International Low Temperature Plasma Community

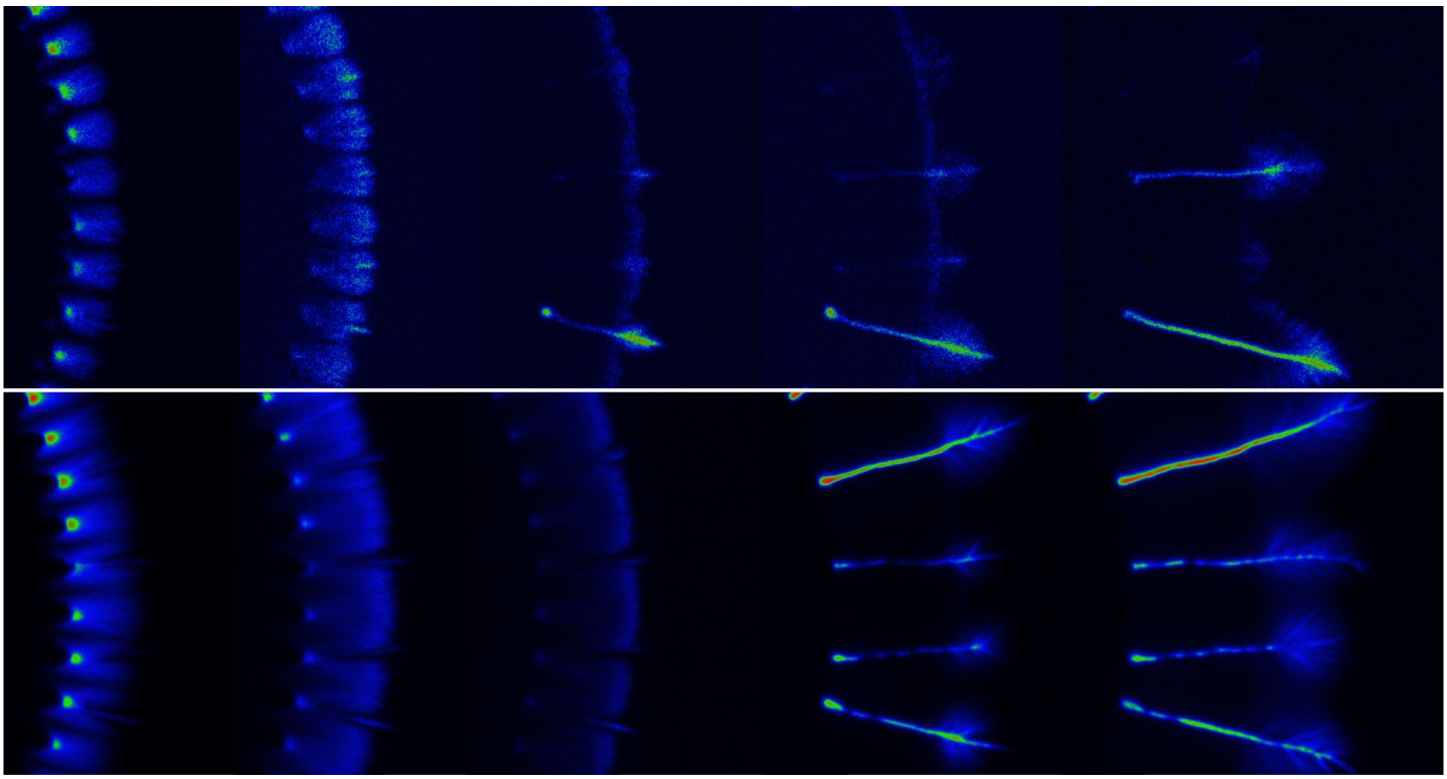
https://mipse.umich.edu/iltpc.php, iltpc-central@umich.edu

