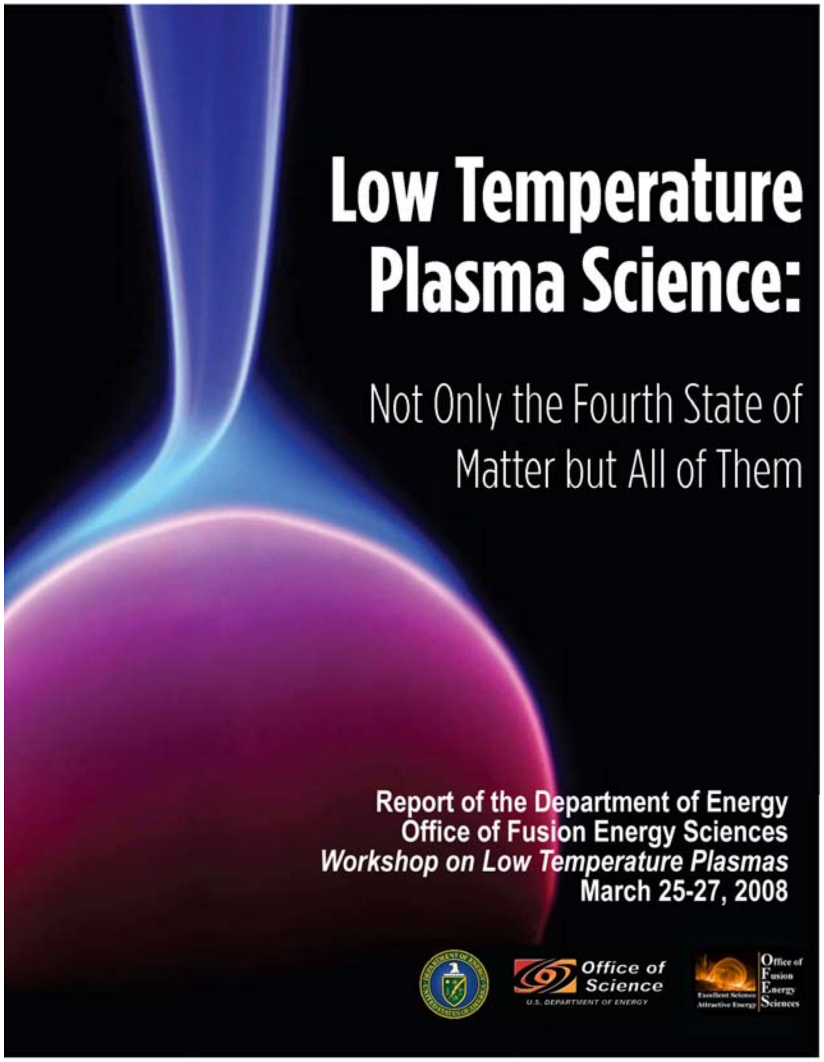

OVERVIEW OF THE LOW TEMPERATURE PLASMA SCIENCE WORKSHOP: LTPS PRIORITIES AND DIRECTIONS

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October 2008

AGENDA

- Background: Plasma 2010 Decadal Study
  - Plasma 2010 Recommendations-LTPSE Focus
  - Low Temperature Plasma Science Conclusions and Recommendations
- Low Temperature Plasma Science Workshop
  - Charge from OFES
  - Organization
  - Research Challenges and Priorities
- Current Status

DECADAL STUDY: PLASMA 2010

- In 2005, National Academies convened the *Plasma 2010 Committee* as part of the decadal survey of physics. The tasking was:
  - Assess the progress and achievements of plasma science over the past decade.
  - Identify new opportunities and compelling science questions, framing the future outlook, and place the field in the context of physics as a whole.
  - Evaluate the opportunities and challenges for applications of plasma science to fusion and other fields.
  - Offer guidance to government programs and scientific communities for addressing these challenges and realizing these opportunities.
  - Steven Cowley, University of California, Co-Chair
    John Peoples, Jr., Fermi National Accelerator Laboratory, Co-Chair

PLASMA 2010: REPORT- AREAS

- ***"Plasma Science: Advancing Knowledge in the National Interest"***
  - **Basic Plasma Science**
  - **Space and Astrophysical Plasmas**
  - **Plasma Physics at High Energy Density**
  - **The Plasma Science of Magnetic Fusion**
  - ***Low Temperature Plasma Science and Engineering (LTPSE)***
- **National Academies Press http://www.nap.edu/catalog.php?record_id=11960**

PLASMA 2010: SUMMARY-LTPSE

- **The expanding scope of plasma research is creating an abundance of new scientific opportunities and challenges.**
- **These opportunities will expand the role of plasma science in enhancing economic security and prosperity, energy and environmental security, national security, and scientific knowledge.**
- **To fully realize the opportunities in plasma research, a unified approach is required.**
- **The Department of Energy's (DOE) Office of Science should reorient its programs to incorporate magnetic and inertial fusion energy sciences, basic plasma science, non-mission-driven high-energy density plasma science, and *low-temperature plasma science and engineering.***

EMPHASIS: CUSP OF A NEW ERA-LTPSE

New Regimes

- **Facilities of the next decade (ITER and NIF) will enable investigation of scientific issues in new regimes.**
- **Increasing overlap with other scientific disciplines is driving whole new frontiers**
    - **High-power, short-pulse lasers.**
    - ***Control and manipulation of atoms and molecules connects LTPSE with atomic, molecular, and optical science.***
    - **Biology, healthcare, environmental remediation now realms of plasma science.**

Predictive capability

- **Advances in theory, computations and diagnostics provide new capabilities in understanding, predicting, and controlling the behavior of plasmas.**

WHAT IS AT STAKE?-LTPSE

- **New research directions necessitate an evolution in the structure and portfolios of federal agencies supporting plasma science.**
- **4 research challenges were identified that the current organization of federal plasma science does not optimally exploit .**

1- Discovery-driven high energy density physics

2- Intermediate-scale plasma science

3- Fundamental low-temperature plasma science and engineering

- ***Basic research fuels a plethora of applications from sterilization in healthcare and environmental remediation to surface-coating treatments for high-performance alloys.***

4- Cross-cutting, interdisciplinary research

- ***There are significant opportunities at the interfaces…with allied science fields. (Unclear how a physicist, materials engineer and medical doctor get funded…)***

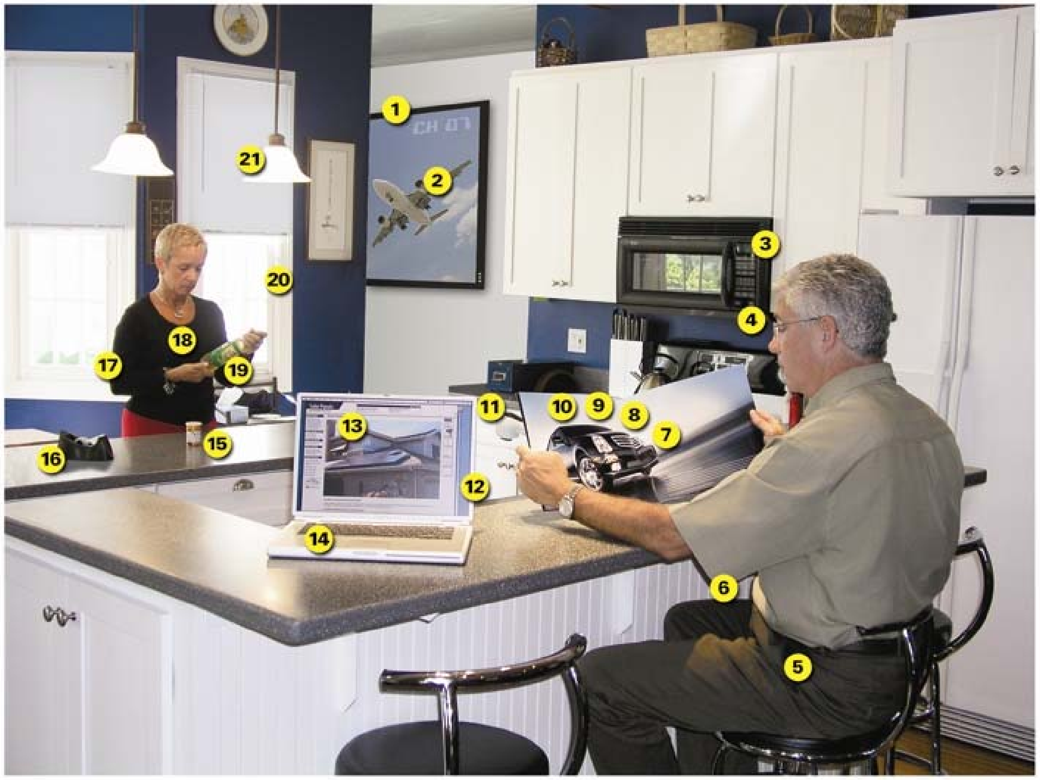
PRINCIPAL RECOMMENDATION I - LTPSE

- **To fully realize opportunities in plasma research across the many sub-fields, a unified approach to funding and coordinating is required.**
- **The Department of Energy's Office of Science should reorient its research programs to incorporate:**
  - **Magnetic and inertial fusion energy sciences**
  - **Basic plasma science**
  - **Non-mission-driven high-energy density plasma science**
  - ***Low-temperature plasma science and engineering***

