# International Low Temperature Plasma Community

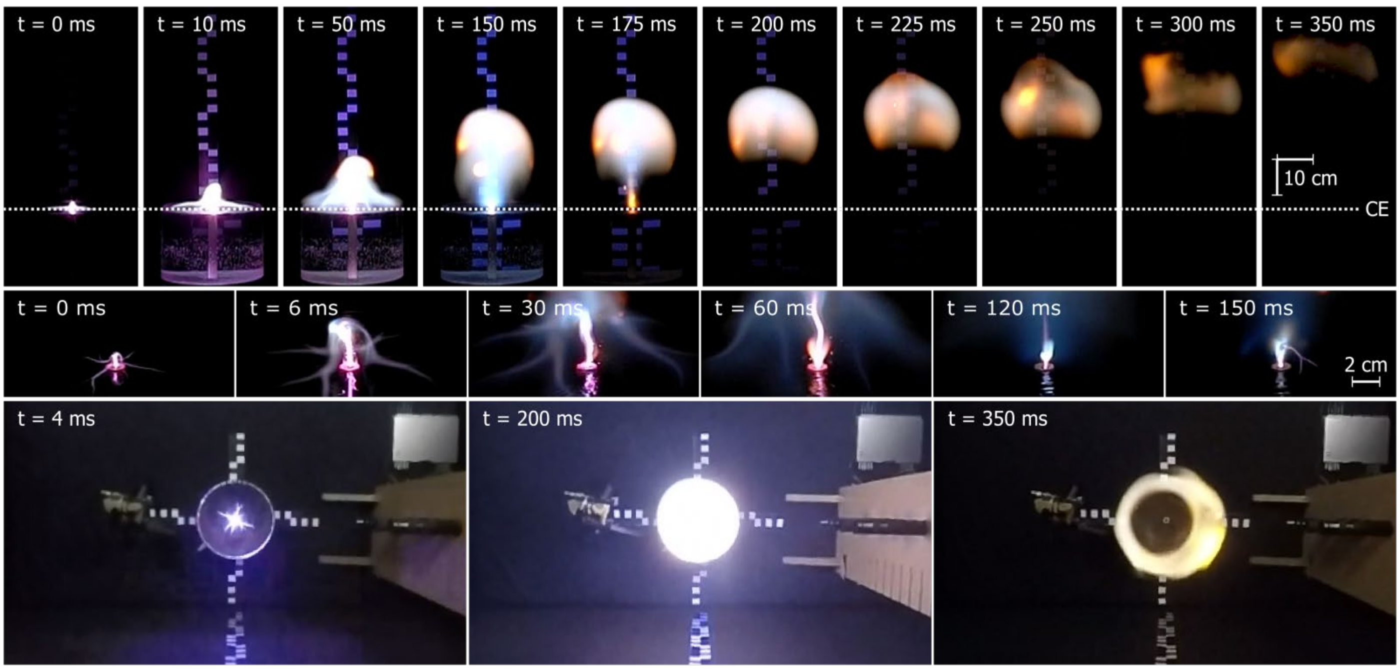
https://mipse.umich.edu/iltpc.php, iltpc-central@umich.edu

