Technical Meeting on Emerging Applications of Plasma Science and Technology

Report of Contributions

Contribution ID: **1** Type: **Invited Oral**

Influential phenotypic traits of living cells and tissues using atm cold plasma source as biocatalysts

Wednesday, September 20, 2023 10:50 AM (30 minutes)

Abstract

Atmospheric pressure (atm) cold plasmas could be utilized as biocatalysts in various bio-medical applications due to their unique properties, such as their ability to generate reactive oxygen and nitrogen species (RONS). Plasma biocatalysts on living cells and tissues have been studied extensively, and researchers have identified several influential phenotypic traits at a proper plasma dose. Some types of atm cold plasmas have been used as biocatalysts in the studies, including gliding arc discharge, Tesla coil, and plasma jet. Each of these sources has unique characteristics that influence their results. E.g., for chicken eggs, Tesla coil plasma treatment has been shown to improve hatching rates, increase the survival of embryos, and even influence the sex of the offspring. Also, in tropical fish eggs treatment via DI water, changes in skin color are crucially distinct. Similarly, gliding arc and H2/N2 plasma jet treatment on plant tissue have been found to have a range of beneficial effects, including enhanced growth and body development, and plausible resistance to diseases.

One challenging atm cold plasma source has its ability to produce a quantifiable oxidizing/reducing agent, inorganic form for wound disinfection and healing. "Nightingale"is an IEC standard/CE-certified, cold air plasma device to provide significantly higher RONS production rates and better handling of larger reaction volumes. Nightingale was able to operate in laboratories and/or clinical purposes with settable plasma-exposed power at 0.28, 0.43, and 0.62 W over an mmˆ2 to several cmˆ2 sample coverage.

Perspective, thus, researchers can tailor the treatment to achieve the desired dose. However, more research is needed to deeply understand the underlying mechanisms and potential risks associated with this upcoming technology.

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Session Classification: Medicine

Track Classification: Medicine

Contribution ID: **2** Type: **Invited Oral**

Plasma nanotechnology for clean energy, green chemistry, and zero-carbon future

Thursday, September 21, 2023 9:30 AM (30 minutes)

Possible avenues for the plasma nanoscience and nanotechnology to help develop and advance clean, green, and sustainable solutions for the future carbon-emissions-free world are critically examined. The underlying scientific and technological approach is based on synergistic application of plasma electrified, catalytic, and hybrid processes and diverse sustainable feedstocks for the effective up-cycling of carbon-rich precursors. Such processing technologies are aligned with the UN Sustainability Goals and the recommendations of the 2021 Climate Change Conference. The examples considered in the presentation include desalination and resource recovery from sea water, fabrication of high-performance catalysts, electrodes, and membranes, production and storage of sustainable energy, capture and reforming of potent greenhouse gases such as CO2 into value-added fuels, chemical products, materials, etc. Effective decarbonization of industry demands de-centralized clean and renewable energy generation and storage, as well as sustainable and energy-efficient resource recovery. The unique effects of the plasma processing in the advances towards the zero-carbon-emissions technologies that are relevant to major heavy carbon emissions-generating industries are explained. Effective decarbonization necessitates substantially new approaches, such as process electrification (using renewable and clean electric/plasma power P) of the production of materials, chemicals, fuels, and other products (X). This presentation focuses on the applications of plasma-power (plasma-P-to-X) to reform abundant feedstocks (such as industrial and agricultural waste, plastic waste, carbon emissions, environmental pollutants, abundant biomass, and some others) to fabricate advanced functional materials. The produced materials are aimed for applications in diverse technologies such as clean and renewable energy conversion and storage, industrial catalysis, chemical engineering, health, food, environmental, and other technological solutions of vital importance for the sustainable future of our society.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **4** Type: **Invited Oral**