PRINCIPAL RECOMMENDATION II-LTPSE

- **The new stewardship role for the Office of Science expands well beyond the current mission of the Office of Fusion Energy Sciences.**
- **A broader portfolio of plasma science beyond the fusion centric research OFES currently supports including two-major thrusts.**
  - **Non-mission-driven high-energy density plasma science**
  - ***Low-temperature plasma science and engineering***
- **This stewardship role will not replace nor duplicate programs in other agencies; rather, it would enable a science-based "point of departure" for federal efforts in plasma-based research.**
- **Changes would be more evolutionary than revolutionary, starting modestly and growing with the expanding science opportunities.**

LTPSE: ROBUST SCIENCE, SOCIETAL BENEFIT



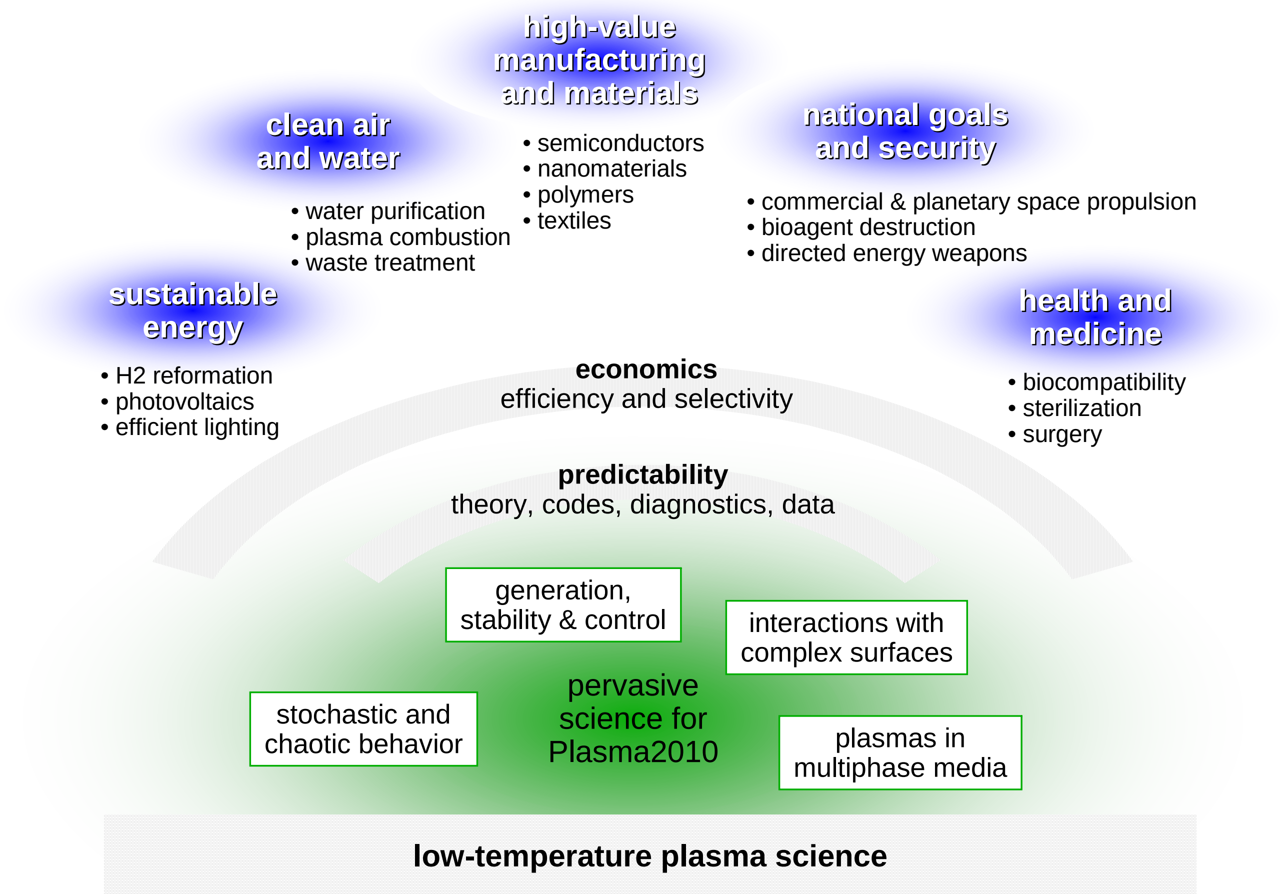
01—Plasma TV
02—Plasma-coated jet turbine blades
03—Plasma-manufactured LEDs in panel
04—Diamondlike plasma CVD eyeglass coating
05—Plasma ion-implanted artificial hip
06—Plasma laser-cut cloth
07—Plasma HID headlamps
08—Plasma-produced H_2 in fuel cell
09—Plasma-aided combustion
10—Plasma muffler
11—Plasma ozone water purification
12—Plasma-deposited LCD screen
13—Plasma-deposited silicon for solar cells
14—Plasma-processed microelectronics
15—Plasma-sterilization in pharmaceutical production
16—Plasma-treated polymers
17—Plasma-treated textiles
18—Plasma-treated heart stent
19—Plasma-deposited diffusion barriers for containers
20—Plasma-sputtered window glazing
21—Compact fluorescent plasma lamp

- **Operating premise:**

  LTPSE has a history and future of robust, interdisciplinary science challenges whose resolution provides immediate and long term societal benefit.

LTPSE: SCIENCE BASED HIERARCHY

- **Societal benefit is built on a science base with the goal of predictability. Challenges are synergistic with other plasma areas.**



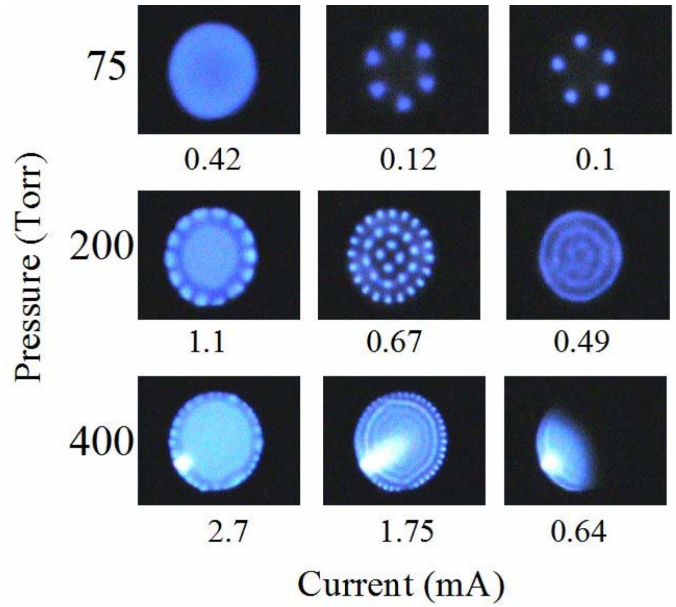
FIELD IS EXTREMELY DIVERSE

- **Diversity of field makes leveraging across science and application areas challenging:**

- ***Size:* From the need for ever larger, stable plasmas (5 m^2 plasmas for LCD television panels) to tiny (100 μm^2) plasmas so intense that the plasma electrons merge with solid electrodes.**
- ***Pressure:* From ever lower pressures used in semiconductor processing equipment (< 1 mTorr) to increasing pressures (>200 atm) for the lamps that power projection displays.**
- ***Chemistry:* From simple rare-gas plasmas used to propel spacecraft to ever more complex chemistries for plasma-augmented combustion and material processing.**

SCIENCE CHALLENGES UNITE FIELD

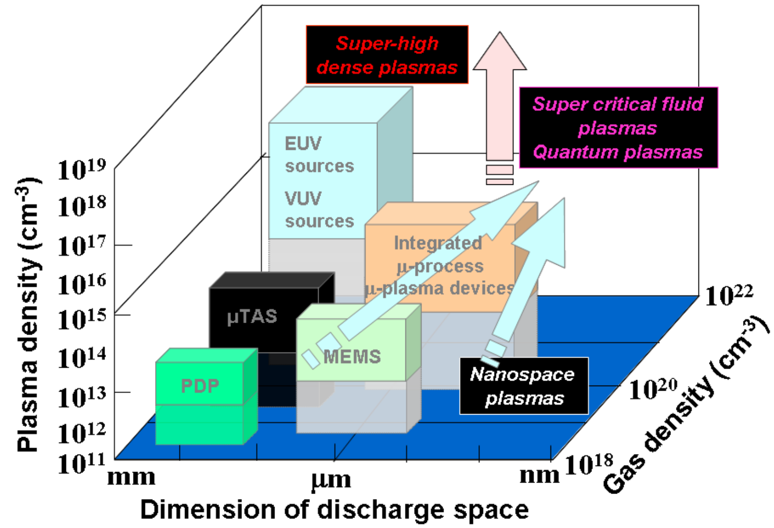
- ***Plasma heating, stability, and control:*** **Connect charged and neutral collisional and collective processes at the atomic level to the behavior of m^2 plasmas.**
- ***Efficiency and selectivity:*** **Quantitatively understand the flow of energy and material.**