# Newsletter 09

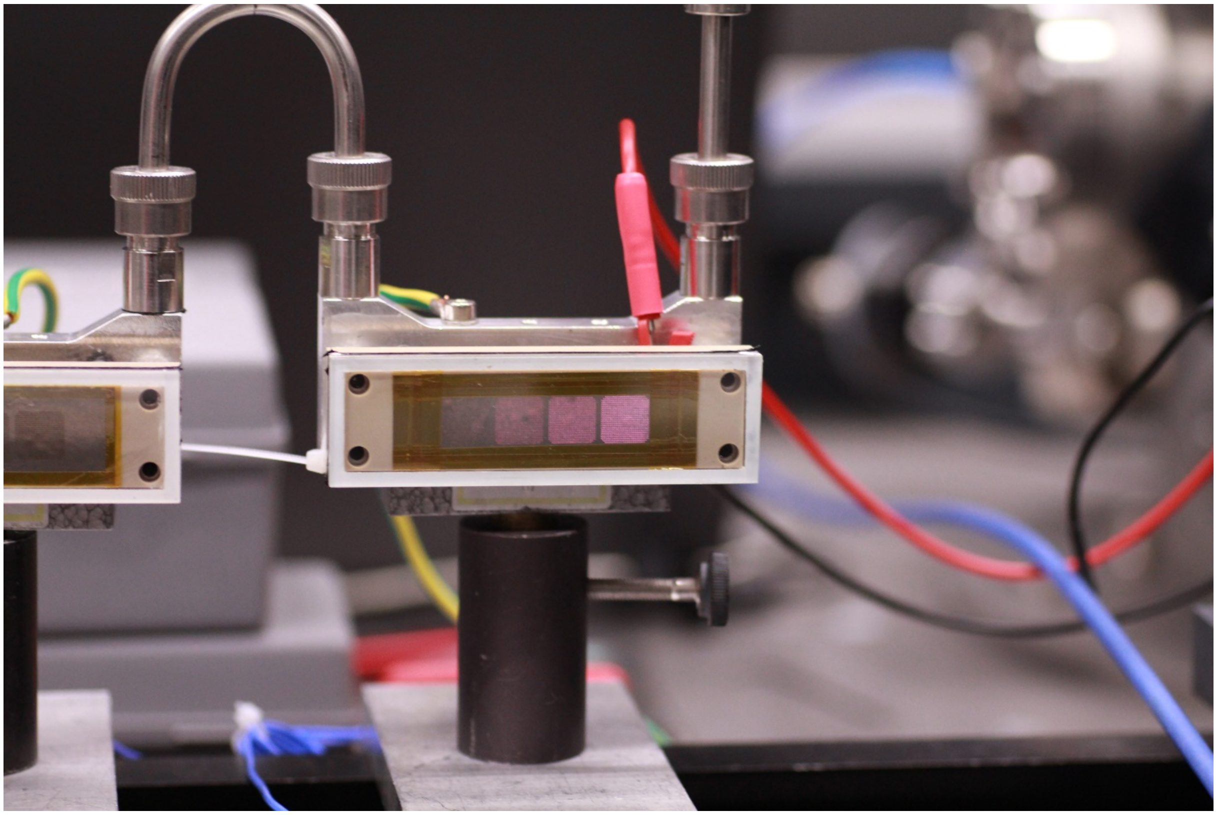
17 December 2020

## Images to Excite and Inspire!

Thank you for submitting your images, some of which are shown here. Those images already submitted will appear in later Newsletters. Please do send your images (with a short description or source) to iltpc-central@umich.edu. The recommended image format is JPG or PNG; the minimum file width is 800 px.




**Plasmoids from Water** - Evolution of long-lived plasmoids (https://www.ipp.mpg.de/2977926/kugelblitze), emerging from a high-voltage discharge above a water surface (6 l of tap water) were imaged by high-speed cameras with different frame rates and at different angles: (top) side view at 600 fps, (middle) focused on the central electrode (CE) at 1200 fps, (bottom) view from top at 240 fps. Streamers above the water surface make a plasma "cloud" (blur effect), which is the electrical connection for the jet emanating from the CE. The jet feeds a spherical plasmoid evolving at its end. At 150 ms the connection to the power supply is capped and the autonomous phase starts, generating a free floating ball-shaped plasmoid with a diameter of 25±2 cm. The plasmoid as a whole is a vortex from the very beginning, which is revealed at the end of its lifetime when it turns into a torus, as seen in the top view video. The luminous lifetime of the plasmoid in the visible spectral range is about 500-600 ms, while in the IR its lifetime is longer than 1.5 s. Spatio-temporal high-speed diagnostics including spectroscopy were applied to analyze the phenomena, confirming that the plasmoid is a low-temperature tap-water plasma. The high-speed videos, from which these frames were taken, can be found at the URL above and in the published article. **Dr. Roland Friedl**, U. of Augsburg, roland.friedl@physik.uni-augsburg.de, **Dr. Ursel Fantz**, Max Planck Institute for Plasma Physics, ursel.fantz@ipp.mpg.de. *Source*: R. Friedl, U. Fantz, I. Pilottek, D. Schmid, and S. Steibel, "Spatio-temporal structure and emission of a large plasmoid in atmosphere", J. Phys. D: Appl. Phys., in press (2020), https://doi.org/10.1088/1361-6463/abc918.



**Micro-plasmas Make Big Impact** – Micro-cavity plasma-arrays (MCPA) show great potential for applications such as plasma catalysis and decomposition of volatile organic compounds (VOCs). For that, a reactor including a metal-grid array device was developed and realized by the following three-layer structure: A magnet working as a grounded electrode is inserted in a plastic carrier and completely covered with a 40 µm thick ceramic foil (zirconium oxide) as a dielectric. A 50 µm thick nickel foil containing four different cavity-structures in a row is then magnetically attached on the top of the dielectric and works as a powered electrode. Each cavity-structure contains thousands of uniformly arranged cavities whose diameter changes from structure to structure. In the case of this image, 200, 150, 100 and 50 µm cavity diameters are simultaneously operated under the same conditions. Finally, this complete structure is enclosed by a glass case whereby a gas flow operating system and optical access for diagnostics are realized. Due to the magnetic character of the nickel foil, this three-layer structure can be dismounted to exchange its components. For example, a dielectric covered with a catalyst (manganese oxide) can be integrated into the device and in place of cavities, channels and trenches can be engraved in the nickel foil. A second nice feature is that these components can be investigated after the plasma operation with surface diagnostics such as the X-Ray photoelectron spectroscopy (XPS). **S. Dzikowski, V. Schulz-von der Gathen, M. Böke**, **A. von Keudell**, Ruhr University-Bochum, Achim.vonKeudell@rub.de.

## Call for Contributions

Please submit content for the next issue of the Newsletter. Please send your contributions to iltpc-central@umich.edu by **January 15, 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_v03.docx. The highlight consists of an image and up to 200 words of text. 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.

## LTP Perspectives: Policy, Opportunities, Challenges

**Can Plasma Save 10 Billion People?**

Every morning, when I flip through the newspaper, I read painful news such as the Corona infection, global warming, environmental deterioration, food problems, and a super-aging society (especially in Japan). The United Nations has set 17 Sustainable Development Goals (SDGs), and many communities are working towards these goals.

One form of core technologies that is expected to contribute to achieving these goals is plasma technology, and it is the subject of active research and development worldwide for the perpetual development of humanity, but is it true? I believe that the answer is, of course, yes, although future directions may not be clear at present.