Newsletter 08

15 November 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.



Winner Takes All – These images of a ns surface dielectric barrier discharge (nSDBD) in N_2 at 6 bar were produced with a gear (1 mm spacing between teeth) as the high voltage (HV) electrode. The camera gate was 1 ns with 1-2 ns between frames (left to right). Streamer-to-filament transitions with both negative (upper line, -25 kV) and positive (lower line, +25 kV) polarities are clearly seen. The streamers start and propagate simultaneously from the edge of the HV electrode along the dielectric surface forming regular structures. The ground electrode is below the dielectric. In a few nanoseconds, a few plasma filaments with diameters much smaller than the average and emission intensity much stronger emerge; and only some of these filaments survive after a few nanoseconds. They will, similar to streamers, form a regular structure around the HV electrode, however their spacing is 4-5 times greater compared to streamer nSDBD. The electron density in survivors is 10^{19} cm^{-3} while a typical electron density in streamers is about 4 orders of magnitude lower. This dramatically sharp and fast change of plasma corresponds to a transition from non-equilibrium to partially equilibrium plasma in the channels of the filaments. The images were taken in the Laboratory for Plasma Physics (LPP, CNRS, Ecole Polytechnique) in 2019-20 by **Chenyang Ding**, **Antonin Jean**, and **Dr. Svetlana Starikovskaia**. The concept of sub-ns transition to equilibrium plasmas was suggested by **Dr. Nikolay Popov** (SINP, Moscow State University).

In this issue:

Call for Contributions

Please submit content for the next issue of the Newsletter. Please send your contributions to iltpc-central@umich.edu by **December 10, 2020**.

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

Non-Equilibrium Plasma and the Transition to a Decarbonized Energy System

The goal of reducing global net carbon and associated greenhouse gas emissions to zero as quickly as possible is now widely accepted. The key steps are to electrify everything and to generate that electricity from renewable sources. Meeting these goals introduces major technological (and other) challenges and will require a serious, sustained effort for decades.

Does non-equilibrium plasma (NEP) have a role to play in this technology revolution? Plasma is the obvious way to take electricity and directly induce chemical reactions in the gas phase. By this simple fact alone, I argue that the answer to this question is unambiguously 'yes.' But what forms will this set of roles take? And how best to get started?

The scale and complexity of the issues we are facing are immense. Further, our perception of optimal paths will no doubt continuously evolve. We live in a non-linear age: linear extrapolations are notoriously unreliable. These facts argue against a 'business as usual,' top-down approach to identifying research directions. We need the creativity and imagination of the entire community to attack this set of unprecedented problems.

For example, NEP researchers should say to themselves: "Let's find scalable ways to use plasma to generate desired products from available raw materials, and then find ways to take the products at the end of their useful lives and re-convert them to raw materials. Let's not worry too much about whether it is the most economical way to do it today, because goals, technologies and constraints all tend to evolve in sometimes unpredictable ways and could easily shift tomorrow. Just be creative. Above all, let's encourage diversity – we should not all be working on the same problems."

This 'bottom-up' approach, relying on the distributed creativity of the NEP research community, is best suited to the diversity and complexity of our global challenges as well as the unmatched flexibility and operational range of NEP. Let's maximize our impact as a community!

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Tribute to Prof. Noah Hershkowitz

With deep sadness, we mourn the loss of Professor Noah Hershkowitz of the University of Wisconsin, a distinguished contributor to and pioneer in the field of plasma physics, who passed away on November 13, 2020. Noah had a long and impactful career spanning many decades, and disciplines. He made groundbreaking contributions to nuclear physics, fusion energy research, fou ndational plasma physics, and low temperature plasmas. Noah received his bachelor's degree from Union College in 1962 and his Ph.D. in physics from Johns Hopkins University in 1966. He served on the faculty of the University of Iowa before joining the University of Wisconsin in 1981, where he held the title of Irving Langmuir Professor of Engineering Physics. Noah was a fellow of the American Physical Society (APS), American Vacuum Society, Institute of Physics, and the IEEE. In 2004, he received the James Clerk Maxwell Prize for Plasma Physics from the APS, and in 2015 the Marie Sklodowska-Curie Award from IEEE. He was the founding Editor-in-Chief of the influential journal *Plasma Sources Science and Technology*.