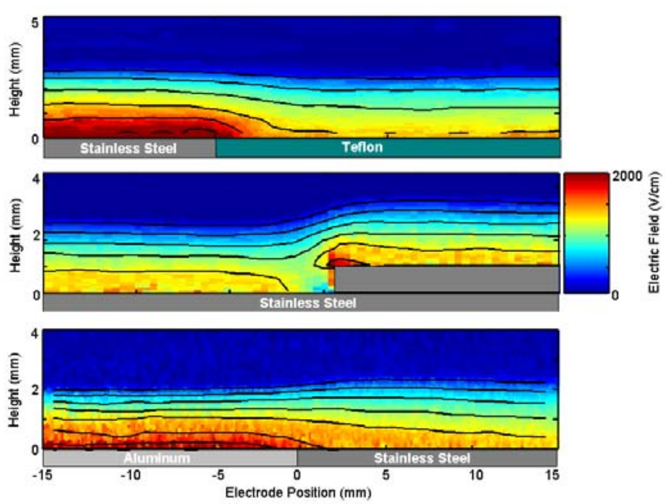


- ***Stochastic, chaotic and collective behavior:*** **Understand and control transitions among the different regimes of behavior**
- ***Plasma interactions with surfaces:*** **Quantify and predict the interactions between reactive plasmas with complex surfaces.**
- ***Diagnostics and models:*** **Develop predictive capability to advance understanding and speed the development of technologies.**

FUTURE SCIENTIFIC OPPORTUNITIES

- **Basic interactions of plasmas with organic materials and living tissue**
- **Methods to describe the behavior of plasmas that contain chaotic and stochastic processes.**
- **Stability criteria for large, uniform, high-pressure plasmas.**





- **Interaction of high-density (micro-) plasmas with surfaces**
- **Flexible, noninvasive diagnostics**
- **Fundamental data**

Plasma 2010: **Low Temperature Plasma Science and Engineering**

KEY RECOMMENDATION-LTPSE

- ***To fully address the scientific opportunities and the intellectual challenges within LTPSE, and so optimally meet economic and national security goals, one federal agency should assume lead responsibility for the health and vitality of this subfield by coordinating an explicitly funded, interagency effort. This coordinating office could appropriately reside within the Department of Energy's Office of Science.***

LOW TEMPERATURE PLASMA SCIENCE WORKSHOP

LOW TEMPERATURE PLASMA WORKSHOP

- **NRC Decadal Study recommends that DOE Office of Science should:**
  - **Assume responsibility for health and vitality of the subfield of low temperature plasma science (LTPS)**
  - **Coordinate an explicitly funded, interagency effort.**
- **To begin implementation, a workshop to identify scientific challenges in LTPS for next decade was commissioned by Dr. Raymond J. Fonck, Associate Director for Fusion Energy Sciences, DOE Office of Science**
- **Workshop held at UCLA 25-27 March 2008**
- **David B. Graves, Mark J. Kushner - co-Chairs**
- **David Goodwin, Michael Crisp – OFES Laisons**
- **Jody Shumpert – ORISE Coordinator**

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CHARGE TO WORKSHOP AND DELIVERABLE

- **Charge for Workshop**
  - **Summarize the status of research in LTPS.**
  - **Identify and communicate outstanding major scientific questions in LTPS.**
  - **Articulate the importance of these questions, both in terms of fundamental science and potential applications.**
  - **Describe basic research activities needed to address these questions.**
  - **Develop a scientific and prioritized roadmap for an initiative in LTPS.**
- **Deliverable:**

  Report to broader scientific community that OFES will use to develop a modest new program in LTPS to be proposed to be part of the *American Competitiveness Initiative.*

WORKSHOP PARTICIPANTS

Igor Adamovich	Ohio State University
Eray Aydil	U of Minnesota
Michael Barnes	Intevac, Inc.
Pascal Chabert	Ecole Polytechnique
Jane Chang	UCLA
Steven Cowley	UCLA
Vincent Donnelly	U of Houston
Demetre Economou	U of Houston
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Alan Garscadden	Wright Aero Labs
Walter Gekelman	UCLA
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Steven Girshick	U of Minnesota
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David Schultz	ORNL
Mark Sobolewski	NIST
Tim Sommerer	General Electric, Inc.
Ken Stalder	Stalder Technologies
Edward Thomas	Auburn University
Lev D. Tsendin	St. Petersburg State Polytechnic University

STRUCTURE OF WORKSHOP

- Initial working groups based on recommendations, themes, opportunities of the Decadal Report *Plasma 2010*
- Starting points…expected some evolution and possible consolidation
- Working groups to deliver chapters for report.
- Example of desired outcome:
  - "Future Science Needs and Opportunities for Electron Scattering: Next Generation Instrumentation and Beyond" http://www.sc.doe.gov/bes/reports/archives.html

CHARGE TO WORKING GROUPS

- **Emphasize science challenges and opportunities…not applications….though science issues can (and should) be motivated by applications.**
- **Working groups deliver….**
- **Introduction to science area and short historical perspective**
- **Motivating technologies and potential societal benefit**
- **Description of science challenges**
  - **Why is this science issue fundamentally important?**
  - **Progress to date**
  - **What science benefit will result?**
  - **What specifically needs to be done?**
  - **What are linkages to other areas of science (e.g., AMO)**
- **Prioritized list of science challenges**

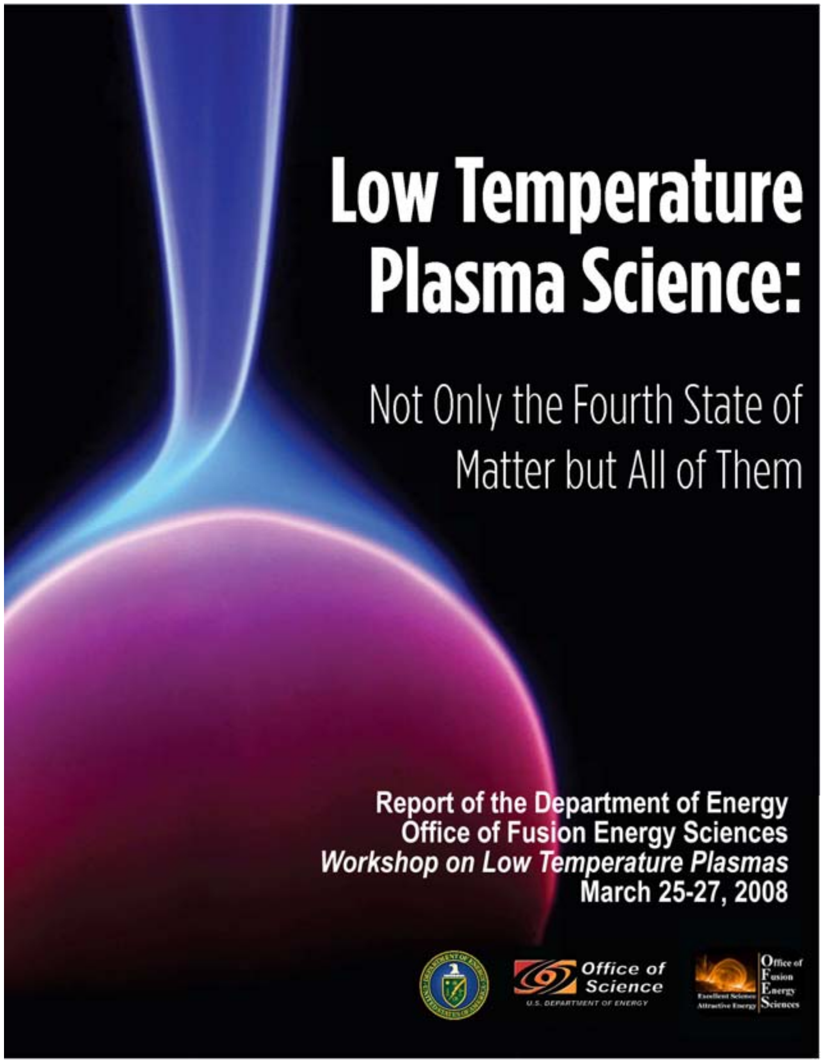
STARTING WORKING GROUPS

Group	***Topic***	***Group Leaders***
1	Interaction of plasmas with complex surfaces including organic materials and living tissue	G. Oehrlein M. Geockner
2	Chaotic, non-linear, stochastic processes, including multiphase and plasmas in liquids	K. Stalder V. Godyak
3	Stability, generation of large, uniform plasmas including high pressure	I. Adamovich
4	High density microplasmas: Interaction with surfaces	D. Economou
5	Interaction of plasmas with, and production of, nanostructures	U. Kortshagen
6	Flexible, noninvasive plasma diagnostics and sensors	G. Hebner V. Donnelly
7	Fundamental data	A. Garscadden

