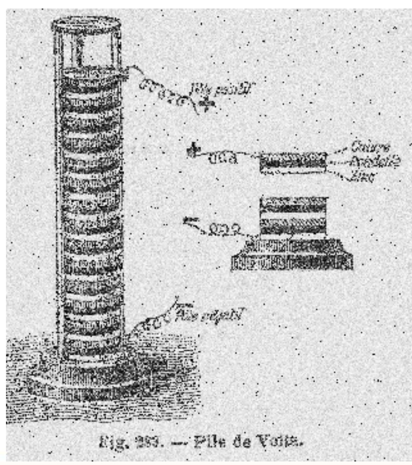
Mercury barometer

The scientific study of electricity

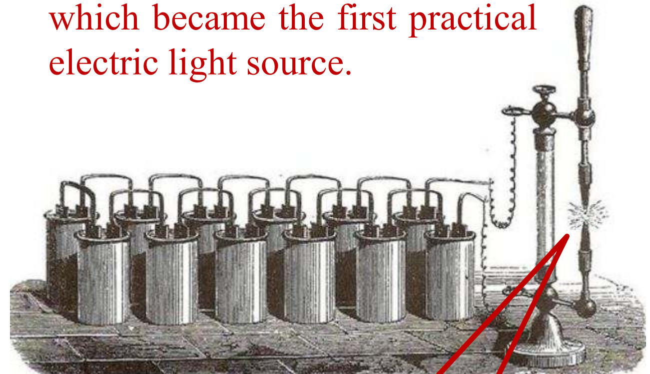
In 1752, Benjamin Franklin 'discovers' electricity!

Although Benjamin Franklin (1706–1790) or now known as Mr. $100 didn't discover electricity, he coined most of the words we use today to describe it such as positive and negative charge, conductor, and battery.

In 1800, Alessandro Volta (1745-1827) invents the battery



Arc Lamp is invented in 1809 by Humphry Davy (1778-1892) which became the first practical electric light source.



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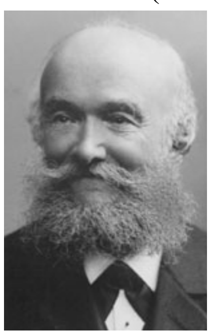
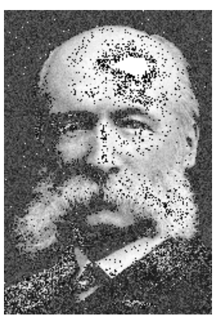
The development of ‘scientific’ vacuum pumps

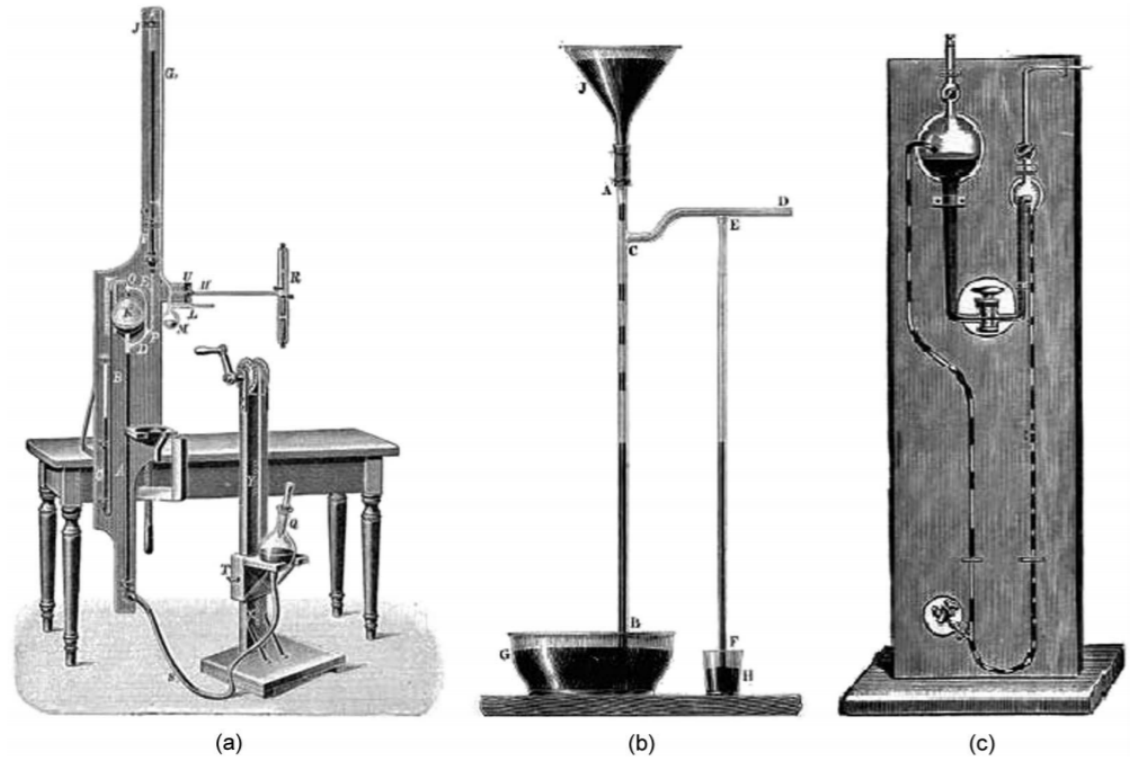
Heinrich Geissler (1814-1879)



August Toepler (1836–1912)



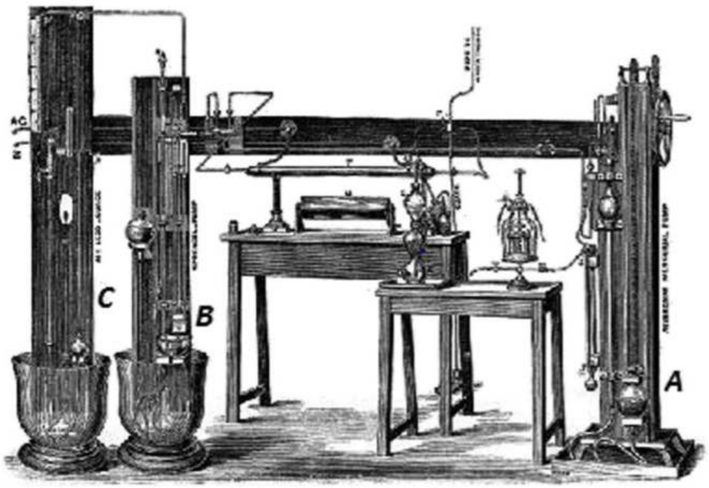
Hermann Sprengel (1834-1906)



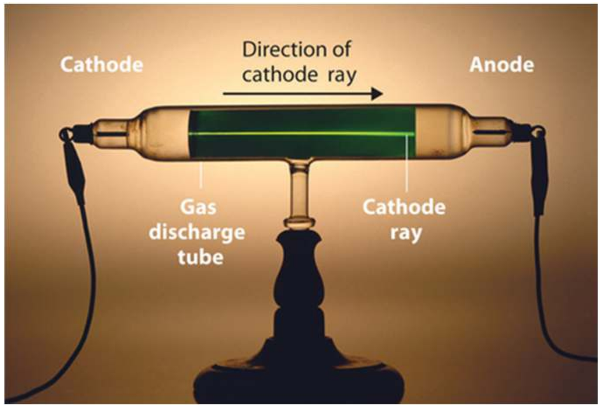
Schematics of the Geissler vacuum pump. (a) Toepler’s pump. (b) Original Sprengel’s pump. (c) Self-recycling Sprengel’s pump.

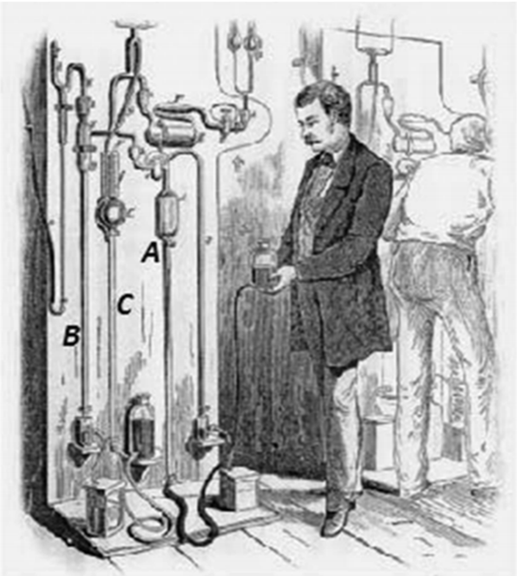
The significance of these vacuum pumps is that they were able to create vacuum of much less than 1 mTorr or 13 mPa or 13 x 10^{-6} Atm / Bar.

The development of ‘scientific’ and ‘industrial’ vacuum pumps



As shown on the left, a circa 1880s research laboratory scale vacuum pump system with a combination of (A) Geissler’s pump, (B) Sprengel’s pump, and (C) McLeod’s gauge. Such vacuum pumps were used to evacuate borosilicate glass chambers to study gas discharges leading to the what were known as Cathode Ray Tubes (CRT) as seen to the right side.





Reference: Simón Reif-Acherman. *Heinrich Geissler: Pioneer of Electrical Science and Vacuum Technology.* Proceedings of the IEEE. Vol. 103, No. 9, September 2015.

A schematic of an industrial-scale vacuum system (right) used in Thomas’s Edison’s incandescent light bulb production. Edison inspecting one of his light bulbs.

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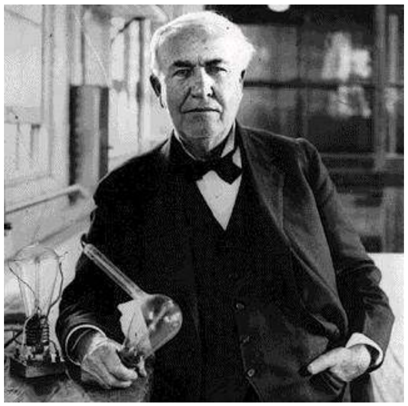
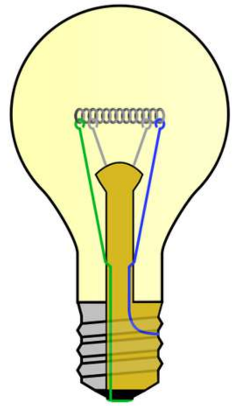
Low Temperature Plasma Lighting Technology



Thomas Edison



Daniel McFarlan Moore

Birthplace of the Fluorescent Light Bulb: Edison (Menlo Park) / West Orange, NJ

ASSOCIATION 18 EDISON 85 ILLUMINATING CO'S

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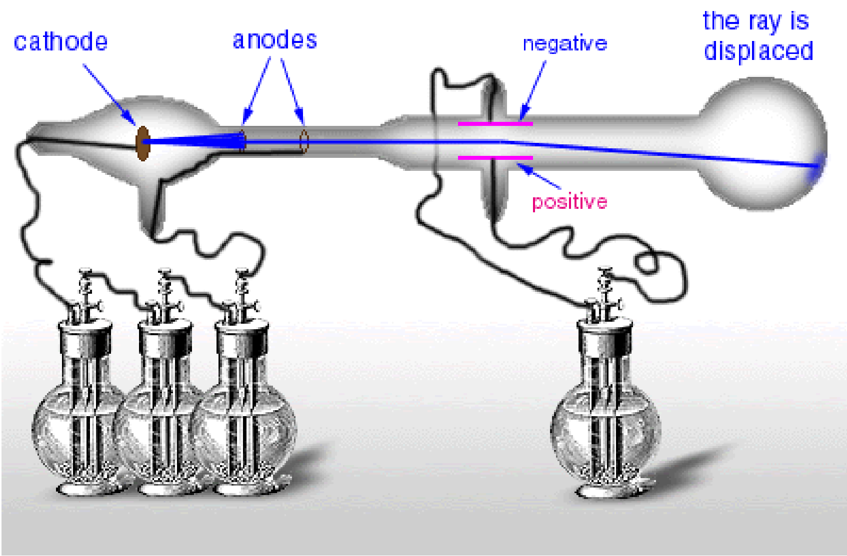
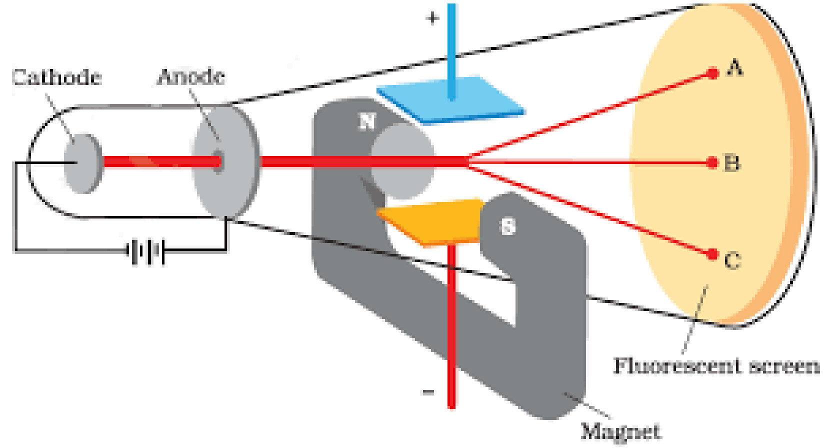
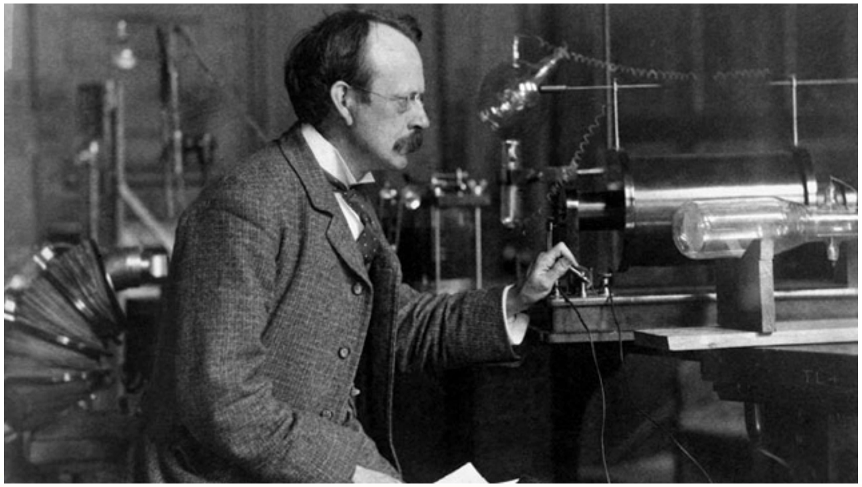
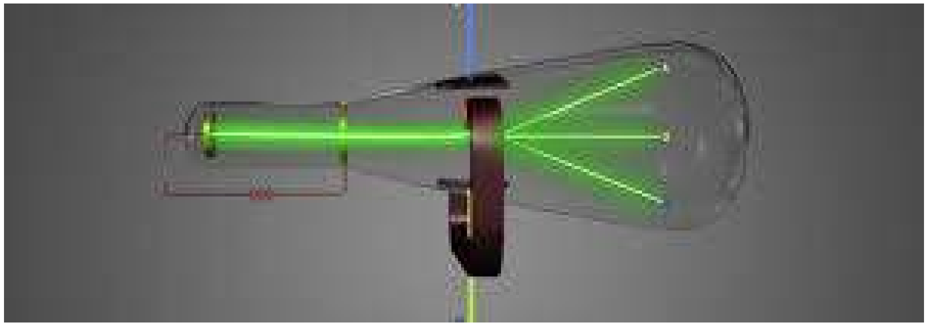
The discovery of the 'electron'



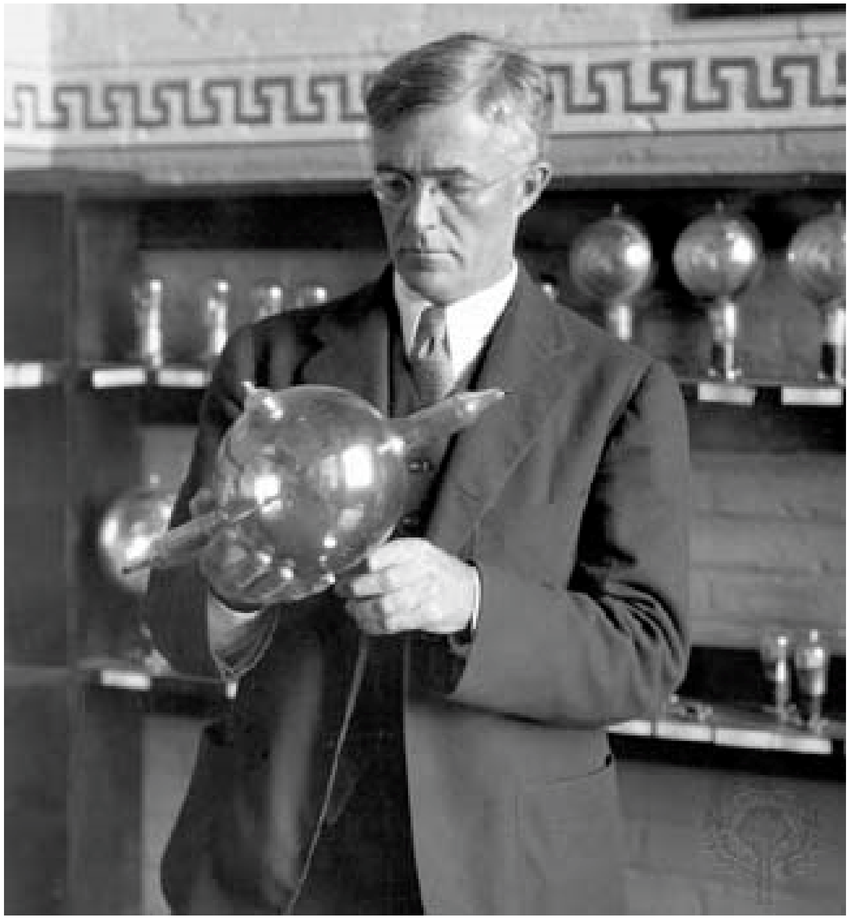






In 1897, Joseph John (J.J.) Thomson (1856-1940) discovers the 'electron' subatomic particle at the Cavendish Laboratory at the University of Cambridge, UK.

The birth place of Plasma Science



Irving Langmuir

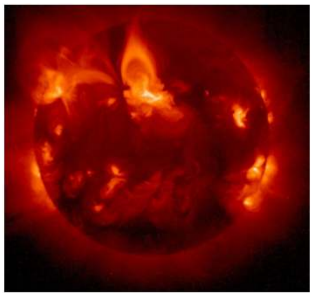
Birth of Plasma Science

Birthplace: Hoboken, New Jersey

Irving Langmuir was one of the first scientists to work on plasmas and the first to refer to this 4th state of matter as ***plasmas*** in 1927, because his perceived descriptive similarity to blood plasma.

Two Types of plasmas

High-temperature plasmas or Hot (Thermal) plasmas



Sun

Electric spark

$T_i \approx T_e \geq 10^7$ K

e.g., fusion plasmas

$T_i \approx T_e \approx T_g \leq 2 \times 10^4$ K

e.g. arc plasma at normal pressure

Low-temperature plasmas or Cold (Non-thermal Plasmas

Aurora Borealis

Compact Fluorescent bulb

$T_i \approx T_g \approx 300$ K

$T_i << T_e \leq 10^5$ K

e.g. low-pressure glow discharge

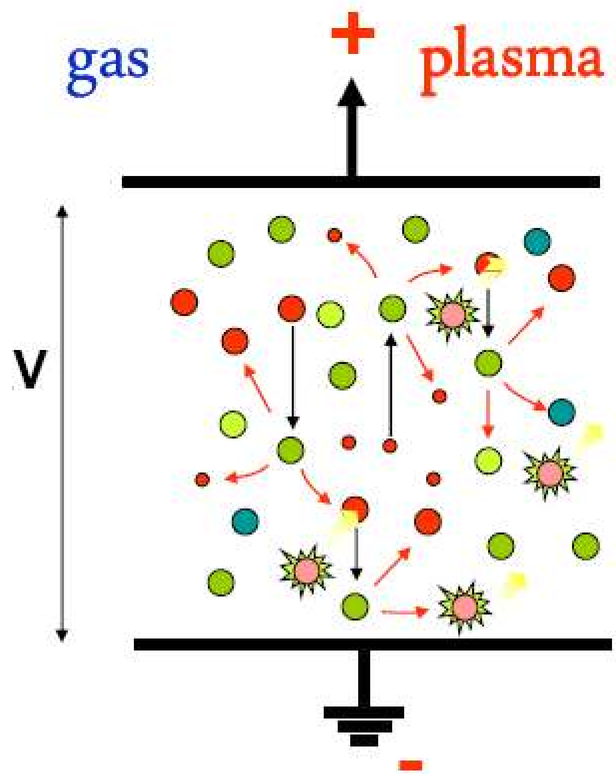
high-pressure cold plasma

How do we make plasmas?

Supply Energy!!!
e.g. Heat transfer, radiation, electric power…

For many plasma applications, an Electric Field is applied to a gaseous environment

Plasma or Gaseous Discharge



- Molecules
- Excited molecules
- Ions
- Electrons

Collisional and radiative processes

- The processes that determine the properties of low temperature plasmas are collisions involving the plasma electrons and other plasma constituents.

- The charge carrier production is governed by
  - Direct ionization of ground state atoms and/or molecules
  - Step-ionization of an atom/molecule that is already in an excited and, in particular, a long-lived metastable state

- The generation of chemically reactive free radicals by electron impact dissociation in molecular plasmas is an important precursor for plasma chemical reactions.