Noah was a key architect in shaping the modern field of experimental low temperature plasmas. His most notable contributions center on his investigations of plasma sheaths and the measurement tools that he pioneered for their study including a variety of electrostatic probe methods. He used these tools to glean profound insight and understanding of the complexities of plasma sheaths, solitons, and double layers. Noah's name is almost synonymous with the emissive probe, a powerful tool to study the electrical potentials within plasma sheaths. Noah perfected the inflection method to study plasmas in diverse environments ranging from thrusters to semiconductor processing.

Noah developed many other methods and tools to investigate plasmas that are now standards in the field, from probes to laser induced fluorescence. His seminal paper "Sheaths: More Complicated Than You Think", which was published in *Physics of Plasmas*, has become a classic and should be required reading for new entries to the field. Noah was also known for deftly using multipole plasma sources to investigate the intricacies of plasma transport. These studies yielded great insight into the puzzling questions of plasma leaking through magnetic cusps. Noah's advances in understanding these complex transport processes enabled optimizing the efficiency and stability of multipole ion sources such as gridded ion thrusters for spacecraft. He also developed plasma sources for specific applications such as the helicon and rf plasma cathode sources for semiconductor manufacturing applications and space propulsion. Noah was a great mentor to many of us, having supervised more than fifty-five students to their Ph.D. degrees. Although we have lost a giant in the field, the legacy of Prof. Noah Hershkowitz and his contributions to plasma physics will live on forever as foundational knowledge for the field.

MIPSE (Michigan Institute for Plasma Science and Engineering)
mipse-central@umich.edu

General Interest Announcements

- 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/1XoD6Fn7AP0HFTQJpPCETrRIQhx8IDisz4XUMyv9X7zo/edit?usp=sharing.

  Contact:
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Meetings and Online Seminars

- **Online LTP Seminar**

  Reminder!! Upcoming seminars: **November 24** and **December 8**. More information on the Online LTP Seminar: https://mipse.umich.edu/ltp_seminars.php.

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

  Reminder!! Upcoming seminars: **November 19**, **December 3**, and **December 17**. More information on the International Online Plasma Seminar (IOPS): https://mipse.umich.edu/online_seminars.php.

  Speaker Nominations: Nominations are solicited for speakers for the January-June 2021 sessions of IOPS. Two types of seminars will be presented:

  *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.

  Please submit nominations via this Google form with a deadline of **30 November 2020**:
  https://docs.google.com/forms/d/e/1FAIpQLSdWSXA_JkSGrKukZ3gDKBFQ6lfFOJ6PC5H5fiuIhg3eE7GSYg/viewform

- **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 Fall. There will be five seminars during Fall 2020 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

Community Initiatives and Special Issues

- **Special Issue *Frontiers in Atmospheric Pressure Plasma Technology* in the Journal *Applied Sciences***

  You are invited to contribute to the Special Issue titled "Frontiers in Atmospheric Pressure Plasma Technology" in the open access journal *Applied Sciences* (Impact Factor 2.474).

  Atmospheric Pressure Plasmas represent a feasible and eco-friendly alternative to conventional physico-chemical methods for treating materials. Topics of interest for this Special Issue include, but are not limited to, the following exciting novel applications of plasma–surface, plasma-liquid and plasma-gas interactions: (bio)medicine (antibacterial / disinfectant / antiseptic agent, wound healing promoter, selective treatment of cancer cells and tumors), pharmacology, food cycle, bioengineering, agriculture (as seed germination inducer or even as a green fertilizer), automotive.

  For more details, visit the website:
  https://www.mdpi.com/journal/applsci/special_issues/atmospheric_pressure_plasma_technology

The deadline for manuscript submission is **31 January 2021**. We also encourage authors to send a short abstract or tentative title to Section Managing Editor (jamie.zhang@mdpi.com) in advance. Submitted papers should not be under consideration for publication elsewhere.

Applied Sciences is an MDPI international peer-reviewed open access journal on all aspects of applied natural sciences published semi-monthly online. The Article Processing Charges (APC) are 1800 CHF per accepted paper. You may be entitled to a discount if you have previously received a discount code or if your institute is participating in the MDPI Institutional Open Access Program (IOAP), for more information see: http://www.mdpi.com/about/ioap.