What we can say for certain is that for creating a society based on artificial intelligence, plasma etching technology is an extremely important tool. In addition, fusion power generation cannot be realized without the use of plasma. In order for plasma technology to continue to evolve, it is important to search for applications that can only be achieved using plasma ("*killer plasma applications*"). New applications in plasma medicine and agriculture are being actively researched, but there are many competing methods. In addition to approaches such as genome editing and iPS (induced pluripotent stem cell) medical care, it is necessary to investigate medical and agricultural applications that can only be achieved using plasma.

If such plasma-only applications are not actively developed, the full benefits of plasma-based technology to humanity will not be realized.

To that end, it will be necessary to expand the range of topics investigated by the plasma research community. There are many unexplored potential plasma applications not only on Earth but also in space, but it seems that we have not yet found a *killer plasma application* or investigated the science behind it.

To quote Dr. Leo Esaki, the Nobel Prize winner in Physics (semiconductors) in 1973: "Leave the path you always walk, dive into unexplored forests, and search for new things." This is the approach we should be taking. In particular, young researchers have sufficient time to spend more than 30 years doing research.

Recently, while observing the interaction between plasma and liquid, I felt a sense of romance about the possibility of new applications of plasma in the oceans (ocean plasma), which occupies 70.8% of the earth's surface but have not yet been used for plasma applications.

So I would like to encourage everyone to take courageous steps forward to venture into the unexplored forest with a strong desire to benefit humanity.

**Dr. Masaru Hori**
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## Tribute to Prof. Vladimir Fortov

With deep sadness, we inform the scientific community that Academician Vladimir Fortov, an outstanding scientist and organizer of science passed away on 29 November 2020 due to the Covid-19 virus.

Vladimir Fortov was born on January 23, 1946 in the city of Noginsk, Moscow region. He received the PhD degree from the Moscow Institute for Physics and Technology (MIPT) in 1971 and his Doctor of Science Degree (the highest scientific degree in Russia) in 1977. In 1991 he was elected to be academician of the USSR Academy of Sciences. In 2013-2017 V. E. Fortov was the President of the Russian Academy of Sciences. He was also the Director and the scientific Adviser of the Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS), and the head of the MIPT department.

Academician V. E. Fortov was a world-class scientist. His scientific research is of fundamental importance for the development of physics of extreme state of matter, plasma physics, space physics, and rocketry. He developed a general theory for constructing wide-range equations of state of matter, developed new methods for converting chemical energy into energy of electromagnetic radiation and electrical energy. He investigated the processes occurring under pulsed action of powerful energy on materials.

Vladimir Fortov carried out pioneering experimental studies of the structural and dynamic properties of plasma-dust crystals. The first experiments on crystalline plasmas in microgravity were carried out on board the Russian space station Mir (Plasma Crystal-1, Crystal-2 projects). Then, the Plasma Crystal-3 experiment was carried out on the International Space Station (jointly with Germany). He is the author of over 30 monographs and over 900 original and review scientific articles. Vladimir Fortov supervised more than 30 students to their Ph.D. degrees and over 10 doctoral theses.

In recognition of his contributions to science, he was awarded numerous prizes in Russia and abroad. In particular, he received international awards: Hannes Alfvén Prize (2003), UNESCO Albert Einstein medal (2005), Order of Merit of the Federal Republic of Germany (2006), Legion of Honour (2006), and Global Energy Prize (2013).

V. E. Fortov was a fellow of a number of foreign academies and scientific societies: the European Academy of Sciences, the Royal Academy of Engineering of Great Britain, the Swedish Royal Academy of Engineering, the Max Planck Society, the German Academy of Sciences, the US National Academy of Engineering, the US National Academy of Sciences, the American Physical Society and many others. He was an honorary member of 11 universities in Russia and abroad.