Electron-Atom collision processes in plasmas

e + A → $A^{*/m}$ + e' A^* → A + *hv*	Excitation of atoms Spontaneous de-excitation
e + $A^{*/m}$ → A + *hv* + e'	Collision-induced de-excitation
e + A → A^+ + e'	Ionization of atoms
e + $A^{*/m}$ → A + e' + E_{kin}	Super-elastic collisions
e + A^m → A^* + e'	Step-wise excitation
e + A^m → A^+ + e'	Step-wise ionization

K. Becker and A. Belkind. 'Introduction to Plasmas'. *Vacuum Technology & Coating (September 2003)*

Electron-Molecule collision processes in plasmas

e + AB → $AB^{*/m}$ + e’ AB^* → AB + *hv*	Excitation of molecules Spontaneous de-excitation
e + $AB^{*/m}$ → AB + *hv* + e’	Collision-induced de-excitation
e + AB → $A^{*/m}$ + B + e’	Dissociation of molecules
e + AB → AB^+ + e’	Ionization of molecules
e + AB → A^+ + B + e’	Dissociative ionization of molecules
e + AB → A^+ + B + e’	Dissociative attachment of molecules
e + A^+ → A + *hv*	Radiative recombination of an atomic ion
e + A^+ + e’ → A + *e’*	3-body dielectronic recombination
e + A^+ + M → A + M + *e’*	3-body heavy particle recombination
e + AB^- → A + B	Dissociative attachment of molecular negative ions

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Heavy particle collision processes in a plasma

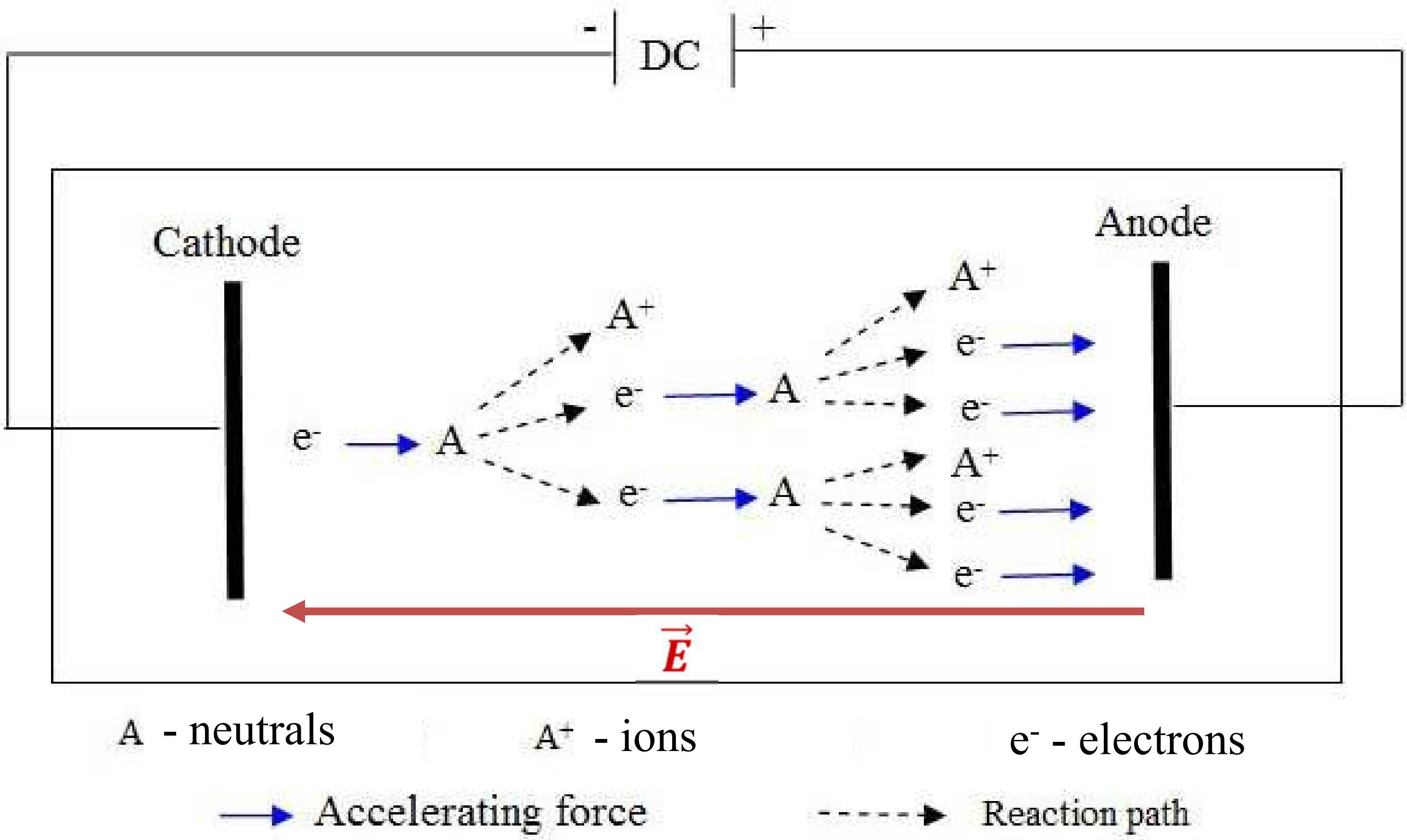
$A + B^{+} \rightarrow A^{+} + B$	Charge transfer
$A + B^{m} \rightarrow A^{+} + B + e$	Penning ionization
$A^{m} + A^{m} \rightarrow A^{+} + A + e$	Pair ionization
$A^{*} + A \rightarrow A_2^{+} + e$	Hornbeck-Molnar ionization
$A^{+} + BC \rightarrow AC^{+} + B$	Ion-molecules reaction
$A^{*/m} + BC \rightarrow AC + B$	Chemical reaction
$R + BC \rightarrow RC + B$	Chemical reaction with plasma radical, R

Low-Temperature ("Cold") Plasmas [Non-equilibrium, Non-Thermal]

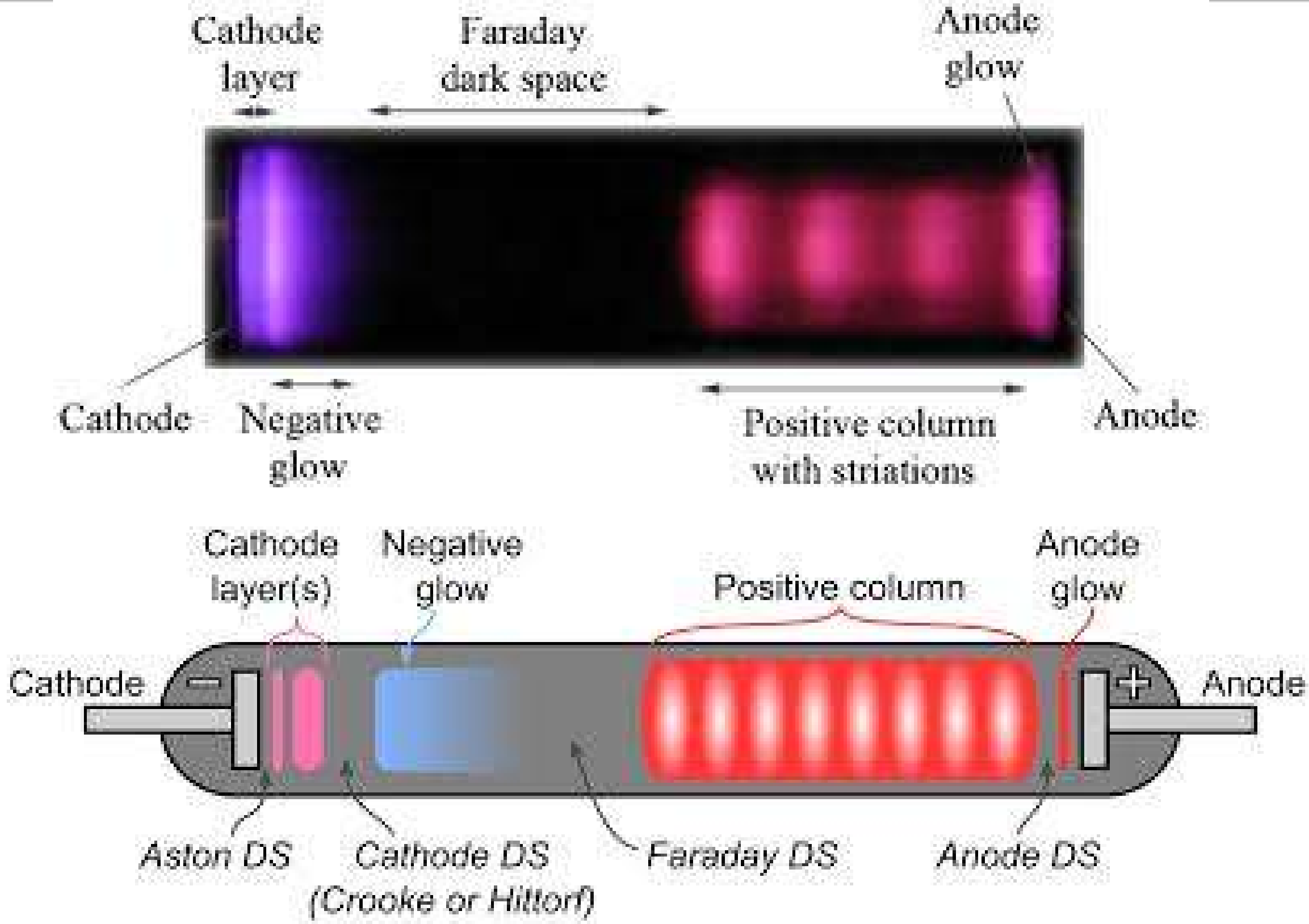
→ $T_e >> T_i, T_n$ with $T_i \approx T_n$ ←

- High "electron temperature" (10,000 – 100,000 K)
  - T_e from 0.5 eV to 10 eV
  - Often highly non-Maxwellian EEDF; "bulk" and "beam" electrons
- Low gas temperature (350 – 2,500 K)
- "High-temperature chemistry" at low ambient temperatures
  - Electron-driven ionization and dissociation (in molecular plasmas) create reactive radicals
  - Electron interactions (in molecular plasmas) create a vibrational non-equilibrium

DC Glow Plasma

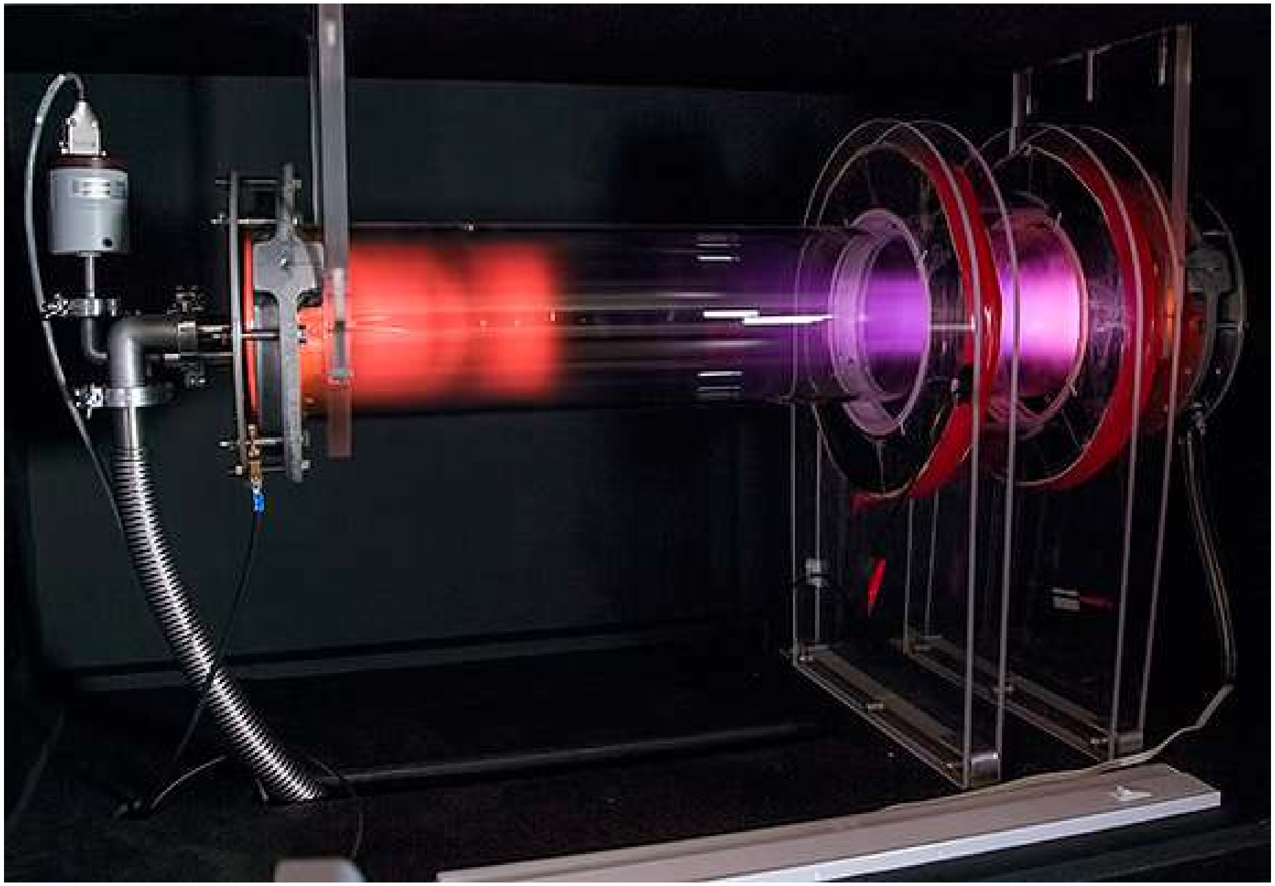


DC Glow Plasma



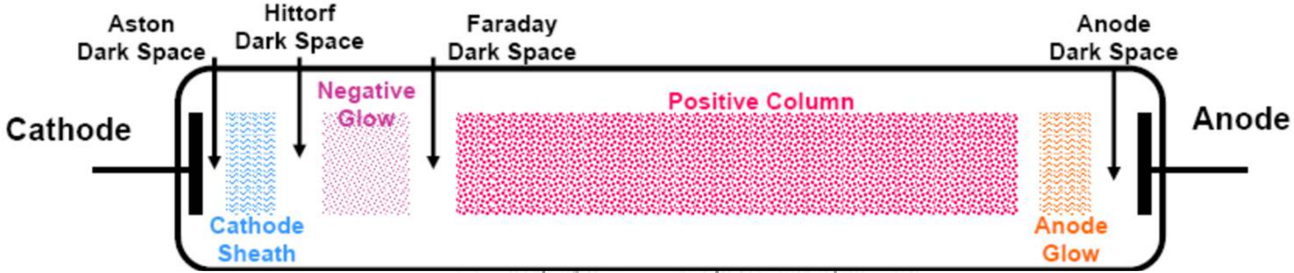
Reference: J.T. Gudmundsson & A. Hecimovic. *Foundations of DC plasma sources.* **Plasma Sources Science and Technology**, Volume 26, Number 12 (2017)

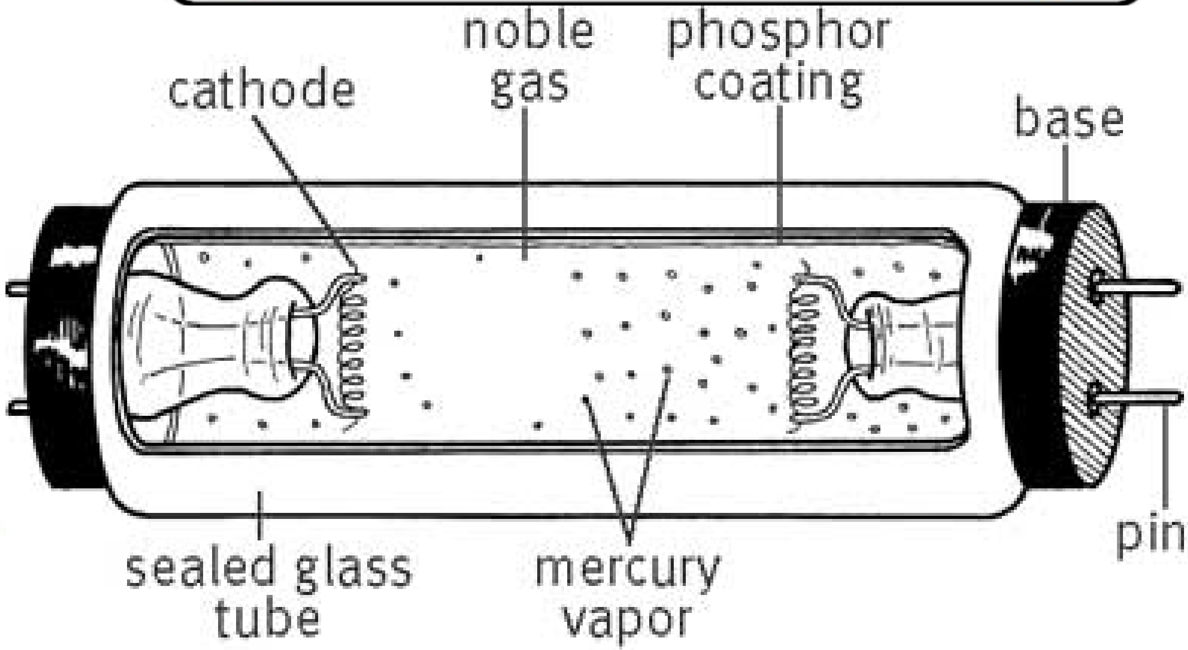
PPPL's Remote Glow Discharge Experiment (RGDX)



https://www.pppl.gov/RGDX

Low-Pressure Glow Discharge Plasmas





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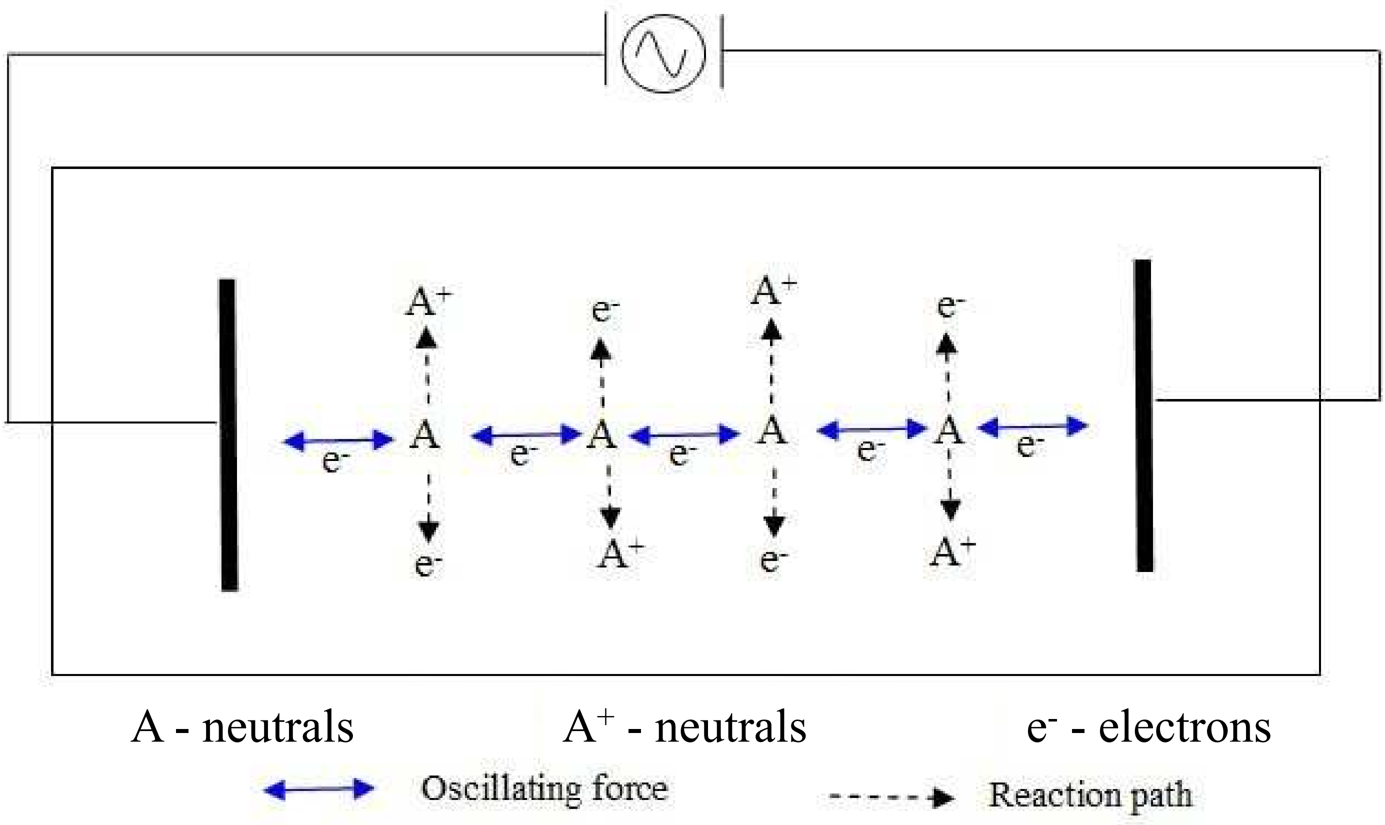
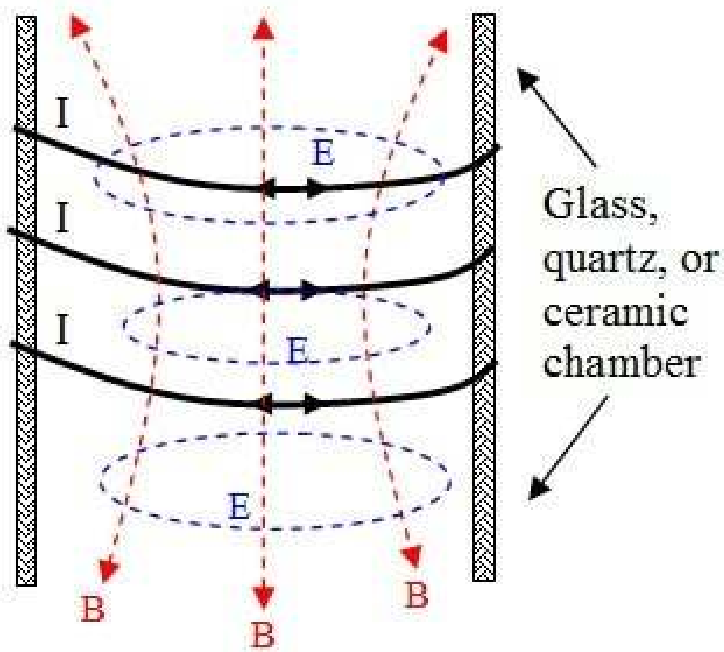
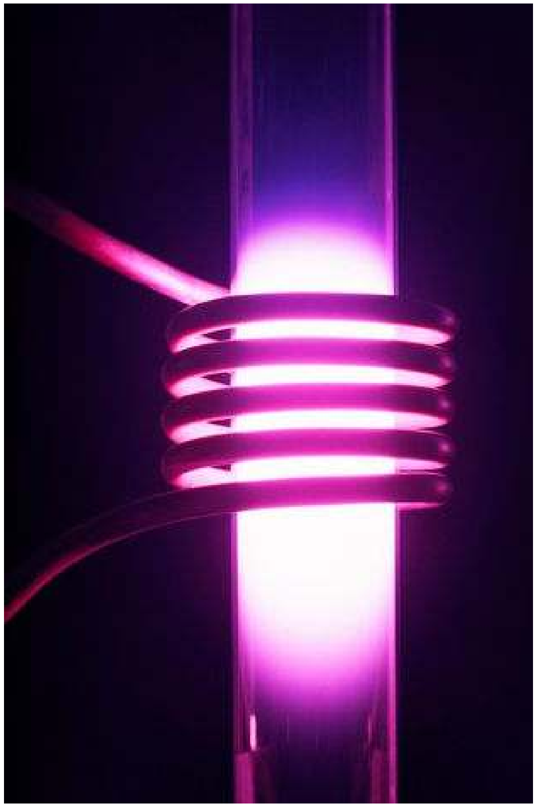
Capacitively coupled plasma