Guest Editor:
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- ***Frontiers in Physics* Has Launched a New Research Topic *Thermal and Non-Thermal Plasmas at Atmospheric Pressure***

One of the typical classifications of plasma systems identifies two major categories: thermal and nonthermal plasmas. Thermal plasmas technology has evolved over the past decades due to the increasing attention in aerospace, microelectronics, automotive, material treatment and processing, melting and welding of metals, plasma chemical synthesis and vapour deposition, plasma and arc spraying, waste destruction. Modelling these phenomena requires the knowledge of thermodynamic properties and transport coefficients of plasmas, which are of relevant importance, not only in equilibrium conditions. Numerical codes reliably evaluating these data can assist the designing and optimizing phases of plasma-based devices.

The main drawbacks of thermal plasmas are represented by low excitation selectivity, very high gas temperature, serious quenching requirements and electrode problems result in limited energy efficiency and applicability of thermal plasma sources. For these reasons, nonthermal plasmas such as low-pressure glow and RF, microwave discharges, dielectric barrier discharges, laser-produced plasmas, have been used due to their high selectivity in plasma chemical reactions, operating effectively at low temperatures and without quenching. More recently non-thermal atmospheric pressure plasmas have been studied for a variety of industrial and medical applications such as sterilization, ozone production for water purification, pollution control applications, car exhaust emission control, volatile organic compounds removal, and polymer surface treatment in order to improve properties such as wettability, printability and adhesion.

The aim of this Research Topic is to present a comprehensive overview of the subject and to highlight the perspectives on thermal and non-thermal plasmas at atmospheric pressure, giving a guide on critical topics for the progress in the field. Contributions on thermal plasmas will focus on plasma sources, diagnostic and modelling, deepening also on approaches used to produce plasmas, to measure and to calculate their properties. Manuscripts investigating applications of thermal plasmas are encouraged, both on experimental, theoretical and numerical aspects. Contributions on non-thermal plasmas will focus on investigating physical and chemical behaviour of discharges, such as corona, dielectric barrier, gliding arc, spark discharge and laser-produced non-thermal plasmas.

More information: https://www.frontiersin.org/research-topics/15660/thermal-and-non-thermal-plasmas-at-atmospheric-pressure

Guest Editors:
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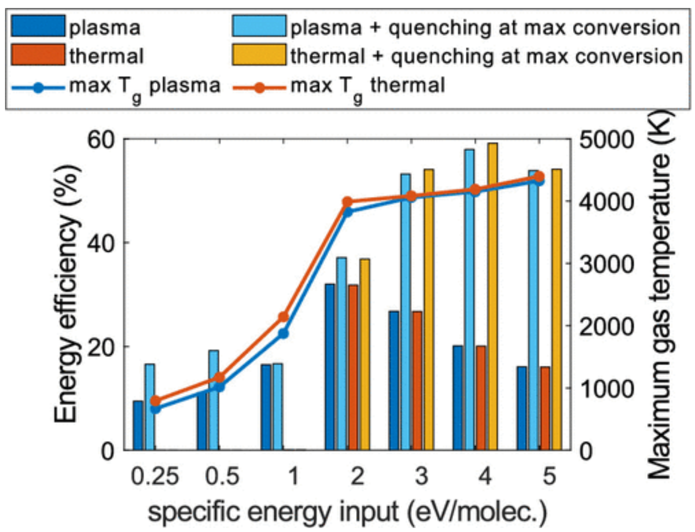
Plasma-Based CO_2 Conversion: To Quench or Not to Quench?



Calculated energy efficiency for CO_2 conversion, as function of SEI, for both plasma and thermal conversion, and the effect of quenching. The corresponding maximum gas temperature is also plotted (right y-axis).

Plasma technology is gaining increasing interest for CO_2 conversion. The gas temperature in (and after) the plasma reactor largely affects the performance. We compared plasma-based conversion to pure thermal conversion. For warm plasmas with typical temperatures of 3000−4000 K, the conversion is roughly thermal. We also studied the effect of cooling/quenching, during and after the plasma, on the CO_2 conversion and energy efficiency, by means of chemical kinetics modeling. We showed that quenching can even increase the conversion beyond the dissociation in the plasma, known as super-ideal quenching.