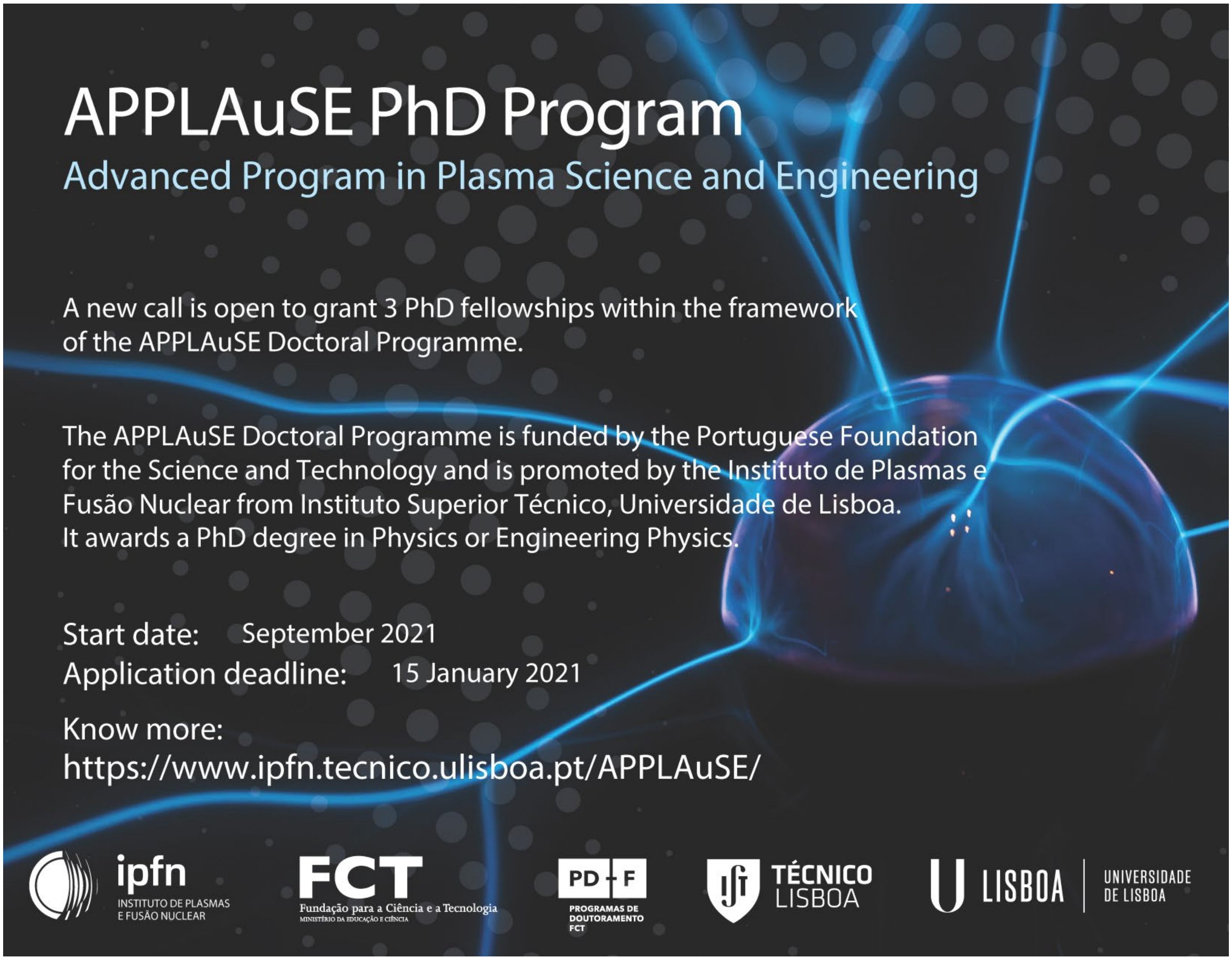
Vladimir Fortov participated in the elimination of the consequences of the accident at the Chernobyl nuclear power plant. He sank in a bathyscaphe to the bottom of Lake Baikal and took part in expeditions to the North and South Poles. Fortov was fond of mountain skiing, tennis and extreme travel. He crossed the Atlantic Ocean on a yacht, bypassed Cape Horn and Cape of Good Hope.

Vladimir Evgenievich Fortov was always full of new ideas. The bright memory of Vladimir Evgenievich will forever remain in our hearts.

**Prof. E. E. Son**
Academician, Russian Academy of Sciences
Joint Institute for High Temperatures & MIPT
**Dr. N. Yu. Babaeva**
Senior Research Scientist
Joint Institute for High Temperatures, RAS, Russia

## General Interest Announcements

- **APPLAuSE PhD Program in Plasma Science and Engineering at the Instituto de Plasmas e Fusão Nuclear from Instituto Superior Técnico, Universidade de Lisboa**




- **Research Internships for Graduate Students at the US Air Force Research Laboratory**

  Fostering the growth of a globally competitive and diverse research workforce and advancing scientific and innovation skills is a strategic objective of the US National Science Foundation (NSF). The NSF and US Air Force Research Laboratory (AFRL) have entered into a partnership to support the training of graduate students to meet both the NSF's strategic workforce development objectives as well as the AFRL's mission to lead the discovery, development and delivery of new technologies for our air, space and cyberspace interests. More information is available from: https://www.nsf.gov/pubs/2021/nsf21029/nsf21029.jsp.

  Interested NSF Principal Investigators are encouraged to consider this opportunity and should contact their cognizant program director at their earliest convenience.

  *For further information, please contact:*
  **Dr. Prakash Balan**
  pbalan@nsf.gov

- **The ILTPC is maintaining a list of LTP conferences**. With many meetings being canceled and rescheduled, we thought this would be useful for minimizing conflicts and planning future trips. The data may not be 100% accurate, so please let us know of changes in conference scheduling. View-only link to the schedule: https://docs.google.com/spreadsheets/d/1XoD6Fn7AP0HFTQJpPCETrRIQhx8ID-isz4XUMyv9X7zo/edit?usp=sharing.

  *Contact:*
  **ILTPC**
  iltpc-central@umich.edu

## Meetings and Online Seminars

- **Online LTP Seminar**

  The Online Low Temperature Plasma (OLTP) Seminar series schedule for January – June 2021 is available at: https://mipse.umich.edu/ltp_seminars.php. The first seminar in the new series will be presented by Prof. Ali Mesbah (Deep Learning-based Controllers for LTPs) on **January 26, 2021**.

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

  The International Online Plasma Seminar (IOPS) will soon announce its schedule of seminars for January – June 2021. The new seminar format will include:

  *Research Highlight (*20 minutes + questions): This presentation is intended to summarize a recent publication and is more highly focused on the topic of the publication.

