International Low Temperature Plasma Community

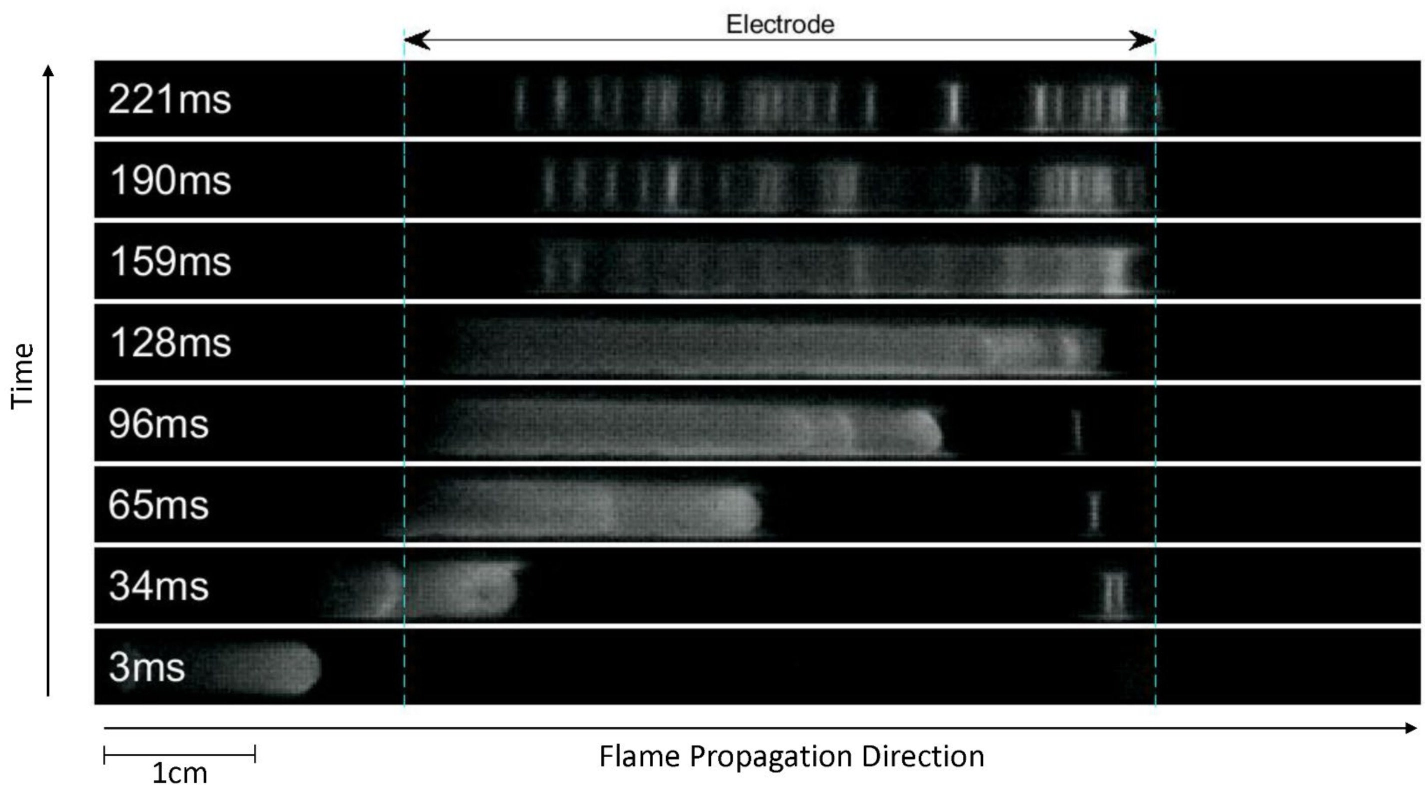
https://mipse.umich.edu/iltpc.php, iltpc-central@umich.edu

Newsletter 17

22 September 2021

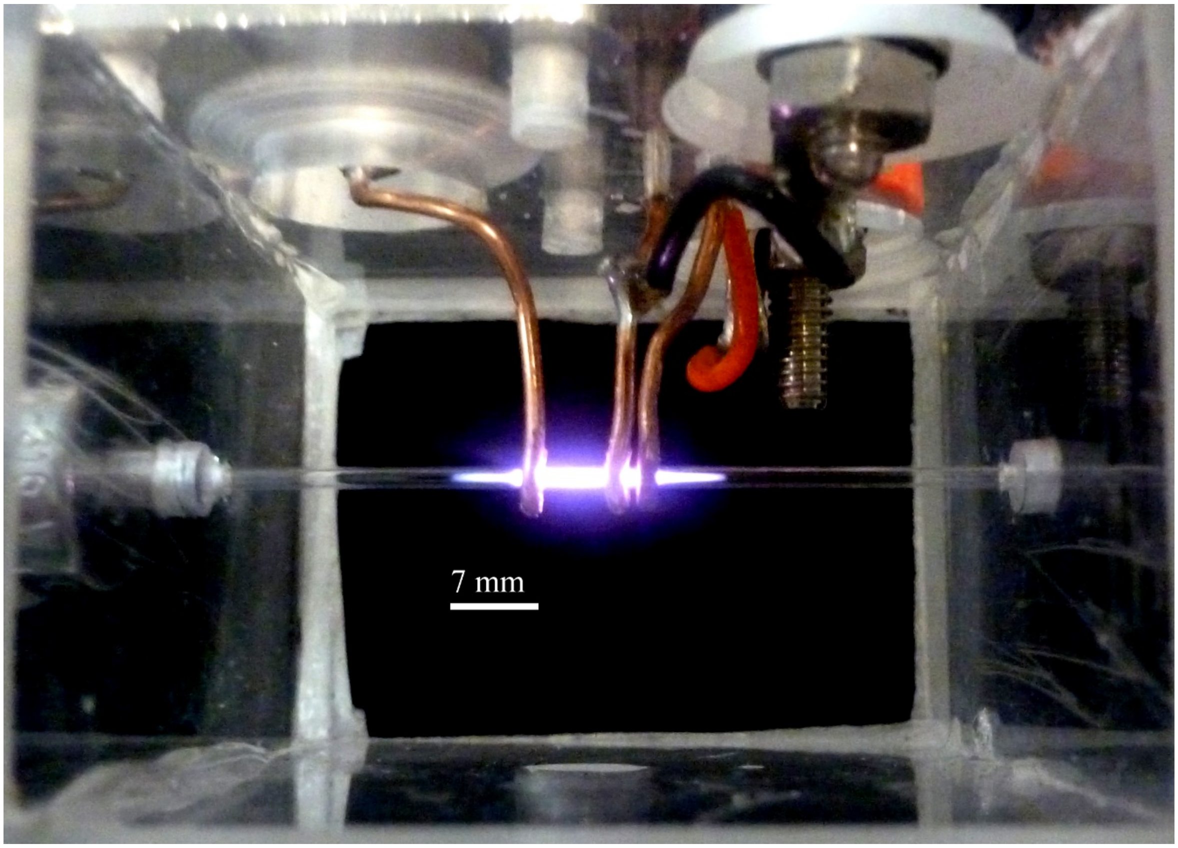
Images to Excite and Inspire!

