The Cutting Edge of Plasma Physics

Presented by

Mahmoud Saad Afify

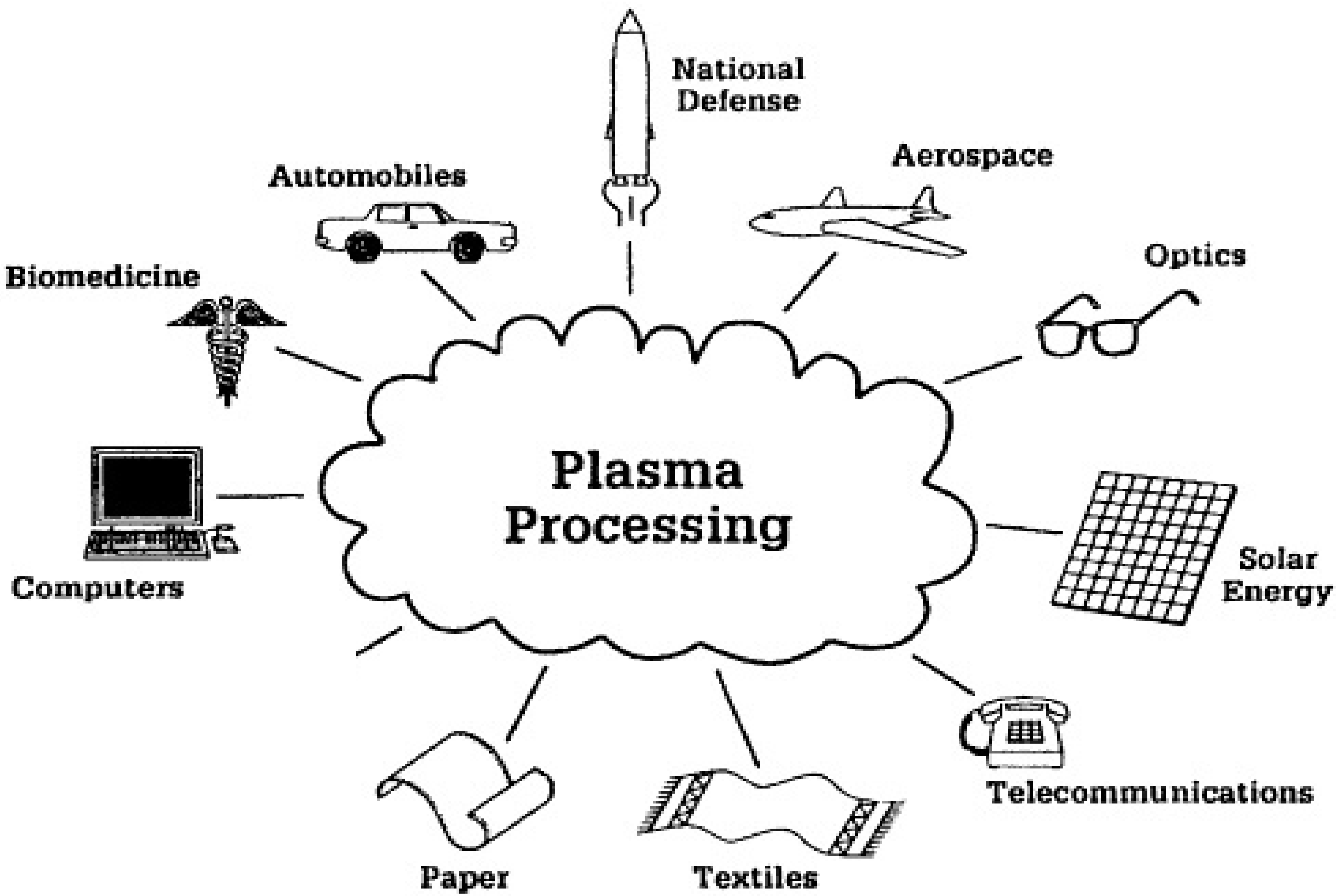
Physics Department, Faculty of Science, Benha University

Outlines

- **Introduction**
- **Significance of plasma technologies for the world economy**
- **Challenges of plasma physics**
- **How to overcome and benefit from facing these challenges**

Report of Prof. Dr. K.-D. Weltman
FIPS Workshop February 201


INP
Plasma
Wind turbine: protective wear coating
Plasma
Architectual glass: thermal insulation, self-cleaning, mirror coating
Plasma
Aircraft turbine: protective wear resistant coating
Plasma
Car: xenon headlights, wear protection, friction reduction
Plasma
Implants: biocompatibility, antimicrobial features
Plasma
Functional clothing: thermal insulation, breathability, flexible sensors, water-repellant
Plasma
Food packaging: barrier layers, antimicrobial features
Plasma
Notebook: LED backlight, reflective coating on CD
Plasma
Tools: polishing, hardening, decoating, hard layer coating
Plasma
PET bottle: barrier layer for product preservation
Plasma
Smartphone: adhesion, battery, semiconductor technology, display
Plasma
Mug: printability of polymers
Plasma
Lenses: anti-reflection coating, lotus effect, scratch protection
Plasma
Camera lens: optical coatings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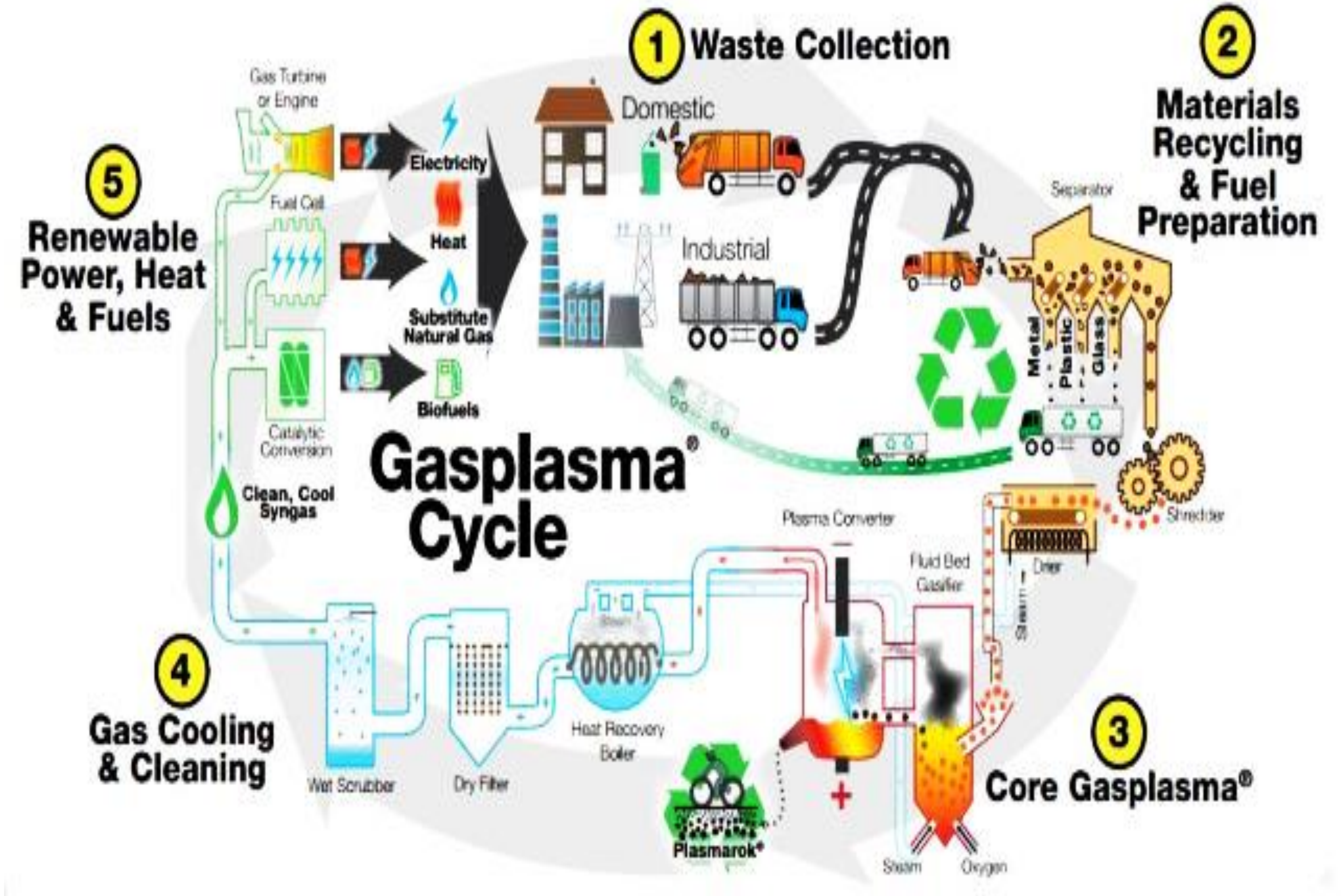
1 Waste Collection
Domestic
Industrial
2 Materials Recycling & Fuel Preparation
Separator
Metal
Plastic
Glass
Shredder
Drier
Steam
3 Core Gasplasma®
Plasma Converter
Fluid Bed Gasifier
Steam
Oxygen
Plasmarok®
4 Gas Cooling & Cleaning
Wet Scrubber
Dry Filter
Heat Recovery Boiler
Steam
5 Renewable Power, Heat & Fuels
Gas Turbine or Engine
Fuel Cell
Catalytic Conversion
Clean, Cool Syngas
Electricity
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Substitute Natural Gas
Biofuels
Gasplasma® Cycle

In 2004, the German government 45 000-60 000 people are directly working on building and maintaining plasma technologies.

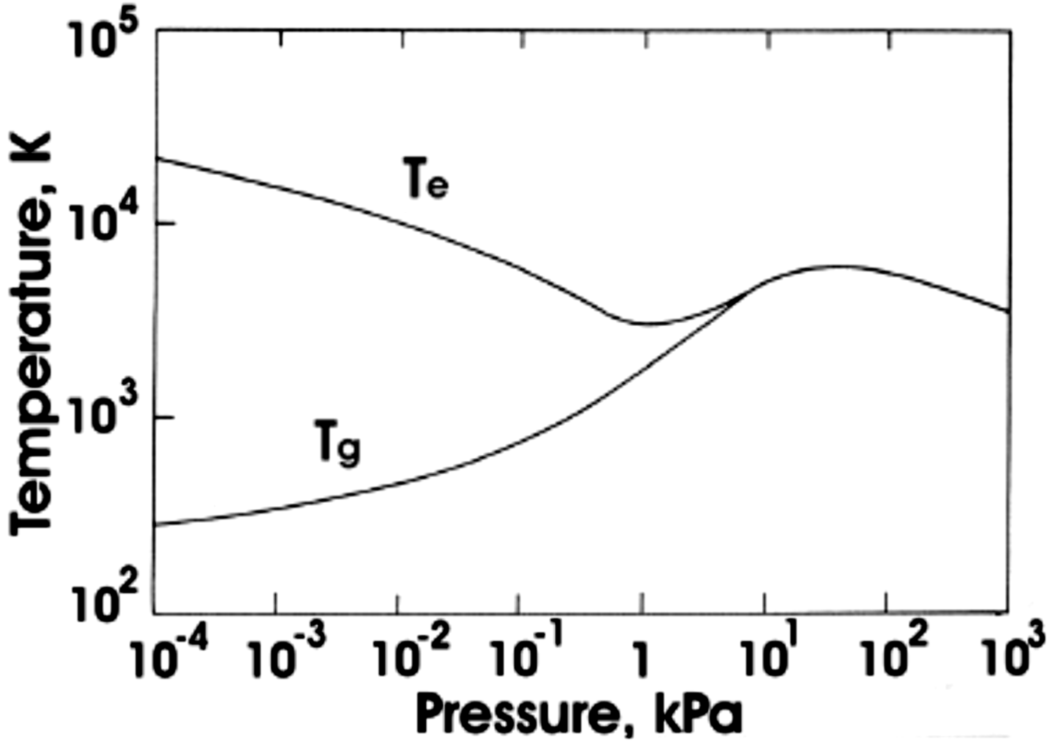
Up to half a million employees were working in manufacturing chains that require a plasma treatment step along the production line.