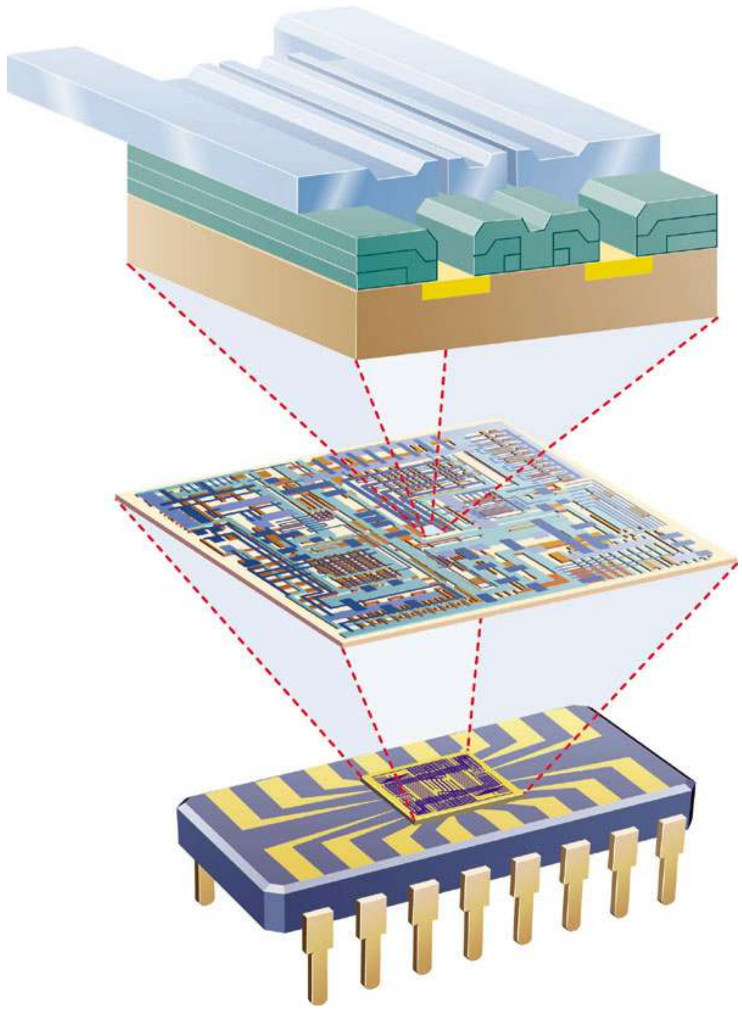
Inductively Coupled Plasma

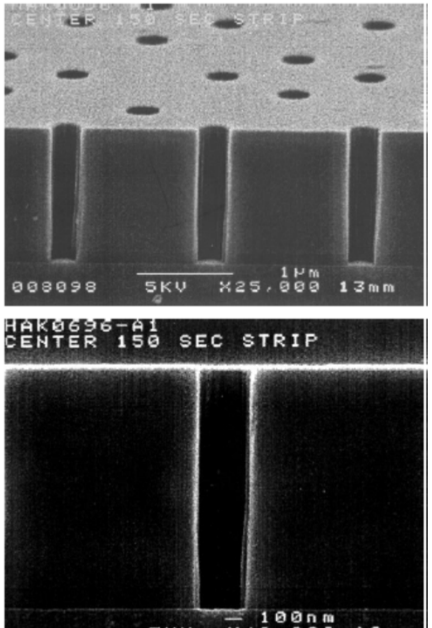
Frequency range: 10s kHz - 10s of MHz range



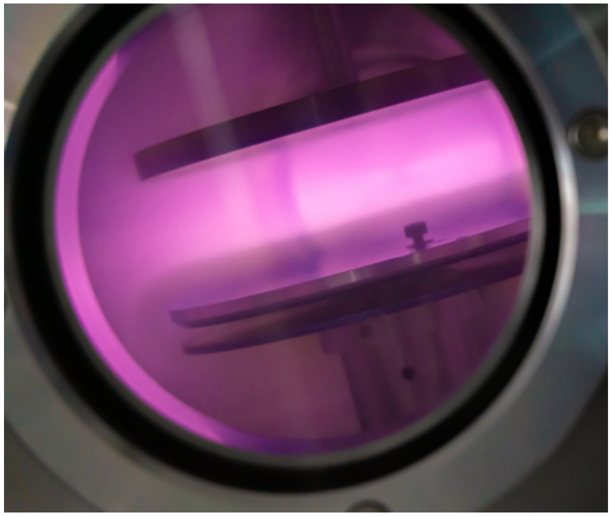


Plasma Enhanced Technologies



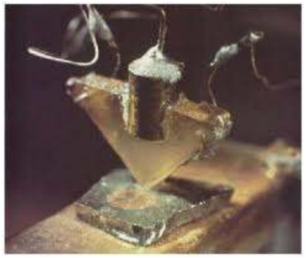


A small section of a



Straight holes like these can be etched with low temperature plasmas.

Bell Laboratories



Birthplace of solid-state microelectronics: Bell Laboratories, Murray Hill, NJ

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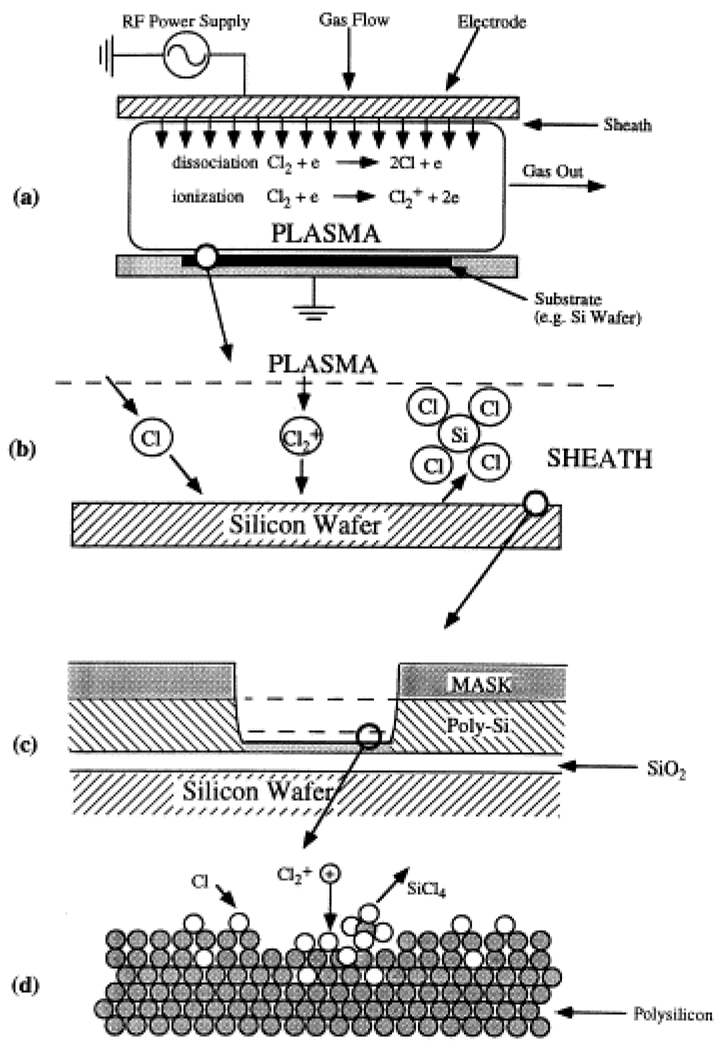
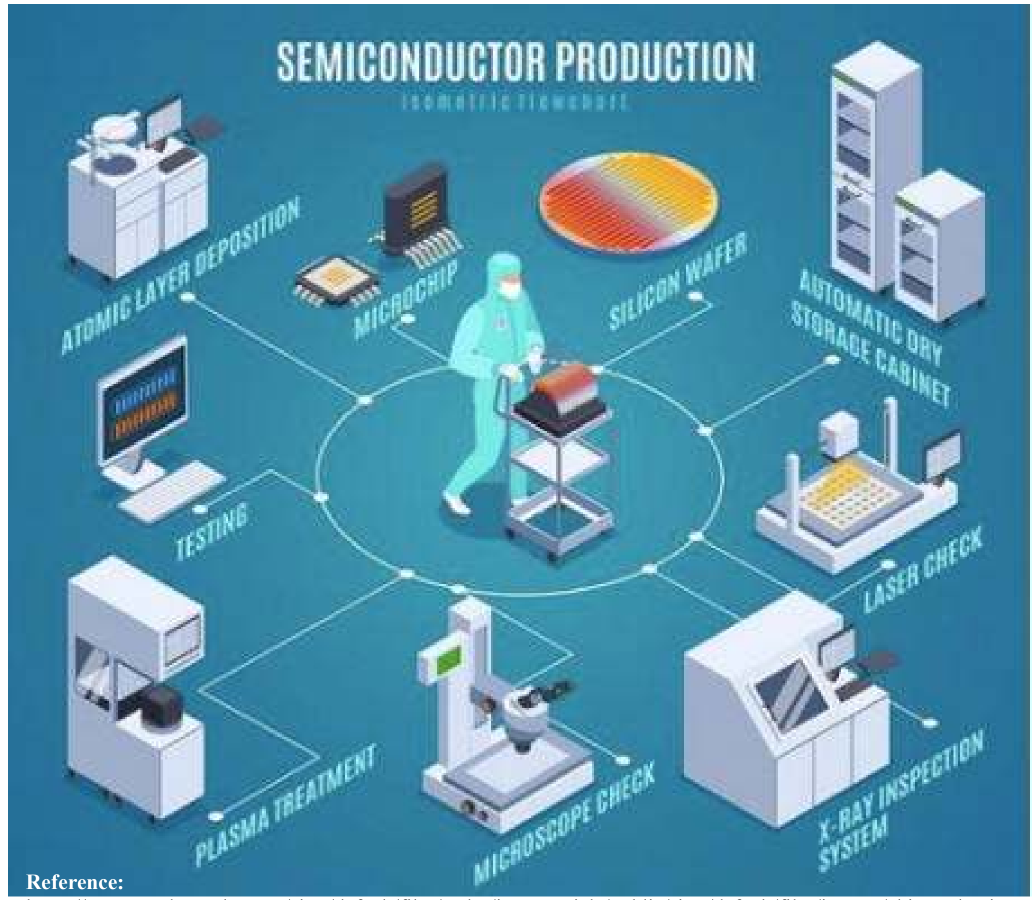
Low- Temperature Plasma enabled Microchip Fabrication

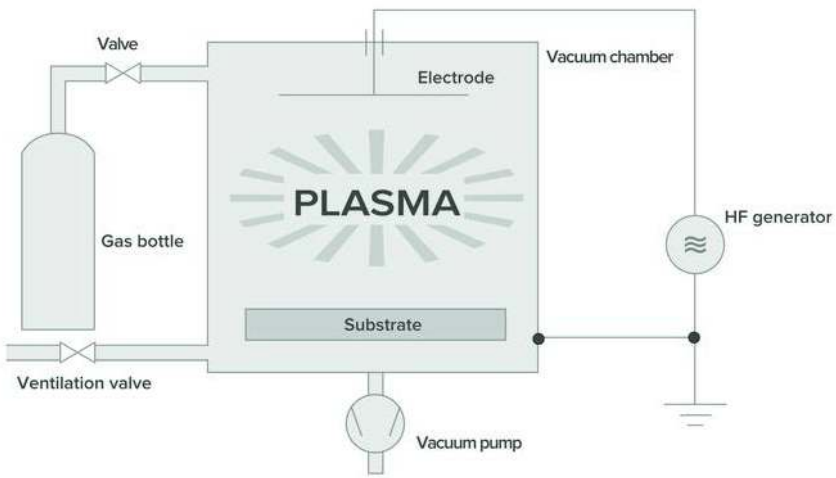




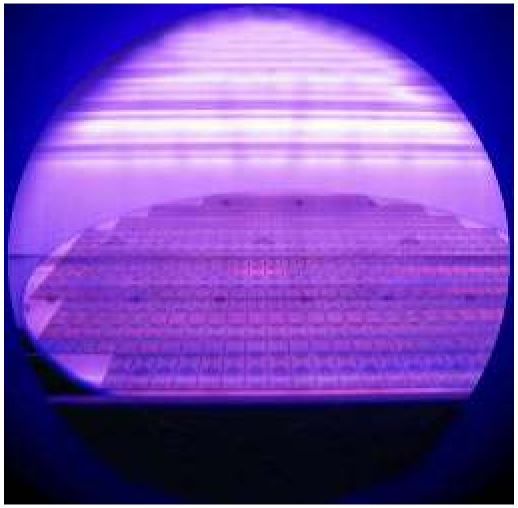
Reference: https://eenews.cdnartwhere.eu/sites/default/files/styles/inner_article/public/sites/default/files/images/chipproductio n630_0.jpg?itok=rzZu2ANq

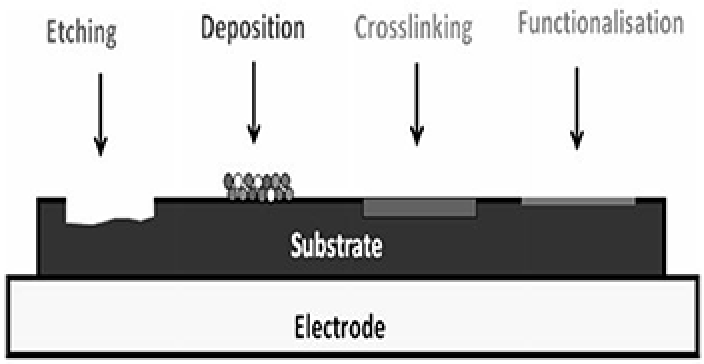
Reference: Demetre J. Economou. Modeling and Simulation of plasma etching reactors for microelectronics. Thin Solid Films. Vol. 365, Issue 2, p. 348-367. April 2000.

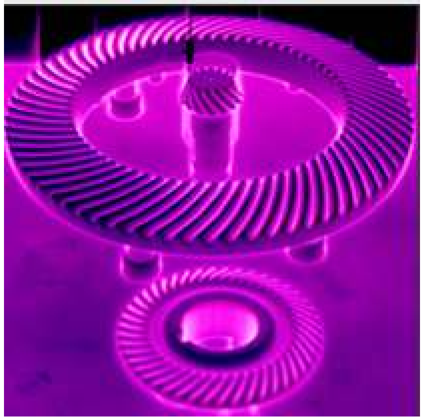
Low-Pressure, Low-Temperature Plasma Processing



Plasma processing of silicon for semiconductor manufacturing.





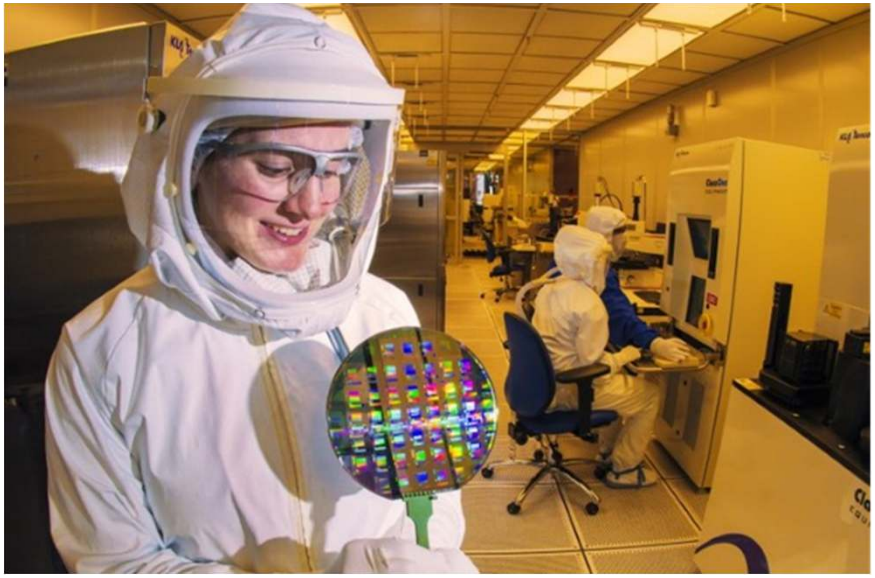


Plasma processing to harden or coat materials.

LTP processing of semiconductor materials

Lawmakers Propose Multibillion Dollar Semiconductor R&D Push

A bipartisan group of lawmakers recently introduced legislation that would channel billions of dollars into manufacturing incentives and new R&D streams to bolster U.S. semiconductor manufacturing in the face of increasing international competition.

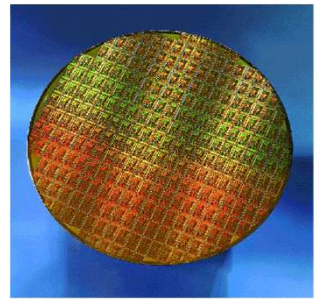


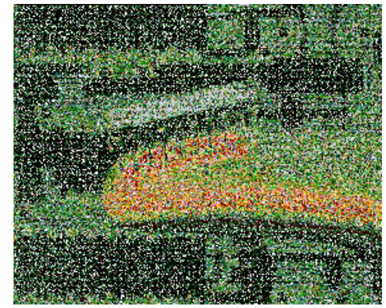
Science Policy Bulletin, Number 61: June 24, 2020

Plasmas are easier to be generated at low pressures

Low pressure plasmas
(1 mTorr ~ a few Torr)

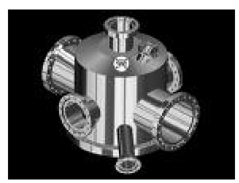
- are well understood
- are used extensively nowadays (e.g. in semiconductor industry for computer chips manufacturing)





However, to generate low pressure plasmas:

- vacuum chambers
- expensive vacuum pumps
- pressure monitoring and pressure control devices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Generate Plasmas at Atmospheric Pressure!!!

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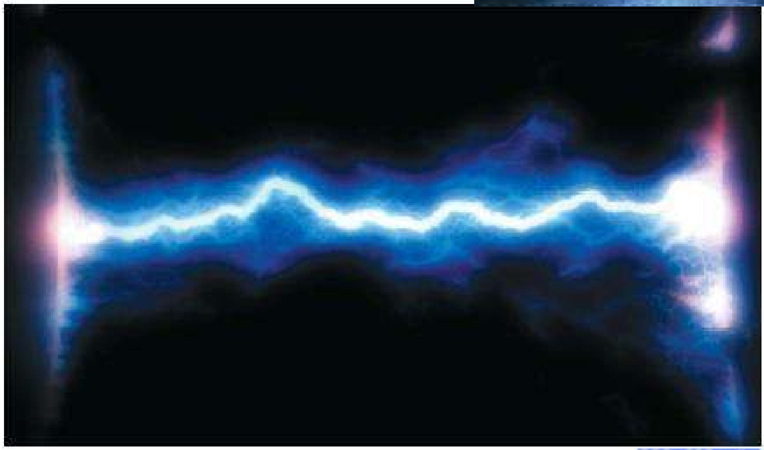
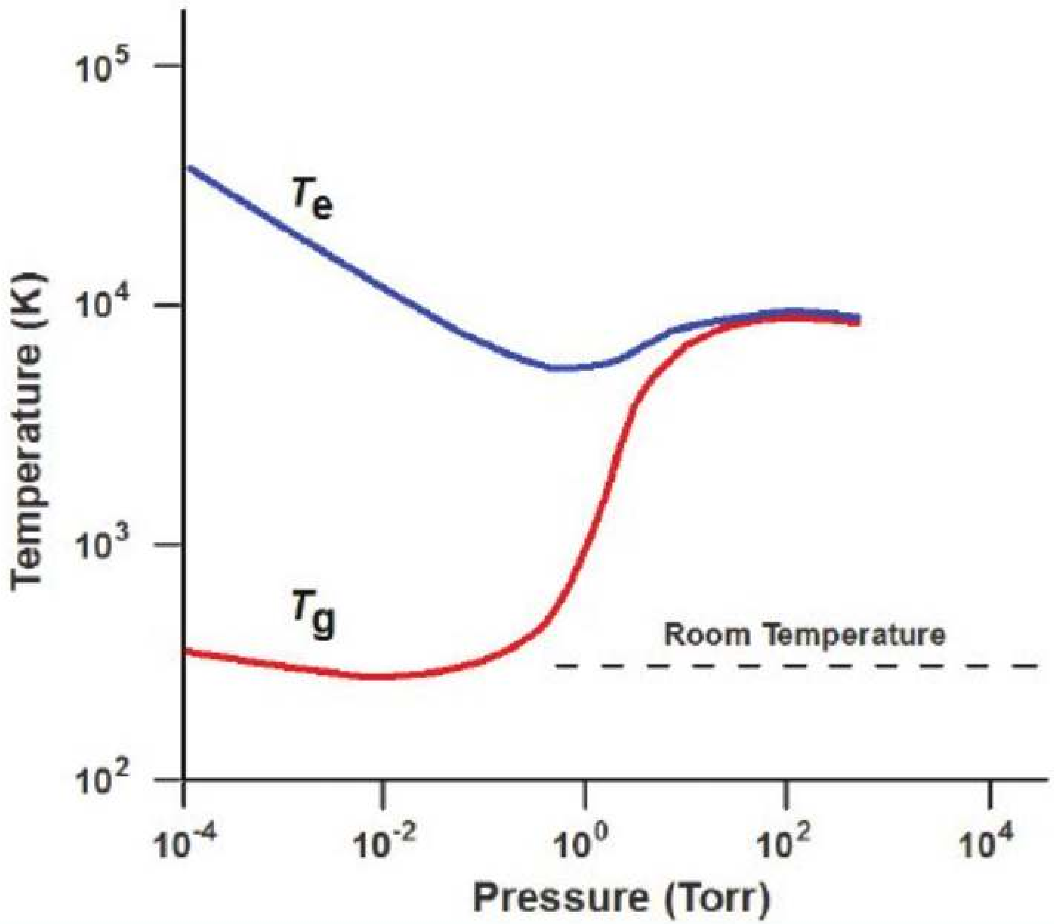
What happens at air pressure?