Please do send your images (with a short description) to iltpc-central@umich.edu. The recommended image format is JPG or PNG; the minimum file width is 800 px.



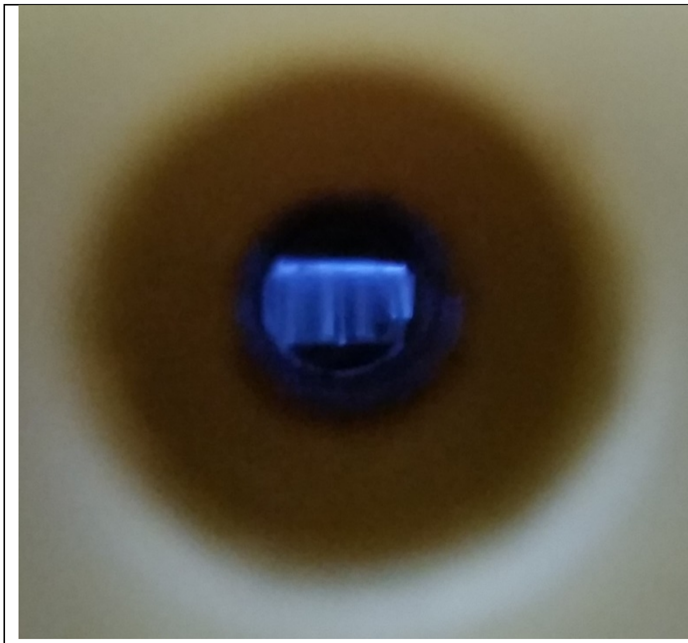
Plasma Aided Combustion: Nonthermal plasmas can enhance ignition and combustion in multiple ways. The combustion environment, often dynamic, also has a strong influence on the plasma, e.g. through sharp temperature gradients (and corresponding changes in the reduced electric field), changes in gas composition and flow field structure. The figure shows the dynamic evolution of a nanosecond repetitively pulsed dielectric barrier discharge during passage of a stoichiometric methane/ air premixed flame propagating along a narrowing channel. As the flame enters the electrode gap (34 ms) a uniform plasma is ignited, which increases in length as the region of hot gas grows (65 ms). When the flame is quenched (159 ms), the discharge transitions to a micro-discharge structure (190 ms). The discharge evolution is particularly relevant when considering dynamic applications of plasma-assisted combustion, such as transient flames, flame stabilization, internal combustion engines or rotating detonation engines.

Prof. Carmen Guerra-Garcia and **Colin Pavan**, Massachusetts Institute of Technology, USA
guerrac@mit.edu.



Plasma Gas Sensors: The image shows a small atmospheric pressure microplasma used as a sensor for trace molecular gas and volatiles detection. Optical emission spectra (from 200 nm – 1100 nm) are analysed using machine learning algorithms based on PLS-DA in order to detect trace gases, e.g., methane, acetylene and hydrogen etc, down to concentration levels of 1 ppm. See, e.g., https://arxiv.org/abs/2109.06326. The overall aim of this work is to develop low cost portable detection systems, for important gases and volatiles, that can be deployed for autonomous continuous environmental monitoring or hopefully breath analysis. We started with methane as an exemplar gas, which has no emission lines in the UV-vis as is common with many such gases. This is an important gas to monitor for climate change, e.g., natural gas pipeline leakage (which can be surprisingly high) and a recent ARPA initiative funded a range of advanced research projects to solve this issue. We thought that maybe the humble microplasma could make a contribution here. Also, methane is an important biomarker in human breath (also cows – again climate change!) but current detection systems are expensive and inadequate for biomedical application. The future development requires us to work with more complex gases, e.g. multiple hydrocarbons and of course air.

Prof. Davide Mariotti (d.mariotti@ulster.ac.uk) and **Prof. Paul Maguire** (pd.maguire@ulster.ac.uk), Ulster University, Northern Ireland, UK.



Plasma Chemical Conversion: The image shows operation of a single modified planar dielectric barrier discharge (DBD) reactor during methane conversion to higher alkanes. The DBD is operating at 37 kHz, up to 13 kV AC pk/pk and 200 W. This technology is promising for replacing the use of liquid fossil fuels as with a renewable electricity plasma-based method for production of high value chemicals.

Lauren Scott, CEO, Alkcon Corp., USA.
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In this issue:	
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Call for Contributions

Please submit content for the next issue of the Newsletter. Please send your contributions to iltpc-central@umich.edu by **October 29, 2021**.

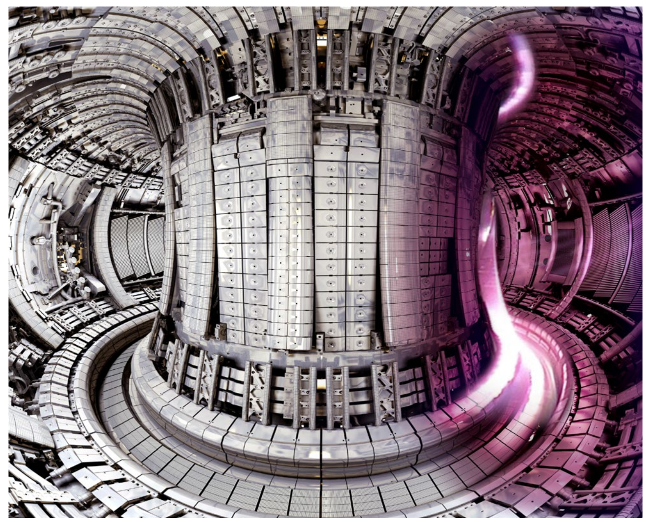
Please send contributions as MS-Word files if possible – and **avoid sending contributions as PDF files**.

In particular, please send **Research Highlights and Breakthroughs** using this ***template:*** https://mipse.umich.edu/iltpc/highlight_template_v05.docx. The highlight consists of an image and up to 200 words of text; please also send your image as a separate file (the recommended image format is JPG or PNG; the minimum file width is 800 px). The topic can be anything you want - a recently published work, a new unpublished result, a proposed new area of research, company successes, anything LTP-related. Please see the *Research Highlights and Breakthroughs* for examples.

Low Temperature Plasmas and Fusion – a Contradiction or an Opportunity?

What are your immediate thoughts on this? The often heard and very quick answers come along the line that LTP and fusion plasmas are very different, having very different temperatures and densities. Fusion deals with big machines, expensive experiments, faces many technological challenges and a tremendous team effort, just to name a few thoughts. This opinion establishes that fusion plasmas have little in common with LTPs, which we also experience by attending separate conferences and publishing in specially targeted journals. This results in little contact between the communities – we can also see it as "two plasma research worlds".