In 2004, this amounted to 6-7% of all jobs in the German economy or a contribution to the GDP of almost 160 billion Euros.

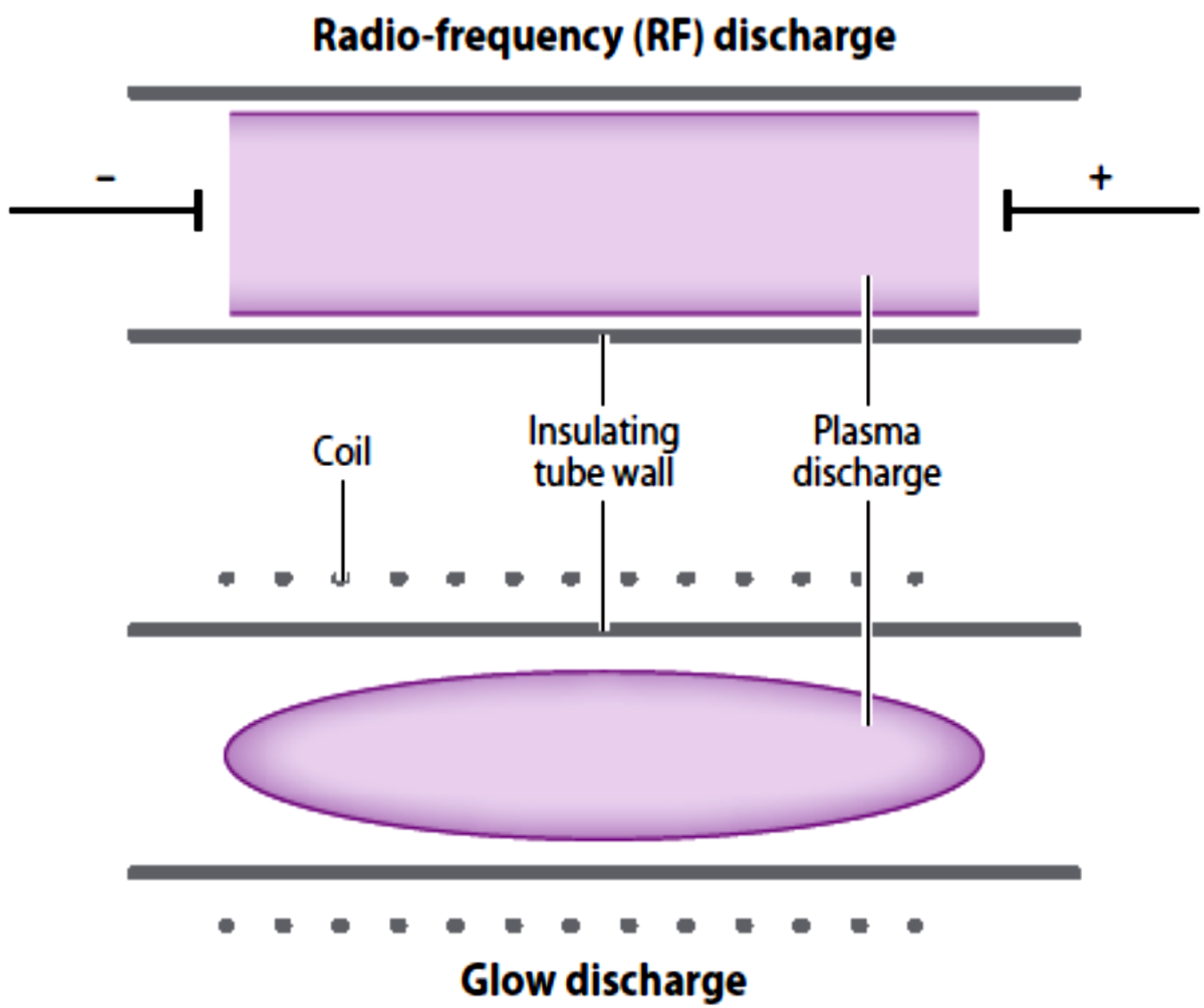
Similar estimates and shares can certainly be assumed for other highly industrialized countries in Europe, in Asia, the Americas, and for Australia.

For a growth of the German GDP by 28% from 2004 to 2014, it is safe to assume that the contribution of plasma technologies has proportionally increased.

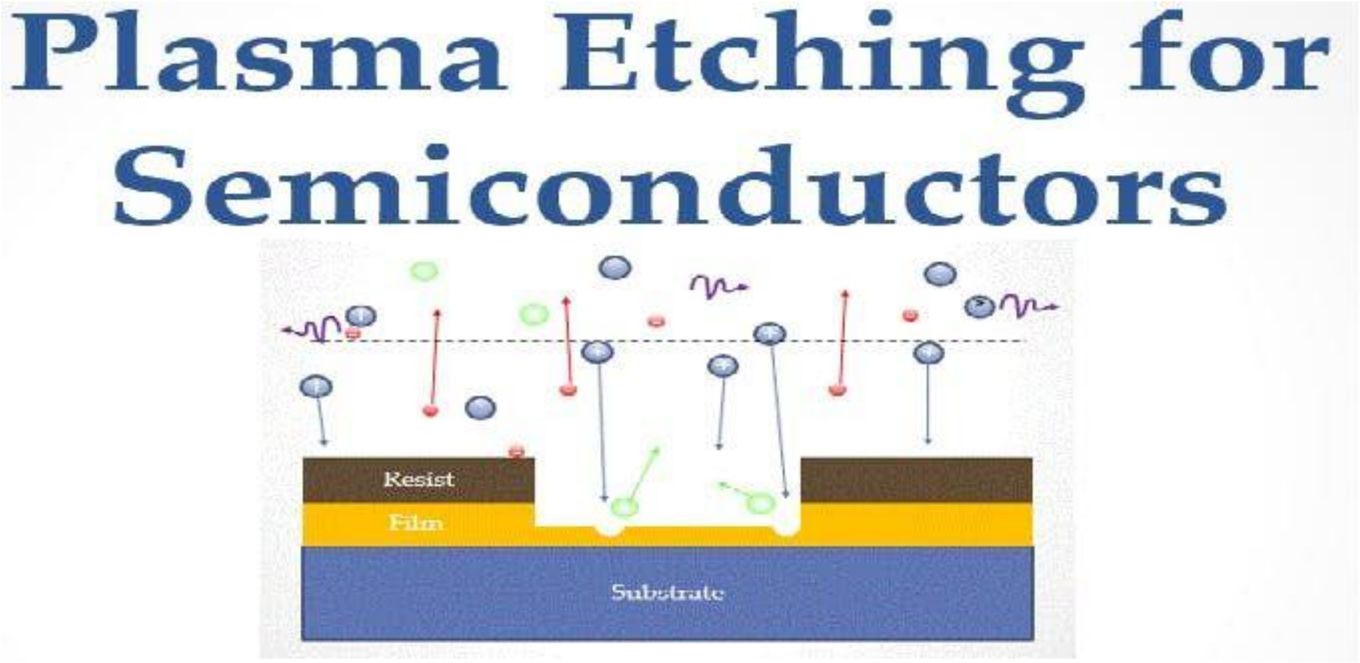
Cold Plasma



$$(T_e >> T_h)$$

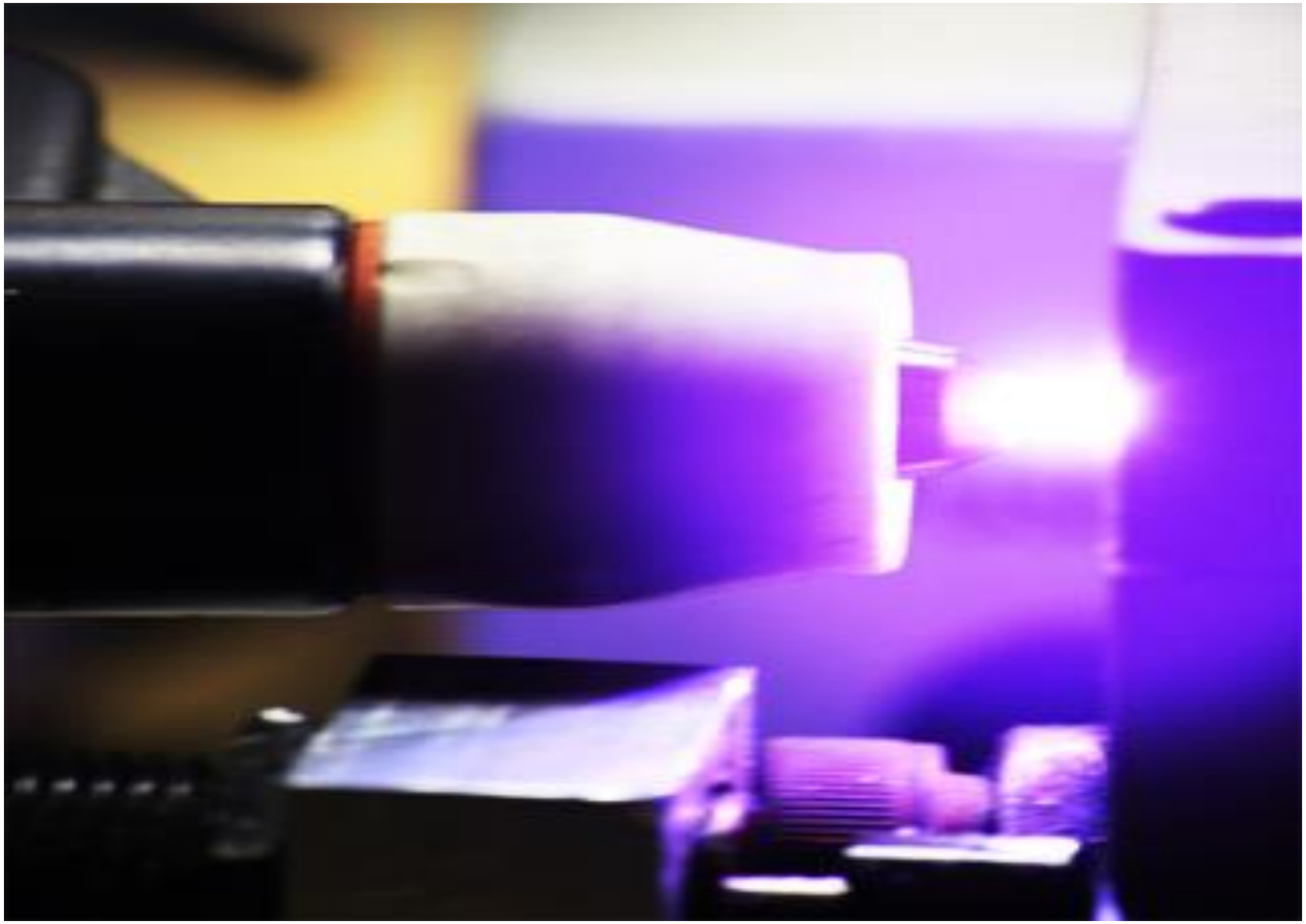

Radio-frequency (RF) discharge
–
+
Coil
Insulating tube wall
Plasma discharge
Glow discharge

For cold plasma methods, their economic potential was evaluated in a recent Market Research Report, predicting a commercial volume of 2.91 billion USD by 2021.