Plasmas for the catalyst applications

With the increasing concerns in the resource, energy, environmental and others, one can expect a further rapid demand for the catalyst or the catalytic process.Plasmas are very promising with it. There are three major directions on the plasma applications for the catalyst. One is to combine the plasma with the catalyst, normally for the activation and utilization of inert molecules like methane, CO2, H2S and nitrogen. The 2nd is to prepare the catalyst with unique structure. The 3rd is to treat or the modify the surface of the catalyst or the catalyst support for the specific properties. The first direction has been extensively investigated but many challenges remained. Two general mechanisms for the combination have been presented. One is the plasma promoted catalytic conversion. The other is the catalyst enhanced plasmas. Because of the challenges in the operando catalyst characterization and in the in situ plasma diagnoses, most of the published works were just reports of the experimental results. A multidisciplinary effort is immediately needed if one would like to see a rapid application of the combination, especially it is expected that the renewable energy will be sufficient for the plasma conversion. In addition, the present plasma generation uses various high voltage techniques.For the future applications, the high electric-field generated plasmas must be developed for the better performances of the plasma conversions.For the 2rd direction with the plasma preparation, huge opportunities exist.The nucleation and crystal growth under the influences of plasmas are totally different from the conventional thermal preparation. Therefore one can get very different crystals or nanoparticles using the plasmas. These crystals or nanoparticles can be good catalysts. Especially, one can use plasmas to create catalysts, which cannot be made using the conventional techniques. These includes the unique alloys and nitrides. One can use the plasmas operated at room temperature to make the catalysts on the thermal sensitive supporting materials or soft materials, like metal-organic frameworks, porous polymers, carbon with ultrahigh surface area, DNA, proteins, gel and others. This has significantly extended the scope of the catalytic materials for applications like bio-conversion. The plasma defect engineering is being also found to be helpful for many unique applications. With the plasma deposition or spray techniques, the metal, glass, diamond, wood and other substrates can be good catalyst supporting materials in the future. The plasma oxidation at low temperatures can find more applications in the regeneration of the catalysts. Site controllable catalyst preparation can be available using plasmas. For the 3rd direction with the treatment or the modification of the surface of the catalyst or the support, it has been found applications in the changes of the surface properties, like the hydrophilicity. It can be used for the removal of the moisture or other contaminants on the surface. With the increasing uses of the organic or polymer based catalysts, plasma modification or treatment will have more applications in the changes of the functional groups. Many other opportunities remain in this direction with challengs as well.

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Session Classification: Catalysis

Track Classification: Catalysis

Contribution ID: **5** Type: **Contributed Oral**

Removal of Dye Contaminates in Water by a Plasma Liquid Interface

Tuesday, September 19, 2023 4:30 PM (15 minutes)

A promising approach for removing methylene blue (MB) in wastewater is the plasma liquid interface (PLI). Indeed, PLI can destroy contaminants at room temperature without adding chemicals due to PLI's ability to provide abundant environmental oxidation at the interface, including OH, O, H2O2, radicals, excited species, electrons, and ions. Herein, the removal of MB in water was investigated by PLI. The PLI was created by a cold plasma jet generated by a gliding arc plasma, and its plasma interreacted with a solution, a concentration from 5 to 20 mg/L. The experimental results indicated that the MB in the solution was entirely removed under adequate time interaction by reactive LPI, which depended on initial MB concentration and experimental conditions such as stirring and injection of oxygen. After a reasonable time, interaction, the solution was examined by FTIR and GC-MS to identify intermediate compounds during PLI in order to suggest a PLI mechanism for MB removal. As a result, feasible reaction pathways for MB removal by PLI will be present, along with recommendations for future research advancements.

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Session Classification: Water Treatment

Track Classification: Water Treatment

Contribution ID: **6** Type: **Contributed Oral**

Recent Developments in Atmospheric Pressure Plasma for Gas Treatment

Thursday, September 21, 2023 10:00 AM (15 minutes)

Gas treatment by atmospheric pressure plasma is gaining interest because the process is environmentally friendly. Specifically, atmospheric pressure plasma features a gas ionization state that consists of energetic electrons, ions, radicals, and excited species; consequently, contaminants compounds can be destroyed under mild conditions: low temperature, fast conversion, and potential low-operating cost by atmospheric pressure. Consequently, plasma for gas conversion or purification is receiving attractive research and applications. Herein, we are summarizing our development recently in atmospheric pressure plasma for gas treatment to present how to be selected plasma systems for specific gas treatments. Particularly, gas purifications are almost required with high throughput gas volume treatment; therefore, a plasma generation in a sandwich-type honeycomb monolith catalyst is an adequate requirement with low-pressure drop, large plasma volume, and effective energy owing to primary input energy used to plasma reaction. When diluting a contaminated compound such as ethylene emission during agriculture products storage, a continuous plasma process for gas treatment results in waste energy. In contrast with an intermittent plasma-catalytic discharge, it is more suitable by temporarily capturing contaminated compounds by catalyst adsorption and then converting by the plasma-catalyst reaction. Furthermore, indirect plasma catalyst by injection method is capable to NOx removal under a low temperature with less energy consumption. In summary, atmospheric pressure plasma systems and their application in particular cases of gas treatment are discussed.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **7** Type: **Invited Oral**