  *Tutorial/Review* (30-45 minutes + questions): This presentation more broadly addresses a topic and is more like a traditional departmental seminar.

  The program for IOPS will be available at: https://mipse.umich.edu/online_seminars.php

  ***Speaker Nominations:*** Nominations are solicited for speakers for the July – December 2021 sessions of IOPS. Two types of seminars will be presented (please see above). Please submit nominations via this Google form with a deadline of **31 May 2021**: https://forms.gle/7B1NxZ6jRXKSTDFJ9.

- **MIPSE (Michigan Institute for Plasma Science and Engineering) Seminar Series**

  The MIPSE seminar series, usually held as an in-person event, will be totally virtual this Winter. There will be five seminars during Winter 2021 covering the full range of plasma topics (not only LTP). The seminars are held on Wednesdays at 3:30 pm (US East Coast Time). The schedule and abstracts can be viewed at https://mipse.umich.edu/seminars_2021.php. Please send a request for the Zoom link to view the seminars to mipse-central@umich.edu. Seminars will be recorded and posted (with slides) at the same website.

  Past MIPSE seminars (recordings and slides) can be viewed from: https://mipse.umich.edu/seminars.php.

  Interviews of past seminar speakers can be viewed from: https://mipse.umich.edu/life_overview.php.

  *Contact:*
  **MIPSE Central**
  mipse-central@umich.edu

- **7th International Workshop on Plasma for Cancer Treatment (IWPCT-2021)**

  It is our pleasure to announce the *7th International Workshop on Plasma for Cancer Treatment (IWPCT-2021)* that will take place at the Universitat Politècnica de Catalunya (UPC), in Barcelona on **June 29-30, 2021** (switching to hybrid or virtual meeting depending on the future travel and sanitary restrictions).

  The field is advancing at a huge pace, so in this challenging period, the intent of the Workshop is to bring together researchers in the field of Plasma Oncology and Plasma Medicine from all over the world, to discuss recent progress and contribute to the advance of plasmas in cancer.

  There will be 8 invited talks - some already confirmed - 18 contributed oral presentations and 2 poster sessions over two days. Abstract submission is open until **January 30, 2021**. For more details, please visit our webpage: https://myevent.upc.edu/go/iwpct2021.

  The workshop will be preceded by a 1 day *Mini-Course on Plasma & Cancer* organized by **Prof. Vandana Miller**, **Prof. Mounir Laroussi**, and **Prof. Annemie Bogaerts** on June 28.

  *Contact:*
  **Prof. Cristina Canal** and **Prof. Cédric Labay**
  Chairs of IWPCT2021
  Universitat Politècnica de Catalunya
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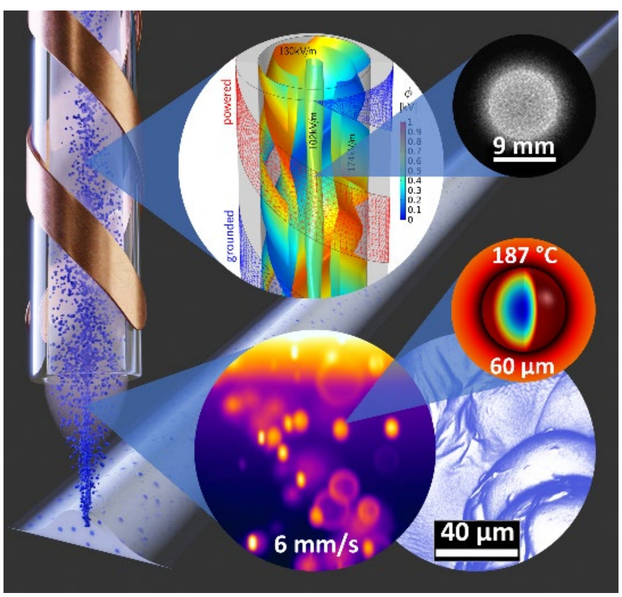
## Community Initiatives and Special Issues

Please submit your announcements for Community Initiatives and Special Issues to: iltpc-central@umich.edu.

## Research Highlights and Breakthroughs

### HelixJet – an Unexpectedly Homogeneous and Stable Form of Plasma at Atmospheric Pressure




HelixJet in action, detailed views combine experiments and modelling (https://doi.org/10.1002/ppap.202070001)

The well-thought-out geometry of double-helical electrodes made it possible to generate a homogeneous glow discharge in argon at atmospheric pressure in a large volume. In view of the complicated three-dimensional structure of the electric field, the homogeneity of this discharge is surprising. Its stability is not disturbed even by small admixtures of other gases or the presence of microparticles. Such a plasma source is suitable for the effective treatment of nanomaterials and microparticles. The HelixJet was designed as a promising plasma source for plasma 3D printing. Other advantages of the source are the low consumption of working gas compared to usual plasma jets and also the low power consumption which allows the operation without active cooling.