…AND THE RECONFIGURATION

Group	Topic	Group Leader
1	Plasma-Surface Interactions: From Nanostructures to Living Tissue	G. Oehrlein
2	Exploring and Utilizing Kinetic Nonlinear Properties of Low-Temperature Plasmas	I. Koganovich
3	Plasmas in Multi-Phase Media	U. Kortshagen
4	Plasma Scaling Laws: Micro-plasmas to Large Area/Volume	I. Adamovich
5	Cross cutting themes in low temperature plasma physics: Diagnostics, Modeling and Fundamental Data	G. Hebner

WORKSHOP REPORT



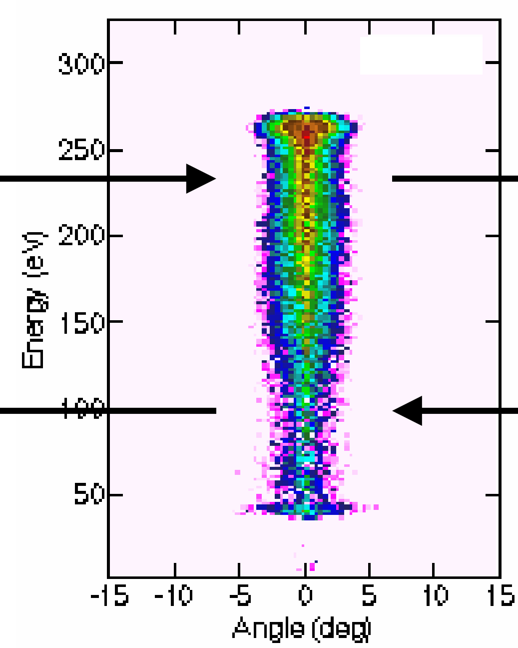
- ***Low Temperature Plasma Science: Not only the Fourth State of Matter but All of Them***
- **Published, September 2008**

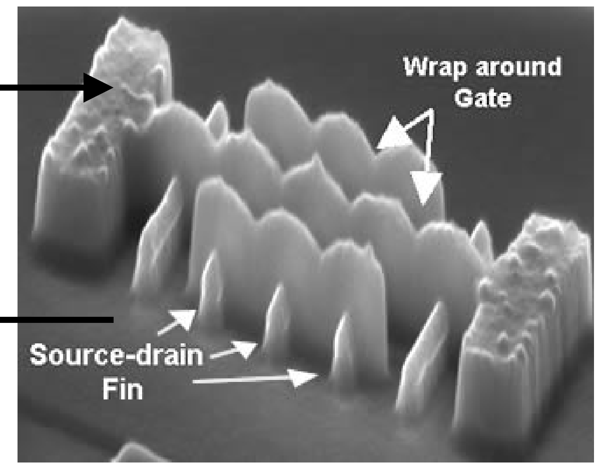
PLASMA SURFACE INTERACTIONS: FROM NANOSTRUCTURES TO LIVING TISSUES

- **Science Challenges**
- ***How do plasma species onto to a complex surface synergistically interact to provide unique reaction pathways for materials processing?***
- ***How do LTPs interact with organics, living tissue analogues, and living tissue?***
- ***How do collisions in nanostructures, porous materials, and textiles change the transport and reaction of plasma species?***
- ***How do plasmas create and modify nanometer sized materials, and their surfaces, to make novel functional nanostructures?***
- ***How do extreme changes gradients in plasma properties influence plasma-surface interactions, resulting in heat fluxes ranging from manageable MW/m² to destructive GW/m²?***
- ***How do plasma-surface interactions affect the composition, stability and dynamics of the plasma?***

PLASMA SURFACE INTERACTIONS:
IT'S ALL ABOUT CONTROL

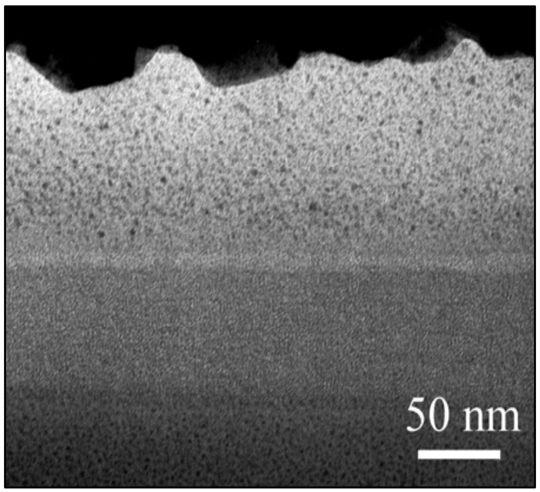
- **The ability to craft structures and functionality on surfaces is critically depends on the ability to control $f\left(\vec{v},\vec{r},t\right)$ of charged and neutral species.**

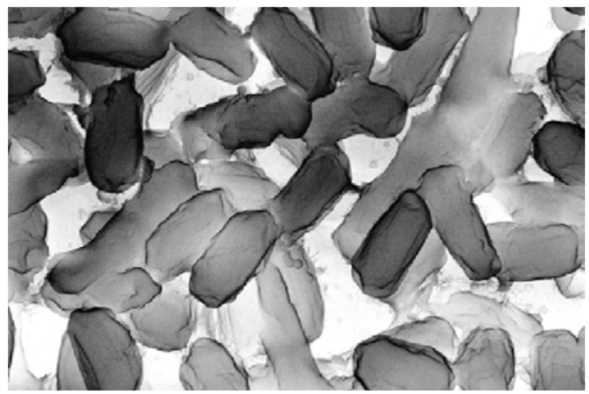




PLASMA SURFACE INTERACTIONS: NON-TRADITIONAL MATERIALS

- **The importance of controlling $f\left(\vec{v},\vec{r},t\right)$ intensifies with new classes of materials and biotechnological applications**





- **Low dielectric constant materials for microelectronics fabrication with nm sized pores.**
- **Bacterial (sterilization)**
- **Human tissue (wound treatment)**
- **Organic materials**

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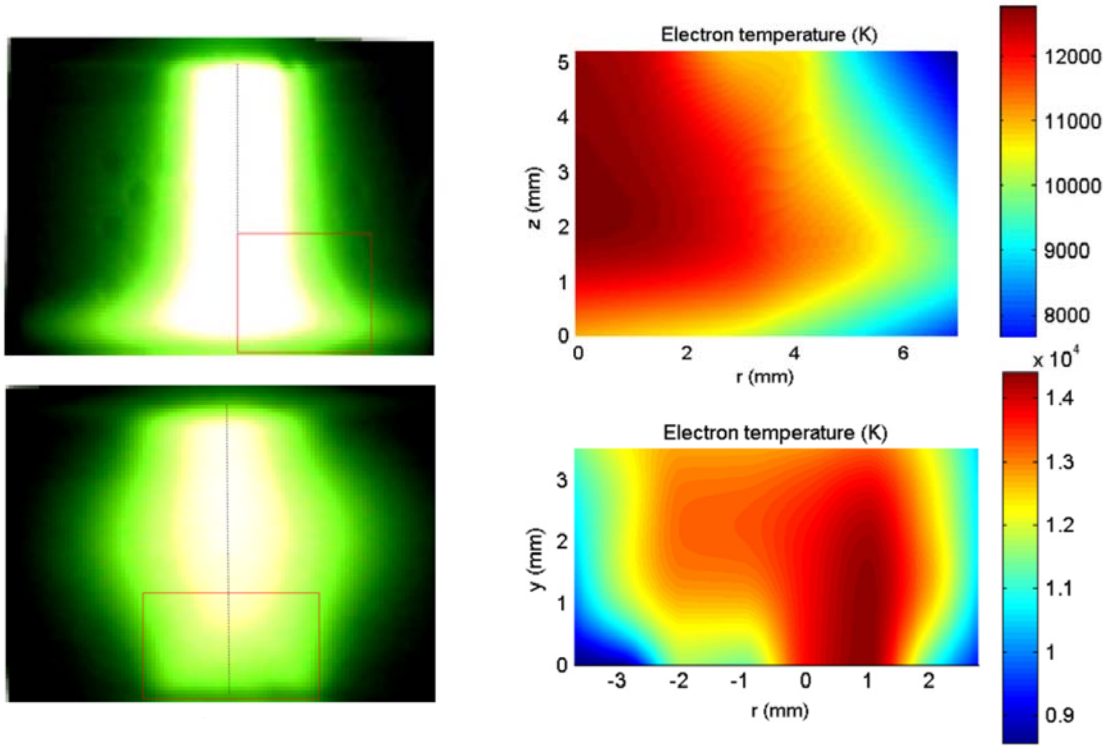
PLASMA SURFACE INTERACTIONS: EXTREME DYNAMIC RANGE

- Thermal plasma arcs are used for deposition of high performance materials (e.g., jet engine turbine blades).