- No vacuum is involved
- Difficult to generate and sustain
- Run into some challenges such as glow to ***arc*** transition – Non controllable

Arc Discharge: thermal plasma
- It's hot and detrimental
- Gas temperature can reach as high as $2x10^4$ K
- Low voltage drop at cathode
- High cathode current density



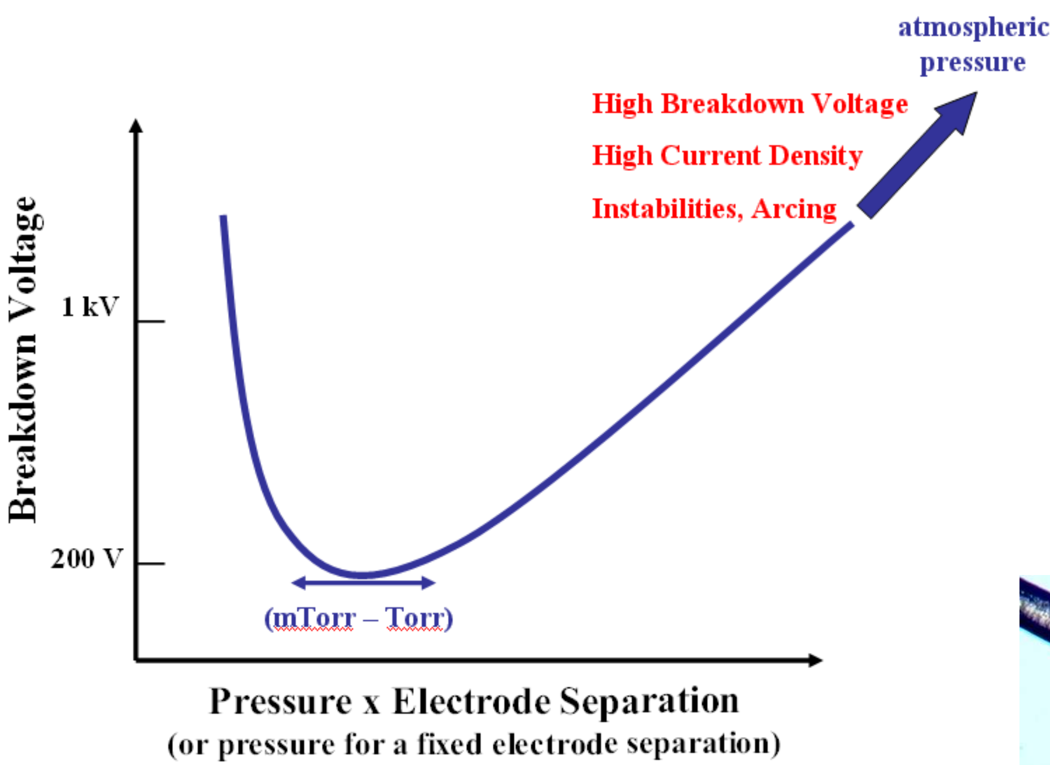
Low-Temperature Plasmas



Electron temperatures (T_e) and **gas temperatures (T_g)** versus pressure for a glow discharge.

Low temperature plasmas will limit the gas (heavy particles i.e. ions, atoms, molecules, dust, etc.) temperature to room temperature.

High Pressure Microplasmas



Paschen Breakdown Curve

Stabilization of high-pressure plasmas: “pd scaling”: “p” ↑, so “d” ↓ to keep breakdown voltage low and minimize instabilities after breakdown -

Microplasmas

Dimension: a few millimeter down to and below **100 μm**

Human Hair: 60 – 100 μm

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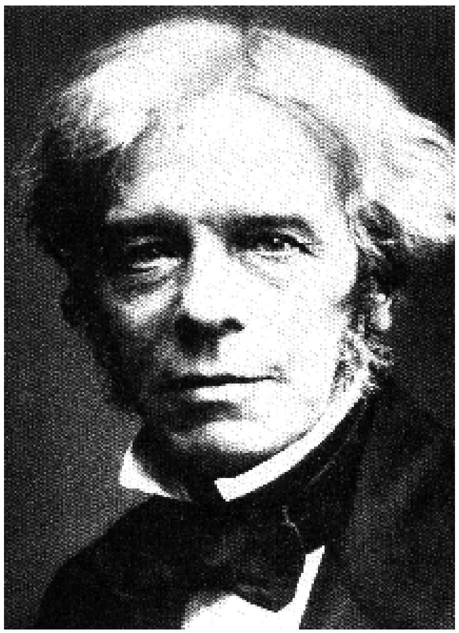
How do we solve this problem?

Micro-confinement: Gas heating occurs in the plasma volume, and the energy is carried away by thermal diffusion/convection to the outside. If the plasma has a small volume and a relatively large surface, gas heating is limited.

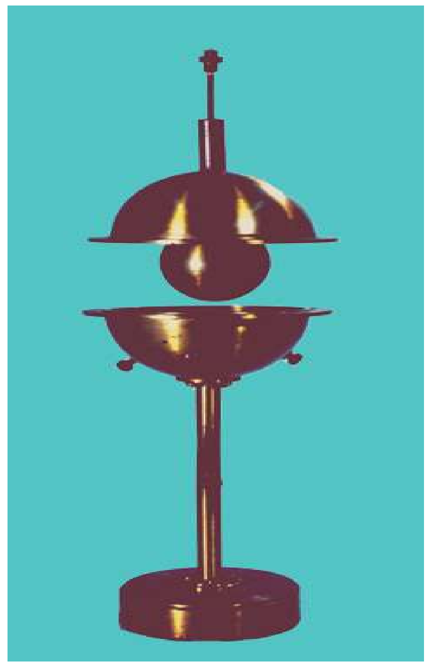
Dielectric Barrier Discharges: These plasmas are typically created between metal plates, which are covered by a thin layer of dielectric or highly resistive material. The dielectric layer plays an important role in suppressing the current: the cathode/anode layer is charged by incoming positive ions/electrons, which reduces the electric field and hinders charge transport towards the electrode. DBD also has a large surface-to-volume ratio, which promotes diffusion losses and maintains a low gas temperature.

Transient (pulsed) plasmas: *In atmospheric* plasmas, *for efficient gas heating at least 100-1000 colli*sions are necessary. Thus, if the plasma duration is shorter than 10^{-6} – 10^{-5} s*, gas* heating is limited. Of course, for practical purposes such plasma has to be operated in a repetitive mode, e.g., in trains of microsecond pulses with millisecond intervals.

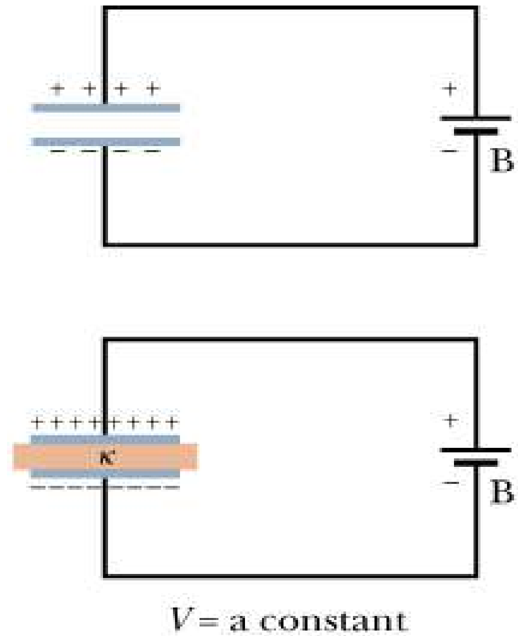
Faraday's Dielectric Capacitors



Michael Faraday (1781 – 1867)

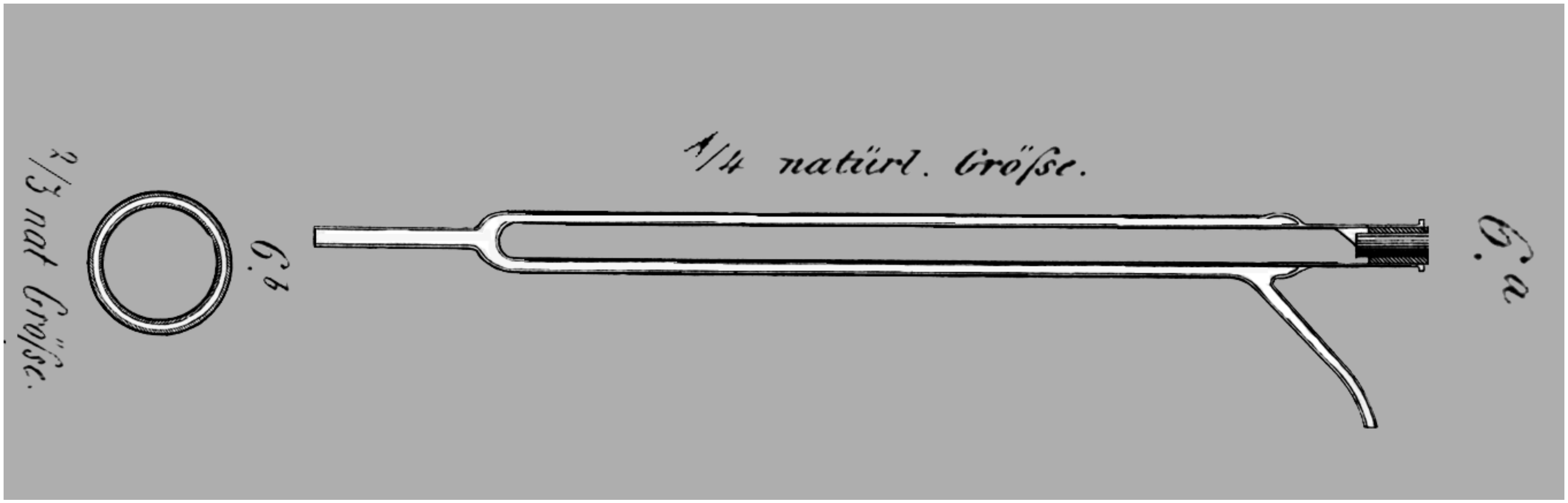


Faraday's Dielectric Capacitor (circa 1837)



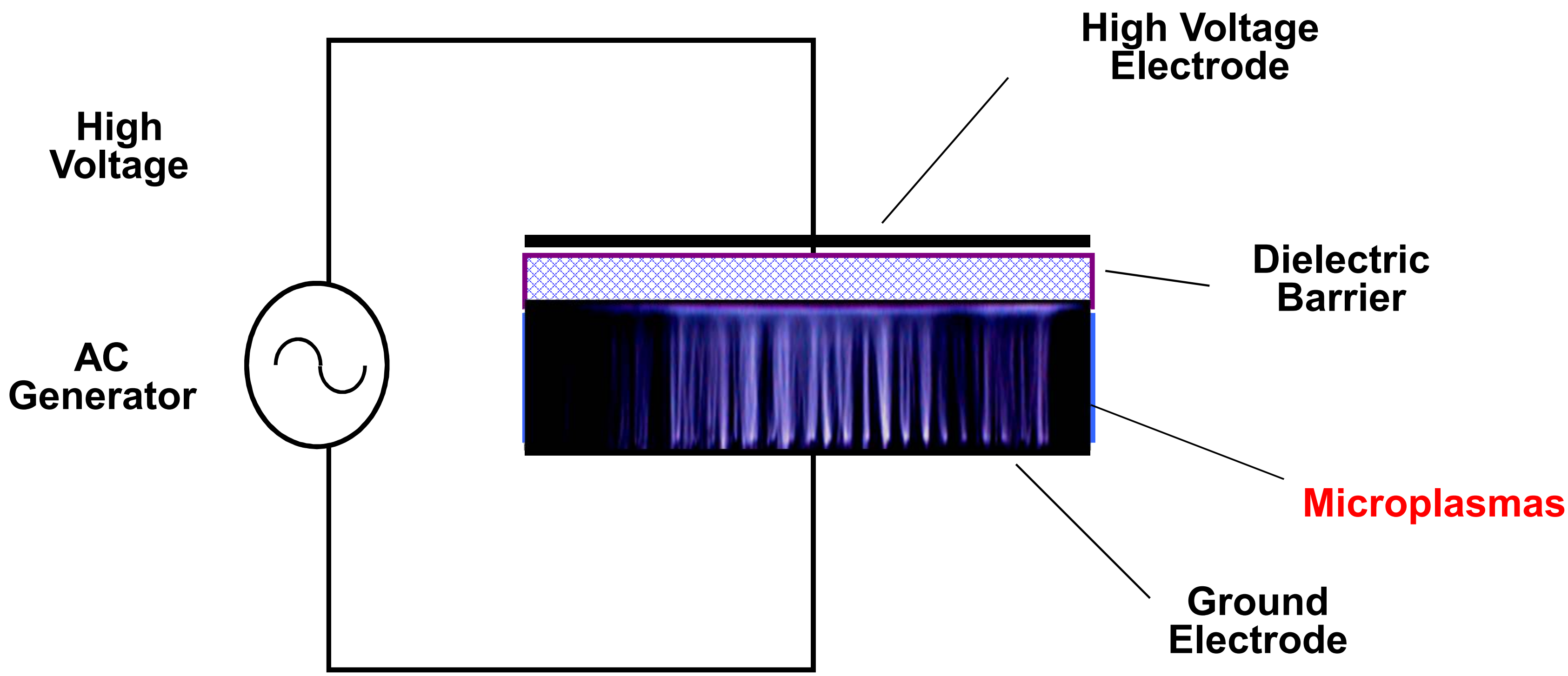
Capacitance INCREASED!

Historical Ozone Tube of W. Siemens (1857)



Werner v. Siemens
Poggendorf's Annalen der Chemie und Physik 102, 66 (1857)
"Ozone Production in an Atmospheric-Pressure Dielectric Barrier Discharge"

Dielectric Barrier Discharge (DBD)



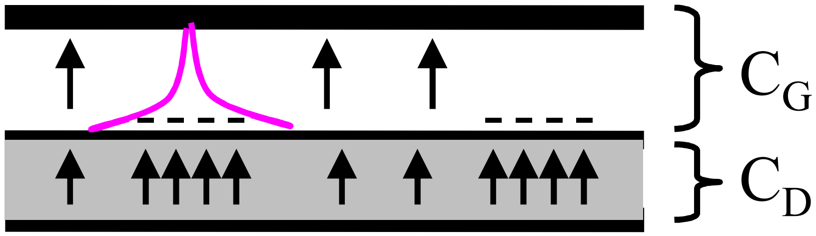
Role of the Dielectric (Insulator)

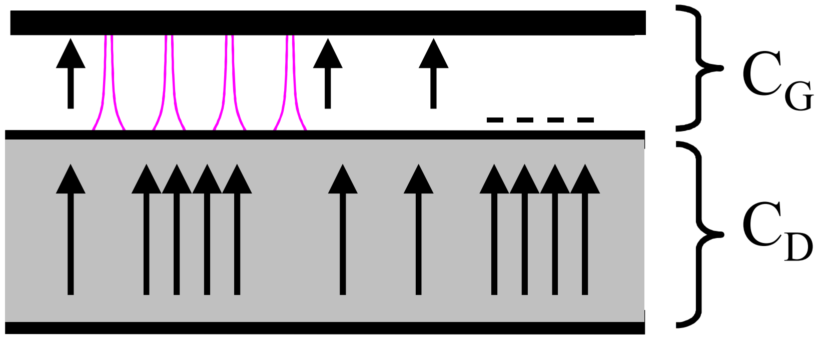
The dielectric is the key for the proper functioning of the discharge.

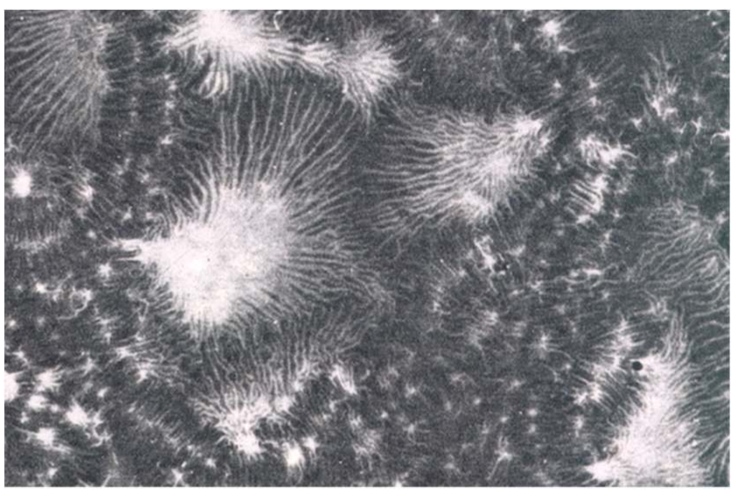
Serves two functions:

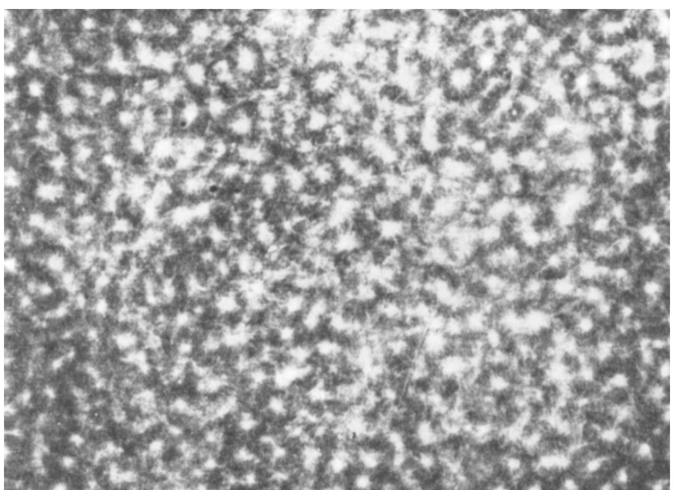
1. Limits the amount of charge transported by a single microplasma
2. Distributes the microplasmas over the entire electrode surface area