The US currently dominates about 50% of the global semiconductor market.

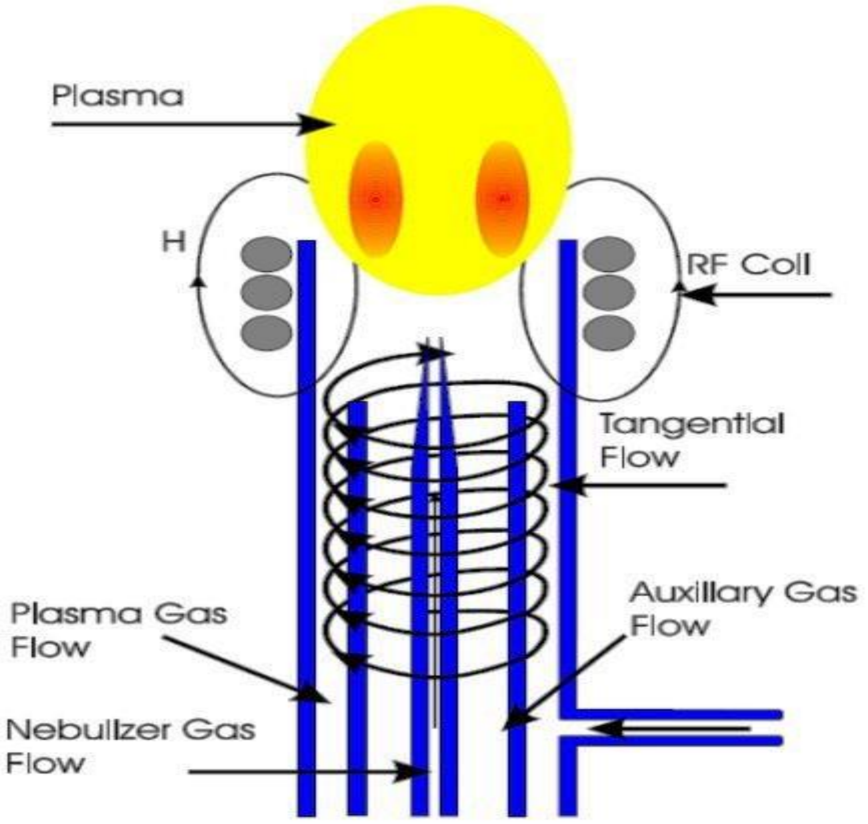
In 2015 the global market for welding products reached 23 billion USD and is expected to exceed 31 billion USD in 2021.

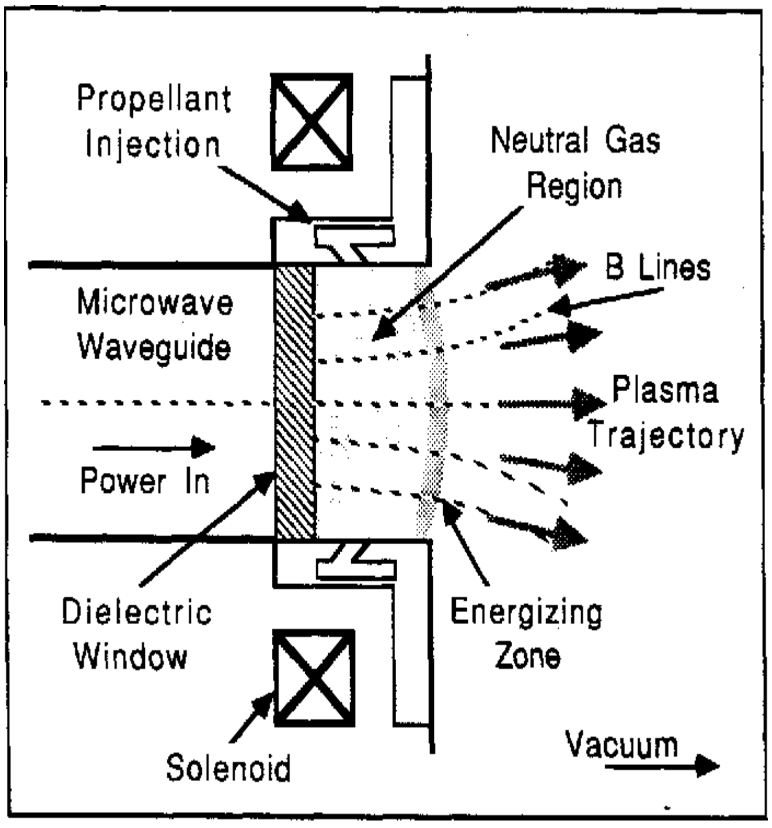


Challenges of Plasma Physics

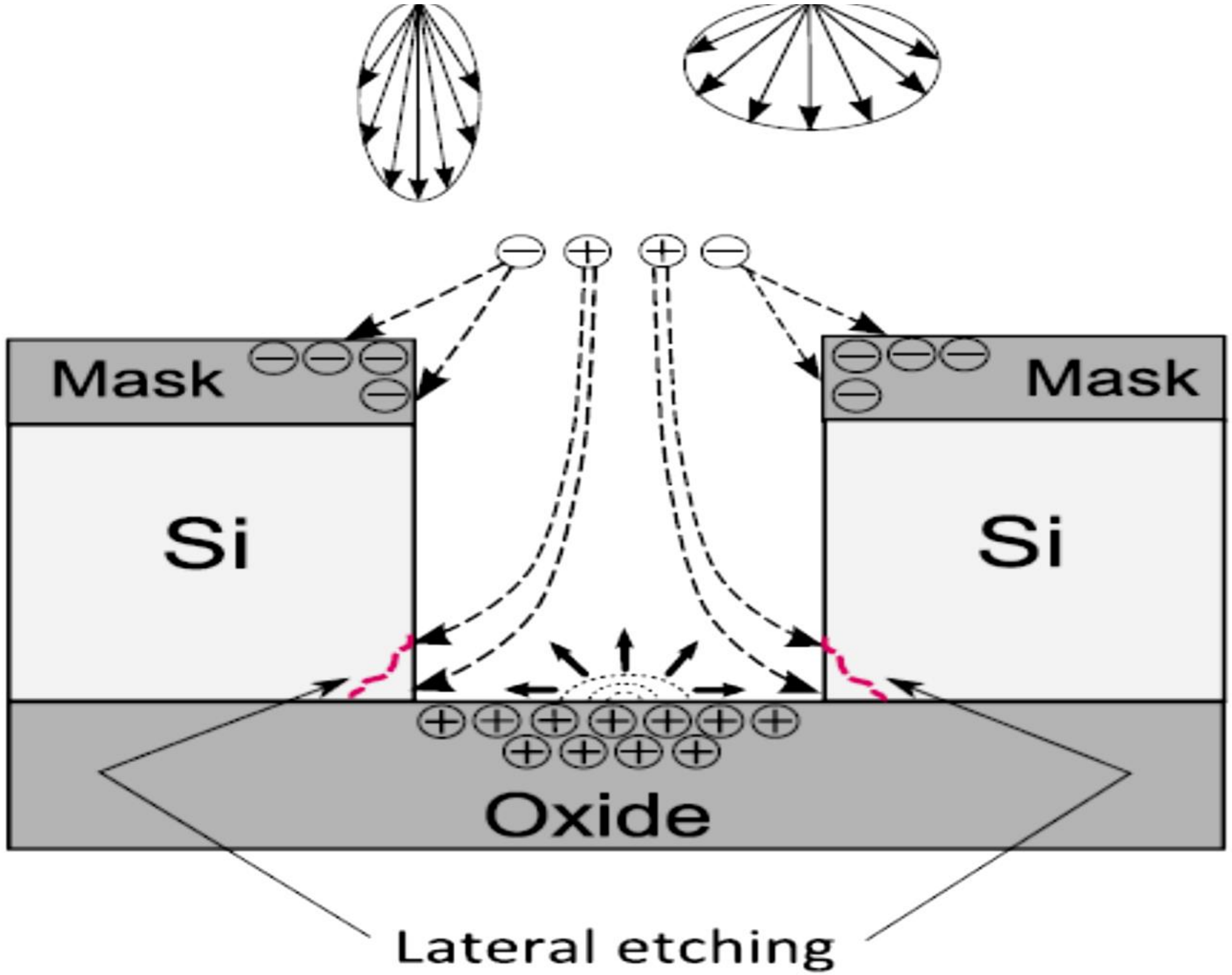
Plasma-etching

For nanosized sample High-density plasma sources, such as inductively coupled plasma (ICP) and electron-cyclotron resonance (ECR) plasma.





charge build-up and UV photon radiation



The defect generation due to charge build-up and UV photons were found to occur at a time constant of 10^{-3} s during plasma etchings.

In the future we can use tens-of-microsecond pulse-time modulated plasma etching and neutral-beam etching processes have been proposed.

However, there is UV radiation and the rate of etching is law.

Pumping process of semiconductors

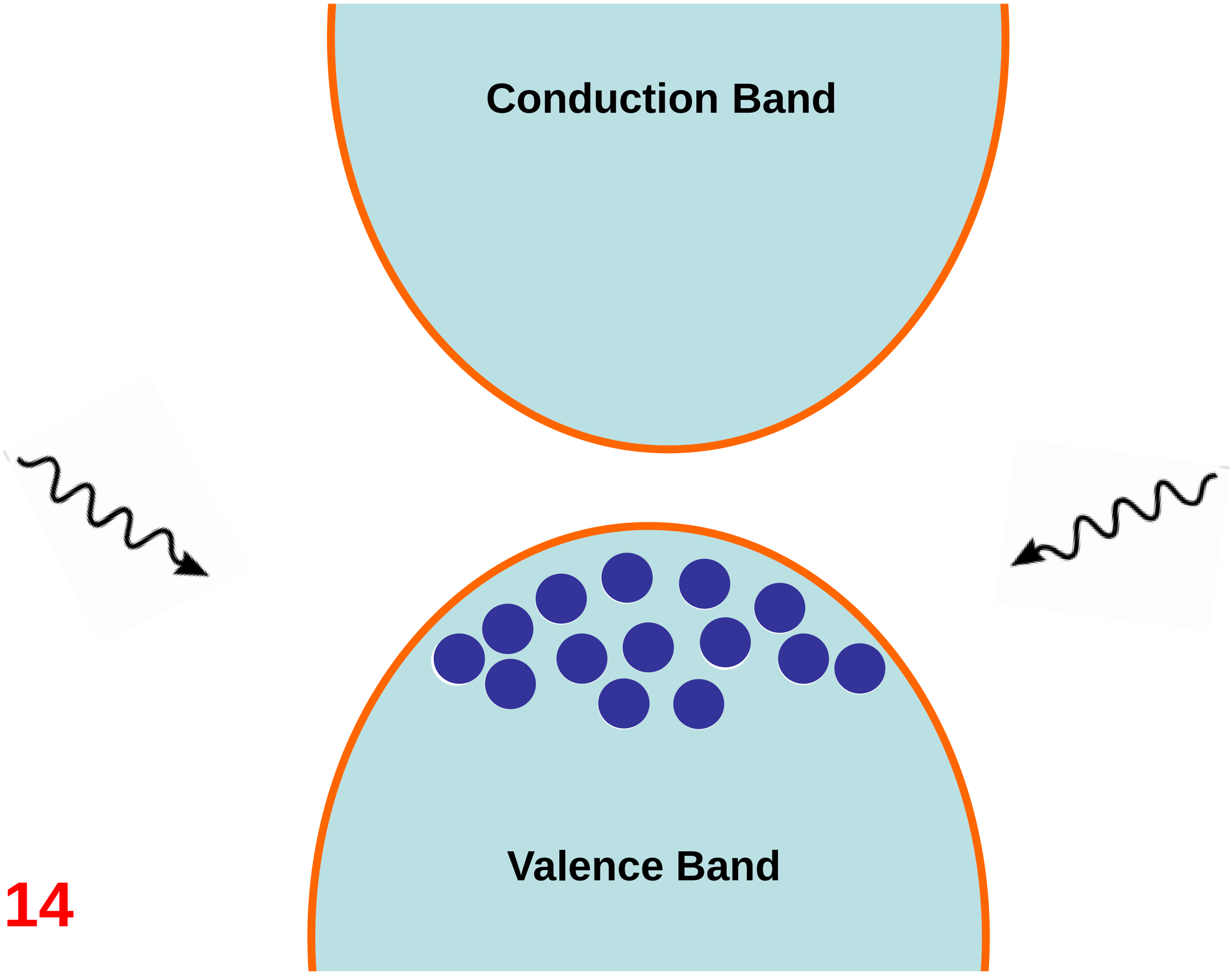


Fig. 14

5- W.T. Silfvast, Laser Fundamentals, Cambridge University Press, (USA), 2004.