Let's give it a second thought – closer look reveals indeed a bouquet of similarities. Low temperature plasma physics is relevant in the boundary layer and in the divertor of fusion devices. Here the plasma cools down to some ten eV to 1 eV or even less, in particular in the divertor where a transition from an ionizing to a recombining plasma takes place in the detached regime. Plasma surface interactions caused by the particle fluxes lead to sputtering, particle recombination, reflection and re-deposition, similar as investigated in LTPs for different applications and in fundamental studies. Now, one could argue that fusion, unlike LTPs, deals mainly with hydrogen or deuterium interacting with carbon, beryllium, or tungsten surfaces (compounds), but in fact the gas injection used to radiative cooling of the hot plasma brings species such as argon, helium, and nitrogen onto the scene. Molecules can survive in the cold plasma and undergo a variety of reactions – the way to plasma chemistry is open. Not only are ro-vibrationally excited molecules are present, but also H_2/N_2 chemistry that ends up in ammonia production. This touches on the exciting LTP research area of conversion of low value molecules into value-added chemicals. The field of plasma diagnostics very much overlaps, ranging from spectroscopy from VUV to IR, Langmuir probe techniques, mass spectrometry, interferometry to laser-based techniques like Thomson scattering, or LIF to name a few examples. Another aspect is modelling. Here the techniques of PIC, fluid models, MC transport codes are used – not to forget the modelling of the plasma kinetics and plasma chemistry.



Wide angle view into the JET tokamak equipped with the ITER-like wall (Be, W). The section on the right-hand side is superimposed by a picture of the plasma. The intense Hα-light reflects the LTP regions. Source: EUROfusion.

Moreover, technological developments have many common aspects. For example, the ion source development for positive or negative hydrogen ions is closely linked to ion sources used in the accelerator community (like CERN) and shares physical and technology aspects of thrusters or ion sources for industrial applications of surface treatment.

Would you have expected these similarities? Certainly not all of the flowers are picked here, and I encourage you to investigate these opportunities. The "two plasma research worlds" have many aspects and challenges in common and the answer is obvious: It is an opportunity! I myself contribute to both and can tell you that it is very exciting.

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Prof. Rod Boswell – From Theory, Experiment, and Entrepreneurship to Virtual Reality

Rod Boswell is a Professor of Physics at the Australian National University (ANU). He began his career with an adventurous, and sometimes difficult, journey as a graduate student. During this period he undertook experiments, the significance of which would become evident later, to study plasma generation by helicon waves with a double-saddle antenna.

Following postdoctoral research in the UK, Netherlands and Germany, Rod returned to Australia and created the SP^3 Group in the early 1980s. Soon afterwards he built upon his PhD to demonstrate the production of non-equilibrium plasmas of exceptionally high density. His invention applied the double-saddle antenna to launch radio frequency (rf) helicon waves across a dielectric window and efficiently deposit their power [Boswell, Plasma Phys. Control. Fusion **26,** 1147 (1984)]. The helicon source was a completely new way to generate high-density plasmas without immersed electrodes, and is extensively used across academia and industry.

Rod's persistence in tackling difficult questions, and producing creative methods to answer them, has made him a driving force for positive change. An example of this came during his early years at ANU, where SP^3 was the first to publish PIC simulations of capacitive rf plasmas [Boswell and Morey, Appl. Phys. Lett. **52,** 21 (1988)]. This and other foundational works provided a wealth of understanding and inspired new and substantial international activity.

The combination of experiments with plasma theory is a hallmark of Rod's research, which includes the investigation – with first measurement – of neutral depletion in rf discharges. Important contributions are also found in the study of beam-plasma interactions, etching and deposition, pulsed discharges, electronegative plasmas, current-free double layers, electron heating, focused ion beams, fuel cells and the *The Wedge* virtual reality environment. He is adept at applying his ideas in industry, particularly in plasma-assisted materials processing and the development of the high-brightness *Hyperion* ion source.

Rod's insights into expanding plasmas and the role of magnetic nozzles in producing thrust have been instrumental to the development, in collaboration with Christine Charles, of a rich program of research in electric propulsion at ANU. They have recently led the significant expansion of the country's space capability by developing a space simulation facility at the Australian Instrumentation Technology Centre, which is nationally unique and built around a giant *Wombat* plasma chamber.

Rod is often found taking a direct route to passionate discussion, particularly on controversial topics. His casual attire belies a remarkable personality, and more than likely the receipt of an astute observation or important question. He has educated a generation of new physicists, students who have been treated to an eclectic mix of skill, skepticism, and powerful talent for interpreting complex findings in terms of basic physics. He also draws upon a love of music, trips into the outdoors, and depending upon the moment, "work harder!" These more personal interactions happen alongside his dedicated efforts in the scientific community, including the organization of conferences and editorial work for *Physics of Plasmas*.

In recognition of his contributions Rod is a Member of the Order of Australia, Fellow of the Australian Academy of Science and holds an honorary doctorate from the University of Orléans.

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General Interest Announcements

- **New NSF Program ECLIPSE (ECosystem for Leading Innovation in Plasma Science and Engineering)**

Recognizing that plasma science is a transdisciplinary field where fundamental studies in many disciplines, including plasma physics, plasma chemistry, materials science, and space science, come together to advance knowledge for discovery and technological innovation, the US National Science Foundation (NSF) has launched the new program ECosystem for Leading Innovation in Plasma Science and Engineering (ECLIPSE). This program capitalizes on opportunities for fundamental plasma science investigations to address problems of societal and technological need within the scope of science and engineering supported by NSF. ECLIPSE was stimulated by the recommendations of the Physics 2020 Decadal Assessment of Plasma Science, "Plasma Science: Enabling Technology, Sustainability, Security, and Exploration" (https://www.nationalacademies.org/our-work/a-decadal-assessment-of-plasma-science). The ECLIPSE program was created to foster an inclusive community of scientists and engineers and spans multiple NSF Directorates in the pursuit of translational research at the interface of fundamental plasma science and technological innovation.

Proposals submitted for consideration by the ECLIPSE program should satisfy the following criteria:

(1) Clearly articulate the fundamental scientific and/or engineering challenge in plasma science and engineering; and

(2) Provide a substantive discussion of how a resolution of the stated scientific and/or engineering challenge will address specific societal and/or technological needs.

The program also encourages inclusion of specific efforts to increase diversity of the ECLIPSE community and to broaden participation of under-represented groups in Science, Technology, Engineering, and Mathematics (STEM) as Broader Impacts of proposed work.

Proposals should be submitted to one of the participating core programs as described in the ECLIPSE program description: https://beta.nsf.gov/funding/opportunities/ecosystem-leading-innovation-plasma-science-and-engineering-eclipse.

NSF Contacts:
Directorate for Engineering

- Chemical, Bioengineering, Environmental and Transport Systems: **Dr. Raymond Adomaitis**, radomait@nsf.gov.
- Electrical, Communications and Cyber Systems: **Dr. Rosa Lukaszew**, rlukasze@nsf.gov.
- Civil, Mechanical and Manufacturing Innovation: **Dr. Jordan Berg**, jberg@nsf.gov, and **Dr. Thomas Kuech**, tkuech@nsf.gov.

Directorate for Geosciences

- Atmospheric and Geospace Sciences: **Dr. Mangala Sharma**, msharma@nsf.gov.

Directorate for Mathematical and Physical Sciences

- Physics: **Dr. Jose Lopez**, joslopez@nsf.gov, and **Dr. Vyacheslav (Slava) Lukin**, vlukin@nsf.gov.