Principals of DBD Microplasmas

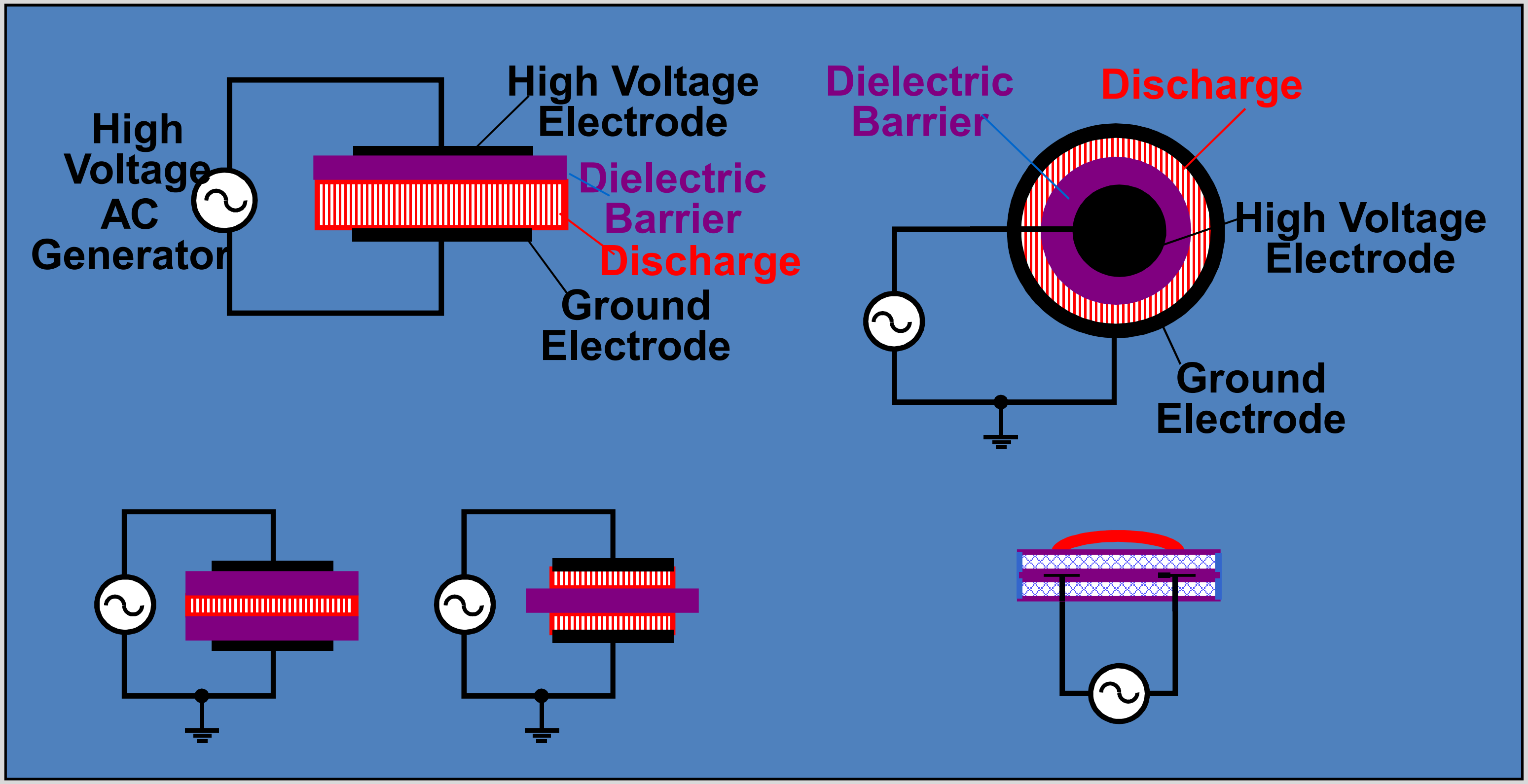








Dielectric Barrier Discharge

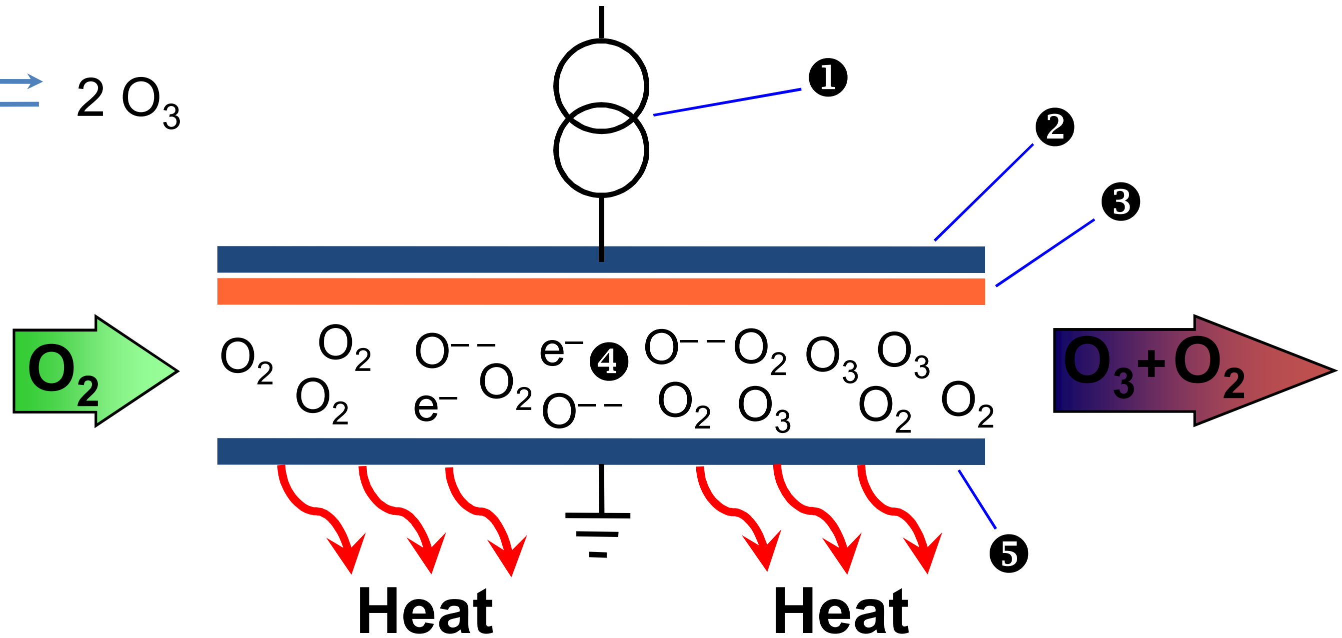


H.E. Wagner, R. Brandenburg, et. al. 'The barrier discharge: basic properties and applications to surface treatment'. *Vacuum*. 71 p417-436 (2003).

Ozone Generator

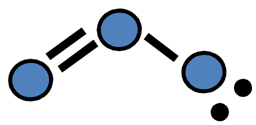
Dielectric Barrier Discharge

$$3\,O_2 \rightleftharpoons 2\,O_3$$



Properties of Ozone (O_3)

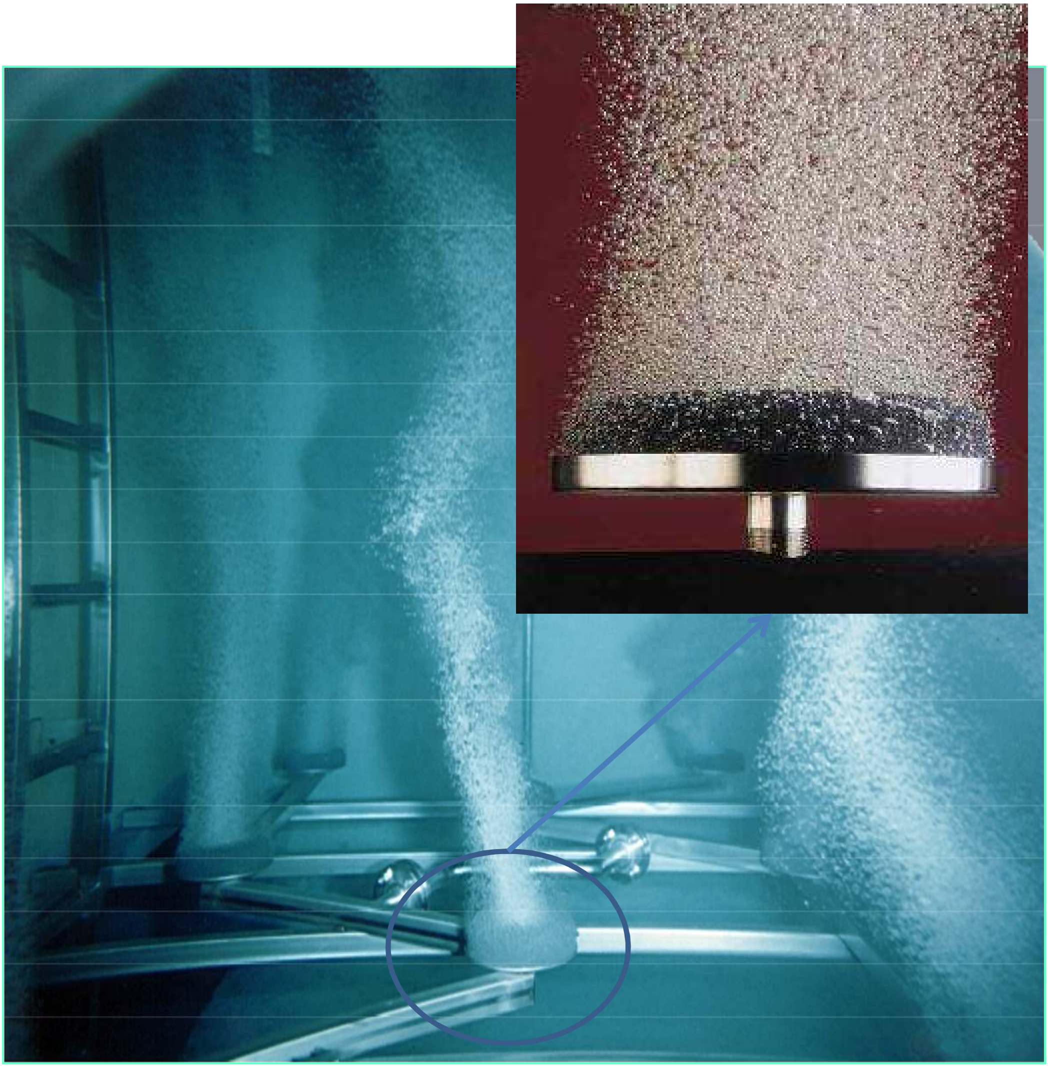
- Tri-atomic form of oxygen.



- Most powerful commercial oxidizing agent
- Unstable - must be generated and used onsite
- Limited solubility in water, but more so than oxygen
- Leaves a dissolved residual which ultimately converts back to oxygen

Ozonia Advanced Technology Ozone Generator

Ozone Water Treatment



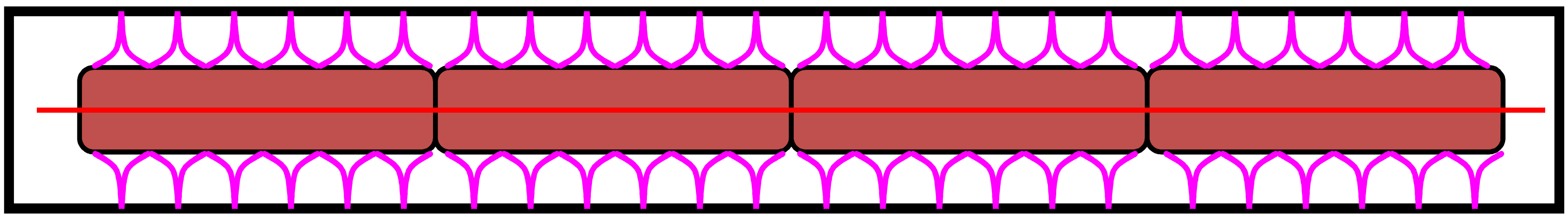
Bubble Diffusion

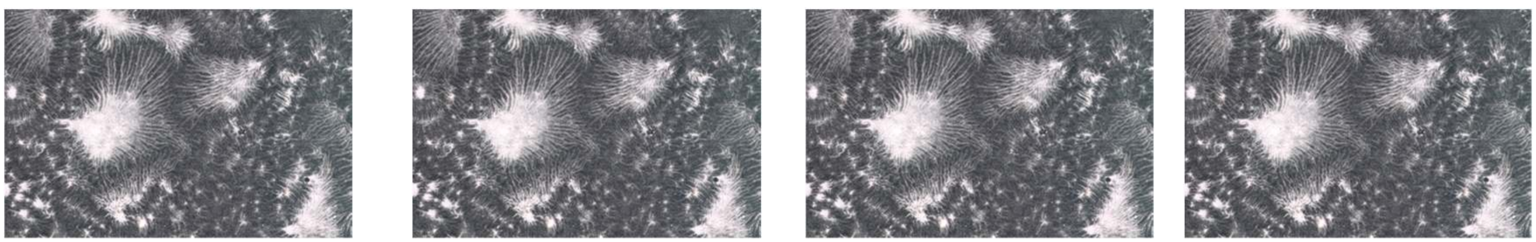
Easy to use

Low energy usage

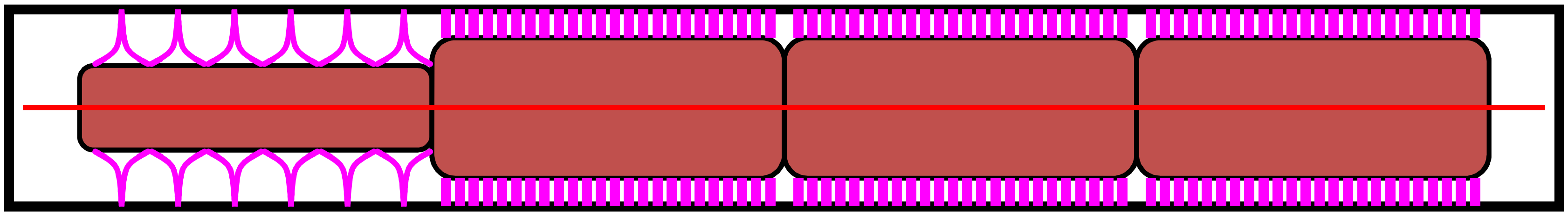
Mass transfer efficiencies to > 90%

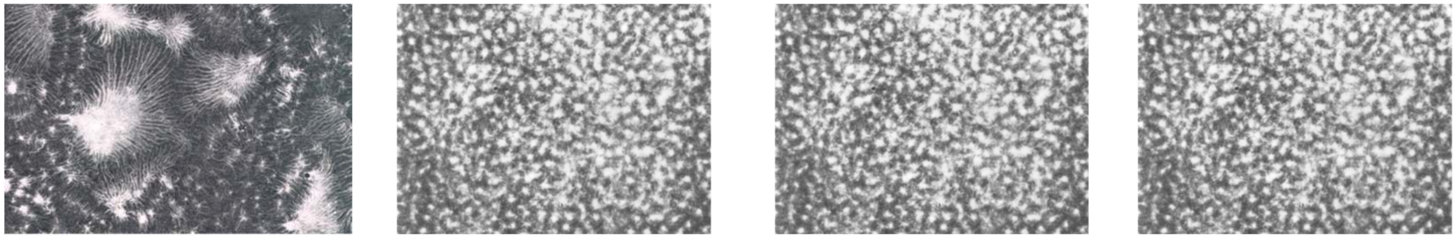
Reference (Traditional) Arrangement



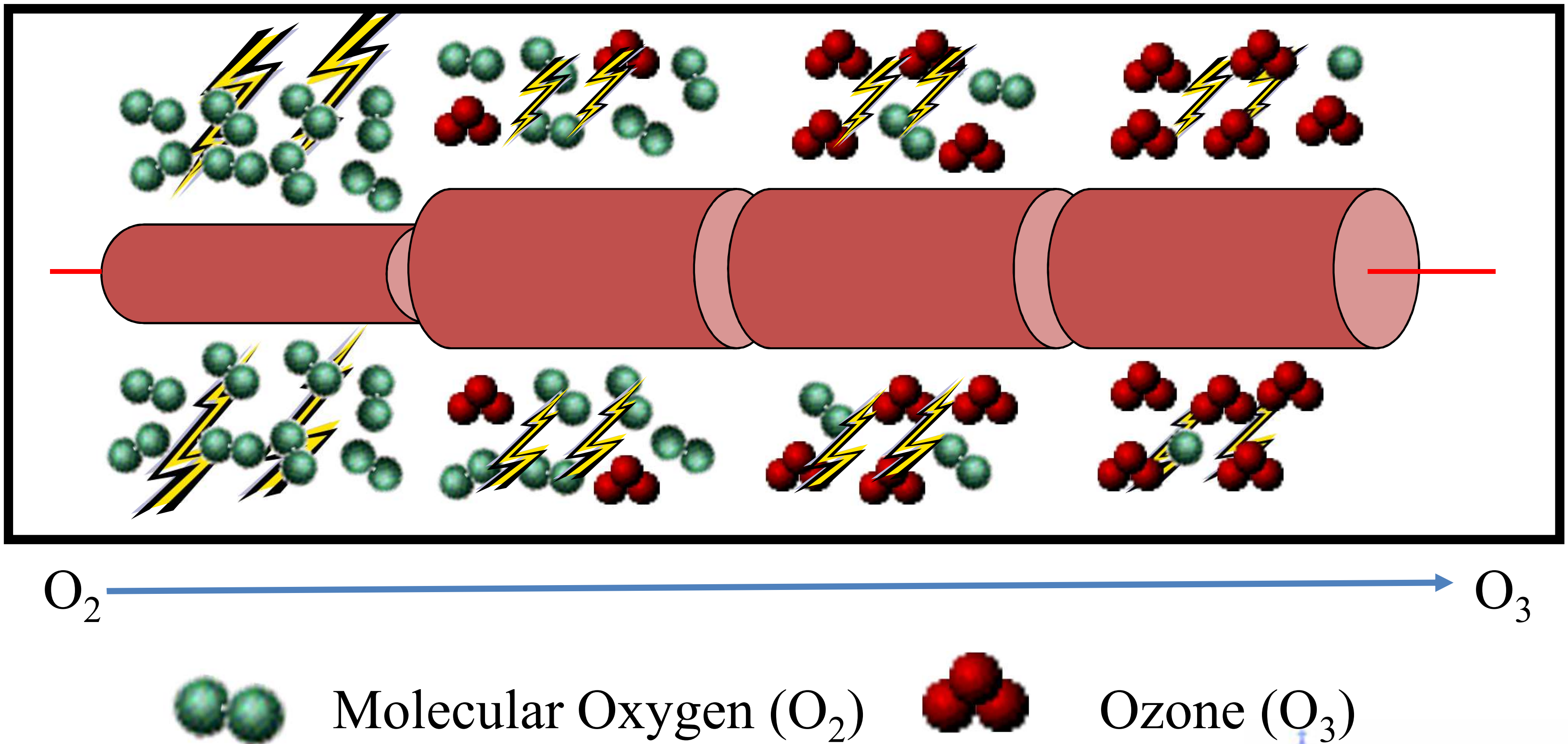


Optimized Arrangement





Intelligent Gap System (IGS)



Environmental and Water Remediation with Plasma Technologies

Intelligent Gap System

5000 kg/day of ozone

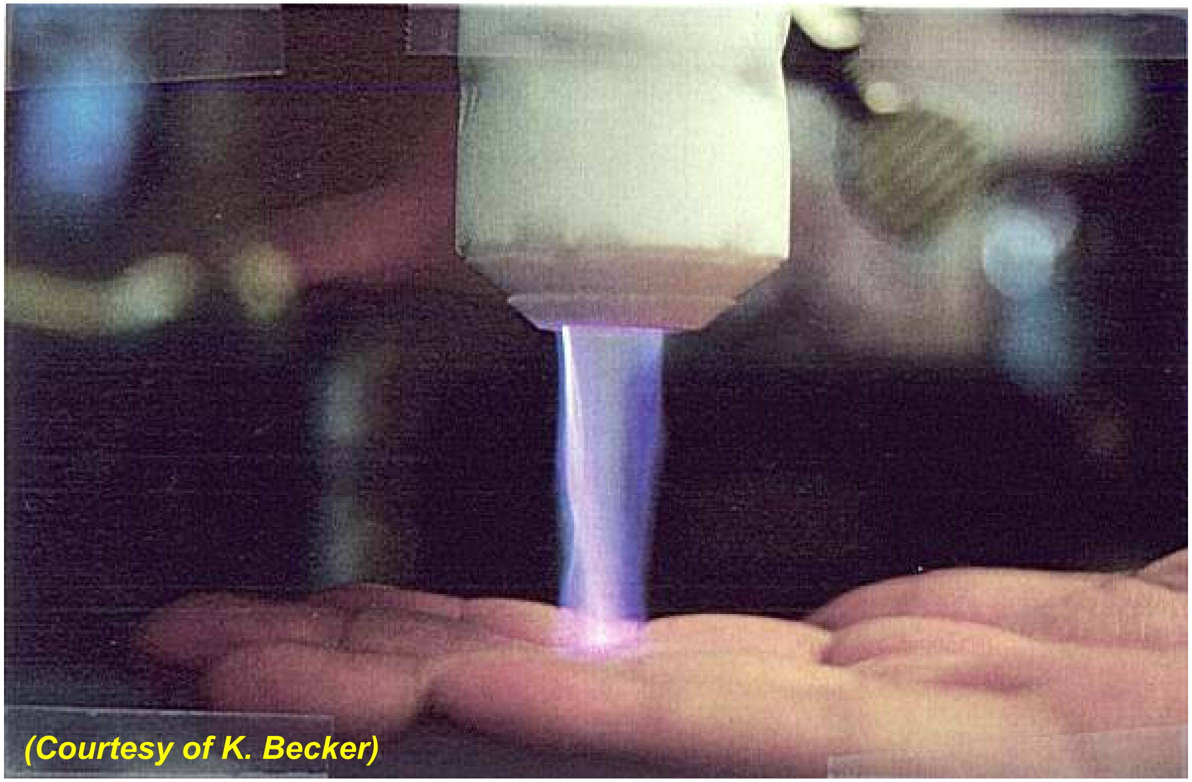
Guido Vezzu, Jose L Lopez, Alfred Freilich, Kurt H Becker. *Optimization of large-scale ozone generators.* IEEE Transactions on Plasma Science. Vol. 37, Issue 6, pp. 890-896 (2009).

Jose L Lopez. *Progress in Large-Scale Ozone Generation*. **Complex Plasmas: Scientific challenges and Technological Opportunities. Editors – Michael Bonitz, Jose Lopez, Kurt Becker, Hauke Thomsen.** Chp 13, pp. 427-453, Springer Publishing (2014).

Atmospheric Cold Plasmas

Erich Kunhardt & Kurt Becker

STEVENS Institute of Technology

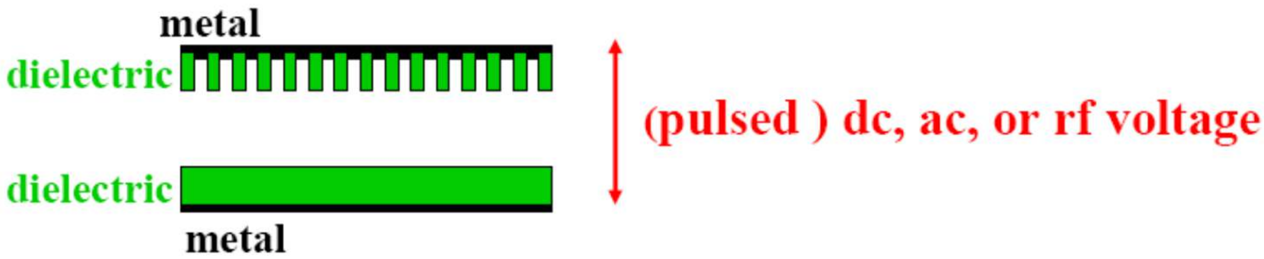


An Atmospheric Pressure Plasma Generated with a Capillary-Plasma-Electrode Discharge

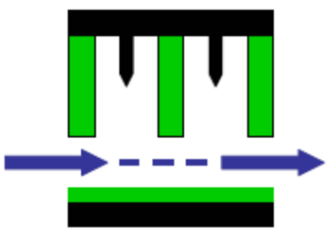
In the late 1990s and early 2000s there was a rapid increase in the basic research of atmospheric or higher pressure low temperature plasma.