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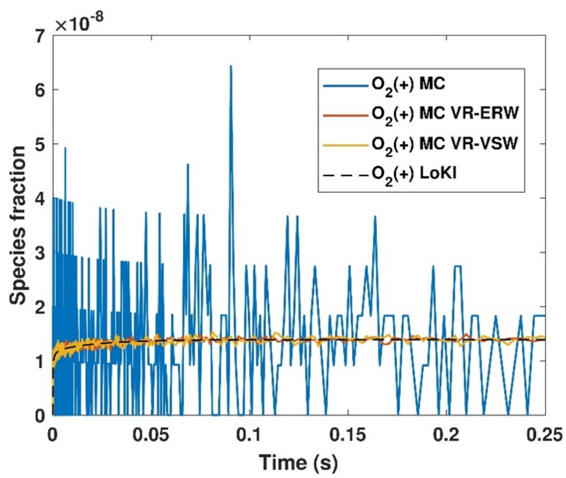
*Source:* J. Schäfer et al, Plasma Process Polym. **17**, e1900099 (2020). https://doi.org/10.1002/ppap.201900099

## Kinetic-Monte Carlo Simulations of Plasma Chemistry




Temporal evolution of the $O_2^+$ fraction in an oxygen glow discharge at 1 Torr. The KMC description (with/without variance reduction) is compared with the results of a system of rate-balance equations obtained with LoKI-C.

The interest in nanosecond pulsed discharges has been rising quickly due to their strong non-equilibrium properties. The typical plasma-chemistry models based on the low-anisotropy and quasi-stationary approximations to the Electron Energy Distribution Function may fail to describe these discharges correctly, due to the high reduced electric fields (E/N) and very short timescales involved. These limitations can be avoided with a self-consistent and unified formulation based on Kinetic Monte Carlo (KMC) techniques. A simultaneous KMC description of the electron and heavy-species kinetics would enable a rigorous inclusion of the time-dependent influence of different excited states in the electron kinetics and vice-versa, and would not be limited to a restricted range of E/N.

As a first step to achieve such unified formulation, a KMC algorithm to solve gas-phase chemistry was implemented and validated in the thermodynamic limit. However, the densities of the minority species have considerable fluctuations. Two novel variance-reduction methods (ERW and VSW) were developed to circumvent this problem. They significantly improve the description of the minority species in relation to the standard method, as illustrated in the figure for $O_2^+$ ions, with gains in computational time by a factor of about $10^4$.

*Contact:*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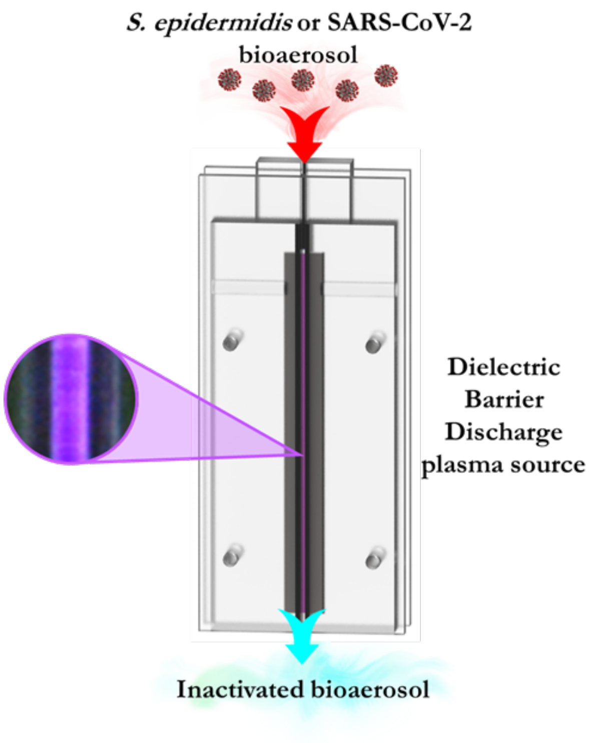
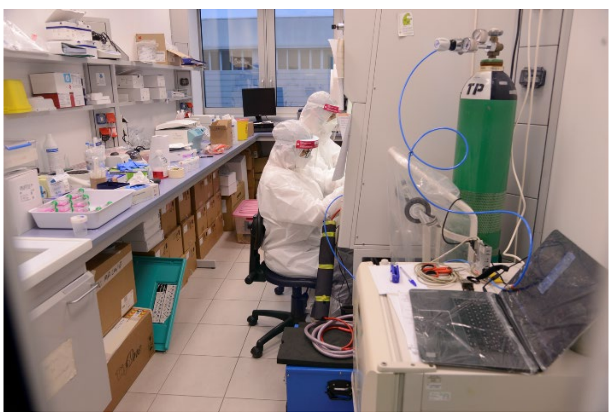
*Source:*

Plasma Sources Sci. Technol. **29**, 115003 (2020).

**Cold Atmospheric Plasma Inactivation of Aerosolized Microdroplets Containing SARS-CoV-2 to Combat Airborne Indoor Transmission**



Schematic of the experimental set-up (top) and experimental setting in Class III biological safety laboratory (bottom).