- **Virtual Reception at the Gaseous Electronics Conference for Undergraduate Students: Free Day and Career Opportunities**

Are you an undergraduate student interested in plasma science and engineering? This year the American Physical Society Gaseous Electronics Conference (http://www.apsgec.org/gec2021/) offers **one-day free registration** to undergraduate students! This free pass allows undergraduate participants access to all sessions on Tuesday (October 5, 2021), where they can learn about cutting-edge research in the fields of aerospace plasmas, plasma agriculture, plasma-liquid interactions, and much more.

In addition, undergrads can participate in a virtual reception organized by the Coalition for Plasma Science (https://www.plasmacoalition.org/), where they can learn about graduate school programs, summer research and training, and employment opportunities in the fields of plasma science and engineering. The CPS reception will feature a panel discussion and break-out sessions, where students can meet the panelists.

The reception organizers also encourage undergraduate participants to attend an informal Zoom meetup on Sunday (October 3, 2021). We will briefly introduce plasma science and engineering and provide content highlights from the GEC sessions. Zoom information will be sent to all undergrads who register.

To get the free registration, each undergraduate student must create a free APS account (https://www.aps.org/membership/student.cfm) and fill in their information in this form: (https://docs.google.com/forms/d/1iZQv_vEU5vcuBZ0UoGhnPt_vtxzEtcWwejK2HjXt-Zw/edit)

CPS Reception details

Title: "Career Opportunities for Undergraduate Students"
Date/Time: 7 – 9 PM CST, October 5, 2021
Place: Virtual GEC Platform (access key will be sent to registered undergrads via email)
Speakers:
Edward Thomas, Jr., Physics Department, Auburn University
Arturo Dominguez, Science Education Senior Program Leader, Princeton Plasma Physics Lab
Shahid Rauf, Managing Director, Plasma Technology at Applied Materials

The CPS reception will be recorded and made available for on-demand viewing on the virtual GEC platform. All registered attendees would be able to attend the panel and /or access the recording.

For more information, see: https://www.youtube.com/watch?v=fPqelPQndtA

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- **The Plasma Connection**

The IEEE Nuclear and Plasma Sciences Society (NPSS) has recently started a new initiative aiming at developing educational briefs on plasma and its applications. These writeups are aimed at educating non-experts on the basics of plasma, the importance of its technological applications, and the role it plays in our modern society. Dr. Mounir Laroussi of Old Dominion University is the main organizer of the initiative and is the editor of this publication, named the *Plasma Connection*. The articles are written by experts in a language that is accessible to non-experts including high school students, science enthusiasts, policy makers, etc. Three articles have already been posted on the Education page of the NPSS website and many more are either in the production stage or in the writing process. To access the *Plasma Connection*, click on the following link and scroll down until you see "Educational Briefs": https://ieee-npss.org/education/.

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Meetings and Online Seminars

- **International Online Plasma Seminar (IOPS)**

  The International Online Plasma Seminar (IOPS) is a seminar series on low temperature plasma science (LTPS). The seminars are presented bi-weekly via Zoom. The goal of the IOPS is to make high quality research results in LTPS widely available to our community and to foster an interactive scientific discussion. The current program and information about IOPS can be found here: https://mipse.umich.edu/online_seminars.php. Nominations for future speakers can also be made from this page.

  The next IOPS (3:00 pm, Central Europe Time) will be given by Dr. Loic Schiesko (**September 30, 2021**), Dr. Alexandros Gerakis (**October 14, 2021**), and Prof. Jonathan Tennyson **(October 28, 2021).**

  To attend IOPS, use the following Zoom link:
  https://ruhr-uni-bochum.zoom.us/j/93889931395?pwd=bFN5dU14RHRMYU5ySW40V1gvbDJpZz09

- **Online LTP Seminar (OLTP)**

  The schedule of the Online Low Temperature Plasma (OLTP) Seminar series is available at: https://mipse.umich.edu/ltp_seminars.php. The next seminars (9:00 am US Eastern Standard Time) will be presented by Prof. Amnon Fruchtman (**October 19, 2021**) and Dr. Shahid Rauf (**November 2, 2021**).

- **11th International Workshop on Microplasmas, June 6 - 10, 2022, Raleigh, NC, USA**

  We are delighted to welcome you in Raleigh for the 11th edition of the International Workshop on Microplasmas. Due to the uncertainties of the COVID-19 pandemic, the conference is currently being planned as a hybrid conference. Sessions will be streamed synchronously and are available to re-watch later for all registered participants.

  Scope of the Workshop: The purpose of this workshop is to bring together researchers from around the world to report on recent progress in understanding and in controlling the properties of plasmas generated in confined geometries. The topics covered by the Workshop are the following:

  - Plasma sources and plasma equipment used for microplasma generation
  - Diagnostics of microplasmas
  - Microplasma modelling
  - Plasmas in liquids and bubbles
  - Applications (material processing, plasma medicine, plasma agriculture, environmental applications, industrial contributions, etc.)

  Stay tuned for more details! Visit: www.iwm11.org.

  Contact:
  Prof. Katharina Stapelmann
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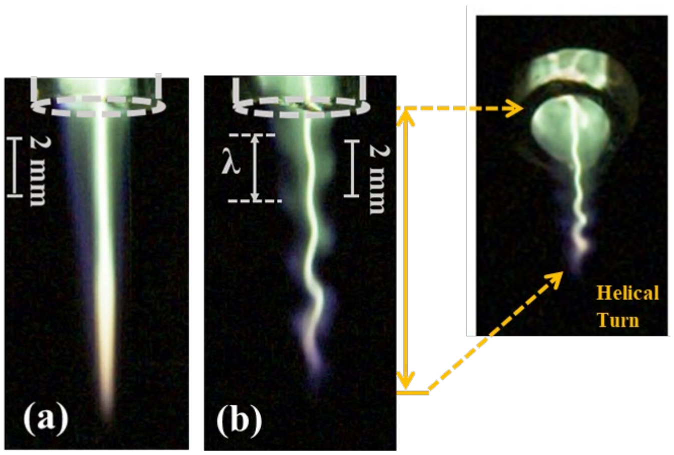
Community Initiatives and Special Issues

Submit your announcement for Community Initiatives and Special Issues to iltpc-central@umich.edu

Helical Shape Atmospheric Pressure RF Plasma Jet



Typical images of argon plasma jet in ambient air: (a) continuous wave RF mode (P= 30 W, Q= 1.5 lpm, plasma length ~ 12 mm, a conventional smooth conical shape plasma jet). (b) Pulse-modulated RF mode (applied power= 50 W, pulse frequency = 2 kHz, duty cycle= 30%, gas flow rate = 1.5 lpm, helical shape plasma jet). The inset shows a tilted image from the bottom captured by pointing the camera ~ 45° angle to the axis, facing the discharge. It clearly shows the filament propagating in a helical path, surrounded by a glow discharge.