Ultrasonics 56 (2015) 36–51

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Nonlinear ultrafast acoustics at the nano scale

P.J.S. van Capel [a,*], E. Péronne [b,c], J.I. Dijkhuis [a]

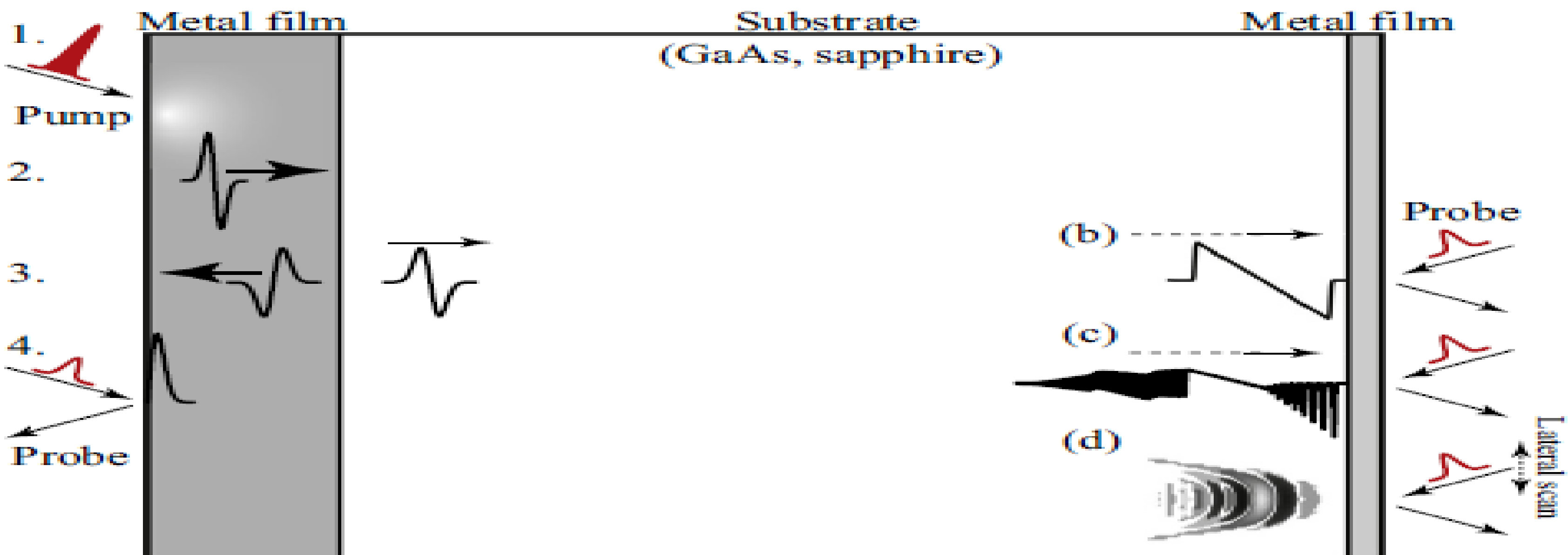

Fig. 11

Nuclear Instruments and Methods in Physics Research B xxx (2017) xxx–xxx

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Electrical characterization of defects induced by electron beam exposure in low doped *n*-GaAs

S.M. Tunhuma *, F.D. Auret, J.M. Nel, E. Omotoso, H.T. Danga, E. Igumbor, M. Diale

Department of Physics, University of Pretoria, Private Bag X20, Pretoria 0002, South Africa

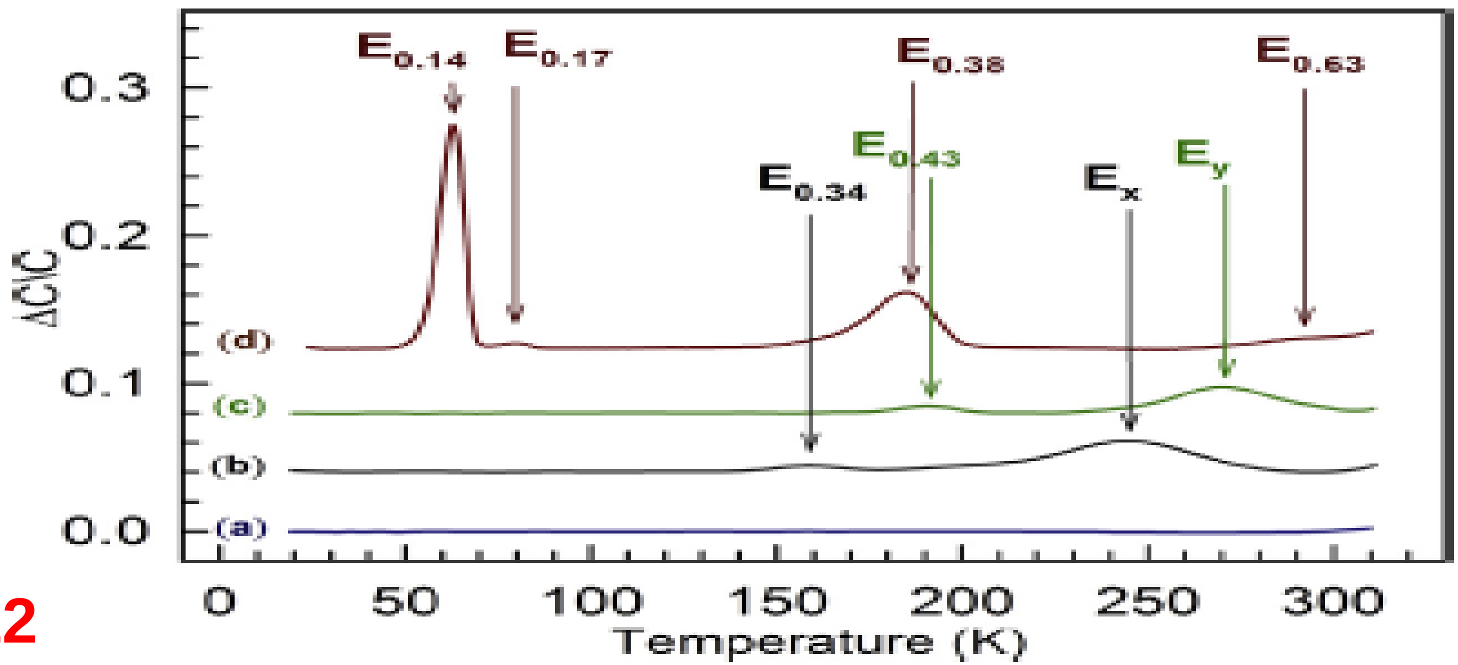


Fig. 12

Special tips and tricks

1- The quantum fluid model had a limit chance in order to employed in electron/hole plasma owing to the electron/hole lifetime should be greater than the plasma oscillation time.

$$T_{\mathrm{osc}} \sim 2\pi/\omega_{\mathrm{osc}} \qquad \tau_{\mathrm{rec}} \sim 1\ \mathrm{ps}$$

$$\tau_{\mathrm{rec}} << T_{\mathrm{osc}}$$

V. NUMERICAL SIMULATIONS AND DISCUSSION

We now present numerical results. Here, the plasma model is that of semiconductor plasmas. Therefore, we apply our results to four cases of semiconductors: (1) GaAs with typical parameters[37,38,43] $n_0 = 4.7 \times 10^{16}\ \mathrm{cm}^{-3}$, $m_e^* = 0.067 m_e$ g, $m_h^* = 0.5 m_e$ g, and $\epsilon = 12.8$, (2) GaSb with typical parameters,[39,40,43] $n_0 = 1.6 \times 10^{17}\ \mathrm{cm}^{-3}$, $m_e^* = 0.047 m_e$ g, $m_h^* = 0.4 m_e$ g, and $\epsilon = 15.69$, $\epsilon = 11.3$, (3) GaN with typical parameters,[41–43] $n_0 = 10^{17} - 10^{20}\ \mathrm{cm}^{-3}$, $m_e^* = 0.13 m_e$ g, $m_h^* = 1.3 m_e$ g, and $\epsilon = 11.3$, (4) InP with typical parameters,[41–43] $n_0 = 5.7 \times 10^{17}\ \mathrm{cm}^{-3}$, $m_e^* = 0.077 m_e$ g, $m_h^* = 0.6 m_e$ g, and $\epsilon = 12.6$.

$Ne = 10^{16}$

$W_{pe} = 1.3 \times 10^{-10}$

$Ne = 10^{17}$

$W_{pe} = 4 \times 10^{-11}$

$Ne = 10^{20}$

$W_{pe} = 1.3 \times 10^{-12}$

Quantum Fluid Equations

For electrons

$$\frac{\partial n_e}{\partial t} + \frac{\partial}{\partial x}(n_e u_e) = 0, \qquad \textbf{(5)}$$

$$\frac{\partial u_e}{\partial t} + u_e \frac{\partial u_e}{\partial x} - \frac{\partial \varphi}{\partial x} + \frac{\partial V_{xce}}{\partial x} + \beta n_e \frac{\partial n_e}{\partial x} + \frac{1}{3} H_e^2 \frac{\partial}{\partial x} \frac{\frac{\partial^2 \sqrt{n_e}}{\partial x^2}}{\sqrt{n_e}} = 0, \qquad \textbf{(6)}$$

For holes

$$\frac{\partial n_h}{\partial t} + \frac{\partial}{\partial x}(n_h u_h) = 0, \qquad \textbf{(7)}$$

$$\frac{\partial u_h}{\partial t} + u_h \frac{\partial u_h}{\partial x} + M \frac{\partial \varphi}{\partial x} + M \frac{\partial V_{xch}}{\partial x} + \beta n_h \frac{\partial n_h}{\partial x} + \frac{1}{3} H_h^2 \frac{\partial}{\partial x} \frac{\frac{\partial^2 \sqrt{n_h}}{\partial x^2}}{\sqrt{n_h}} = 0; \qquad \textbf{(8)}$$

For electron beam

$$\frac{\partial n_b}{\partial t} + \frac{\partial}{\partial x}(n_b u_b) = 0, \qquad \textbf{(9)}$$

$$\frac{\partial u_b}{\partial t} + u_b \frac{\partial u_b}{\partial x} - \mu \frac{\partial \varphi}{\partial x} + \mu \beta n_b \frac{\partial n_b}{\partial x} = 0. \qquad \textbf{(10)}$$

Poisson's Equation

$$\frac{\partial^2 \varphi}{\partial x^2} = n_e + \nu n_b - \rho n_h. \qquad \textbf{(11)}$$

Technique

Exac
t

Perturbation Techniques

Numerical Solution

Stretching

$$\xi = \varepsilon^{1/2}(x - \lambda t) \quad \text{and} \quad \tau = \varepsilon^{3/2} t, \quad (12)$$

Expansion

$$\begin{pmatrix} n_e \\ u_e \\ n_h \\ u_h \\ \varphi \\ n_b \\ u_b \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 1 \\ 0 \\ 0 \\ 1 \\ u_{b0} \end{pmatrix} + \varepsilon \begin{pmatrix} n_{e1} \\ u_{e1} \\ n_{h1} \\ u_{h1} \\ \varphi_1 \\ n_{b1} \\ u_{b1} \end{pmatrix} + \varepsilon^2 \begin{pmatrix} n_{e2} \\ u_{e2} \\ n_{h2} \\ u_{h2} \\ \varphi_2 \\ n_{b2} \\ u_{b2} \end{pmatrix} + \varepsilon^3 \begin{pmatrix} n_{e3} \\ u_{e3} \\ n_{h3} \\ u_{h3} \\ \varphi_3 \\ n_{b3} \\ u_{b3} \end{pmatrix} + \ldots. \quad (13)$$

8- H. Leblond, J. Phys. B: At. Mol. Opt. Phys. 043001, 41 (2008).