Plasma diffusion treatments and coatings for industrial applications

Tuesday, September 19, 2023 11:30 AM (30 minutes)

Modifying the surface properties is often a necessary part of the industrial process as most of the components manufactured by common material processing methods have limited abilities when operated for specific applications. These applications require improvement in surface properties like wear resistance, corrosion resistance, biocompatibility, etc.

Surface modification by plasma is extremely versatile and used in a range of industries. Plasma processing is frequently used for surface modification without sacrificing the bulk properties for more than a few decades due to its numerous advantages, as it provides good adhesion and high homogeneity, can be easily tailored, and for less power and consumable consumption than compared to the conventional process. Institute for Plasma Research (IPR) has developed several low and sub-atmospheric pressure plasmas for modifying the surfaces to improve their functional properties [1-3]. Such coatings enhance wear and corrosion resistance properties or improve biocompatibility, all from a value-driven and green alternative to harsh chemical techniques point of perspective.

The present talk elaborates on the different plasma-based diffusion processes like plasma nitriding along with their variant processes, plasma-assisted physical vapor deposition (PVD), to name a few which are beneficial to society at large. Diffusion-based coatings have been found to be an alternative technique to enhance the corrosion resistance of metallic materials, thus expanding the life span of the metal components pertaining to different industrial applications. Protective coatings by PVD on implants and yarn have also been found to significantly improve biocompatibility and antibacterial properties.

Hence, plasma engineering of surfaces has several unique features allowing modification of the sub-surfaces of a variety of materials. The plasma-based methods of surface engineering provide cost-effective, environmentally friendly, and scalable solutions for both research and industry with an enormous potential still to be fully explored.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **8** Type: **Invited Oral**

Physics-Informed Data Driven Plasma Equipment/Process Control Technologies for Plasma Applications.

Tuesday, September 19, 2023 1:40 PM (30 minutes)

The fundamental idea in Machine Learning (ML) is that, for many applications, training a computer algorithm for predicting or finding patterns in the behavior of a complex system by observing many input-output samples of its behavior can be significantly simpler than developing physics-based models.

Many of the ideas underlying this data-driven approach to understanding complex systems have been known for years, but only recently has it become more practical to obtain and analyze the enormous quantities of data needed for the schemes to work. However, it requires time-consuming

Thus, effective implicit feature extraction is of paramount importance, especially in semiconductor manufacturing Virtual Metrology (VM). As a result, the analysis of the data is a big challenge. Thus, this talk introduces physics-informed plasma equipment intellectualization research based on a data-informed model platform and proposes a virtual metrology approach based on the neural network architecture for predicting and controlling process results.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **9** Type: **Invited Oral**

Atmospheric pressure plasma and its application in textile and polymers

Thursday, September 21, 2023 1:15 PM (30 minutes)

Textile industries use huge quantity of water and chemicals for surface treatment in scouring process before dying. This process is hazardous and pollute the environment. Government has zero liquid discharge (ZLD) norms for controlling such discharge. Further, nonthermal plasma treatment of surfaces could be one solution to this problem and it is a dry process. However, there are many challenges and limitations in generation of such nonthermal plasma with economical viabilities.

It is well known that non-thermal plasma can significantly improve the surface properties. Plasma can make the surface hydrophilic and hydrophobic using the suitable particular gas. In non-thermal plasma, electron temperature is of order of 2 to 3eV and gas temperature is maintained much lower than 100 degree C particularly. Such plasmas are generated using Argon or Helium gases easily. However, these gases are costly and thus, use of nonthermal plasma is limited to high end products. Further, the inline treatment may be possible with atmospheric pressure plasma and generation of atmospheric pressure nonthermal plasma involves many complexities.