There was further much interest in the investigations of applications and new technologies using these kinds of LTPs.

Capillary Plasma Electrode (CPE)

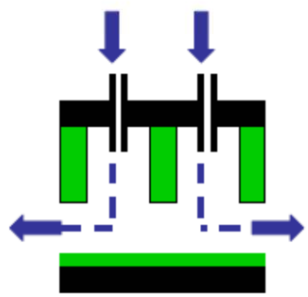


Capillary Plasma Electrode (CPE) Realizations



Solid Pin Electrodes

(Cross Flow)



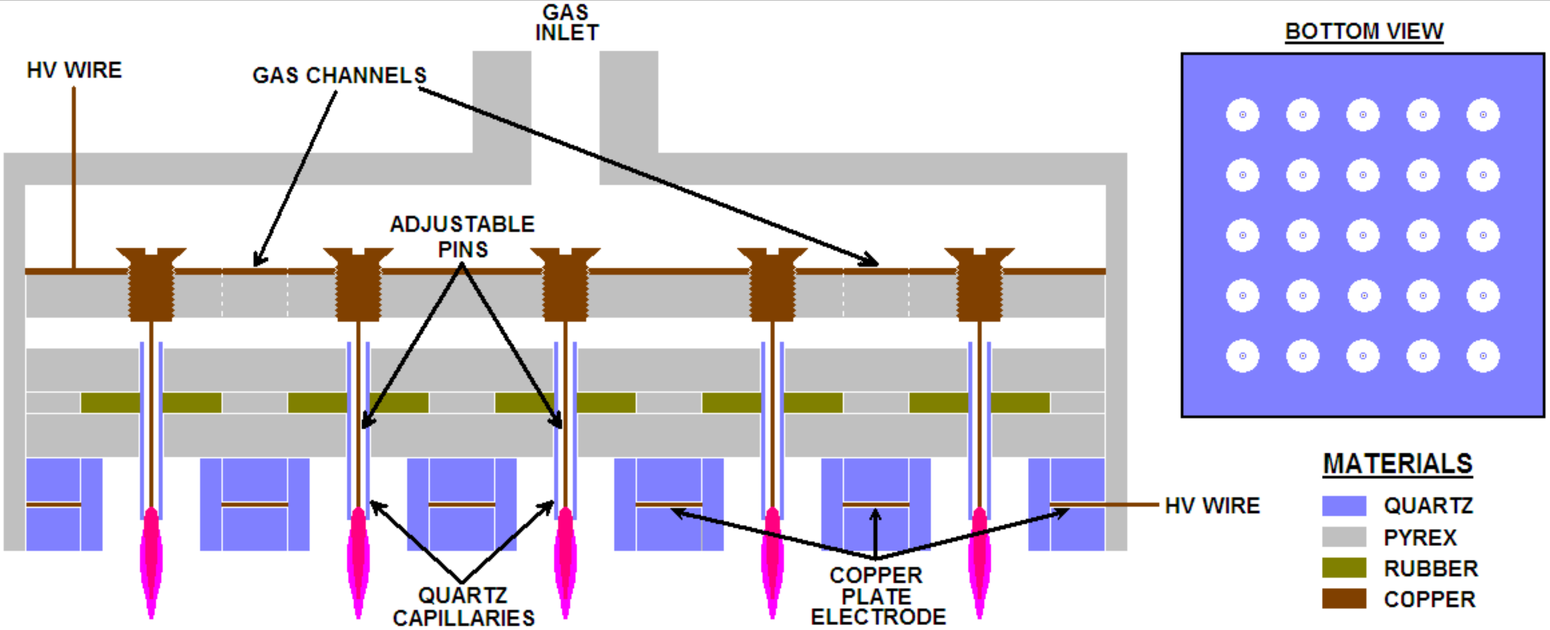
Hollow Pin Electrodes

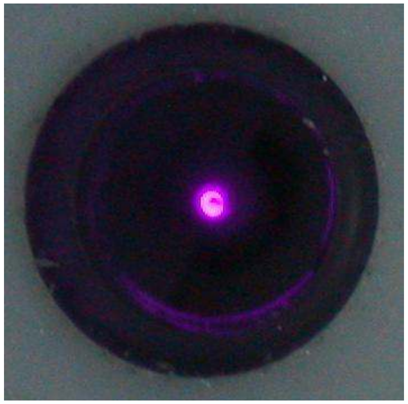
(Flow-Through)

Cylindrical Electrodes

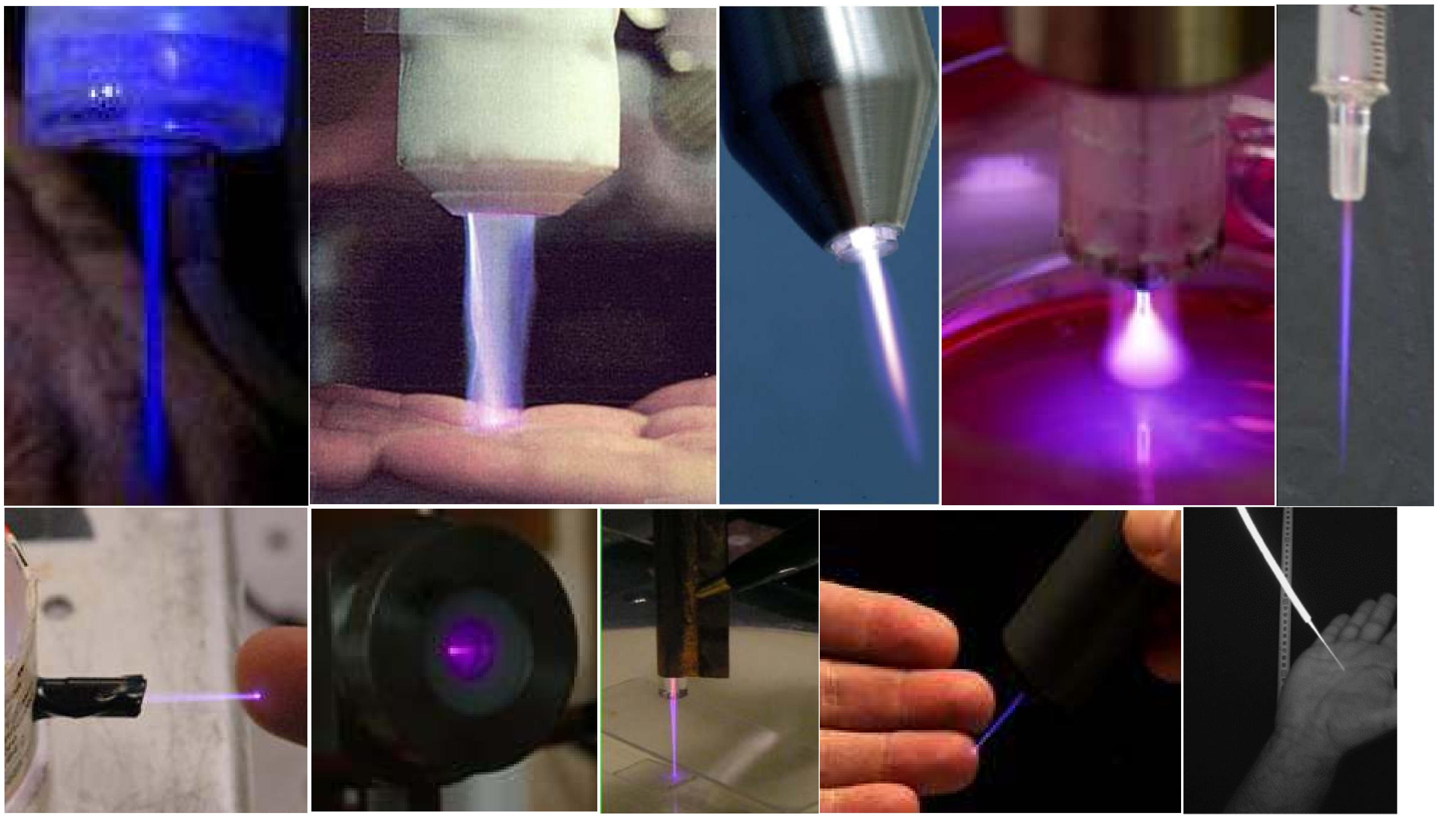
(Longitudinal Flow)

Multi-Capillary Plasma Electrode





A Brief Collection of Atmospheric Pressure Plasma Jets (APPJ)

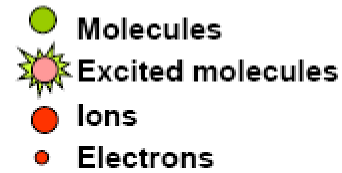


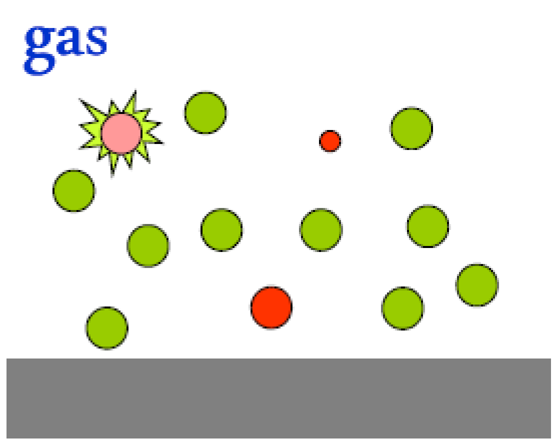
Gases used: Helium, Argon… or mixed with reactive gases (O_2, CH_4…)

AC, pulsed DC, rf or microwave

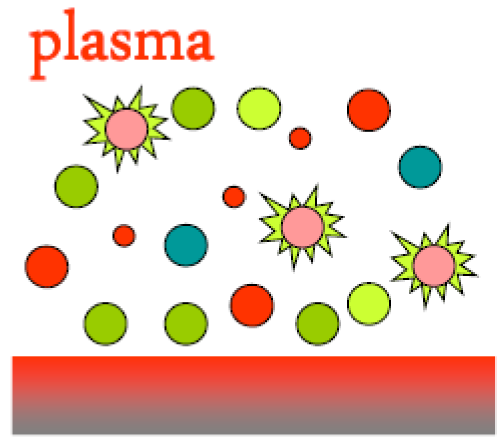
Surface Effects of Microplasmas

For instance, if we want to modify the surface of a material (e.g. a silicon wafer)





Small changes at the surface



Energy & reactive species can change the surface

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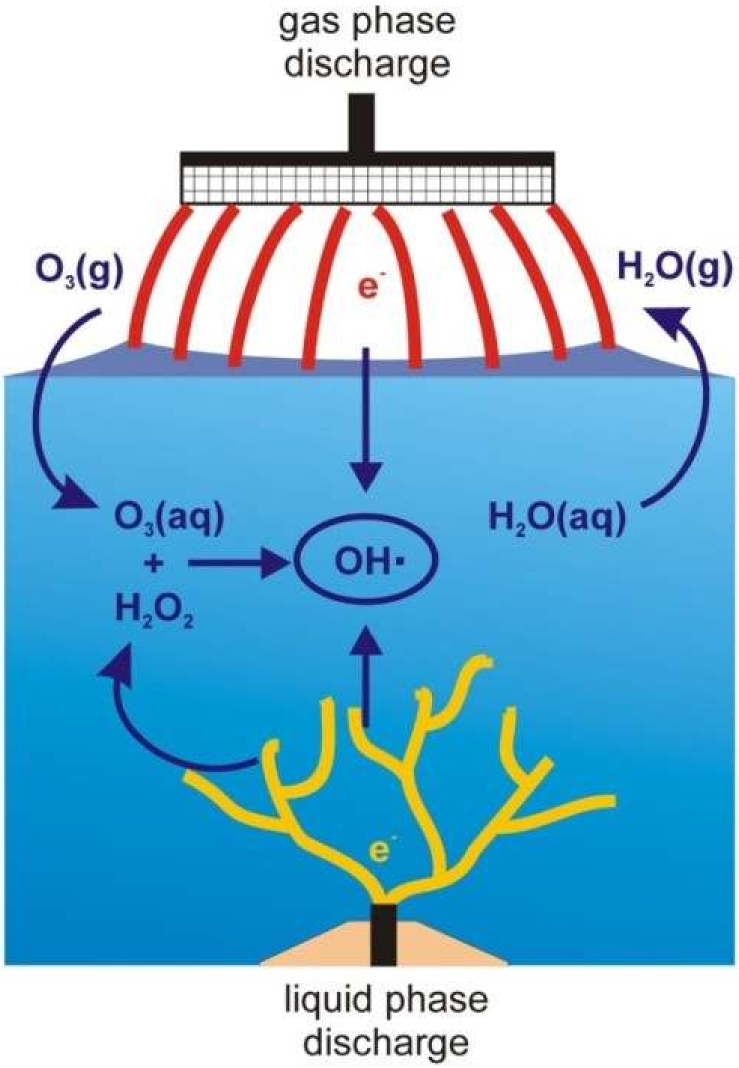
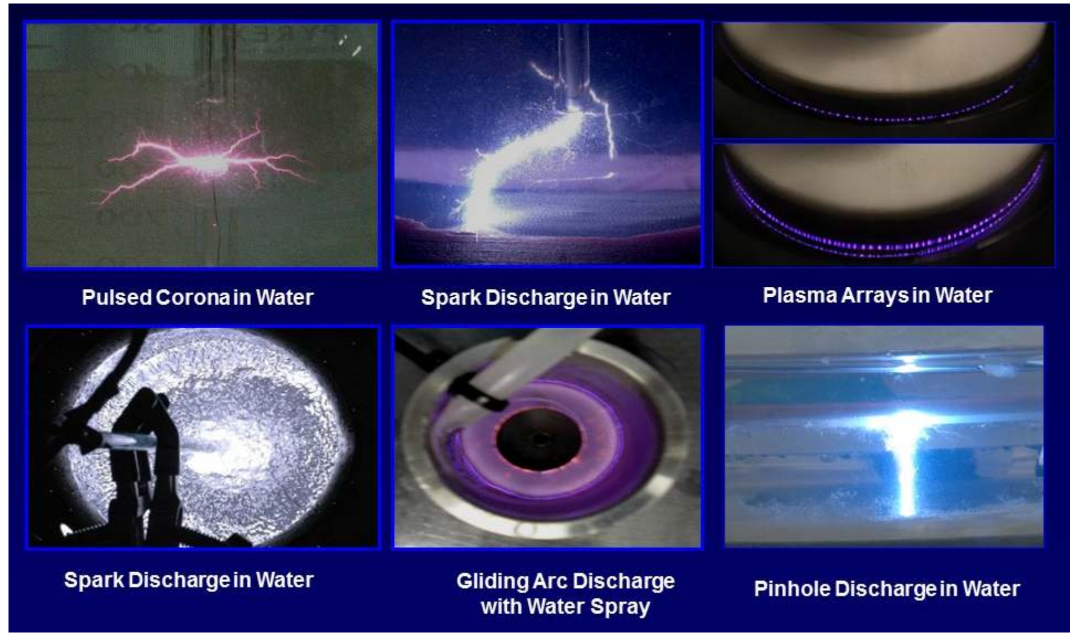
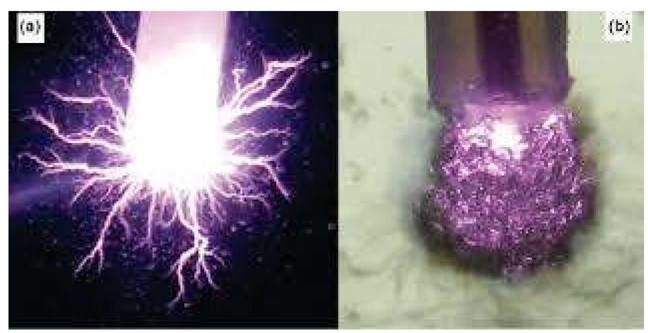
Plasma Discharges in Liquids







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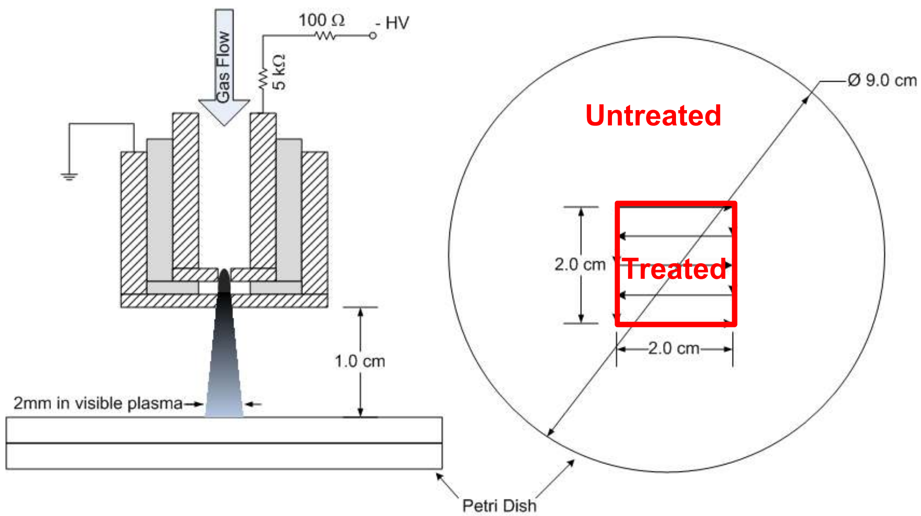
Inactivation of Bacteria

Experimental Set-up



	Bacteria	Gram stain
A	Escherichia coli	Negative
B	Staphylococcus aureus	Positive
C	Micrococcus luteus	Positive
D	Bacillus megaterium	Positive
E	Bacillus subtilis	Positive
F	Bacillus natto	Positive

Spore Forming

List of bacteria cultures studied

Experimental Procedure

Total path length: 120 mm
Moving speed: 4 mm/s
Time per path: 30 s
Total treatment time: 30s / 60s / 90 s
Area exposure/path: < 1 s (visible plasma),~10 s (radical exposure)

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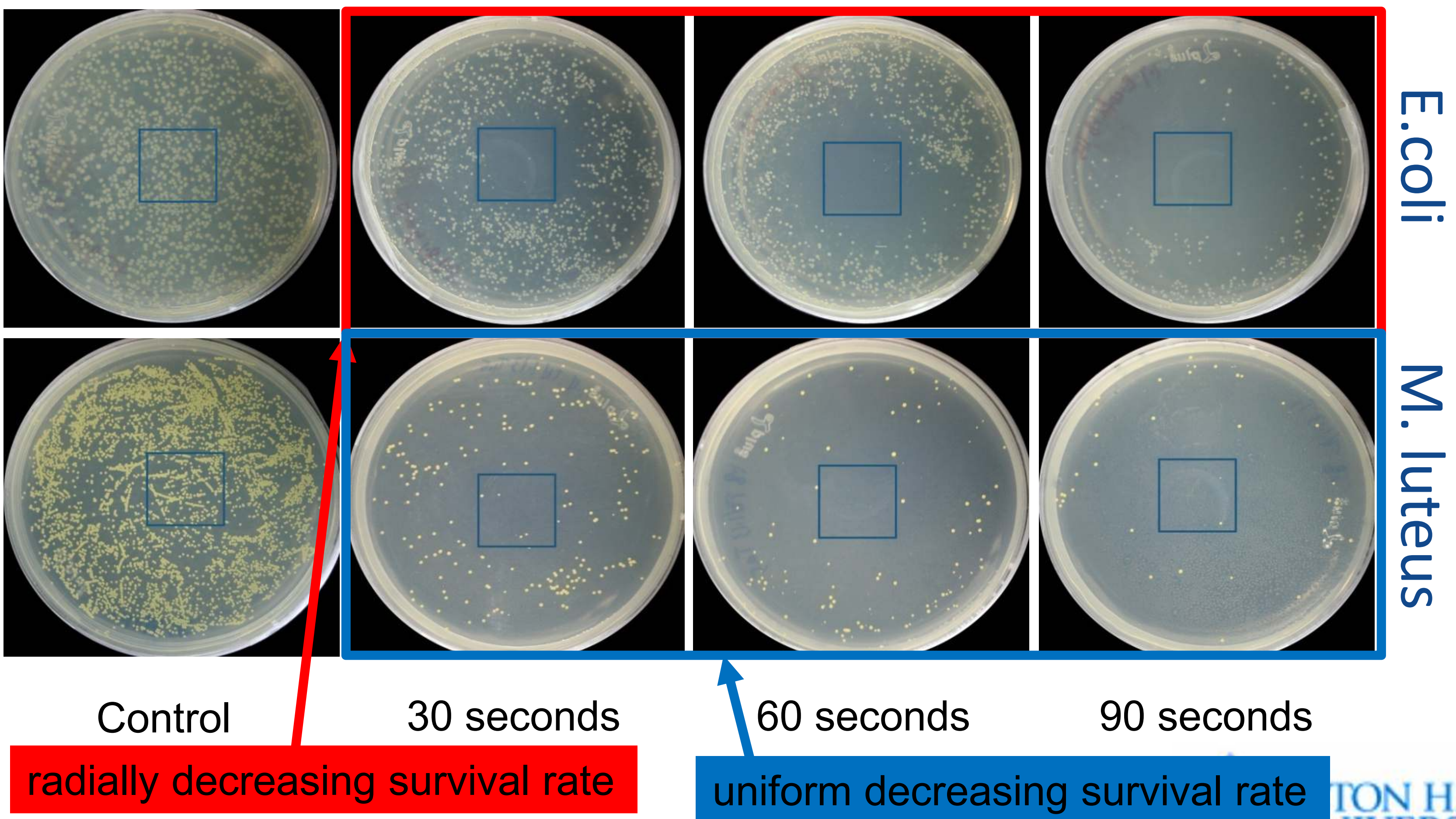
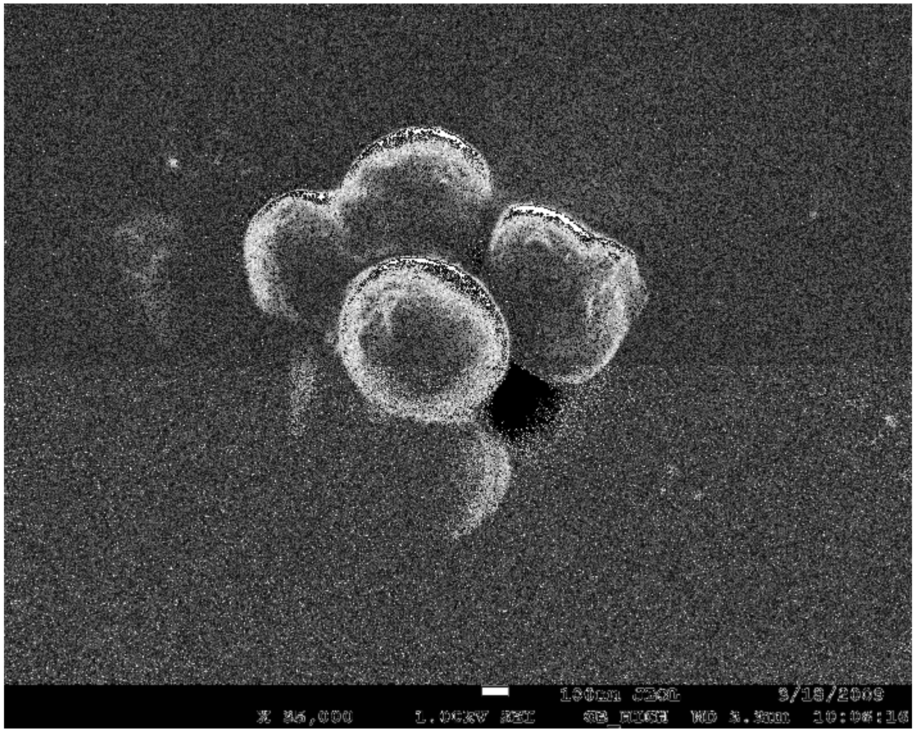
Plasma Dose Effect