To better understand the effects of quenching at different plasma conditions, we studied the dissociation and recombination rates, as well as the vibrational distribution functions of CO_2, CO, and O_2. When a high vibrational−translational (VT) nonequilibrium exists at the moment of quenching, the dissociation and recombination reaction rates both increase. Depending on the conversion degree at the moment of quenching, this can lead to a net increase or decrease of CO_2 conversion. In general, however, and certainly for equilibrium plasmas at high temperature, quenching after the plasma helps prevent recombination reactions and clearly enhances the final CO_2 conversion.

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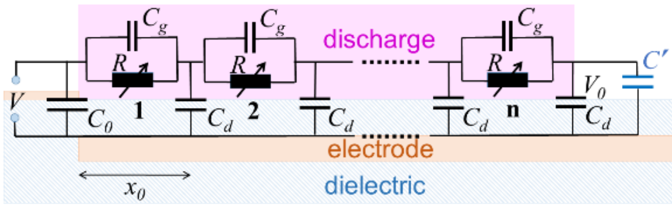
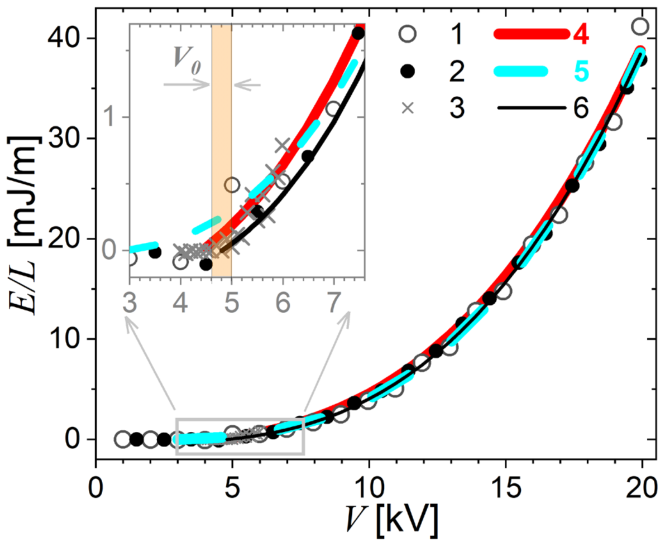
Source:
J. Phys. Chem. C, 124, 18401 (2020).
doi:10.1021/acs.jpcc.0c04257

Dependence of Dissipated Power on Applied Voltage for Surface Barrier Discharge from Simple Equivalent Circuit



The electrode configuration of a surface dielectric barrier discharge (SDBD) and its simplest equivalent circuit.



The dependence of the dissipated energy (E) normalized by electrode width (L) as a function of the peak-to-peak amplitude of the applied voltage (V). Points are the measurements, lines are fits using different approximations.

This study is devoted to surface dielectric barrier discharges (SDBD), a specific type of the dielectric barrier discharge (DBD) where the discharge develops along the dielectric surface. Among several other applications, the SDBD's ability to generate ion wind makes it attractive for the aerospace community as an actuator for active flow control. Recently, its potential for anti-icing applications has been demonstrated.

The concept of the simple equivalent circuit of volume DBDs is expanded to SDBDs. This approach delivers an analytical relationship for the dissipated power (P) as a function of the applied voltage amplitude (V) in the form $P = aV^3 - bV + c$. The equation includes the previous empirical observation expressed by $P = AV^n$, but resolves the ambiguity of the power factor n and suggests a physical meaning for the fit parameters. It applies to SDBDs with sufficiently long embedded electrodes and operated by sinusoidal high voltages. The obtained relation was validated by comparison with experimental data obtained from previous work.