There are many challenges in generation of nonthermal air plasma at atmospheric pressure using conventional dielectric barrier discharge (DBD) technique. These challenges include requirement of very high voltage for generation of air plasma safely as it is susceptible to breakdown in any dielectric medium, challenges in avoiding localized discharge in the gap due to very high electric field and avoiding the high energy streamers formations, non-availability of feedback technique for control of current in such highly dynamic discharge. Conventional power sources are basically high voltage pulsed DC and high frequency AC sources in which the output current waveform is governed by the geometry of plasma system in which gap, dielectric material and geometry of electrodes and its surfaces, emissivity play very important role in controlling and maintaining the plasma discharge current in nonthermal mode. Since, impedance of air plasma is highly dynamic at atmospheric pressure, controlling of discharge in uniform glow mode to treat larger surface is another complexity. Hence, there is a need to devise a technique in power supply and geometry of electrodes that can be adopted for generating economical viable discharge for all textile treatment not limited to high end product only.

In this direction, very low cost power supply topology was devised by Institute for Plasma Research (IPR) in India that could generate almost uniform glow discharge plasma in air between two cylindrical electrode having dielectric layer at one or both electrodes. Plasma density was observed to be 0.25W/cm2 in air gap at 5kV and 100mA current. A system was built by IPR for treatment of 2.5 meter wide textile at a moderate speed using multiple pair of cylindrical electrodes DBD plasma discharge in air that could be achieved due to low cost of power supply for each electrode pair. The surface energy of PE film was improved significantly from 38 dyne/cm to ˜ 55 dyne/cm. The study performed by IPR in this context will be presented.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **10** Type: **Invited Oral**

Safe Disposal of Different Solid Waste Streams and Energy recovery using Thermal Plasma Technology

Wednesday, September 20, 2023 4:05 PM (15 minutes)

Disposal of different waste streams including hazardous and biomedical waste in an environment friendly manner is a serious concern all over the world. Poorly designed incinerators and wrong operational practices produce extremely harmful carcinogenic compounds such as dioxins, furans, poly aromatic hydrocarbons (PAH) etc. which are released in the environment. Thermal plasma technology is becoming increasingly popular due to the disposal of various waste streams in a safe and environment friendly manner. Further, several companies in the world have successfully demonstrated energy recovery from organic waste such as papers, plastics, polymers, MSW and industrial waste using thermal plasma technology in a gasification mode. The sustainability of the thermal plasma technology is shown in a large scale waste disposal reactors.

Plasma torches or plasma arc systems are used to generate high temperature thermal plasma which efficiently converts electrical energy to heat energy. The high temperature created by plasma in the absence of fuel and air, disintegrate the infectious biomedical waste into CO, H2 and lower hydrocarbons and residual ash. High temperature conditions (>5000oC in the plasma zone), oxygen starved environment and quenching of hot gases effectively restricts the recombination reactions and eliminate the formation of toxic molecules such as dioxins, furans, PAH etc. Institute for Plasma Research's constant efforts have resulted in recognition of plasma pyrolysis technology by Ministry of Environment and Forest and Climate Change (MoEF & CC, India) for safe disposal of biomedical waste in India in the year 2016. The institute has been granted 3 Indian Patents on plasma pyrolysis technology and this technology has been transferred to 6 Indian industries [3-5].

The presentation will briefly cover present status of plasma pyrolysis/gasification technology in waste disposal arena and energy recovery from waste in the world. The presentation will elaborate on current technological developments that are taking place in this field at Institute for Plasma Research such as development of Common Biomedical Waste Treatment Facility (CBWTF) along with 5 ton per day capacity plasma pyrolysis system to dispose waste that will be generated from 10,000 beds from various hospitals and health care facilities in and around Varanasi, India. Future opportunities in waste to wealth creation using thermal plasma technology and some of the challenges this technology is facing will also be discussed.

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[4] An Indian Patent on "Plasma Pyrolysis System for Safe Disposal of Organic Waste using Plasma Torch with a Novel Endogenous Gas Source"; Indian Patent Number : 281257
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Session Classification: Municipal Solid Waste Treatment

Track Classification: Municipal Solid Waste Treatment

Contribution ID: **11** Type: **Invited Oral**

Mechanism and Applications of Plasma Gene/Molecular Transfection

Wednesday, September 20, 2023 11:20 AM (30 minutes)

1 Introduction: Molecular/gene introduction by plasma
The authors examined various plasma sources for gene/molecular introduction into cells1. We found that the micro-discharge plasma with a counter electrode provides electrical current to cells in this configuration, simultaneously achieving high transfection efficiency and cell viability[1,2]. Since the plasma treatment time is short as 10^{-2} s or less, damages to cells and plasmid DNA are suppressed.