- Manageable and unmanageable anode attachment (left) emission (right) T_e

- Quality of materials and lifetime of electrodes depend on control of arc attachment, from “beneficial” MW/m^2 to destructive GW/m^2.
- Extreme temperature gradients 10^8 K/m produce positive feedback to instabilities.

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PLASMA SURFACE INTERACTIONS: FROM NANOSTRUCTURES TO LIVING TISSUES

- **Priorities:**
- ***1 - Develop novel experimental and modeling tools to understand and control the production of desired functionality on surfaces, including the synergistic role of multiple species. The materials priorities are:***

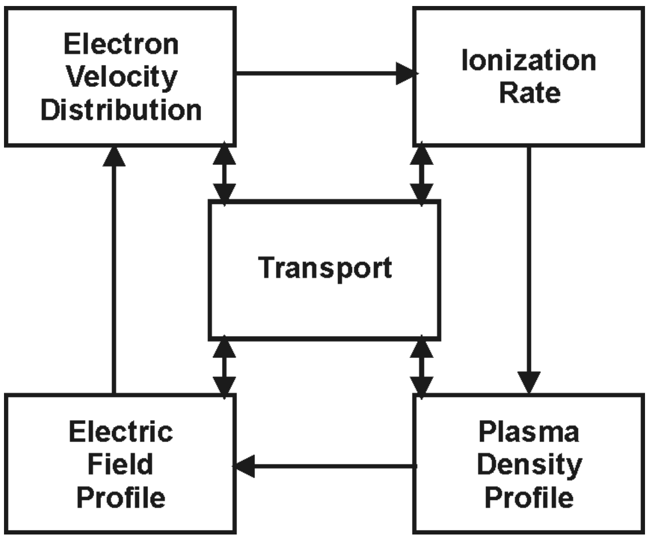
  (a) organic materials and living tissues
  (b) nanostructures, nano-materials, nano-particles and porous materials.
- ***2 - Investigations to understand and predict plasma-surface interactions in the presence of large plasma gradients.***
- ***3 - Understand and predict the effects of plasma-surface interactions on plasma composition, stability and dynamics.***
- ***4 - Design and model plasma systems to elucidate the governing principles of high-priority plasma-surface interactions.***

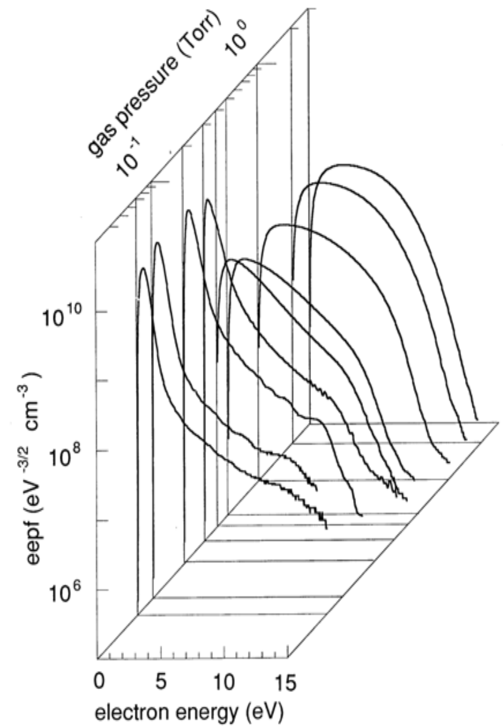
EXPLORING AND UTILIZING KINETIC NON-LINEAR PROPERTIES OF LTPs

- **Science Challenges**
- ***What are the fundamental principles governing generation of nonlinear structures appearing in low-temperature plasmas?***
- ***Develop theoretical and numerical tools for active plasma control via plasma boundaries and external electromagnetic fields.***
- ***Apply of concepts in non-linear dynamics from LTPs to chemical and biological systems*.**

EXPLORING AND UTILIZING KINETIC NON-LINEAR PROPERTIES OF LTPs

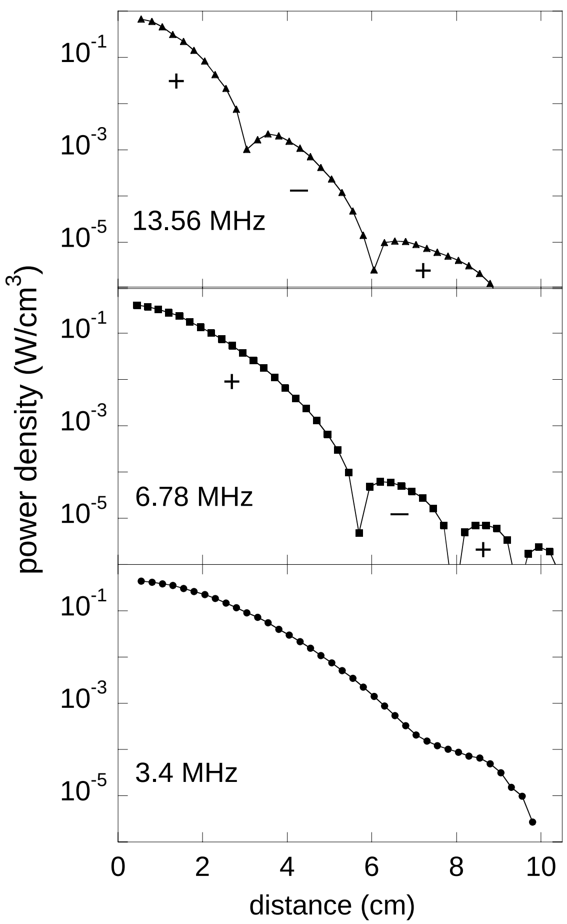
- LTPS is perhaps unique among plasmas in the ability (and need) to control the shape of $f(\vec{v},\vec{r},t)$ for the production of excited states and radicals.





- The partially ionized nature of the plasma and the non-Maxwellian $f(\vec{v},\vec{r},t)$ produce non-linearities which can lead to instabilities.

KINETIC NON-LINEAR PROPERTIES OF LTPs



- **Nonlinear coupling between** $f(\vec{v}, \vec{r}, t)$ **and ionization through self-consistent electric field leads to formation of self-organized plasma structures (streamers, striations, double layers).**
- **Example:**
- **Time averaged negative power absorption in wave heated plasma** $P = (1/\Delta t)\int_{\Delta t} \vec{j}(t) \cdot \vec{E}(t)dt$
  - **Normal skin depth:** $J = \sigma_p E$, $\delta_J = \delta_E$
  - **Anomalous SE:** $J \neq \sigma_p E$ $\delta_J \neq \delta_E$
- **Different propagation mechanisms (dynamic screening for *E* and electron thermal motion for *j*) provide an arbitrary phase difference between *E* and *j*.**

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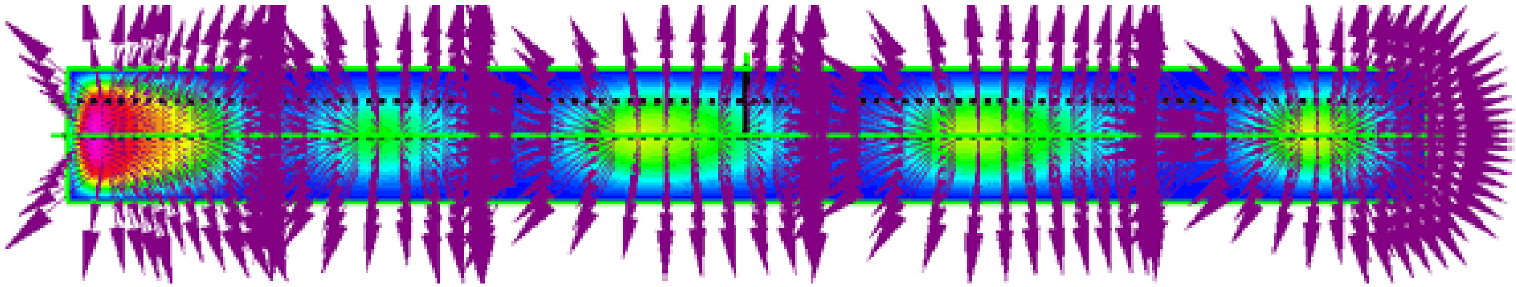
KINETIC NON-LINEAR PROPERTIES OF LTPs



- Plasma density and electric field vectors in positive column.
- At low currents coherent structure exists for 10s of cm in spite of 1000s of collisions and even recombination in volume and walls.
- The potential drop over the spatial period is close to the ionization potential.
- How do collective effects maintain memory with this degree of collisionality?