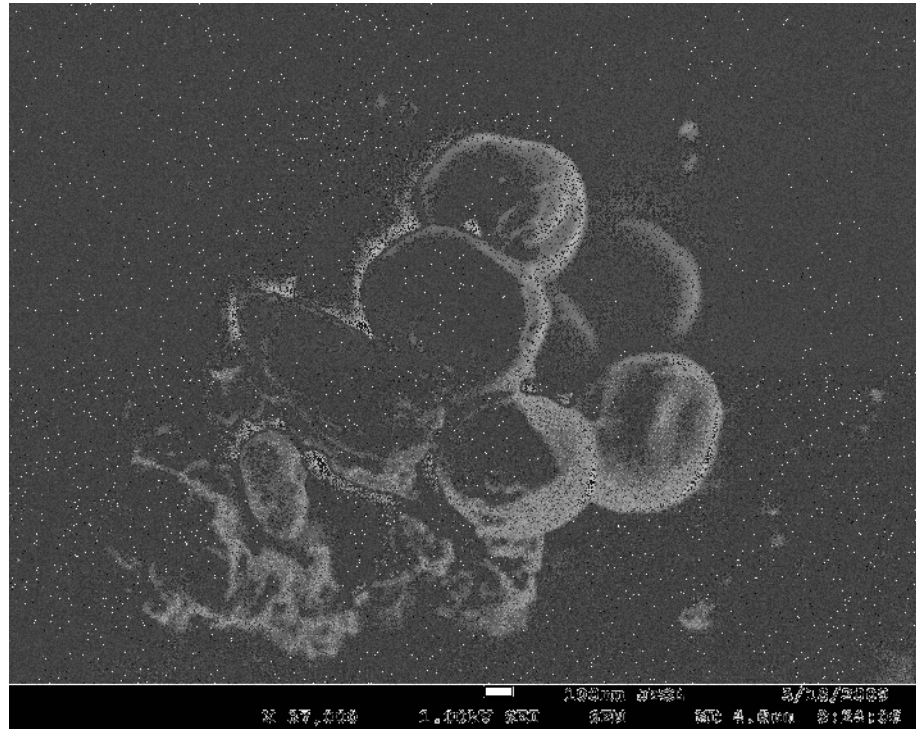


SEM Pictures

SEM pictures of S. aureus before and after PMJ treatment



Control

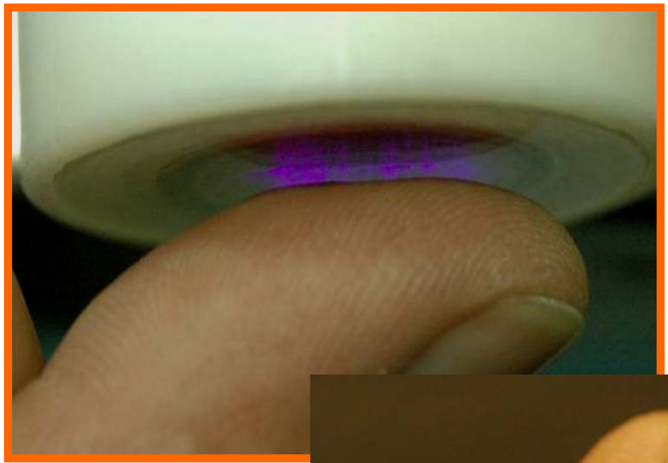


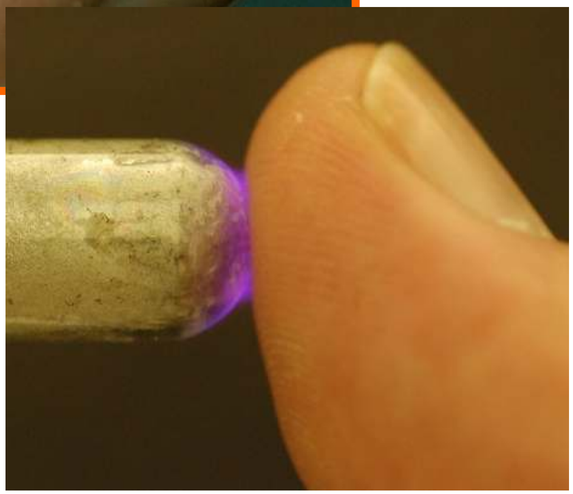
PMJ treatment

SEM of PMJ treated S. aureus show clear poration on cell membrane as well as the change of the cell morphology.

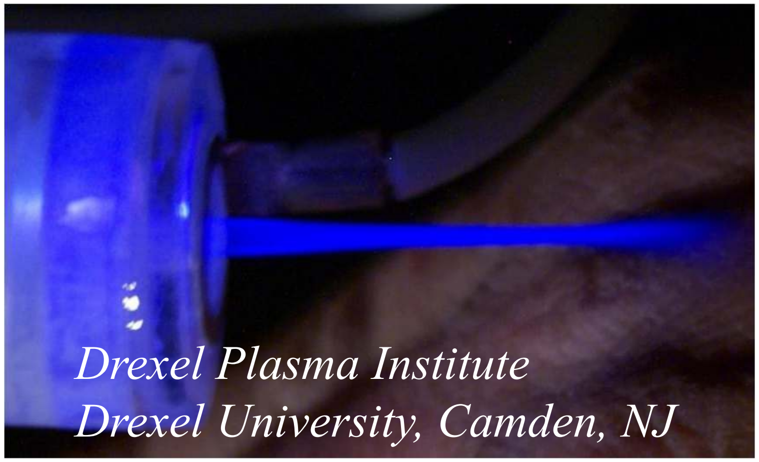
Plasma Application in Medicine

Direct Plasma – Charges on Tissue, Produced In Air or Oxygen





Indirect Plasma – Jet, Often NOT in OXYGEN



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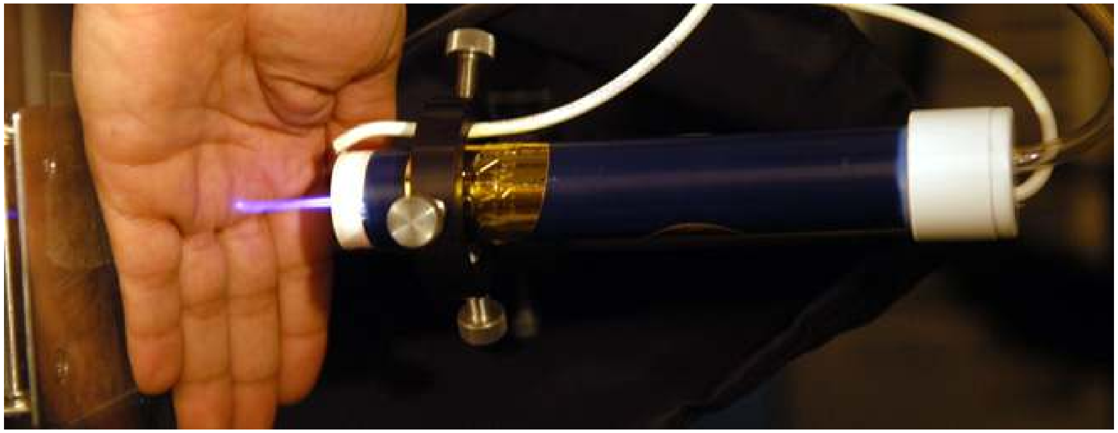
Plasma Oncology – cancer treatments

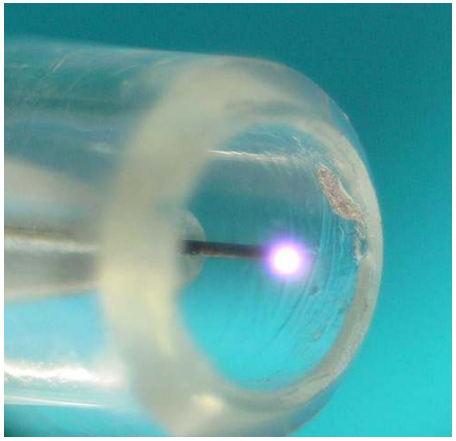


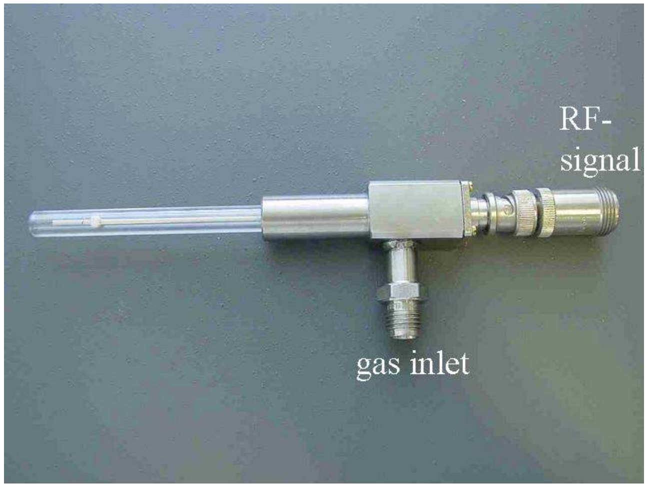
Mounir Laroussi, Old Dominion University in Norfolk, VA, USA

Michael Keidar, George Washington University, Washington DC, USA

M. Laroussi, X. Lu, and M. Keidar. *Perspective: The physics, diagnostics, and applications of atmospheric pressure low temperature plasma sources used in plasma medicine.* Journal of Applied Physics **122**, 020901 (2017).

Dental Application



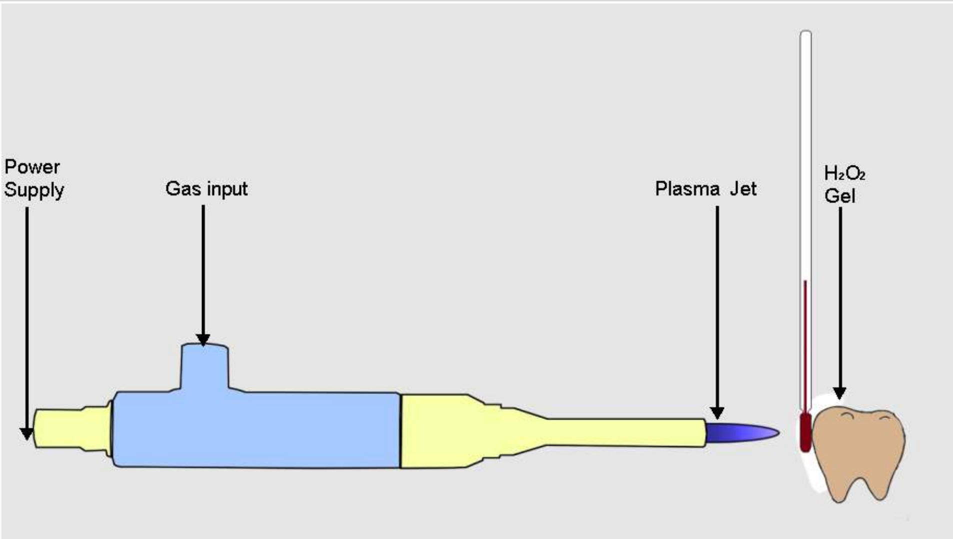


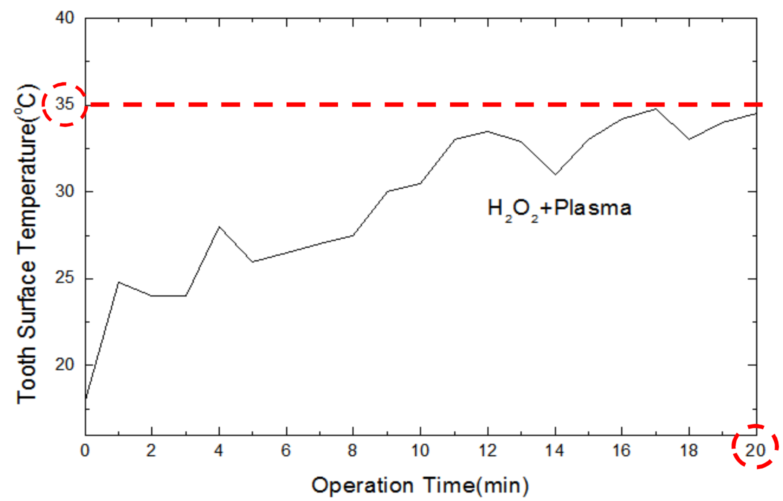
Cleaning of Dental Cavities

Other Applications

- **Bio Decontamination**
- **Sterilization of Medical Instruments and Wounds**

Teeth Whitening with non-thermal plasma





- The plasma jet did not heat tooth surface over **37 degrees**.
- Heating the tooth over **42 degrees** can causes severe damages to the nerves inside a tooth.

"No thermal-damages"

Teeth Whitening with non-thermal plasma

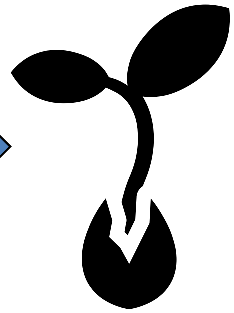
H_2O_2 20min **H_2O_2**
before **after**

Plasma+H_2O_2 20min **Plasma+H_2O_2**
before **after**

Our Version of the Atmospheric Pressure Plasma Jet

Gerald J. Buonopane, Cosimo Antonacci, & Jose L. Lopez. *Effect of cold plasma processing on botanicals and their essential oils*. Plasma Medicine. Vol 6, Issue 3-4 (2016).

Plasma Processing: Experimental Plan



Plasma Treatment

Measure Plants

Harvest

Distillation

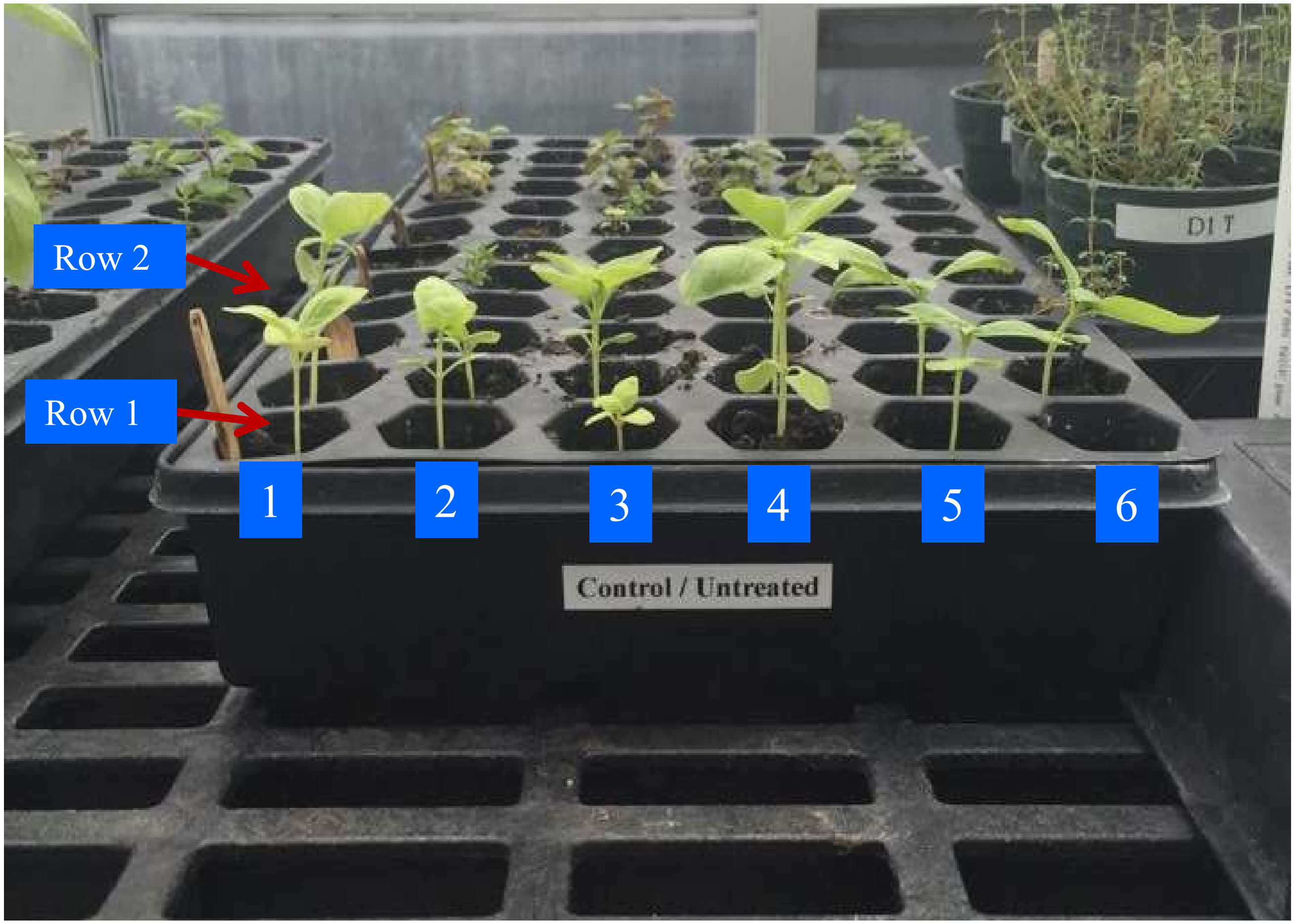
Antioxidant Testing

GC-MS

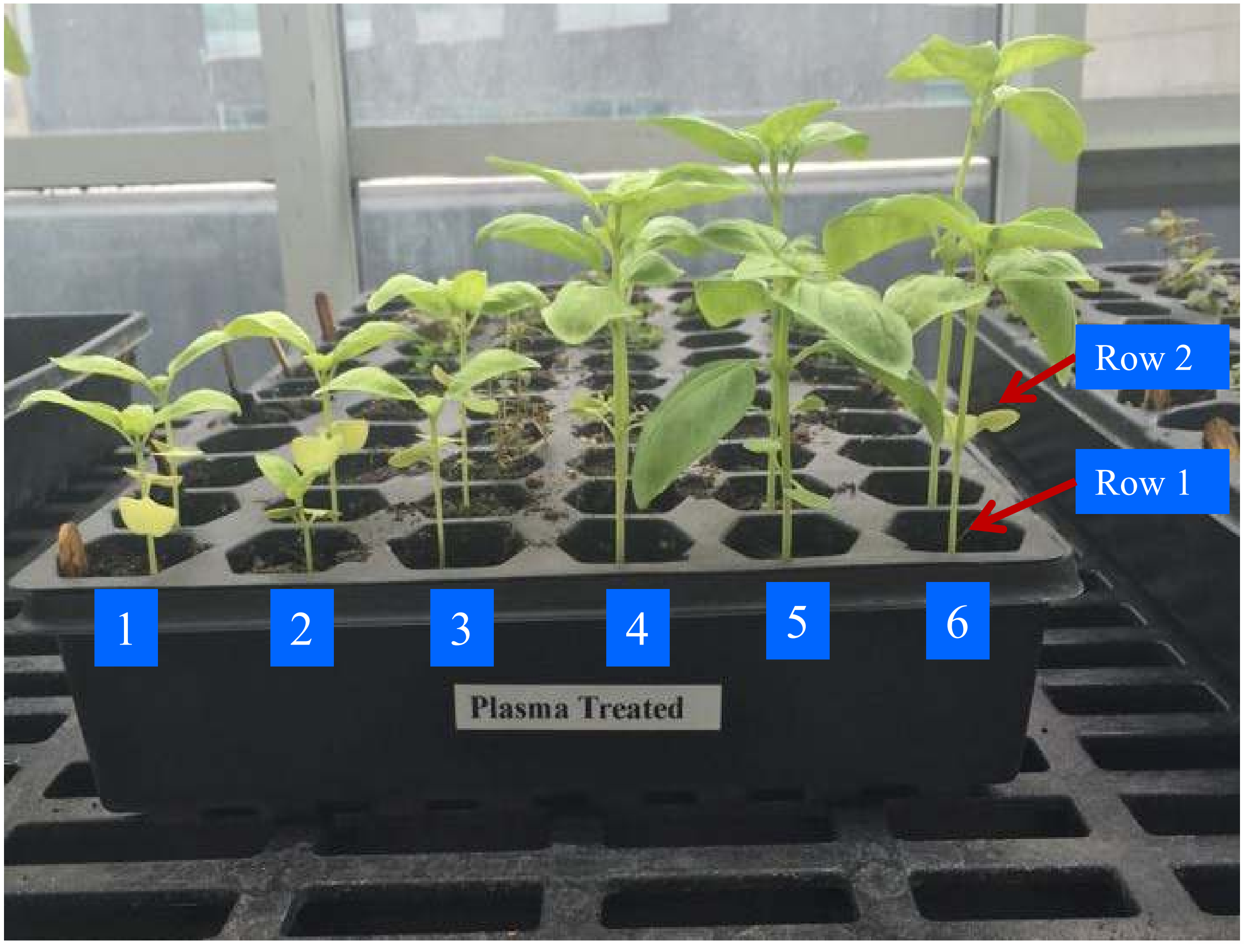
Plasma Seed Treatments

(a) Side-view of basil seedlings grown from plasma treated seeds (left) and untreated seeds (right). (b) Top-view of basil seedlings grown from plasma treated seeds (left) and untreated seeds (right).