2 Mechanism: Spontaneous introductions by complex stimuli
The Zeta potential measurement shows that after plasma treatment, cells are charged up by positive charges. Since plasmid DNA, which is naturally charged in negative, collides easily with the charged cell membrane due to the relaxation of the Coulomb repulsion, the collision frequency between plasmid DNA and cell increases. We also experimentally found that large-size molecules such as plasmid DNA are transferred into cells by endocytosis and that ROS and electrical stimuli are required to trigger endocytosis. In our plasma methods, large molecules are transferred into cells by endocytosis, spontaneous cell membrane transfer, by complex stimuli of electric current and ROS[3,4].
In genome editing, it is preferable that the editing molecules are introduced into cells without any random genome integration. The plasma method is expected to be free from random genome integration because cells spontaneously take external DNA molecules up into themselves by plasma-induced endocytosis. The authors proved that the plasma method is random genome integration-free through the experiment[5]. The GFP gene-coded plasmid DNA was introduced into target cells using plasma, electro-poration, or lipofection. The cells were continuously passaged every 3 or 4 days as they reached confluence. After 25 days, many colonies were formed by electro-poration and lipofection methods. On the other hand, only a few colonies were formed by the plasma method. These results prove that plasma treatment introduces a plasmid DNA without random genome integration, so-called "Genome Integration-free."

4 Applications
The plasma induces the spontaneous uptake of cells by endocytosis without random genome integration. The Genome Integration-Free characteristics are unique and expected to be a valuable tool for genome editing. This high level of safety is a feature unique to the plasma method and not found in conventional gene transfer methods. Therefore, the plasma method is expected to enable gene medicine, cell medicine, and regenerative medicine, which could not be realized with conventional gene transfer methods due to a lack of safety. In addition, as clean genome editing is possible, it is also expected to be applied to breeding in agriculture and fisheries.

Acknowledgments
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References
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[5] M. Jinno et al. *Jpn. J. Appl. Phys.*, **60**(3) 030502 (2021).

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Session Classification: Medicine

Track Classification: Medicine

Contribution ID: **12** Type: **Invited Oral**

Plasma-based approaches for removing micropollutants/emerging contaminants from water; Case study of PFAS

Tuesday, September 19, 2023 3:30 PM (30 minutes)

Removal of micropollutants (MPs)/emerging contaminants (ECs) is crucial for ensuring water quality and safeguarding human and environmental health due to their carcinogenic, mutagenic and endocrine disruptive effects on living organisms (i.e. humans and animals) (EU Directives 2013/39/EU). These contaminants include pharmaceutically active compounds (PhACs) 1, heavy metals, and xenobiotic organic micropollutants like PFAS [2], [3]. Emerging contaminants pose a challenge to traditional water treatment processes because they often have unique properties, such as being resistant to degradation or occurring in low concentrations [4], [5]. Advanced oxidation processes (AOPs) (e.g. ozone (O3) treatment or hydrogen peroxide (H2O2) with UV light, Fenton and photo-Fenton processes, electrocoagulation, etc.) that rely on the generation of highly reactive OH radicals mainly, have proven to be effective for most of the ECs [4], [5] except for a few highly stable ones e.g. PFAS [6]. The use of extra chemicals in AOPs, however, increases costs as well as threatens the environmental compatibility of effluents that might still contain chemical residues. [7]. For various reasons, non-thermal plasma-based systems have emerged as the most suitable options for utilizing advanced oxidation and reduction processes (AOP/ARP) simultaneously [2] without requiring added chemicals. However,

Contributions from our laboratory to the treatment of MCs/ECs with a main focus on PFAS contaminated water will be discussed. The results will be compared in terms of reactive species generation (e.g. O3, H2O2 and OH radicals) and with a particular emphasis on the selection of the type of efficient plasma discharge with regards to the properties of the contaminant in question. Notably, results of a liquid contact plasma reactor, a newly patented RAdial Plasma (RAP) discharge reactor and a Corona discharge system will be presented. Particularly for PFAS, RAP has demonstrated to be the most energy-efficient method for achieving a high degree of PFAS mineralization with degradation efficiencies >99% for initial concentrations between 41 μg/L to 41 mg/L. Energy efficiencies greater than 2000 mg/kWh for 41 μg/L –4.1 mg/L of PFOA initial concentrations were obtained. Electron density measurements using Optical Emission Spectroscopy (OES) results presented distinctive features of the RAP system compared to a liquid contact plasma reactor. The results obtained with RAP compare most favourably with those of state-of-the-art plasma systems and reinforce the notion that plasma-based technology is among the most effective options available for MCs/ECs degradation in water decontamination.