The excitation of a novel helical shape atmospheric pressure RF (13.56 MHz) plasma jet is reported without using any external helical coil, rotating electric field, or external magnetic field. The helical shape of the argon plasma outside the discharge tube is a unique observation in pulse-modulated (2 kHz pulse frequency) RF plasma jets that originate in the glass nozzle and propagates downstream into the atmosphere. This plasma jet shape is different from those reported earlier, which are usually of smooth conical shape. Periodic pressure variations produced by the pulsed RF discharges and the acoustic wave carrying angular momentum are likely to be the cause of this helical shape formation. Understanding the phenomenon of helical structure dynamics will have an impact in diverse fields including, lasers, communications, solar atmosphere, turbulent flows, biophysics, and other areas. In addition, this unique structure can promote the enhancement of plasma-chemical features by efficient mixing of the air into the ionized plasma region which could be an active mechanism in biomedical applications.

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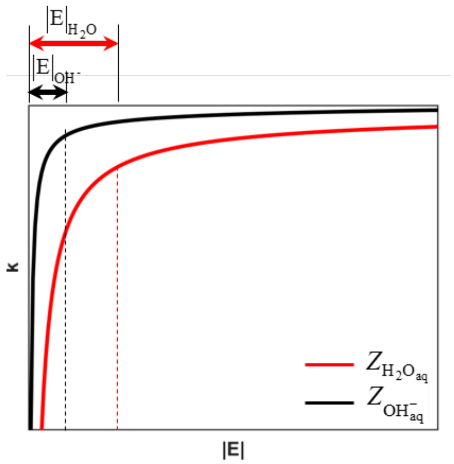
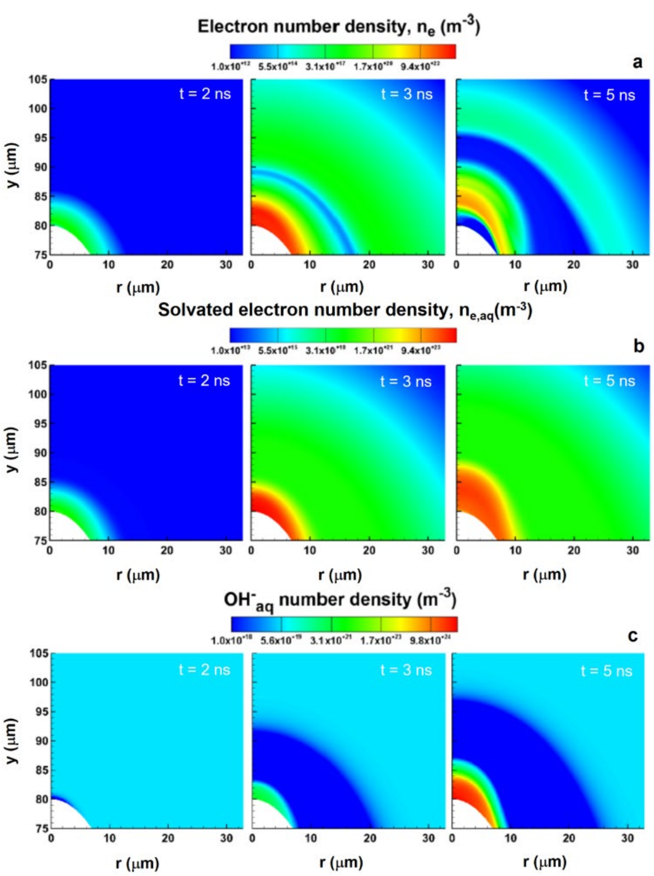
Source:
J. Appl. Phys. **130**, 083301 (2021).
https://doi.org/10.1063/5.0058000

Plasma Formation in Liquid Water: Role of Negative Hydroxyl Ions on Breakdown



Schematic presentation and comparison of rate constants of field dependent ionization of water and tunneling detachment of electrons from OH^{-}_{aq} as a function of electric field magnitude.



Evolution of electrons, solvated electrons and OH^{-}_{aq} under a nano-second pulsed voltage.

In recent years plasma in liquids and multiphase has been a topic of immense interest as it can offer a plethora of new, physical, and chemical synergies that can yield new reaction channels, intermediates, and reaction products. In tandem with applied research, efforts have been made to develop a fundamental understanding of plasma formation in the liquid and/or multiphase. In this work a modeling platform has been developed to investigate plasma discharge formation in liquid water and identify the role of negative hydroxyl ions on the breakdown process. Two tunneling sources for electrons are considered – tunneling ionization of water molecules and tunneling detachment of negative hydroxyl ions (OH^{-}_{aq}) together with additional reaction steps. Theories suggest the probability of electron detachment from negative OH^{-}_{aq} ions, is higher than the probability of field ionization of water molecules. This detachment can take place at a lower energy barrier.

The study shows that the electron detachment due to its lower threshold energy requirement provides stream of electrons during the initial rise time. The electron detachment tunneling process is not limited by the electric field, but rather by the availability of negative hydroxyl ions in the system and ceases when these ions are depleted. The tunnel ionization of water molecules forms the electron wave at a higher applied voltage, but the resulting peak electron number density is much larger than the detachment tunneling. The higher electron number density allows the recycling of depleted negative hydroxyl ions in the system and can reestablish tunneling detachment. A strong and coupled recycling of the negative hydroxyl ions can allow both tunneling processes to remain active throughout the initiation process of the discharge. Irrespective of the initial electron sources (i.e., ionization or detachment) the reduced electric field is not sufficient to allow electron impact ionization to be active and make a significant contribution.

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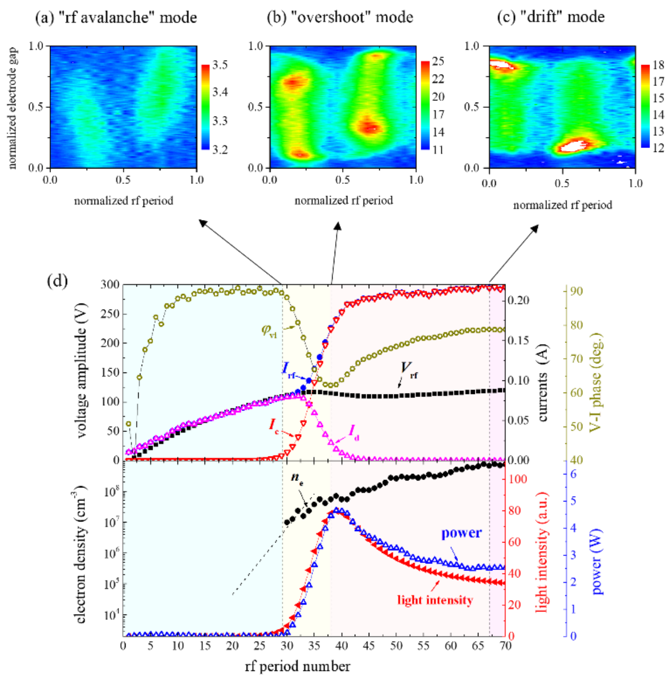
Source: A. Aghdam and T. Farouk, Plasma Sources Sci. Technol. **30**, 065025, (2021).
https://iopscience.iop.org/article/10.1088/1361-6595/abfbc7

Breakdown Phenomena in Capacitively Coupled Plasmas



Spatiotemporal plots of the measured excitation rate by phase resolved optical emission spectroscopy at the times t_1 (a), t_2 (b), and t_3 (c), which are defined in (d). (d) shows electrical parameters, including rf voltage and current amplitudes (V_{rf} and I_{rf}), conduction and displacement currents at the discharge center (I_c and I_d), V-I phase (ϕ_{vi}), and power deposition, and plasma parameters, including electron density (n_e) and light intensity as a function of the number of rf periods since the beginning of pulse.