K-dV Equation

$$\frac{\partial}{\partial \tau}\varphi_1 + AB\varphi_1 \frac{\partial}{\partial \xi}\varphi_1 + AD\frac{\partial^3}{\partial \xi^3}\varphi_1 = 0, \quad \textbf{(14)}$$

Non-linear term

Dispersion term

Soliton solution

$$\varphi_1 = \varphi_0 \; sech^2\left(\frac{X}{w_1}\right), \quad \textbf{(15)}$$

$$X = \xi - U\tau \qquad w_1 = \left(\frac{4AD}{U}\right)^{\frac{1}{2}} \qquad \varphi_0 = \frac{3U}{AB}$$

Travelling parameter

Width

Amplitude

Soliton Wave

Movie. 3

Shock-Like Wave

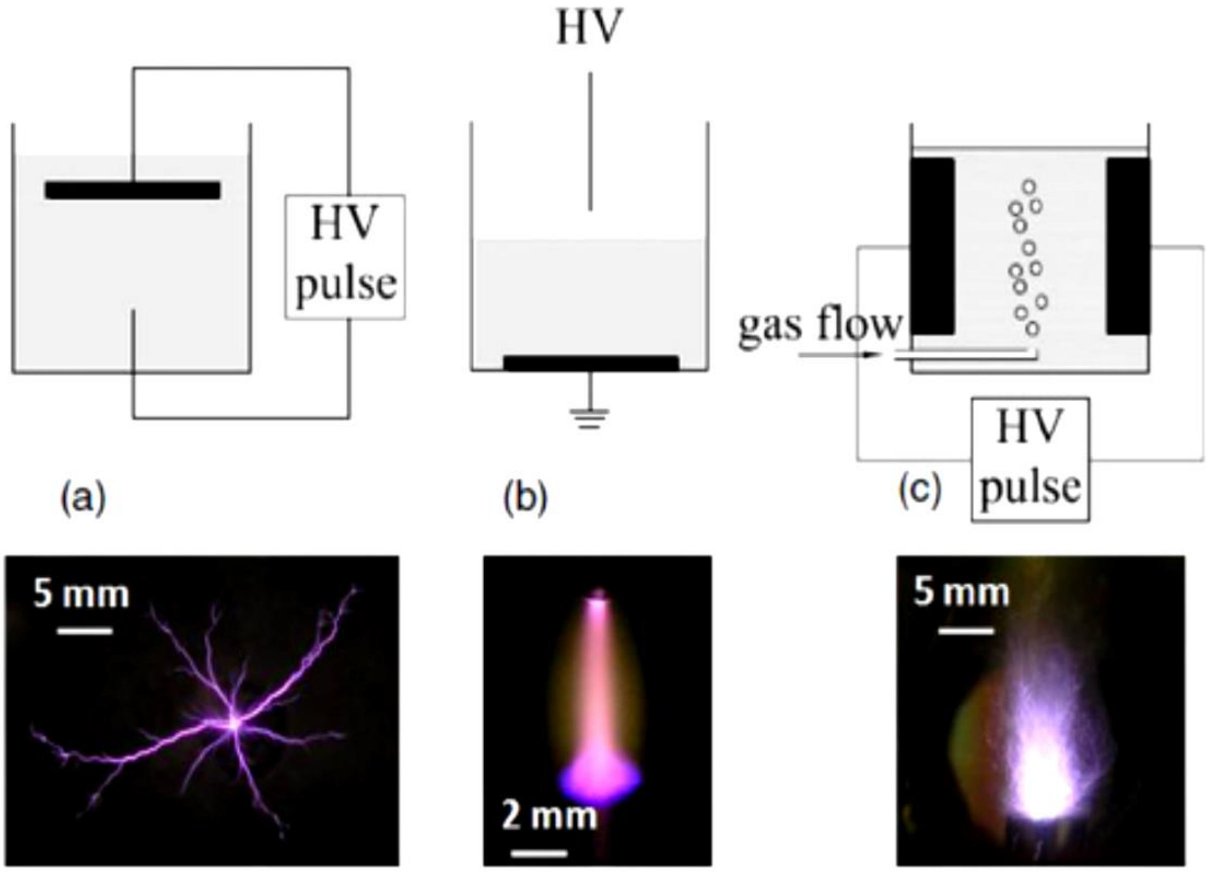
Movie. 4

Rogue Wave

Movie. 5

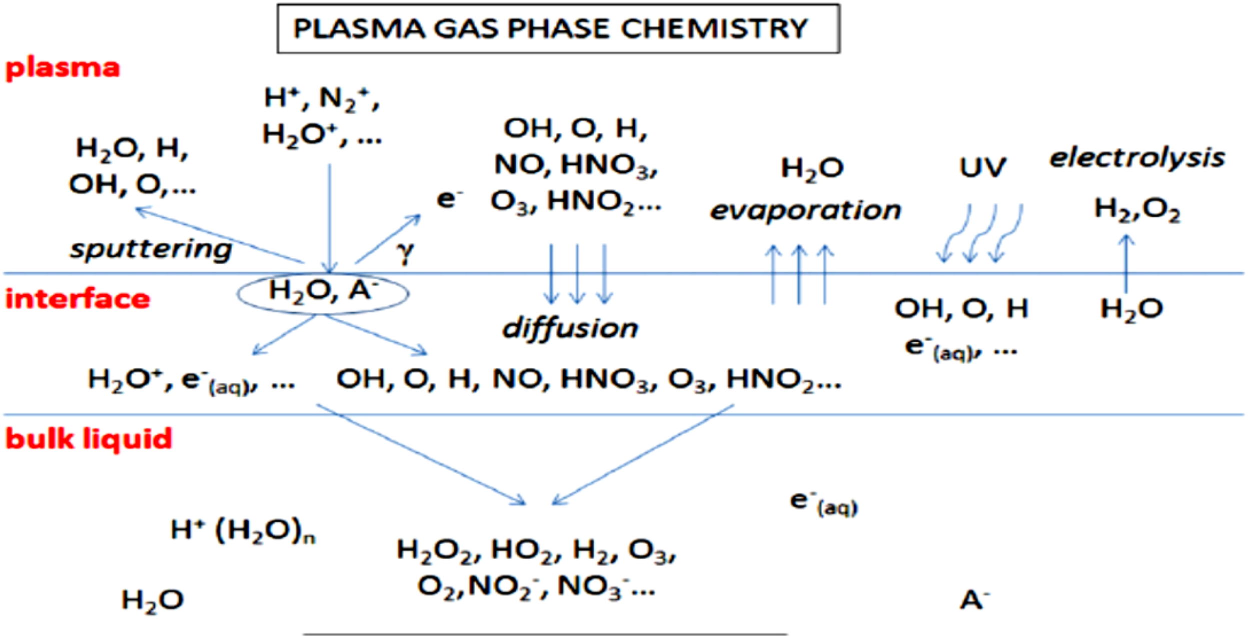
Plasma-Liquid Interaction

Biological, Chemical, Material and Environmental Applications.

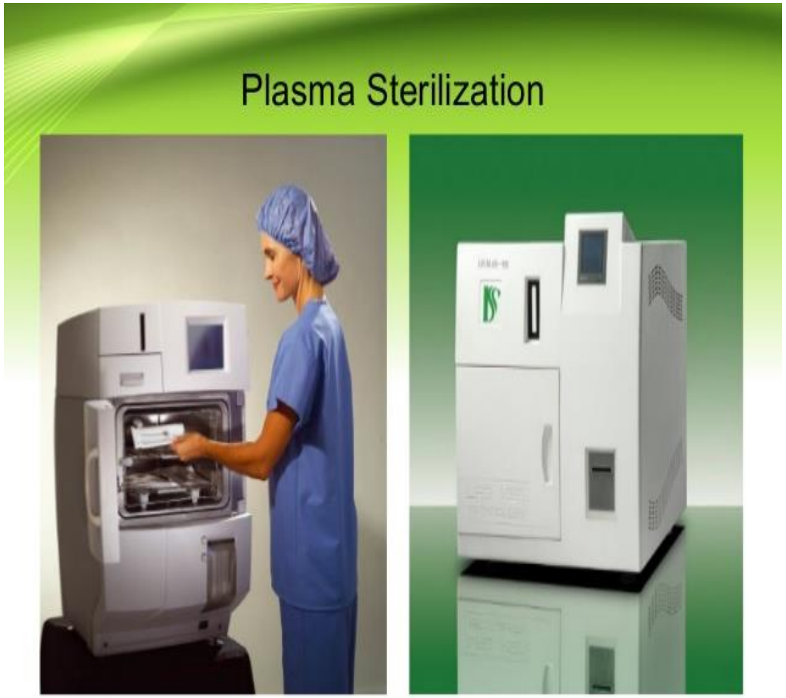


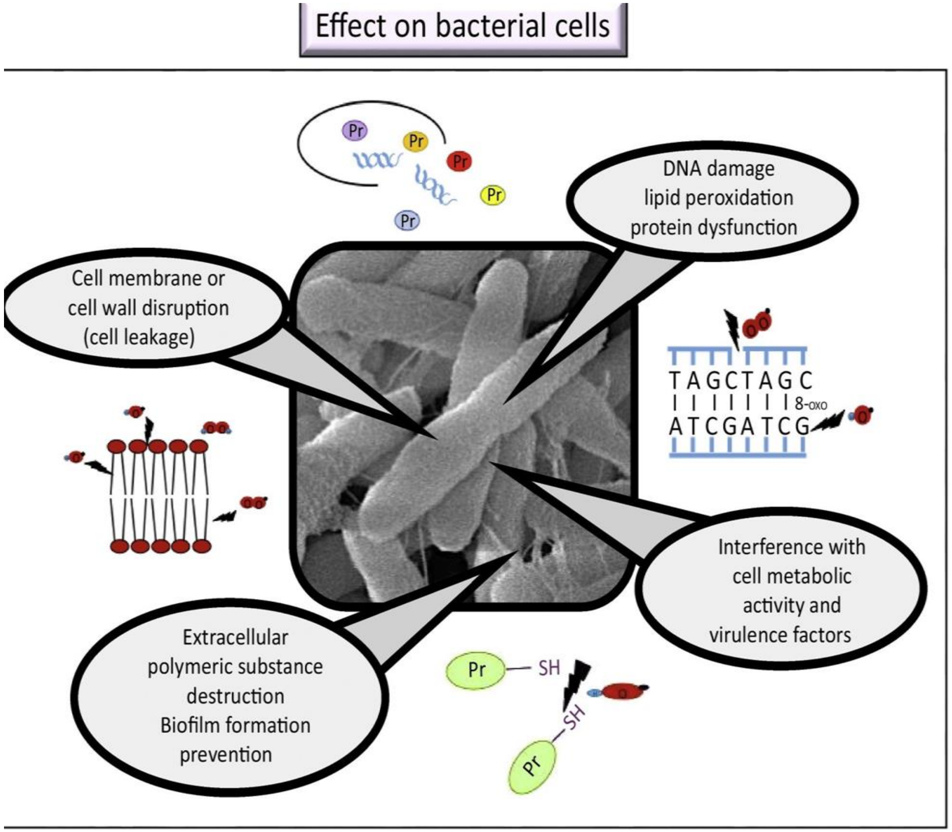
- The first challenge deals with the breakdown processes and mechanisms in liquids.