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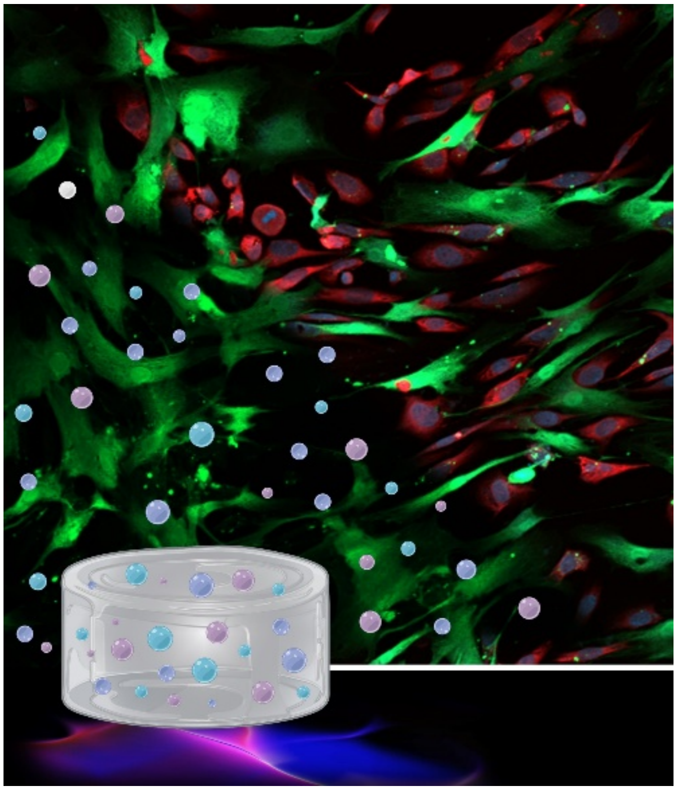
Source: Andrei Pipa *et al*, 2020 Plasma Sources Sci. Technol., in press.
https://doi.org/10.1088/1361-6595/abc415

Recent Advances Towards Entrapment of Plasma-generated RONS in Biopolymer Solutions



Cold Atmospheric Plasma-treated hydrogel-forming solutions, a first step in the design of RONS-loaded biomaterials able to act a RONS delivery systems for cancer therapy applications.

In the framework of the ERC APACHE project (Atmospheric Pressure plAsma meets biomaterials for bone Cancer Healing) we recently published several advances in the generation of reactive oxygen and nitrogen species (RONS) by cold atmospheric plasma jets in biopolymer solutions. As it is well known, plasma treatment of physiological liquids, generates a variety of RONS that have the potential to selectively kill cancer cells without affecting healthy cells.

Using hydrogel-forming solutions to entrap these reactive species in semi-liquid material enable the design of new hydrogel-based biomaterials able to act as carriers and delivery systems of plasma-generated reactive species for applications in cancer therapy.

After a first work focused on alginate (*Scientific Reports*, 2019), our latest publication in *ACS Applied Material & Interfaces* shows that much higher amounts of RONS are generated in gelatin solutions by plasma jets, and that they are efficient and selective towards osteosarcoma cells. The ability to entrap and release these RONS from biopolymer solutions opens interesting avenues in research towards entrapment of plasma-generated reactive species for therapeutic use.

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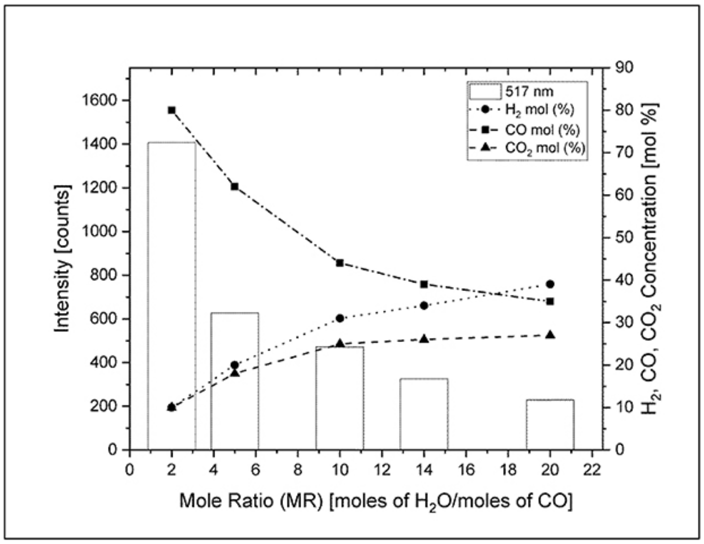
More information: https://ercapache.upc.edu/
Source:
https://pubs.acs.org/doi/abs/10.1021/acsami.0c12930

Experimental Investigation of a Non-catalytic Cold Plasma Water-gas Shift Reaction



The plasma C_2 (Swan band in nm) vibrational band intensity (primary axis) and the gas composition (secondary axis) versus the MR at 1300 ms of gas residence time and 70 W of plasma power.