Gas breakdown is a spectacular phenomenon that takes place on every tinitiation of any gas discharge. Breakdown is an unwanted phenomenon in electrical insulation, but in both cases a detailed understanding of the relevant physical effects is of high importance. The simplest form, the Townsend breakdown in a dc electric field, has been investigated for many decades. However, under radio-frequency (rf) excitation the breakdown process is highly complexity. Most studies of this topic have determined a "breakdown curve", the dependence of the breakdown voltage on the product of the gas pressure and the electrode gap. Details of the gas breakdown process, e.g., the time evolution of electrical and plasma characteristics, under rf excitation are far from being well understood.

Through a combination of experiments, particle in cell / Monte Carlo simulations and an analytical model, the time evolution of electrical and plasma parameters, and their intrinsic correlations during gas breakdown were investigated in a pulsed capacitive rf argon discharge with a relatively long power-off duration (Toff =400 µs) at 450 mTorr. Figures show that the system undergoes a sequence of distinct electron power absorption modes, i.e. "rf-avalanche", "overshoot", and "drift" modes, which were found to be highly correlated with the rapid changes of the system impedance as the plasma is building up.

The experiments show that the ignition process depends strongly on Toff, primarily because of the sensitivity to the remaining charge density. For longer Toff (e.g., Toff > 400 µs), the ignition process behaves like a gas breakdown, while for the cases of shorter Toff, the system goes through different mode transitions of electron power absorption.

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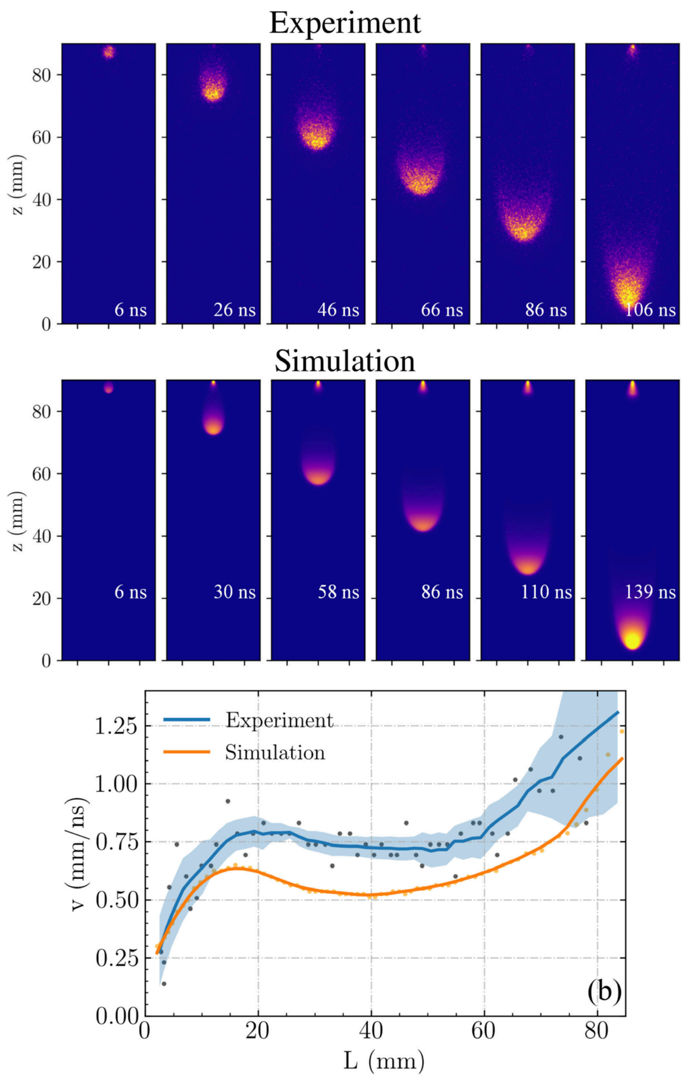
Dalian University of Technology, China

Source:
Y. X. Liu, et al., Plasma Sources Sci. Technol. **29**, 12LT03 (2020), https://iopscience.iop.org/article/10.1088/1361-6595/abcc7a
X-Y Wang, et al., Plasma Sources Sci. Technol. **30,** 075011 (2021), https://iopscience.iop.org/article/10.1088/1361-6595/ac0b56

Comparing Simulations and Experiments of Positive Streamers in Air: Steps toward Model Validation



Top: comparison of light emission between experiments and simulations. **Bottom:** comparison of streamer velocity versus streamer length.

In a recent collaboration we have quantitatively compared streamer discharge simulations and experiments, aiming towards model validation. The comparison was performed in air at 100 mbar using a plate-plate geometry with a protruding needle.

The experimental part of this investigation was carried out by the EPG group at Eindhoven University of Technology, where it was possible to capture the complete time evolution of reproducible single-filament streamers with a ns gate-time camera. The simulation part was carried out by the Multiscale Dynamics group at CWI, Amsterdam. A standard axisymmetric drift-diffusion-reaction fluid model was used to simulate streamers under conditions closely matching those of the experiments. Light emission profiles were used to directly compare streamer properties between simulations and experiments.

We observed good qualitative agreement during the entire discharge evolution, as shown in the figure. Quantitatively, the simulated streamer velocity was about 20% to 30% lower at the same streamer length. The effect of various parameters on the agreement between model and experiment was studied, such as the used transport data, the included plasma chemistry, the background ionization level, the photoionization rate, the gas temperature, the voltage rise time and the voltage boundary conditions. An increase in gas temperature due to the 50 Hz experimental repetition frequency could probably account for some of the observed discrepancies.