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EXPLORING AND UTILIZING KINETIC NON-LINEAR PROPERTIES OF LTPs

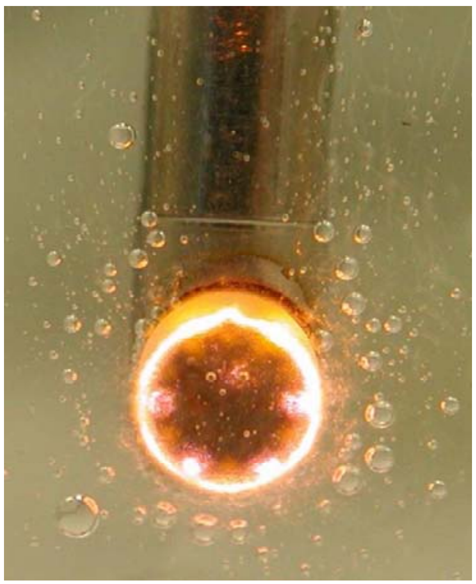
- **Priorities**
- ***1 -Understand the kinetic phenomena of non-linear structures especially electronegative plasmas.***
- ***2 - Translate this understanding into the creation of comprehensive, multidimensional, parallel kinetic codes.***
- ***3 - Develop novel diagnostics to measure electron and ion velocity distributions in the presence of complexity of real discharges, including magnetic and rf electric fields.***
- ***4 - Develop and exploit methods to control plasma parameters and nonlinear behavior through manipulation of external electromagnetic fields and plasma sheaths.***
- ***5 - Relate LTP nonlinear dynamics and structures to analogous phenomena in biological and other collective, nonlinear systems.***

PLASMAS IN MULTI-PHASE MEDIA

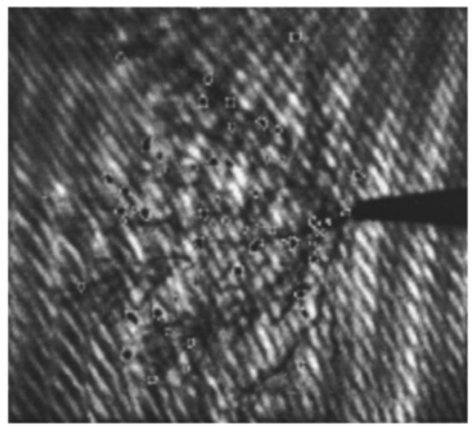
- **LTPs are perhaps unique in their purposely being sustained in media having multiple phases.**
- **Science Challenges**
- ***Nucleation and Growth – How do entities of a new phase nucleate and grow in a plasma ?***
- ***Plasma-nano-particle interactions – What processes govern the coupling of the plasma to suspended nano-particles***?
- ***Plasmas in liquids – How do plasmas interact with liquid-gas multiphase media*** ?
- ***Plasma Metamaterials – What unusual properties can be found in plasmas containing dispersed nanoscale and quantum-confined objects?***

PLASMAS IN LIQUIDS

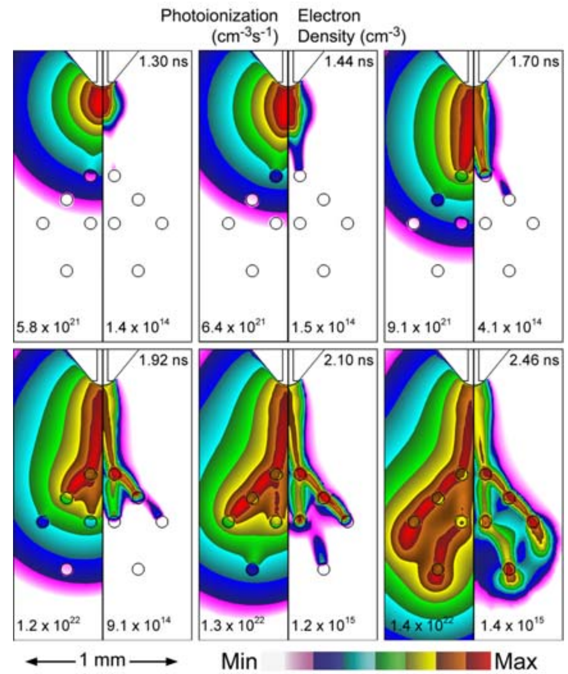
- Plasmas in liquids are unique to LTPs and an emerging science area. Applications include VOC remediation from water to surgery.
- The most fundamental of properties (e.g., penetration of plasma through the gas-liquid boundary) are not understood.



- ***Surgical Instrument (discharge in saline solution).***



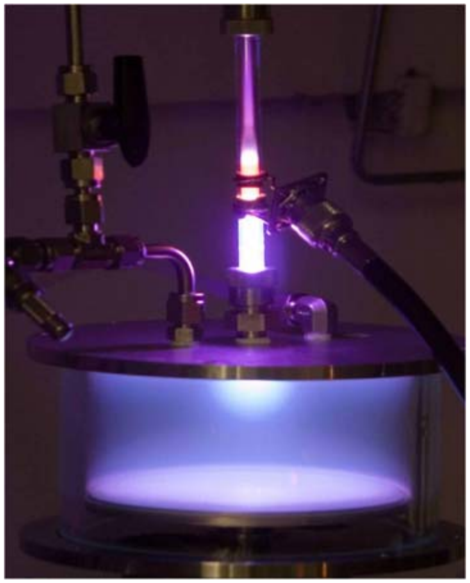
- ***Qian, et. J. Appl. Phys. 97, 113304 (2005).***

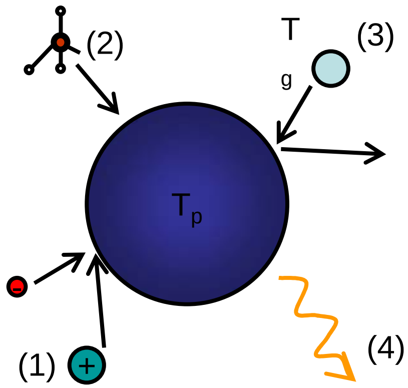


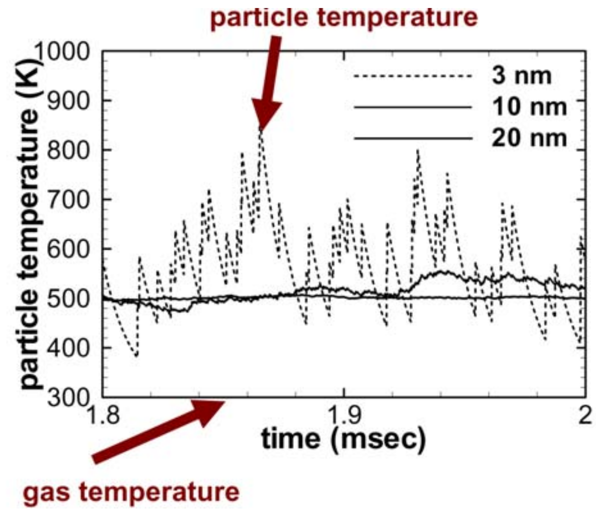
- ***"Bubbles" for streamer propagation.***

Low Temperature Plasma Science Workshop

SYNERGISTIC PLASMA PARTICLE INTERACTIONS



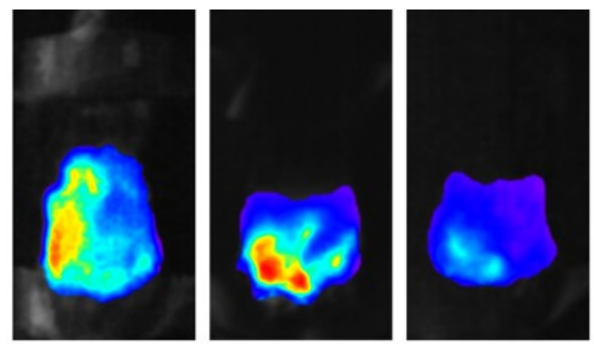




- **Nucleation and stochastic heating of nano-particles**

- **LTP-injected feed stock gases**

- **Synergistic coupling between plasma and chemically active particles could lead to a new class of meta-materials.**