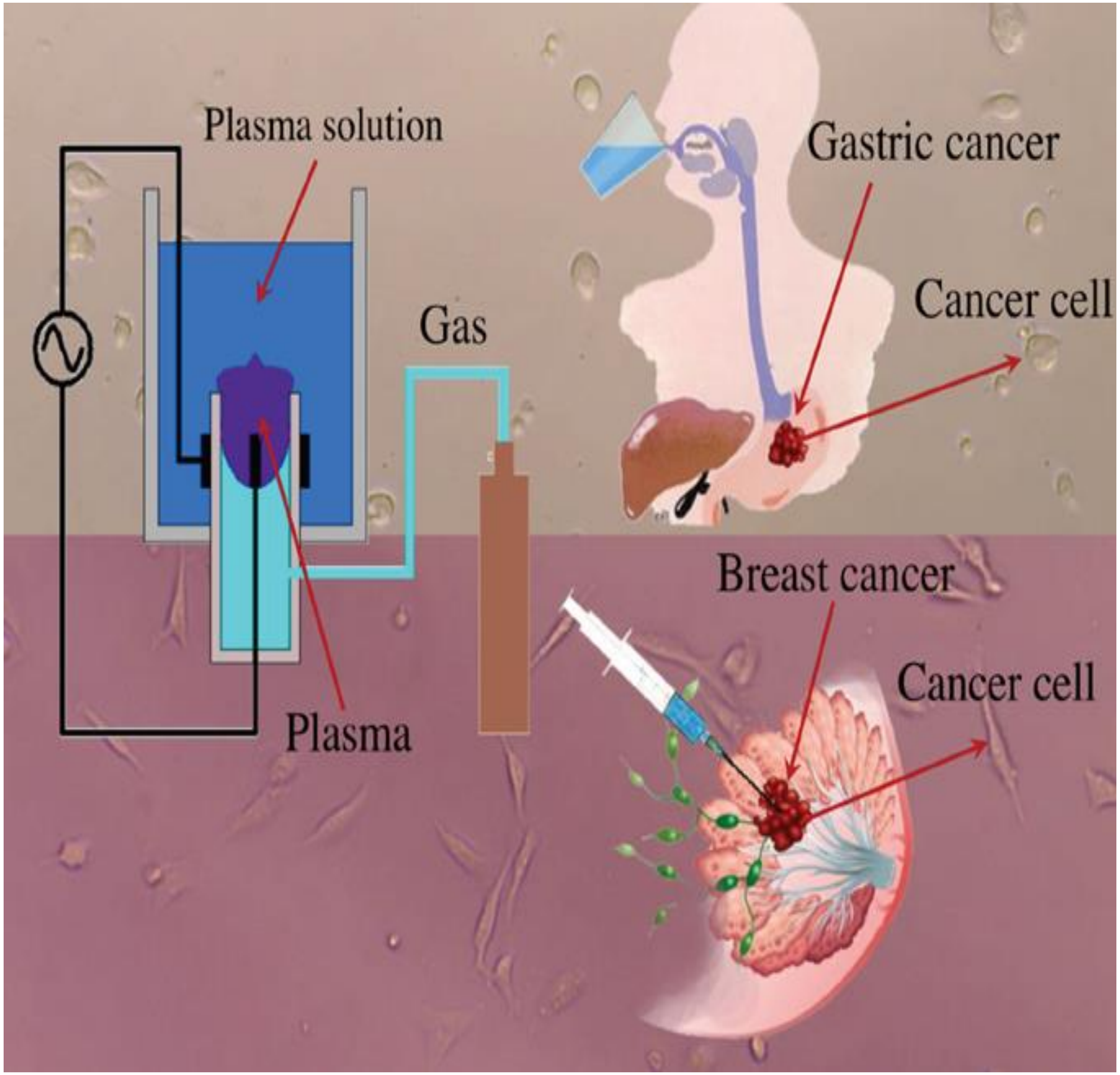
- The second main challenge is the understanding of the physical and chemical processes occurring at the plasma– liquid interface.



Plasma Medicine






Plasma solution
Gas
Plasma
Gastric cancer
Cancer cell
Breast cancer
Cancer cell


AD-TEC

- **What are the fluxes and energies of the various species that the plasma delivers to the cells and tissues?**

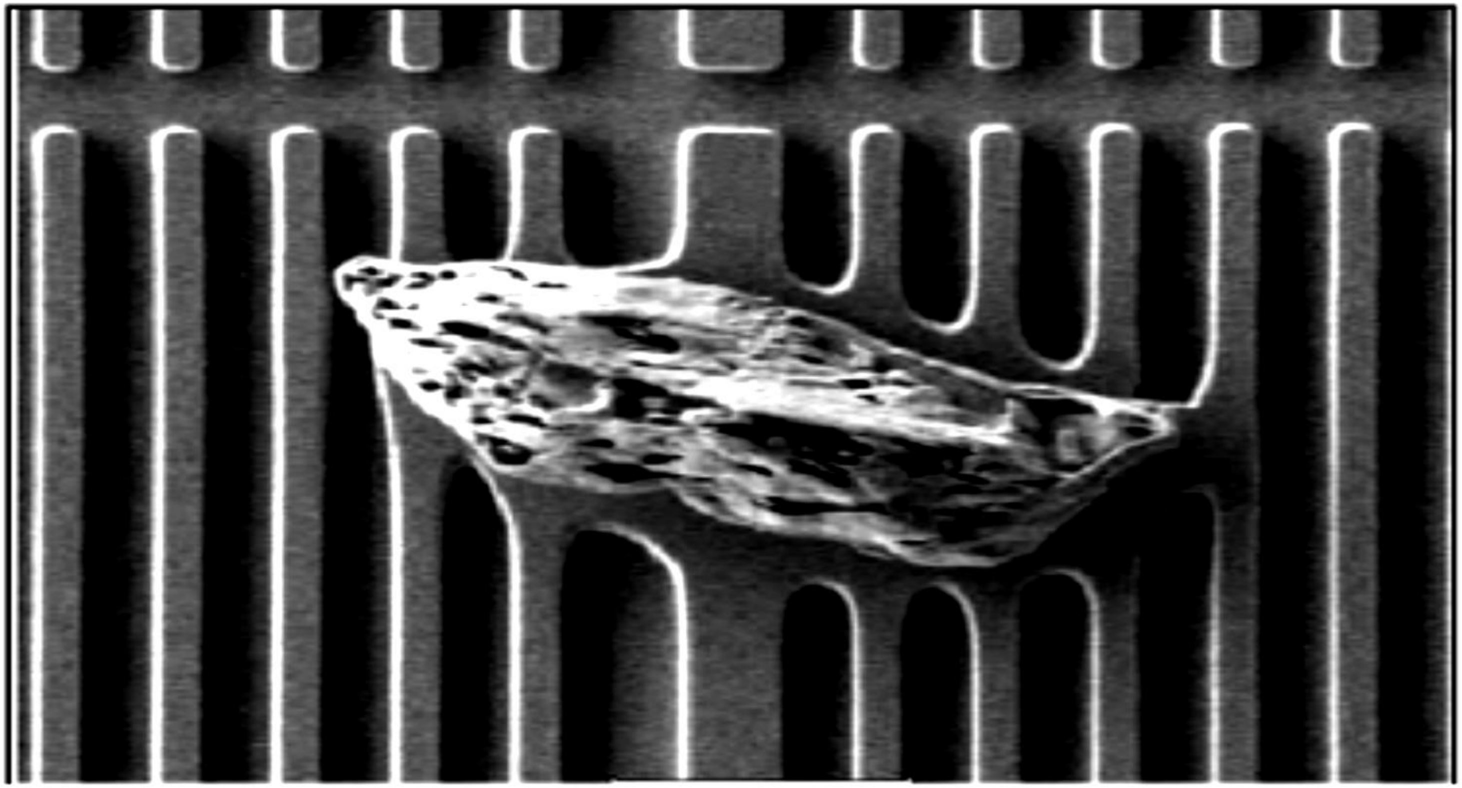
- **How do human tissues and human beings react when subjected to plasma treatment?**

(Micro)biology and medicine

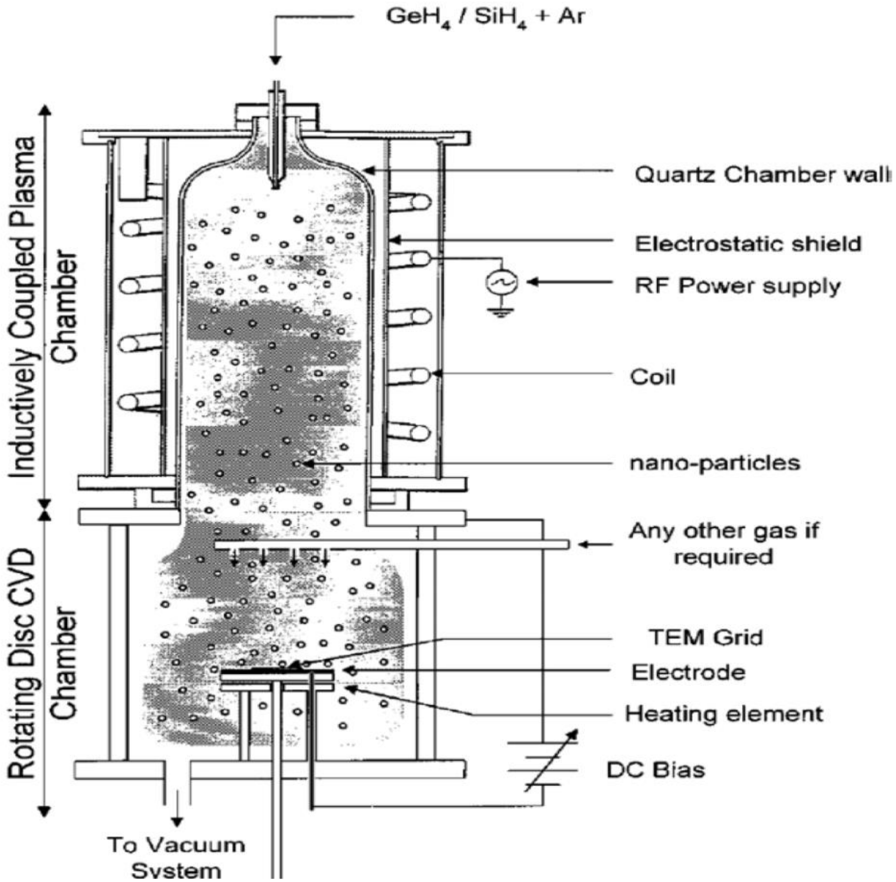
- **How do bacteria and their signalling, spores, fungi and prions behave under plasma exposure?**
- **How do animal or human cells behave under plasma exposure? How cytotoxic is the plasma?**
- **How do human tissues and human beings react when subjected to plasma treatment?**