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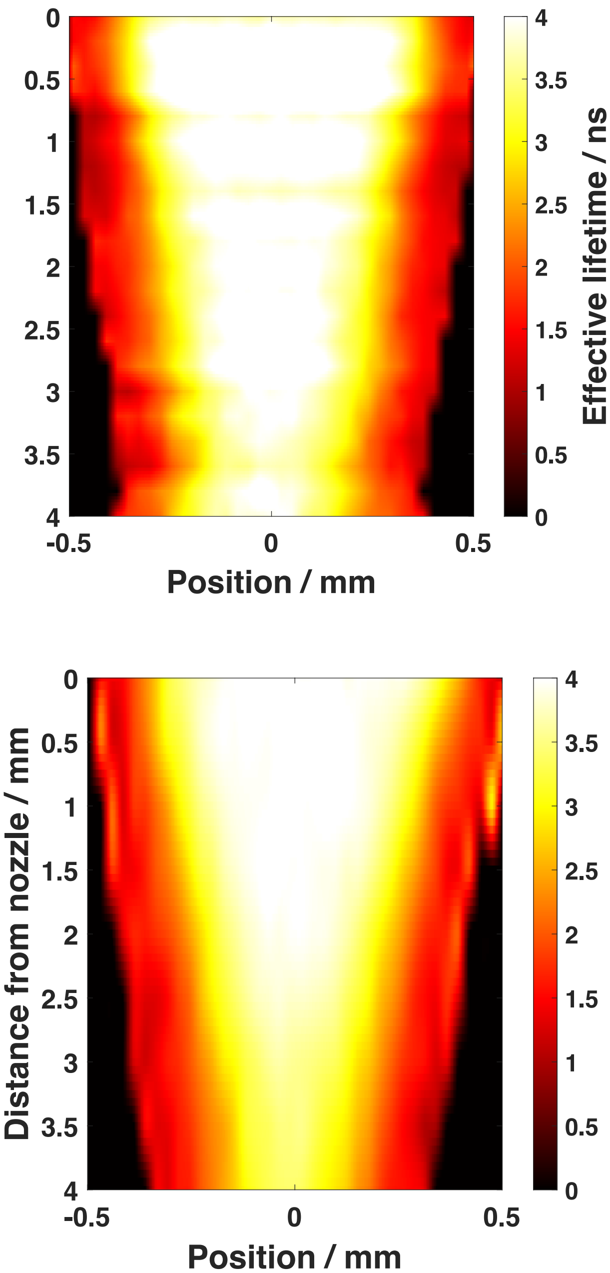
Source:
X. Li, S. Dijcks, S. Nijdam, A. Sun, U. Ebert, J. Teunissen, Plasma Sources Sci. Technol. **30**, 095002 (2021). https://doi.org/10.1088/1361-6595/ac1b36

Atomic Oxygen Density Determination in the Effluent of the COST Jet Using *in situ* Effective Lifetime Measurements in the Presence of a Liquid Interface



Spatially resolved effective lifetimes of laser-excited atomic oxygen in the eflluent of a He/O_2 (0.6%) plasma in an (**top**) open effluent out to 4 mm and (**bottom**) in the presence of a liquid surface at 4 mm. Effective lifetimes remain nearly unchanged in the presence of a liquid, with the exception of a small expansion of the helium core, indicated by longer lifetimes near the water surface.

Spatially resolved, absolute densities of atomic oxygen were measured for several helium-based admixtures in the effluent of the COST Reference Microplasma Jet using two-photon absorption laser induced fluorescence (TALIF). Admixtures investigated include a helium-only admixture, four helium/oxygen admixtures (0.1%, 0.5%, 0.6%, and 1.0% oxygen), and a helium/water admixture (2500 ppm water), chosen to coincide with previously published characterizations of plasma-treated liquid.

Measurements are conducted for the jet operating in ambient air with both an open effluent and a liquid surface present. The presence of a water surface does not appear to alter the background chemistry in the effluent but reduces O densities close to the liquid interface when compared to a similar distance from the nozzle in an open effluent case. This may be the result of a reduction in flow velocity caused by the liquid obstructing the gas flow.

Additionally, measurements near the liquid surface revealed a region of atomic oxygen well outside of where the core of the effluent impinges on the liquid. This is likely relevant for applications as it considerably expands the surface area subject to O absorption. Critically, *in situ* measurements of the effective lifetimes of the laser-excited $3p^3P_J$ state of atomic oxygen were recorded in the effluent by employing a picosecond (ps) laser and a nanosecond (ns) ICCD. By experimentally determining the contribution from collisional quenching via the *in situ* effective lifetime measurements, significant improvements in the accuracy of the atomic oxygen density calibration were made, with differences of approximately 30% from existing methods of estimating quenching rates at atmospheric pressure.

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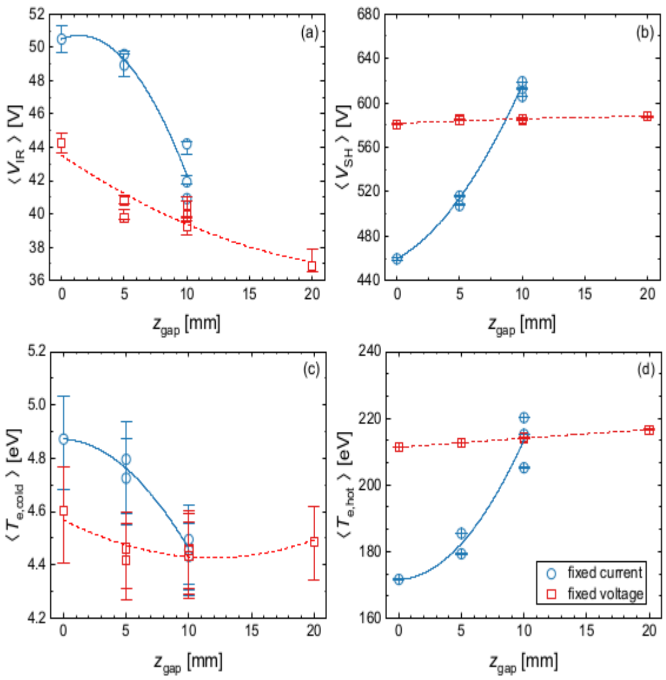
The Magnetic Field and Discharge Physics in the HiPIMS Discharge



Discharge parameters derived from the IRM: (a) potential drop over the IR V_{IR}, (b) cathode sheath potential V_{SH}, (c) temperature of the cold electron group, (d) temperature of the hot electron group. All parameters are averaged over the pulse length.

In a magnetron sputtering discharge the residence time of the electrons in the vicinity of the cathode target is extended by the presence of a static magnetic field. This transverse magnetic field enables a potential drop to exist outside the cathode sheath, the ionization region (IR). The discharge voltage thereby falls over the cathode sheath and the IR, i.e., $V_D = V_{SH} + V_{IR}$. We use the sum of the two distances of the central and the edge magnet from the rear of the target $z_{gap} = z_C + z_E$ to describe the magnetic field.

In a recent study we explore how the magnetic field affects internal discharge parameters of a high-power impulse magnetron sputtering (HiPIMS) discharge. The discharges were controlled by keeping the peak discharge current constant (fixed current mode) or by keeping the discharge voltage constant (fixed voltage mode) while the magnetic field configuration was varied and adjusting the pulse repetition frequency to keep a constant average power.

The ionization region model (IRM), a global plasma-chemistry model based on energy and particle balance, is used to obtain a set of internal discharge parameters. For both fixed current and fixed voltage operating modes V_{IR} decreases with increasing z_{gap} (correlated to weaker magnetic fields). The fixed voltage cases have only a small increase of V_{SH}, the fixed current cases show a strongly increasing V_{SH}, with increasing z_{gap}. The trends in V_{IR} for both discharge modes are mimicked by the temperature of the cold electron group (compare Figures (a) and (c)) as the Ohmic heating depends on V_{IR}. Most of the power delivered to Ohmic heating is deposited on the cold electrons, simply because they have a higher number density compared to the hot electron group.

Similarly, the trends in V_{SH} for both discharge modes are mimicked by the temperature of the hot electron group (compare Figures (b) and (d)). This observation can be explained by the hot electrons gaining their energy in the cathode sheath and that the energy gain corresponds to exactly the sheath voltage V_{SH}.