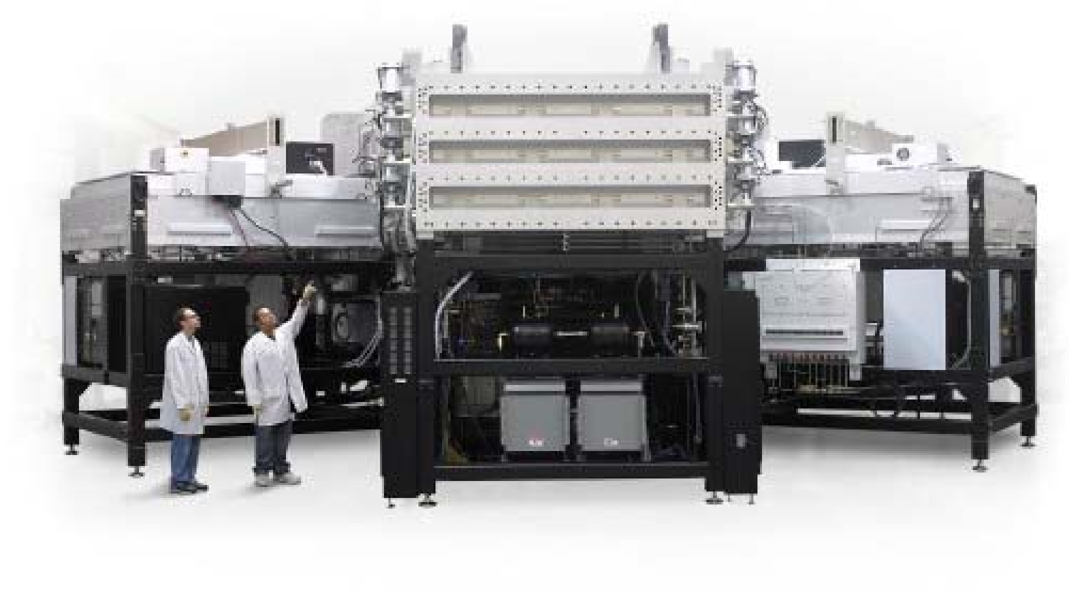
- **Near-IR photoluminescent nanocrystals**

Low Temperature Plasma Science Workshop

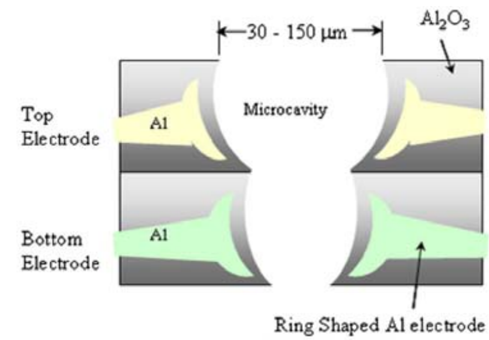
PLASMAS IN MULTI-PHASE MEDIA

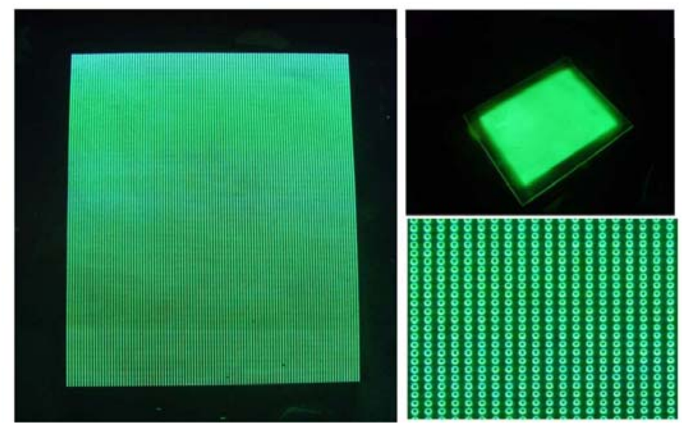
- **Priorities**
- ***1- Develop a fundamental knowledge base for the production and sustaining of plasmas in liquids and plasmas in contact in liquid boundaries.***
- ***2 - Leverage the unique abilities and properties of particles in plasmas for the possible creation of new classes of multiphase metamaterials.***
- ***3 – Quantify nucleation and growth of solid phases in plasmas producing unique and otherwise unattainable functionality.***
- ***4 – Understand Plasma and nano-particle interactions.***

PLASMA SCALING LAWS: MICRO-PLASMAS TO LARGE AREA/VOLUME



- **Applied Materials PECVD platform for LCD panels and solar cells.**





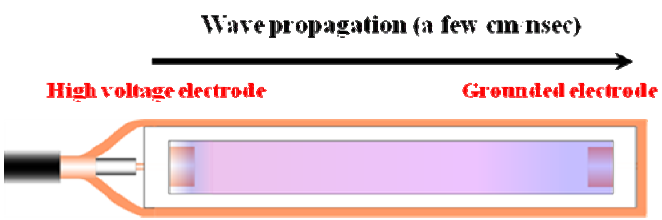
- **Microplasma arrays (Ref: J. G. Eden)**

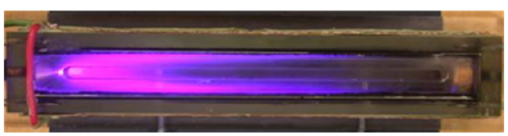
PLASMA SCALING LAWS: MICRO-PLASMAS TO LARGE AREA/VOLUME

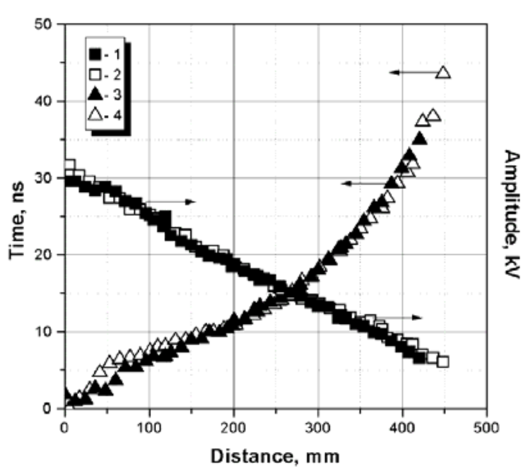
- **Science Challenges**
- ***Electromagnetic-plasma coupling for high-aspect-ratio, low-pressure plasmas with extreme uniformity constraints.***
- ***Producing uniform high-pressure plasmas generated by short ionizing pulses***
- ***Designing at kinetic level: Development of new approaches to affect and control plasma parameters using waveform manipulation***
- ***Nonlinear interactions between RF power supplies and plasmas; constraints to short-pulse generation for high-power, high-E/N plasmas.***
- ***Understanding micro-plasmas and leveraging their unique properties***
- ***Diagnostics and computations***

PLASMA SCALING LAWS

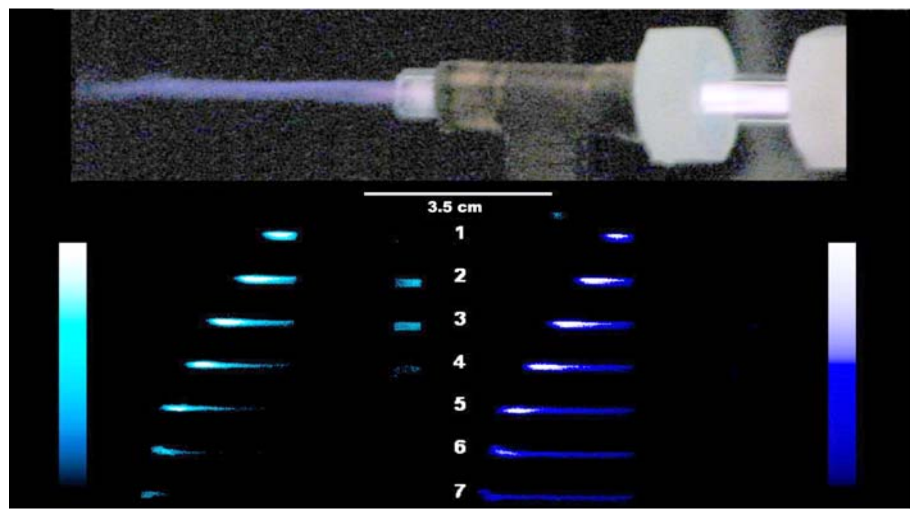
- Specific dynamics of large and small systems are, to some degree, unique.
- Scaling processes ultimately depends on leveraging excitation waveforms and mechanisms to prevent onset of instabilities.
- Understanding breakdown, power coupling, optimization of distribution functions and feedback, at very high power levels, are required. – Must be some leveraging across size.







- Repetitively pulsed (10 kHz), fast ionization wave plasma in air.



- Plasma bullets emanating from an atm pressure microplasma (5 ns gate separated by 10 ns).