This work explores the use of an atmospheric pressure, low temperature, cold non-thermal plasma (obtained by dielectric barrier discharge (DBD)) to achieve a water-gas shift (WGS) reaction ($CO + H_2O \leftrightarrow H_2 + CO_2$). This work establishes the use of a DBD to generate hydroxyl radicals that initiate and enhance the WGS reaction at low temperatures. The effect of the steam to CO molar ratio (MR) and the gas residence time on the CO conversion (X_{CO}) to H_2 was studied. The results show that, at an MR of 20, with 2600 ms of gas residence time and a plasma power of 70 W, a maximum CO conversion of 63±4% can be achieved with an H_2 concentration of 48±2 mol% in the product. Preliminary studies of reaction pathways for the enhanced hydrogen formation confirm the role of C formed from the CO_2 dissociation. A reaction mechanism for the plasma WGS reaction is proposed and the hydrogen yield is calculated.

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Source:
https://iopscience.iop.org/article/10.1088/1361-6463/aba92d/meta

UV Light Sources for Disinfection

UV electrodeless lamp.

First results showed that UVC light in the region of 190 nm -280 nm, emitted from electrodeless light sources, produced in our laboratory, effectively kills viruses and bacteria, and could be applied for disinfection of surfaces and spaces.

The Light source technology laboratory at the Institute of Atomic Physics and Spectroscopy of University of Latvia is taking part in the State Research program "To Reduce the Effects of Covid-19" with its project "Integration of reliable technologies for protection against Covid-19 in healthcare and high-risk areas". In the frame of the project we tested the UV high frequency electrodeless lamps filled with Thallium.

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More information:
www.asi.lu.lv
wrebl.rtu.lv/

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

- **Director Positions at the US National Science Foundation**
  - Assistant Director for Engineering:
    https://www.nsf.gov/news/news_summ.jsp?cntn_id=301484&org=ENG
  - Division Director, Division of Chemical, Bioengineering, Environmental, and Transport Systems
    https://www.nsf.gov/news/news_summ.jsp?cntn_id=301507&org=ENG
  - Small Business Innovation Research Program Director
    https://www.nsf.gov/news/news_summ.jsp?cntn_id=301508&org=ENG

- **Postdoctoral Position in Atmospheric and Space Electricity, Department of Physics and Astronomy & Institute for the Study of Earth, Oceans and Space (EOS), University of New Hampshire (USA)**

  The Lightning research group in the Department of Physics and Astronomy & the Institute for the Study of Earth, Oceans and Space (EOS) at the University of New Hampshire (UNH) USA is seeking an exceptional candidate to fill a postdoctoral position in the field of atmospheric and space electricity. The successful candidate will focus on developing numerical code to model electrical discharges and plasmas, but will also work with optical and radio observations of lightning and transient luminous events. Experience with parallel computing and adaptive mesh refinement is highly desirable but not required. A Ph.D. in physics, engineering, or related fields is required. The initial appointment is for one year with subsequent annual renewal for up to two additional years contingent upon satisfactory performance, and availability of resources.

  Review of complete applications will commence on **November 23, 2020** and will continue until the position is filled. Inquiries about the position should be addressed to **Prof. Ningyu Liu** at Ningyu.Liu@unh.edu. Applicants should submit their application electronically as a single PDF document in the following order – cover letter including a summary of research experience, CV, and the names and contact information of at least three references – to Ningyu.Liu@unh.edu.

  The University of New Hampshire is a major research institution, providing comprehensive, high-quality undergraduate and graduate programs (www.unh.edu). UNH is located in Durham on a 188-acre campus, 60 miles north of Boston and 8 miles from the Atlantic coast. The Department of Physics and Astronomy confers both undergraduate (B.A., B.S.) and graduate (M.S., Ph.D.) degrees and currently includes 26 faculty members. EOS is the largest research institute at UNH, with more than 275 faculty, staff, and students.