Untreated (Control) Basil



Plasma Treated Basil



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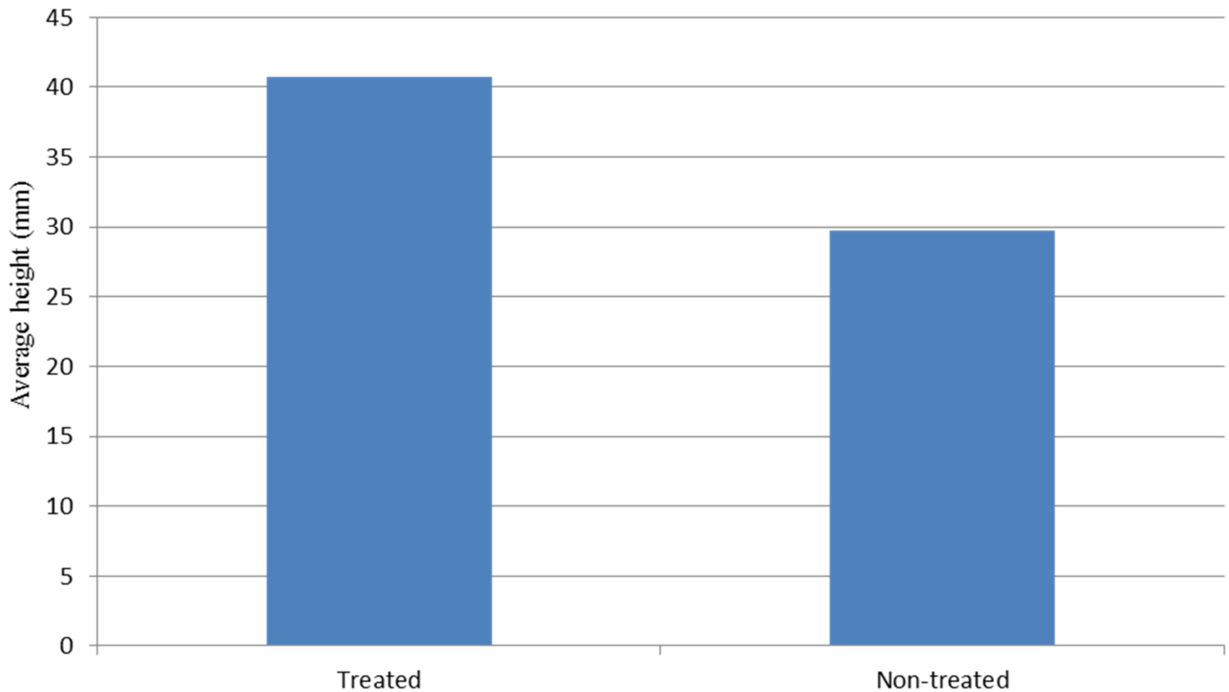
Basil: Plasma Treated vs. Untreated

Basil: Plasma Treated vs. Untreated



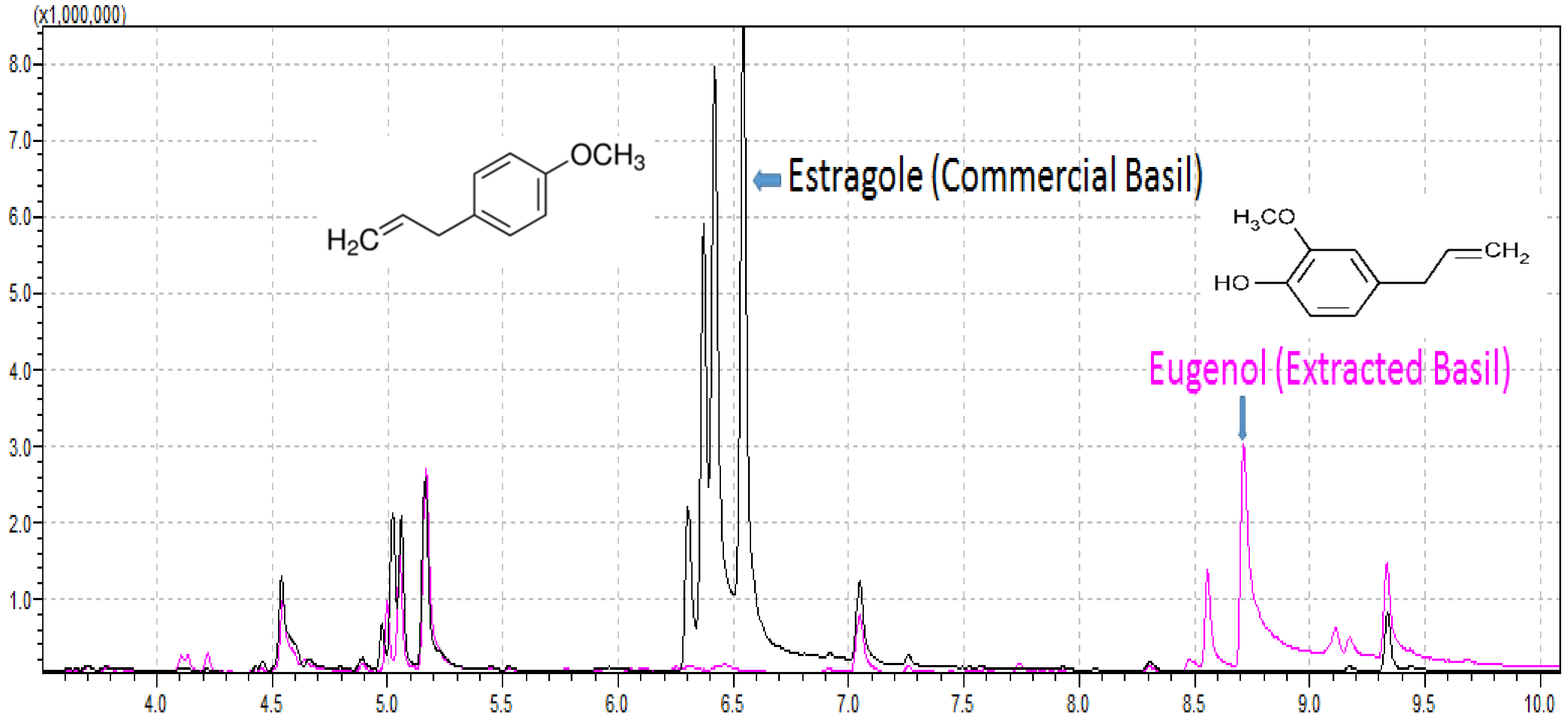
Graph demonstrating average final height of twelve treated and non-treated sweet basil plants after a month of growth from seeds.

Percent Antioxidant Activity – Home-Grown Basil (seed treated)

Antioxidant / Concentration	15 µg/mL	25 µg/mL	50 µg/mL	125 µg/mL	250 µg/mL
Plasma-Treated Basil	48.00%	62.55%	81.55%	90.55%	94.82%
Non-Treated Basil	19.55%	26.91%	46.36%	78.27%	90.64%

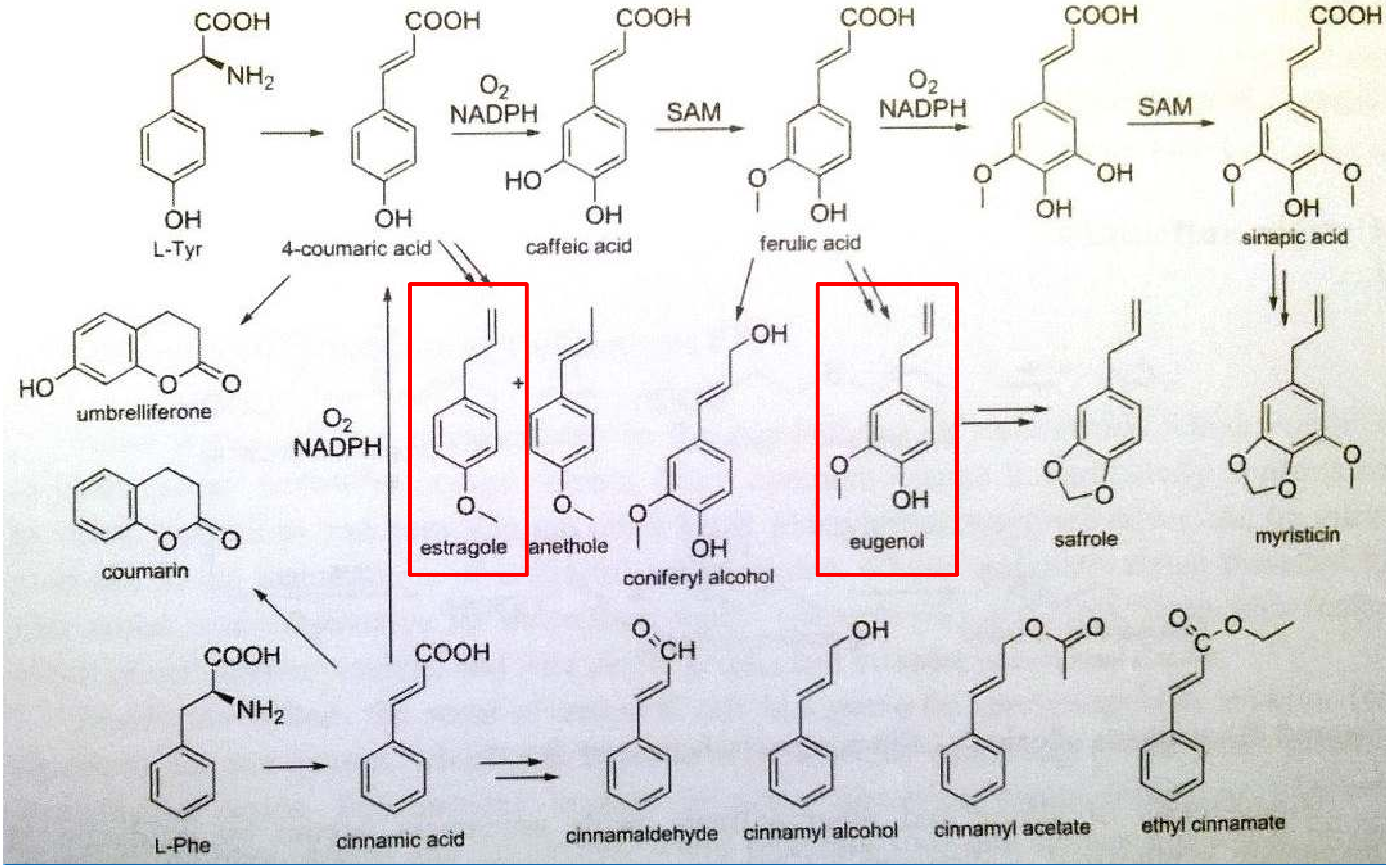
Gas Chromatogram: Overlay of Commercial Oil and Extracted (T + NT)

Shimadzu GC-MS; Column: RTX-5 MS: 15m X 0.25mm X 0.25µm

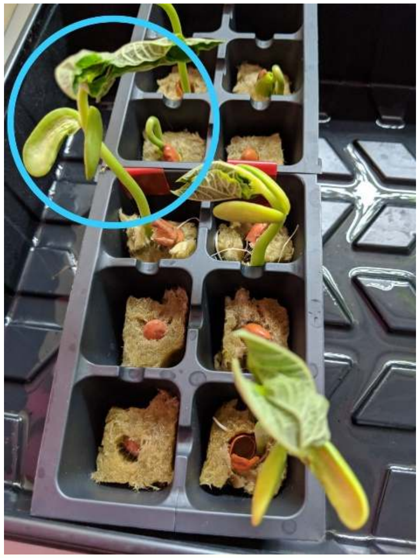


Biosynthesis of Phenylpropanoids and Phenolic Compounds

(Valgimigli, 2012)



Aeroponic & Aquaponic Investigations



Kidney Bean Research

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Living tissue sterilization without harm: Recent pig experiments

Courtesy: Drexel Plasma Institute

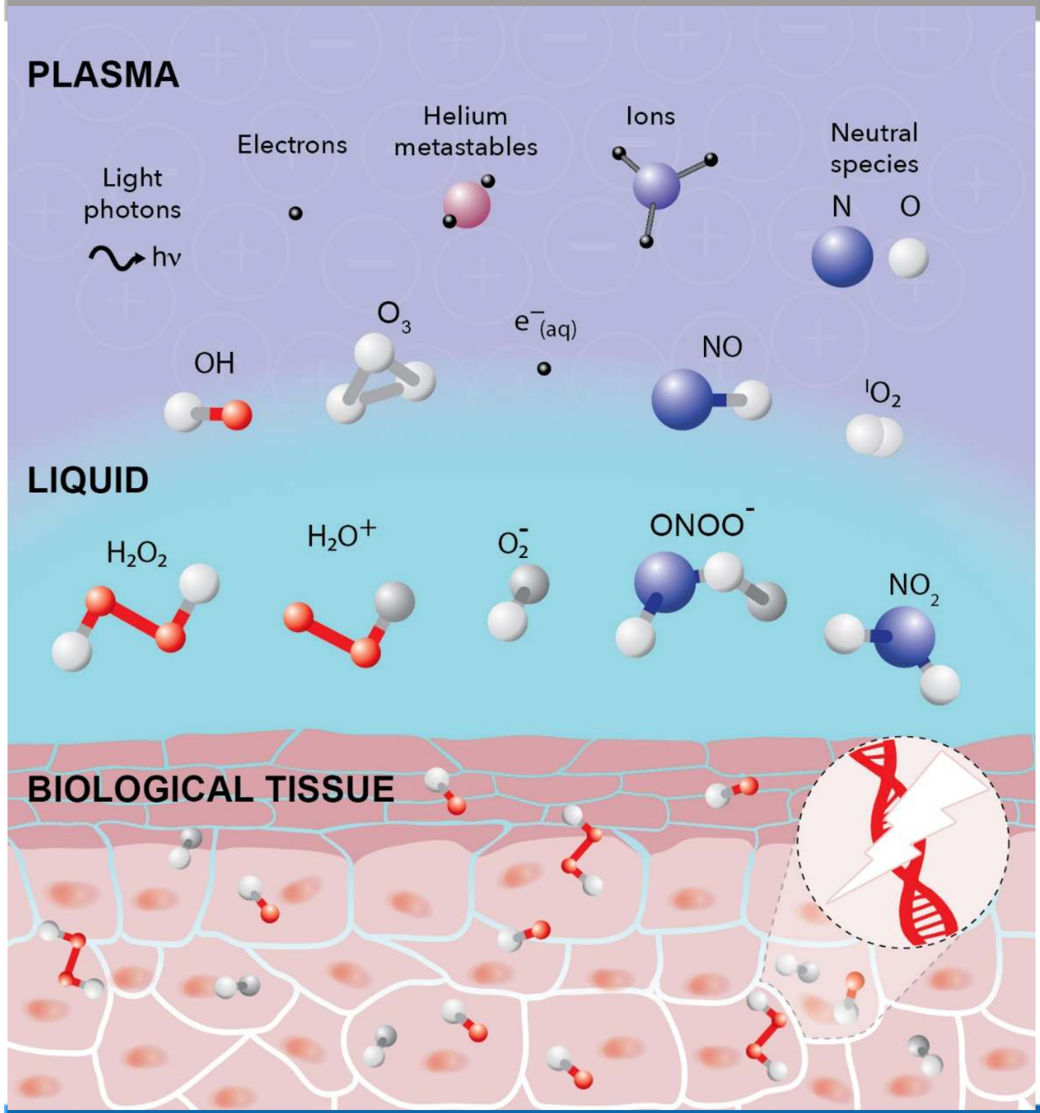
Hemostasis and coagulation in Hairless mice, not immunocompromised (SKH_1)


Saphenous vein cut: without plasma animal continues to bleed for 10-20 minutes.

15 seconds of FE-DBD clots the blood and seals the vessel <u>without damaging tissue</u>, preventing additional bleeding.

Courtesy: Drexel Plasma Institute

Microplasma interaction with biological materials???



Many unanswered questions as to the role of plasma in the biological interactions with biological materials.

- What are the microplasmas doing to the live biological materials?
- Can microplasma sources be tailored to better control interactions with biological materials?

Star Trek's Dermal Regenerator

STAR TREK
THE NEXT GENERATION

On *Star Trek*, the dermal regenerator is a hand-held device that instantly heals cuts and burns without leaving a scar. It's used not just for injuries, but also for quick healing after surgery, making for a very speedy recovery.

Star Trek's Dermal Regenerator

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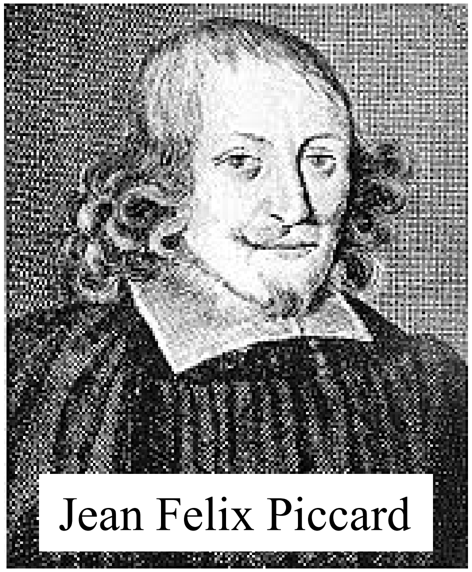
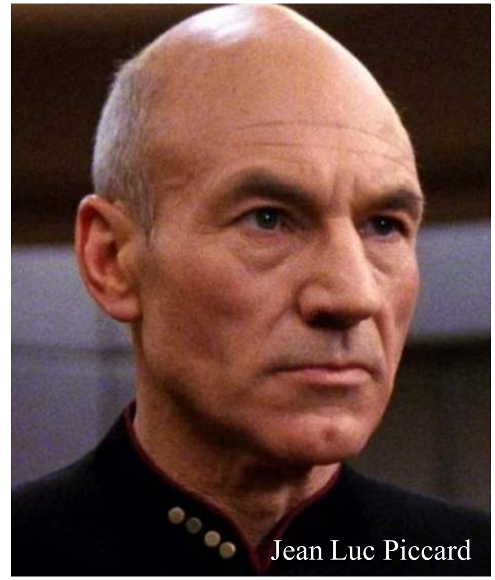
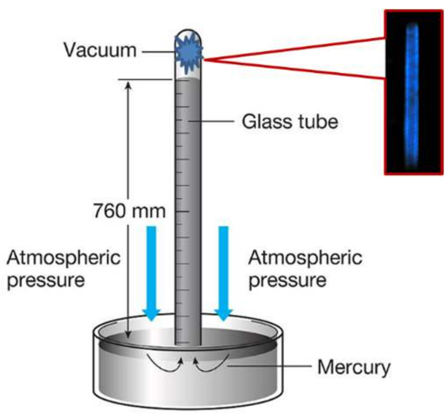
What LTP technologies will the future bring???







Mercury barometer

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Senior Editor of Industrial, Commercial, and Medical Applications of Plasmas

SETON HALL UNIVERSITY

Princeton Collaborative Low-Temperature Plasma Research Facility (PCRF)

PCRF Princeton Collaborative Low Temperature Plasma Research Facility

Facilities | Personnel | Information for Users | Links

About

The Princeton Collaborative Low Temperature Plasma Research Facility (PCRF) is focused on low temperature plasma physics and is open to all users.

The PCRF provides state-of-the-art research capabilities and expertise for comprehensive characterization of low temperature plasma (LTP) properties with the goal to advance methods of predictive control of LTP with a focus on plasma-liquid and plasma-solid interactions, collective phenomena in LTP, and use of LTP in modern applications (e.g. material synthesis and processing).

The facility is formed from the existing low temperature plasma laboratories at PPPL and the Mechanical and Aerospace Engineering (MAE) Department of Princeton University (PU), with a total collective lab space greater than 7000 sq. ft., each located within 3 miles from each other.

The PCRF research and facility program are built on the existing and fruitful collaboration between PPPL and PU MAE researchers, and demonstrated excellent track record of successful integration of experimental and modeling research in their collaborative efforts. PCRF users will be able to access PPPL/PU computer network and helpdesk services, and use PPPL engineering, facilities, and administrative services. Staff of PCRF and PCRF users have direct access to specialized laboratories and institutes at the Princeton University such as the Princeton Institute for the Science and Technology of Materials (PRISM) with state-of-the-art materials evaluation diagnostics.

pcrf.pppl.gov

Yevgeny Raitses

Facility Director, PI

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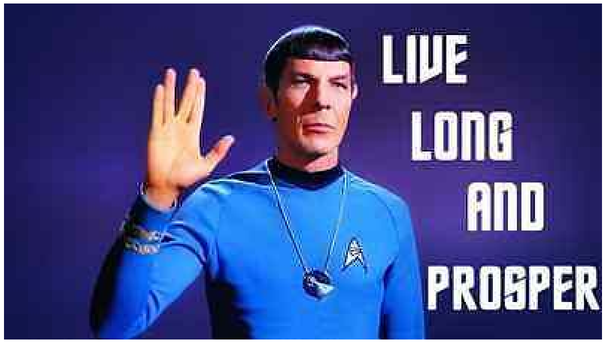
Phone: (609) 243-2268

Questions???

Thank You!



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