PLASMA SCALING LAWS: MICRO-PLASMAS TO LARGE AREA/VOLUME

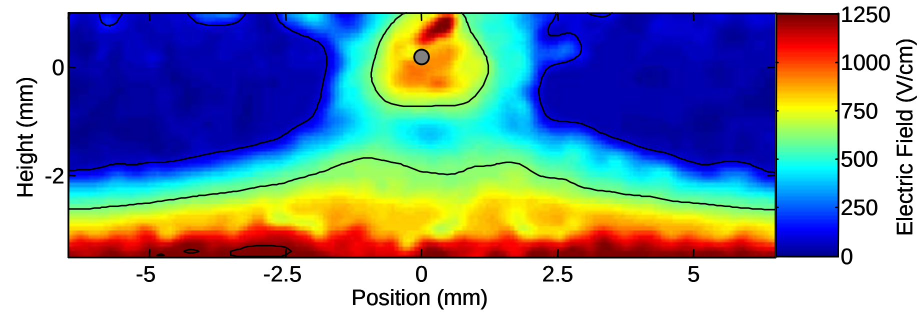
- **Priorities**
- ***1 - Nonlinear dynamics of the coupling of electromagnetic fields to plasmas in realistic geometries, molecular and electronegative gas mixtures and under transient conditions.***
- ***2 - Understanding the unique phenomena of micro-plasmas and their relationship to scaling of macro-plasmas.***
- ***3 - Electric field penetration using short ionizing pluses, including breakdown development on sub-Debye-length scales.***
- ***4 - Multi-scale dynamics by manipulation of the excitation waveforms and their optimization for desired performance.***
- ***5 - Non-linear interactions between power supplies and plasmas.***

CROSS CUTTING THEMES IN LTPS: DIAGNOSTICS, MODELING, FUNDAMENTAL DATA

- **Advances in diagnostics, modeling and fundamental data are required to enable and sustain progress in topic-specific areas.**
- **Diagnostics: Science Challenges**
- ***Discover breakthrough methods to quantitatively characterize the complex chemical and physical nature of dynamic surfaces immersed in low-temperature, non-equilibrium plasmas***
- ***Invent new tools with unprecedented time and space resolution to measure the neutral and charged particle velocity and energy distributions in the bulk plasma and sheath.***
- ***Develop techniques to understand the complex and nonlinear interaction between a plasma and external power sources.***

CROSS CUTTING THEMES IN LTPS: DIAGNOSTICS, MODELING, FUNDAMENTAL DATA

- **Diagnostics: Priorities**
- ***1 – Innovate methods for probing chemical composition of surfaces while they are immersed in plasmas.***
- ***2 - Develop diagnostics capable of interrogating 3-dimensional structures inside the plasma.***

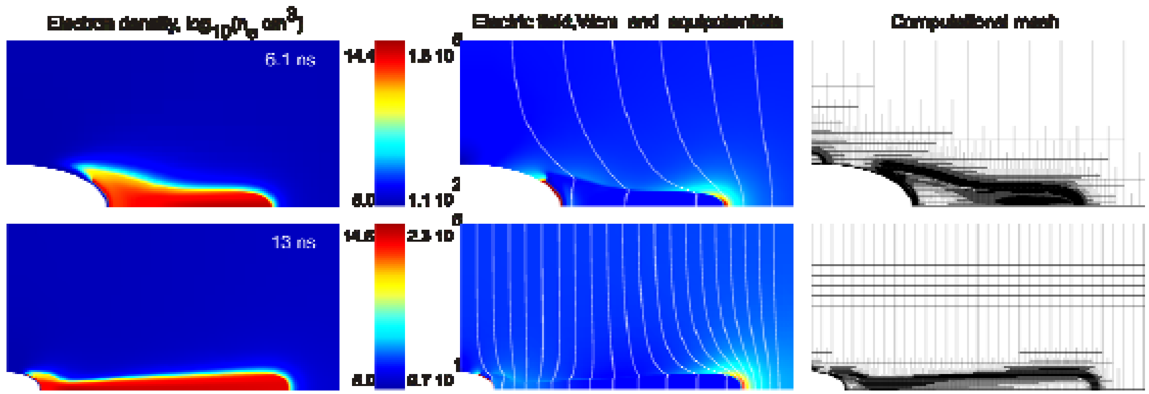


- **LIF measurements of E- fields around a Langmuir probe above an rf biased electrode (resolution 100 μm).**

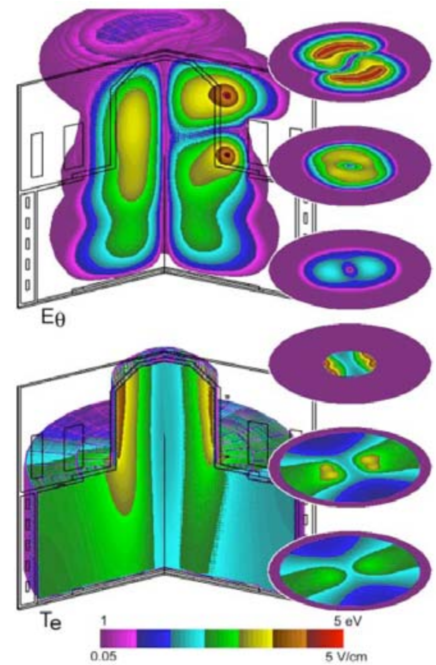
- ***3 - Develop diagnostic techniques for 5 μm spatial and 5 ns temporal resolution usable in the bulk plasma and plasma sheath for large, low pressure plasmas to atmospheric pressure microplasmas.***
- ***4 - Develop techniques to understand the complex and nonlinear interaction between a plasma and its external power sources, including model, scalable systems.***

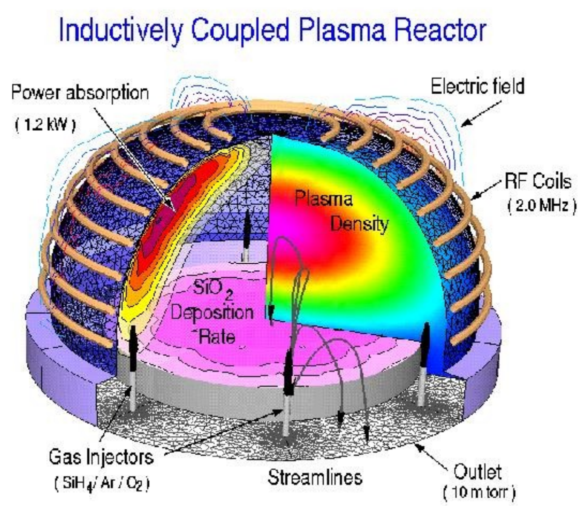
CROSS CUTTING THEMES: MODELING AND SIMULATION

- **Science Challenge:** ***Revolutionize modeling and simulation tools to predict plasma physics and chemistry spanning length scales from angstroms to meters and time scales from picoseconds to minutes.***



- **Streamer between a needle-like elliptic cathode and a flat anode: *p* = 760 Torr, voltage 600 kV, gap *d*=1 cm**





- **Multi-physics modeling**

- **Helicon plasma sustained by multi-mode waves (E-field and T_e.)**

Low Temperature Plasma Science Workshop

CROSS CUTTING THEMES IN LTPS: MODELING AND SIMULATION

- ***Priorities***
- ***1 - Expand plasma capabilities to combine theory (e.g., nonlocal methods), simulation (e.g., Monte Carlo), and reacting flow equations to model closely-coupled, stochastic processes (e.g., breakdown, instabilities, turbulence).***
- ***2 - Improve the computational infrastructure to exploit state-of-the-art high performance computing (e.g., parallel algorithms).***
- ***3 - Identify the mechanisms governing plasma-liquid and plasma-living tissue interfaces.***
- ***4 - Develop multi-scale methods describing interactions of plasmas with nanoscale features such as nano-particles and nano-textured surfaces.***
- ***5 - Implement "diagnostics" to predict directly measurable quantities (e.g., Langmuir probe IV) to enhance the interpretation of diagnostics.***

CROSS CUTTING THEMES IN LTPS: FUNDAMENTAL DATA

- **Science Challenge:** ***: Develop new methods to rapidly measure and calculate the fundamental atomic-scale interactions that support the entire field of plasma physics.***
- ***Priorities***
- ***1 - Establish a clearinghouse for fundamental data for LTPS.***
- ***2 – Establish a standing body to identify needs, set priorities and validate fundamental data in LTPS.***
- ***3 - Develop new approximate methods, scaling laws, and empirical formulas that can be used to quickly estimate unknown data.***
- ***4 - Via computation, provide fundamental data for large molecules, clusters, nano-particles, and surfaces.***
- ***5 - A program of experimental measurements needs to be revitalized.***

CURRENT STATUS

- **The report has been accepted by OFES.**
- **LTPS was included in the RFPs for Plasma Science Centers and the DOE-NSF Plasma Science Partnership.**
- **OFES is considering organizational changes that would enable programmatic support for LTPS.**
- ***Summary Statements:***
- **The *Plasma 2010* and *LTPS Workshop* reports have had impact in OFES.**
- **Final resolution of opportunities for LTPS in OFES await new Associate Director.**