Dust Plasma

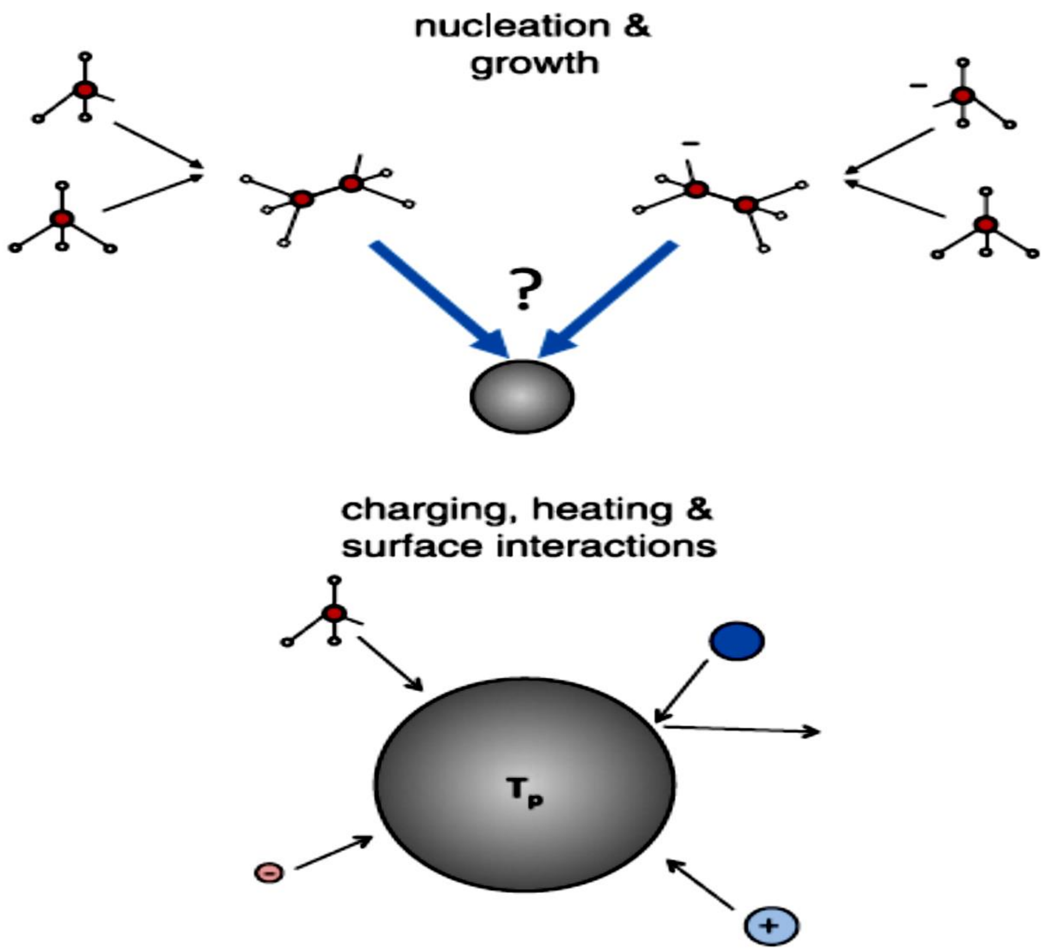
It was initially viewed as a contamination problem in semiconductor processing.



Using plasmas as sources of new nanomaterials.



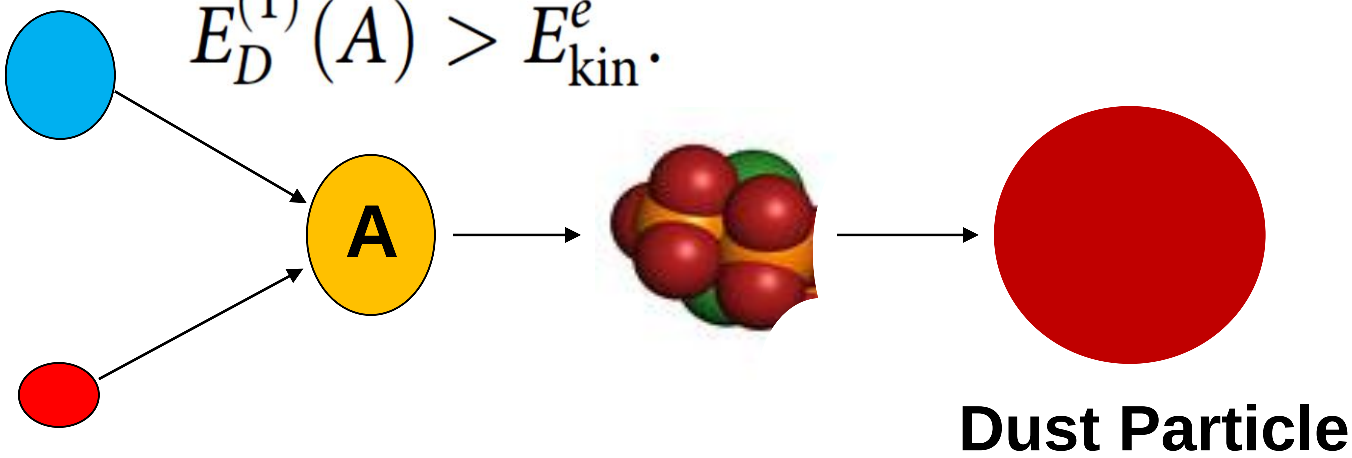
Challenges in understanding nanodusty plasmas: nucleation, growth, charging, heating and surface interactions.



4- The concept of quantum dusty plasma

objects as white dwarf stars and the outer envelope of neutron stars, as well as metals and micro- and nanoelectromechanical devices.

$$E_D^{(1)}(A) > E_{\mathrm{kin}}^e .$$



$$E_D^{(N_A)}(A) \sim 1 \ldots 5\,\mathrm{eV} \ \ (\text{where } N_A \geq 100),$$

$$T_e \sim 11\,500\text{–}60\,000\,\mathrm{K}, \qquad T_m \lesssim 5000\,\mathrm{K}$$

$$E_D^{(1)}(A) > \frac{3}{5} E_{Fe}.$$

The heat flux to the grain surface due to energy deposition of collected ions and electrons and their recombination. ⟺ The energy loss flux due to radiation.

$$T_s > \left(n_e T_e^{3/2} + T_e^4 \right)^{1/4}$$

$$n_e \gtrsim 10^{23}\ \mathrm{cm}^{-3}$$

$$T_s > 10^5\ \mathrm{K}$$

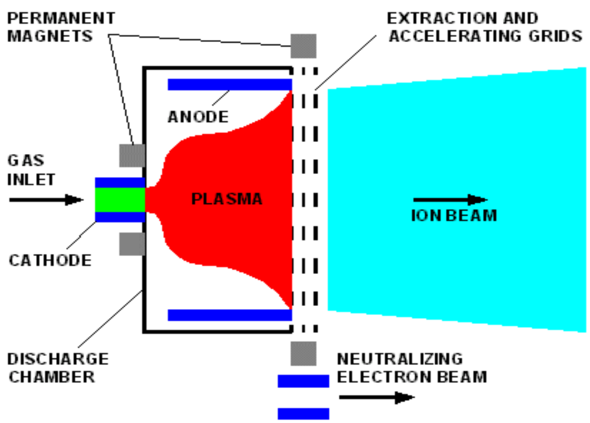
Sputtering of the dust material.

Plasma Thrusters

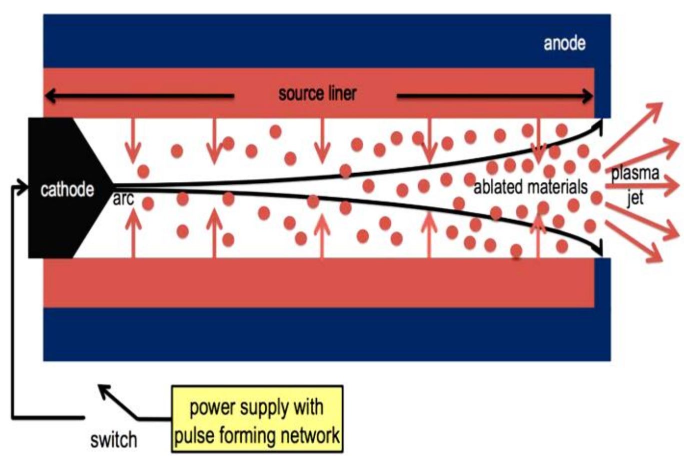
i) **Electro static propulsion** uses a high voltage electrostatic field to accelerate ions to large velocities.

ii) **Electro thermal propulsion** relies on thermal heating of the wall of the tube increasing the exhaust velocity.

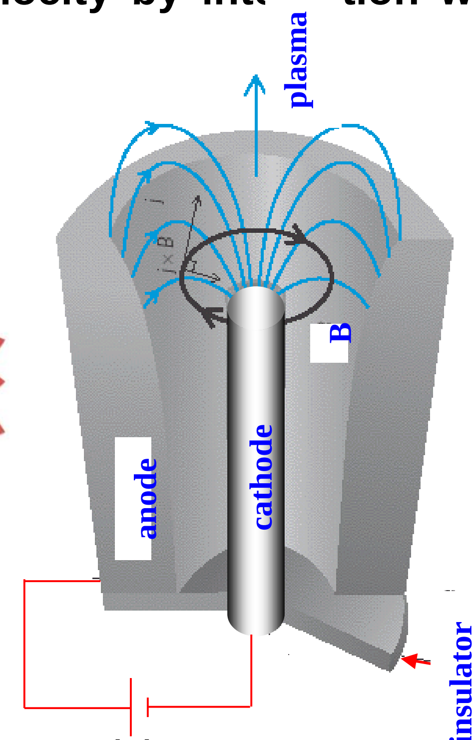
iii) **Electro magnetic propulsion** is accelerated to exhaust velocity by inte tion with electromagnetic fields .



(a)



(b)



(c)

(1) Performance improvement: efficiency, lifetime and cost effectiveness.

(2) Design of more versatile thrusters, i.e. able to operate at different combinations of thrust/propellant velocity.

(3) Extension of domain of operation to lower power (μN to 10mN thrust range) for micro-satellites or very precise attitude control.

(4) Extension to higher power for orbit raising of telecommunication satellites (several tens of kW) and interplanetary missions (100kW and more).

Solar Wind

the Solar wind originates from the Solar Corona, expands into the universe and impacts the Earth' magnetosphere and ionosphere, the two plasma layers surrounding Earth's gaseous atmosphere.