Among the COVID-19 pandemic spreading routes, airborne transmission seems to have a key role as highlighted by the growing evidence that SARS-CoV-2 virus can survive indoor in aerosolized microdroplets up to 3 hours, travelling many meters. Cold atmospheric pressure plasmas (CAPs) represent a promising solution to combat airborne transmission, thanks to their ability to produce a blend of many reactive species, which have antimicrobial properties. Recently, our research team evaluated the efficacy of a lab-scale dielectric barrier discharge plasma device in the inactivation of aerosolized *Staphylococcus epidermidis* and purified RNA of SARS-CoV-2. Results (through bacterial log reduction and RT-PCR assay, respectively) show that direct contact between plasma and bioaerosol can induce a log R around 3.76 on bacteria and fully degrade viral RNA, with a particle residence time in the discharge zone of 0.18 seconds. In the frame of a Region Emilia-Romagna funded industrial research and innovation project to combat the spread of COVID-19, investigations on the effects of CAPs on bioaerosols containing viable SARS-CoV-2 virus have been conducted in the Class III biological safety lab of the Microbiology Unit, Great Romagna Hub Laboratory, Pievesestina, Italy. Results show a complete reduction of the virus infectivity induced by CAP treatment (results soon to be published).

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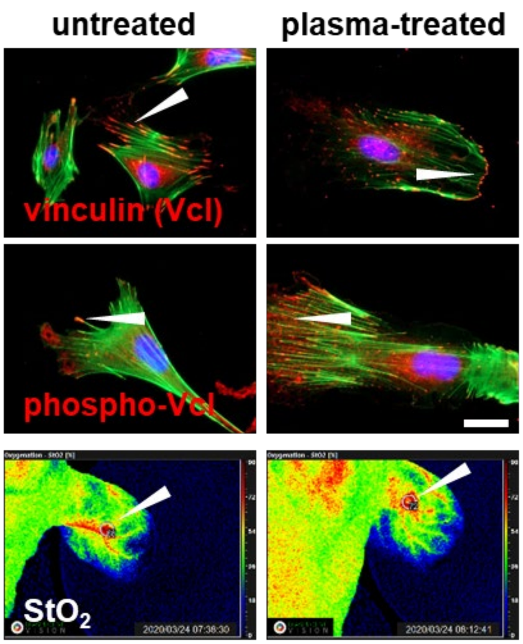
*Source*:
https://doi.org/10.1002/ppap.202000154

*More information*: http://plasmagroup.ing.unibo.it

## Gas Plasma-spurred Wound Healing is Accompanied by Regulation of Focal Adhesion, Matrix Remodeling, and Tissue Oxygenation




The structural adapter protein vinculin (Vcl, red) regulating actin network (green) was found to stain stronger at the leading-edge lamellipodia and filopodia (arrowhead) in gas plasma-treated skin cells (nucleus, blue). Gas plasma exposure increased skin oxygenation ($StO_2$) and tissue perfusion during ROS-driven wound healing.

We combined in vitro analyses in primary dermal fibroblasts isolated from murine skin with in vivo studies in a murine wound model. Our model highlights gas plasma treatment mechanisms as a critical modulator of cell adhesion during wound healing via several molecular elements.

Substantial gene expression changes accompanied gas plasma-driven migration and the spreading of skin cells together with dynamic regulation of integrin adhesions. These results were supported by finding: i) phosphorylation of the focal adhesion kinase and paxillin, ii) alterations of structural proteins (e.g., vinculin) and actin organization, and iii) formation of new cell-matrix contacts. Gas plasma-derived ROS promote the physical integrity of healed skin, presumably via modulation of collagen deposition, the extracellular matrix degradation, and a wound healing stage-dependent regulation of proteinases (e.g., MMPs). This was attended by an enhanced oxygenation and tissue-hemoglobin perfusion of the superficial skin layer. These findings shed further light on targeting distinct cell populations (e.g., dermal fibroblasts) and novel therapeutic interventions using gas plasma technology to alleviate defective wound healing.

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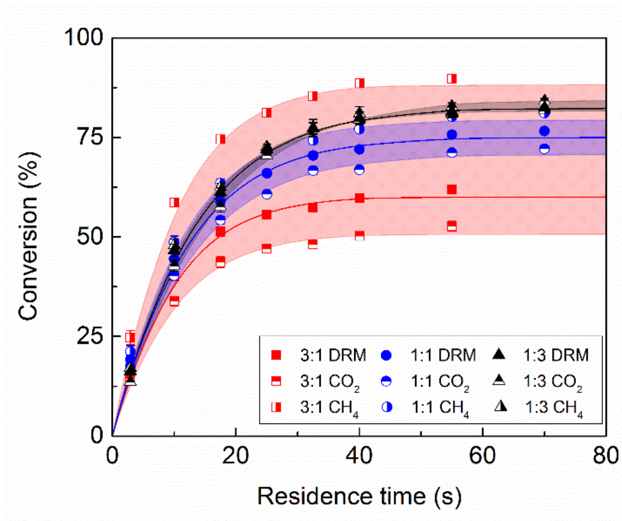
*Source:*
Redox Biology **38**: 101809 (2021).
https://doi.org/10.1016/j.redox.2020.101809

## On the Kinetics and Equilibria of Plasma-based Dry Reforming of Methane




Total conversion of dry reforming of methane (DRM), for three different $CO_2$:$CH_4$ ratios, and the individual $CO_2$ and $CH_4$ conversions, plotted as function of residence time, as well as apparent first-order reversible reaction fits.