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New Resources

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Career Opportunities

- **Post-Doctoral Position in Ionic Liquid Ion Sources for Materials Fabrication, University of Southampton, UK**

Applications are invited for a Post-Doctoral Research Assistant (Research Fellow) position within the Astronautics Group, in the Department of Aeronautics and Astronautics at the University of Southampton UK (https://www.southampton.ac.uk/engineering/about/staff/cnr1e15.page).

Gallium Liquid Metal Ion Sources (LMIS) are the standard choice for ion beam material etching, facilitating ion beam lithography as the go-to technique for in situ microfabrication. Many microfabrication applications would benefit though from a more flexible ion beam source, with different ion beam species significantly influencing the physical and chemical nature of the milling results, for example reducing ion implantation or enhancing etching through using chemically reactive ions. One such option is Ionic Liquid Ion Sources (ILIS), where rather than extracting ions from a liquid metal such as gallium, ions can be extracted from a molecular ionic liquid. Through the use of Ionic Liquids, there is a far greater choice of ion type that can be emitted, across a much larger range, offering the ultimate flexible ion source. Recently there have been great improvement in the operation of ILIS's through the development of their use for ion thrusters for spacecraft.

The post will work on the development of Ionic Liquid Ion Sources as focused ion beam sources for material fabrication. It will involve detailed characterisation of these sources and their interaction with substrates, in collaboration with the Optoelectronics Research Centre and their world class clean room facilities, through collaboration with Dr. Oleksandr Buchnev, ORC. The work is a direct spin out of our work on electrospray ion thruster technology, and we welcome people who have worked in this field to apply. We also welcome applicants from other disciplines such as ion beam technology, experimental plasma physics, materials engineering, etc.

The post is offered on a full-time, fixed term basis for 3 years. The start of the position is October/November 2021, but can be flexible up to March 2022. There will be excellent flexibility within the post to investigate various aspects of ionic liquid ion source technology, as part of this large Research Council funded project:

https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V04995X/1

It is desirable that the person has experience in designing and testing ion thruster technology or ion beam experience, or a demonstrated aptitude for learning new fields of research. The person should have a PhD in aerospace engineering, experimental beam physics, or materials engineering focused on ion beam uses. It is desirable that the person has experience of operating large vacuum chamber facilities, and a strong aptitude towards experimental testing. Additionally, a strong track record of high-quality journal publications is an advantage.

If you are interested in this position, further information and the application procedure can be found here: https://jobs.soton.ac.uk/Vacancy.aspx?id=26421&forced=2

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- **PhD Studentship - Using Ionic Liquid Ion Sources for Focused Ion Beam applications: Investigating the fundamentals, University of Southampton, UK**

  Applications are invited for a PhD studentship within the Astronautics Group, in the Department of Aeronautics and Astronautics, University of Southampton, UK, investigating the fundamentals of the emission process from ionic liquid ion sources (https://www.southampton.ac.uk/engineering/about/staff/cnr1e15.page).

  Gallium Liquid Metal Ion Sources (LMIS) are the standard choice for ion beam material etching, facilitating ion beam lithography as the go-to technique for in situ microfabrication. Many microfabrication applications would benefit though from a more flexible ion beam source, with different ion beam species significantly influencing the physical and chemical nature of the milling results, for example reducing ion implantation or enhancing etching through using chemically reactive ions. One such option is Ionic Liquid Ion Sources (ILIS), where rather than extracting ions from a liquid metal such as gallium, ions can be extracted from a molecular ionic liquid. Through the use of Ionic Liquids, there is a far greater choice of ion type that can be emitted, across a much larger range, offering the ultimate flexible ion source. Recently there have been great improvement in the operation of ILIS's through the development of their use for ion thrusters for spacecraft.

  The post will work on the development of Ionic Liquid Ion Sources as focused ion beam sources for material fabrication. It will involve detailed characterisation of these sources and their interaction with substrates, in collaboration with the Optoelectronics Research Centre and their world class clean room facilities, through collaboration with Dr. Oleksandr Buchnev, ORC. The work is a direct spin out of our work on electrospray ion thruster technology, and we welcome people who have worked in this field to apply. We also welcome applicants from other disciplines such as ion beam technology, experimental plasma physics, materials engineering, etc.

  The PhD will investigate the fundamentals of ion emission from an Ionic Liquid Ion Source, investigating the properties of the beam using various diagnostic techniques, using the excellent facilities at the David Fearn Electric Propulsion Laboratory:
  https://www.southampton.ac.uk/engineering/research/facilities/analytical_facilties.page

  The PhD studentship will focus on experimental investigating fundamental aspects of ILIS's. Particular emphasis will be put on gaining insight into the ion emission process, the use of novel ion liquids, and the imaging of the ion emission source. The PhD is part of a large EPSRC funded project:
  https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V04995X/1

  The project is a collaboration between the Astronautics Group at the University of Southampton, through Dr Charlie Ryan, and the Optoelectronics Research Group, through Dr Oleg Buchnev. The PhD will have unique access to both the Electric Propulsion Laboratory, and the world class clean room of the ORC:
  https://www.orc.soton.ac.uk/facilities

  Entry Requirements: a very good undergraduate degree (at least a UK 2:1 honours degree, or its international equivalent). Start of post: October 2021, but can be flexible up to March 2022.

  If you are interested in this position, further information and the application procedure can be found here:
  https://jobs.soton.ac.uk/Vacancy.aspx?ref=1467521DA

  Contact:
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  University of Southampton, UK
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- **Post-Doctoral Position, Development of Laser-Based Measuring Systems, Leibniz Institute for Plasma Science and Technology, Greifswald, Germany**

The department of Plasma Diagnostics at the Leibniz Institute for Plasma Science and Technology (INP) in Greifswald, Germany, invites applications for a postdoc position.

The department of Plasma Diagnostics is engaged in the development and application of laser-based diagnostics for the characterization of plasma-chemical processes and plasma-surface interactions. Within our running research activities, the main task will be the further development of AOM-lasers for applications in laser spectroscopy, a new approach for enhanced tuning of diode lasers based on the frequency controlling of intra-cavity acousto-optic modulators (AOMs).

Our institute ranks among the largest and most modern institutions in the field of low-temperature plasmas worldwide. In an international working environment, we conduct socially relevant research within our core areas *Materials & Energy* and *Environment & Health*. Currently the INP employs about 200 scientists and staff at three locations (Greifswald, Rostock and Karlsburg). For further information, please visit our website at https://www.inp-greifswald.de/en/.

Full details of the advertised position can be found under the following link:

https://inp-greifswald.dvinci-easy.com/en/jobs/20287/0437-post-doc-fmx-development-of-laser-based-measuring-systems.

Applicants should send their application (motivation letter, CV, copies of academic degrees, and letters of reference) to **Mrs. Gabriele Lembke** giving the keyword "0437 Post Doc Laser-based Measuring Systems" - *preferably via our online application form* – **until 3 October 2021**.

Alternatively, the application can be sent to the Human Resources Department, e-mail: bewu@inp-greifswald.de.

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Collaborative Opportunities

Please submit your notices for Collaborative Opportunities to iltpc-central@umich.edu.

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