Solar energetic particle events are important, as they can arise suddenly and lead to space weather conditions near Earth that can be potentially harmful to astronauts. Unraveling the sources, acceleration and transport of solar energetic particles will help us better protect humans in space in the future.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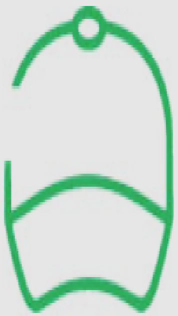

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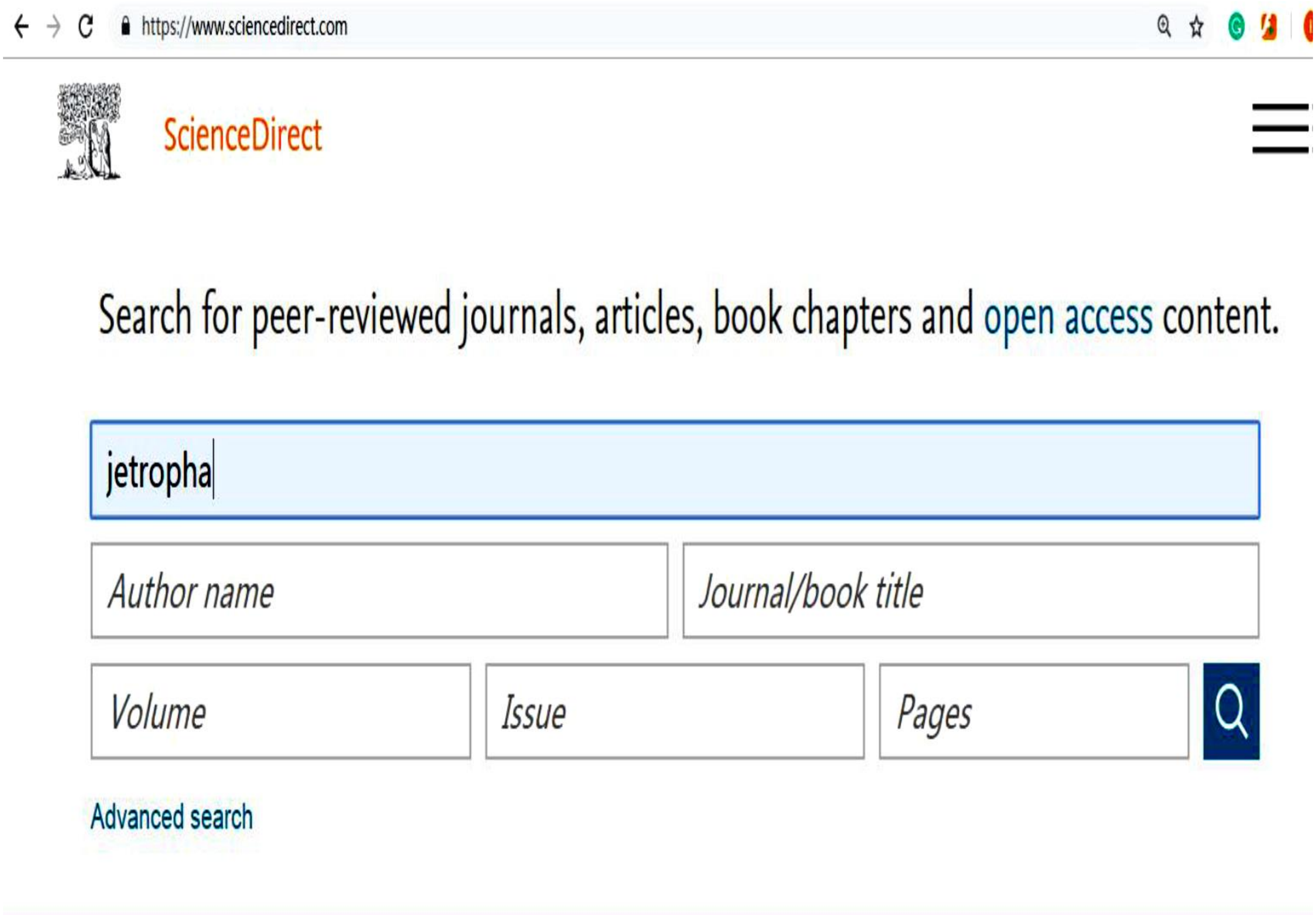
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Process Safety and Environmental Protection, Volume 111, October 2017, Pages 283-291

Yuvarajan Devarajan, Dinesh Babu Munuswamy, Arulprakasajothi Mahalingam

Research article ○ Abstract only

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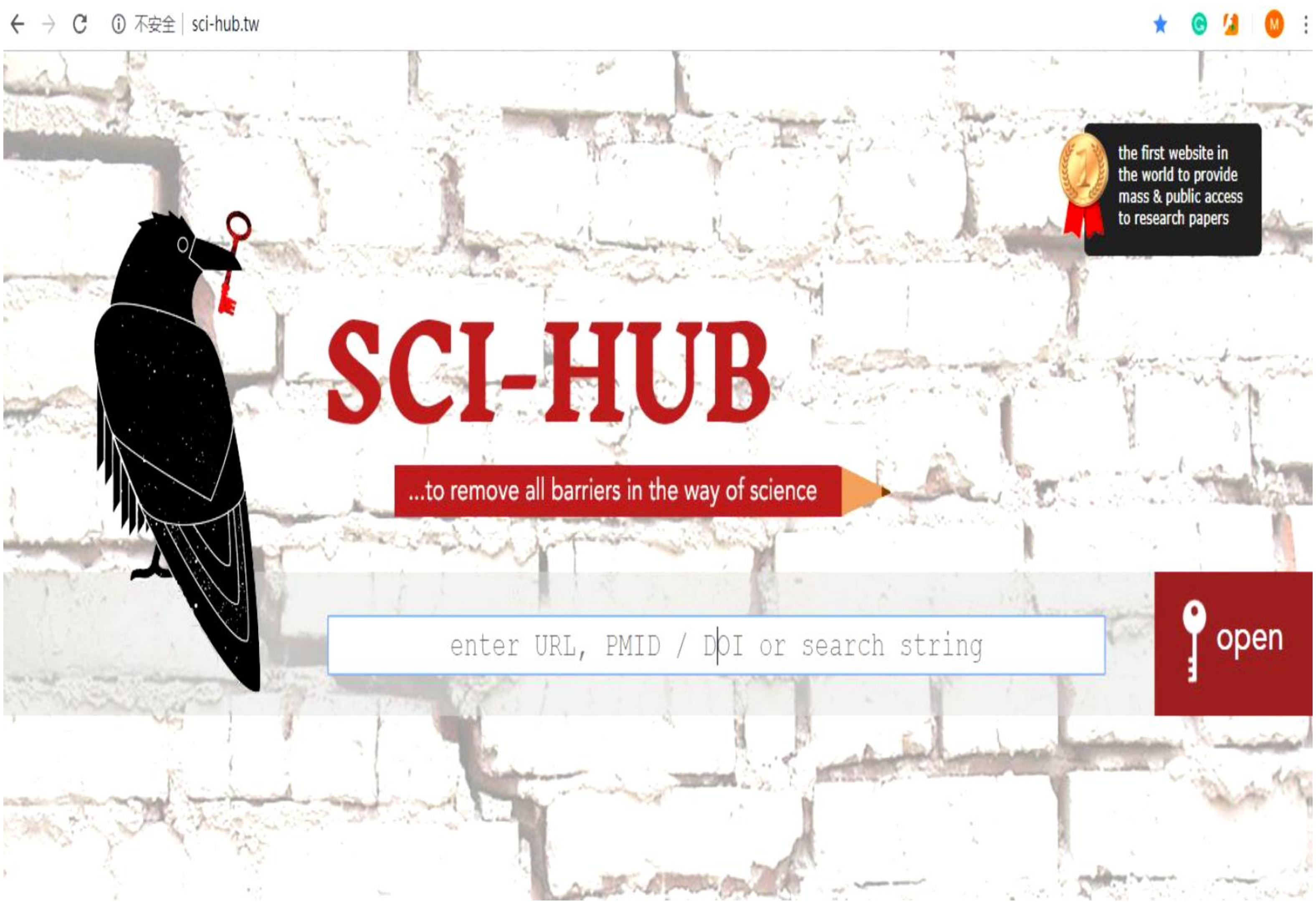
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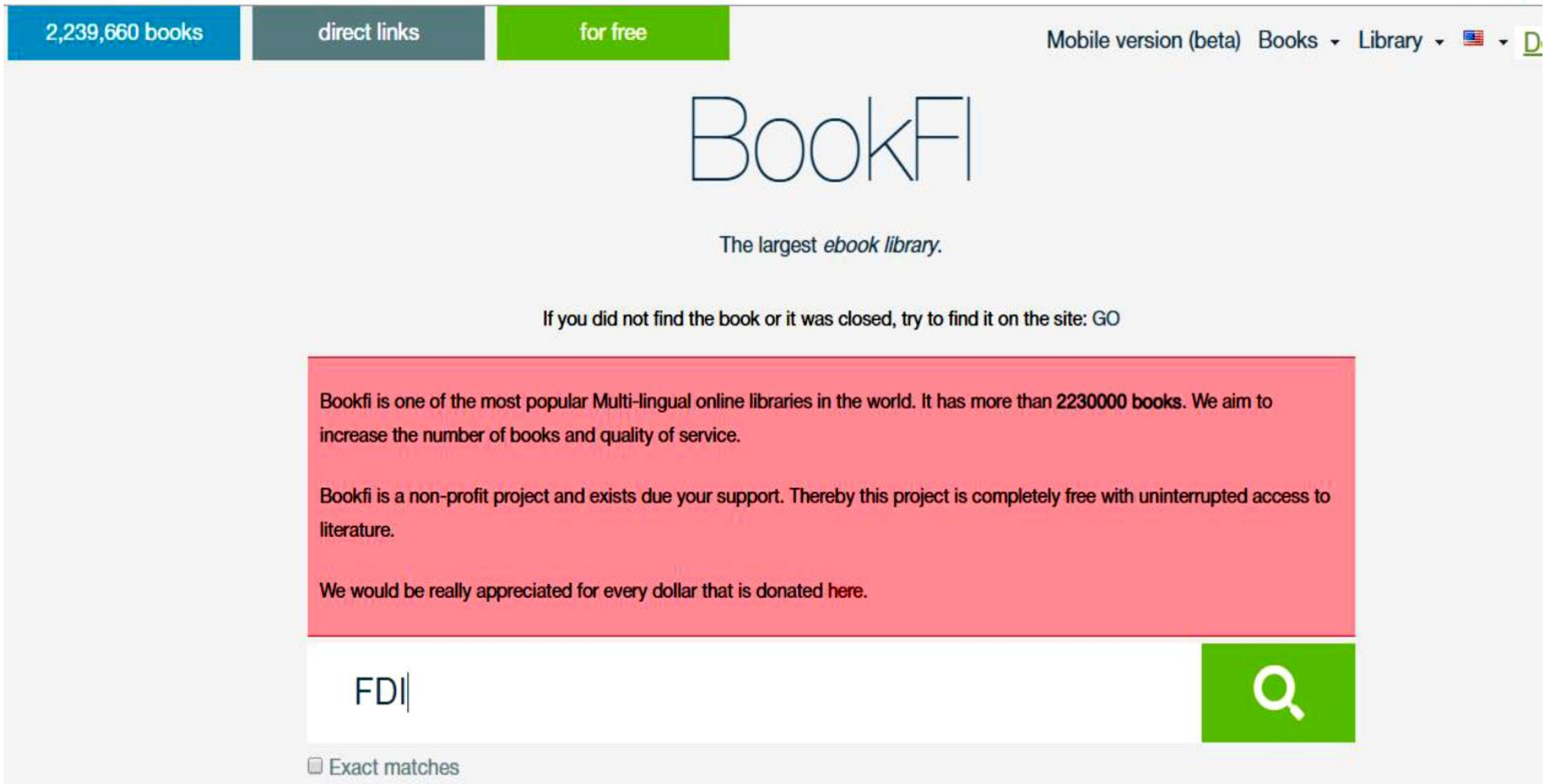
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