We performed experiments for dry reforming of methane (DRM) in an extended residence time range (2–75 s) in a dielectric barrier discharge plasma, and fitted the gas composition to a first-order kinetic model of the evolution towards partial chemical equilibrium (PCE), to extract apparent kinetic parameters for the loss and formation processes of $CO_2$ and $CH_4$. We investigated the differences in kinetic characteristics and PCE state of the $CO_2$ dissociation and $CH_4$ reforming reactions, how these are mutually affected when combining both gases in DRM, and how they change upon adding a packing material. $CO_2$ dissociation is characterized by a relatively high reaction rate coefficient of 0.120 $s^{-1}$ compared to $CH_4$ reforming at 0.041 $s^{-1}$; whereas $CH_4$ reforming reaches higher equilibrium conversions, 82% compared to 54% for $CO_2$ dissociation. Combining both feed gases enables DRM to proceed at a relatively high rate coefficient (0.088 $s^{-1}$), and high conversion (75%) compared to $CO_2$ dissociation, through accessing new chemical pathways between the products of $CO_2$ and $CH_4$. This study reveals the delicate balance of the combined chemistry: $CO_2$ drives the loss reactions in DRM, whereas $CH_4$ appears to suppress back reactions.

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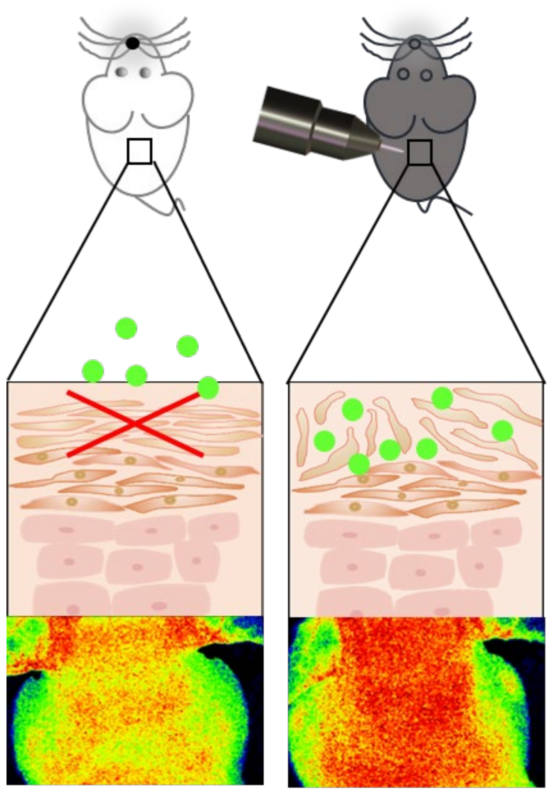
*Source:*
Chem. Eng. J., **405** 126630 (2021).
https://doi.org/10.1016/j.cej.2020.126630

**The Molecular and Physiological Consequences of Gas Plasma Treatment in Murine Skin and Its Barrier Function**



Exposure to gas plasma-derived reactive species enhanced the penetration of a lipophilic substance (green) into the stratum corneum and oxygenation of intact skin in a mouse model (hyperspectral images of the neck of a mouse).

Gas plasma technology is an emerging tool facilitating the spatially controlled delivery of a multitude of reactive species (ROS) to the skin. While the therapeutic efficacy of plasma treatment has been observed in several types of diseases, the fundamental consequences of plasma-derived ROS on skin physiology remain unknown.

Transcriptomic analysis of plasma-treated skin revealed a modulation of genes involved in regulating the junctional network (tight, adherence, and gap junctions), which was confirmed using quantitative PCR, Western blot, and immunofluorescence imaging. Plasma treatment increased disaggregation of cells in the stratum corneum (SC) concomitant with increased tissue oxygenation, gap junctional intercellular communication, and penetration of the model drug curcumin into the SC. This was preceded by altered oxidation of skin lipids and their composition in vivo as shown by LC/MS. These findings suggest plasma technology to be an innovative tool to modulate the barrier function of the skin. This might be of relevance for future therapy of inflammatory skin diseases or the subcutaneous penetration of substances.

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*Source:*
Free Radic Biol Med. **161**:32-49 (2020).
https://doi.org/10.1016/j.freeradbiomed.2020.09.026

## New Resources

Please submit your notices for new resources (e.g., newly published special issues, new databases, new reviews) to iltpc-central@umich.edu.

## Career Opportunities

- **Plasma Scientist/Engineer, Lam Research, Tualatin, Oregon (USA)**

  Lam Research is seeking a plasma scientist/engineer to develop plasma metrology and diagnostics for plasma processing equipment used in the semiconductor fabrication industry. The candidate will be responsible for research and development of new technology and investigate the feasibility of applying scientific principles to industrial products for plasma fabrication of microelectronics devices.

  Qualifications
  - MS/PhD in Physics or Engineering (Chemical, Electrical, Mechanical, or related field).
  - Extensive background in low temperature plasmas and related technology
  - Hands-on experiences in research and development
  - Excellent problem-solving and trouble-shooting skills
  - Ability to work independently in a highly dynamic and fast-paced environment
  - Ability to effectively communicate with colleagues in cross-functional team environment

  Skills and knowledge
  - Expertise in optical/electrical plasma diagnostics (OES, LAS, LIF, Langmuir probe, Capacitive probe, RFEA, QMS, etc.)
  - Proficiency in automated data collection and analysis with LabView, Matlab, etc.
  - Experience in computational modeling will be a plus

  *Contact:*
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## Collaborative Opportunities

Please submit your notices for collaborative opportunities to iltpc-central@umich.edu.

### *Disclaimer*

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