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- **Faculty Opening in Low Temperature Plasmas, Department of Mechanical Engineering, University of Minnesota-Twin Cities, Minneapolis (USA)**

  The Department of Mechanical Engineering (DME) at the University of Minnesota-Twin Cities (Minneapolis, USA) invites applications for a full-time, tenured or tenure-track position with a particular interest in the area of low temperature plasmas (https://cse.umn.edu/me/research/plasmas) or heat transfer (https://cse.umn.edu/me/research/thermo-heat) beginning Fall 2021. We are seeking a faculty candidate who complements current expertise in the DME and who plans to grow strategic synergistic collaborations within the Department and the University.

  Applicants are expected to hold, or complete by Fall 2021, a Ph.D. in Mechanical Engineering (or a closely related discipline) and have demonstrated the potential to conduct a vigorous and innovative research program as evidenced by their publication record and supporting letters from recognized leaders in the field. The ability to teach effectively at both the graduate and undergraduate levels to a diverse group of engineering students is required. The candidate's expertise and documented research and teaching activities must demonstrate a strong potential to enhance the department's research and teaching missions.

  The DME values and is committed to diversity, equity, and inclusion. We strongly encourage candidates from diverse backgrounds to apply. We further welcome candidates whose experience in teaching, research, or community service has prepared them to contribute to our commitment to diversity and excellence.

The DME (https://cse.umn.edu/me) is home to 43 faculty, 280 graduate students, and 800 undergraduate students. Research in the department addresses the needs of the future, and includes applications to energy, environment & sustainability, human health, manufacturing, and robotics & mobility. The department is part of the College of Science and Engineering (https://cse.umn.edu/), a highly interdisciplinary college comprised of 12 departments covering engineering, physical sciences, and mathematics.

Applicants should submit the following documents electronically to http://apply.interfolio.com/80640: a cover letter, current CV, statement of research vision, and statement of teaching philosophy and interests. Applicants are encouraged to include an optional diversity statement describing demonstrated and future commitments to diversity, equity, and inclusion in scholarship, teaching, mentoring, service, and engagement. Applicants must arrange to have at least three letters of reference (signed and on official letterhead). To receive full consideration, these materials, including the reference letters, must be received by **January 1, 2021**. Applications will be considered until the position is filled and this position will remain open until filled.

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Collaborative Opportunities

- **Plasmadynamic System for Powder Metallurgy Thermal Technologies**

Atmospheric plasma generation has attracted much attention due the possibility of carrying out unique plasma technological processes in air. Electromagnetic plasmadynamic systems (EMAPS) are promising for a number of applications: surface hardening, thermal spraying, surface modifications. These systems are capable of accelerating powder particles to speeds up to 2500-3000 m/s. Such high particle velocities are unattainable by other spraying methods. However, EMAPS operates only at low pressures of the ambient gas (100- 1000 Pa) and low frequency of operation < 0.1 Hz which presents challenges for industrial applications.

Attempts to obtain high-energy pulsed plasma flows at atmospheric pressure are challenged by producing homogeneous discharges in the plasma accelerator channel. A high power atmospheric electromagnetic plasmadynamic system (AEMAPS) has been designed, which operates at atmospheric pressure.

The new method for obtaining high-energy repetitively pulsed plasma flows at atmospheric and high pressure consists of forming a region of reduced-density gas with a high degree of ionization at the beginning of the acceleration channel of the AEMAPS device, where a plasma current sheath is formed. A new hybrid two-stage plasmadynamic system has been developed. The first stage is in the form of one or more DC plasma torch with flow temperatures of 3000 K – 4000 K at atmospheric pressure. The second stage is the form of a coaxial plasma accelerator. In this system plasma from the DC torch fills the acceleration channel. A high-voltage impulse is applied to the accelerating gap.

Collaborations are sought for development and application of the AEMAPS system.

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US Department of Energy Office of Science

University of Michigan Institute for Plasma Science and Engineering