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Session Classification: Water Treatment

Track Classification: Water Treatment

Contribution ID: **13** Type: **Invited Oral**

Plasma technologies for a sustainable future: unique plasma processes for applications in biomedicine and space with opportunities in cellular agriculture and vaccine development

Tuesday, September 19, 2023 11:00 AM (30 minutes)

Australia's enviable endowment of untapped solar energy renders it very attractive for investment in solar energy infrastructure. This is exemplified by Sun Cable Pty Ltd who are planning to build the world's largest solar power plant in outback Australia. The time is ripe to create advanced plasma-based manufacturing capabilities that leverage our vast renewable energy reserves and develop new plasma technologies to facilitate the transition to renewable energy economies.

Plasma technology is a Power-to-X (P2X) processing technology with inherent potential for coupling with renewable electricity to create value-added products. As plasmas do not require heating or pressurization of reaction vessels, they can be switched on and off rapidly, providing opportunities for materials synthesis and processing, that can take advantage of the peaks inherent in renewable electricity generation.

This presentation will describe unique plasma processes for applications in biomedicine and space, developed at the University of Sydney and currently being commercialized, as well as highlighting future opportunities.

Materials used in biomedicine are selected according to bulk properties, such as mechanical, electrical and optical, required for particular in-vivo and in-vitro applications. However, their surfaces almost always provide suboptimal biological microenvironments that do not promote the desired biological responses. To address this problem, we have developed sustainable and readily scalable plasma surface modification processes that enable resilient and easily tailorable biomolecule immobilization on all materials and structures, including the internal surfaces of multi-well plates, porous scaffolds and micro/nanostructures. This technology can be deployed to create bioinstructive cell microenvironments for cell culture (being commercialized by Culturon Pty Ltd), tissue integration, and nanomedicine. Typical time scales of cell culture and tissue integration necessitate covalent immobilisation to prevent interface instability due to desorption and exchange of the immobilized molecules with molecules in the surrounding aqueous environment. Our processes are suitable for a range of materials and structures and enable spontaneous, reagent-free, covalent functionalisation with bioactive molecules and hydrogels. Functional molecules that can be immobilised to create tailored biological microenvironments include but are not limited to, oligonucleotides, enzymes, peptides, aptamers, cytokines, antibodies, cell-adhesion extracellular matrix molecules, and histological dyes. The covalent immobilisation occurs on contact via radicals embedded in the surface by energetic plasma species. Strategies to immobilise biological microenvironment patterns and hydrogels onto the plasma-activated surfaces and to prepare multifunctionalisable nanoparticles will be described, together with strategies to control the density and orientation of surface-immobilised biomolecules. Potential opportunities in cellular agriculture, drug delivery and rapid vaccine development and deployment will be noted.

Plasma-deposited coatings to optimize surface properties outside of biomedicine are well established. Highly ionized plasmas in sources such as high-power impulse magnetron sputtering (HiPIMS) and cathodic arc are attractive as the depositing species'energies can be easily tailored to optimize microstructures. Recent examples in the development of electrochromic and high entropy alloy coatings will be presented, together with the application of our centre-triggered cathodic arc as a unique space thruster (being commercialized by Neumann Space Pty Ltd), which is capable of using space junk as fuel.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **14** Type: **Invited Oral**

Inactivation of water-transmissible viruses by combining advanced oxidation techniques

Tuesday, September 19, 2023 3:00 PM (30 minutes)

Water scarcity is among the most pressing problems of the modern world. Water usage estimates vary, but about 70% of worldwide water is used for irrigation for growing crops 1. With the latest advancements in climate change and shortage of food, pressing issues with water scarcity will only escalate. Stated facts point to minimizing agricultural water usage, which can be achieved by expanding the network of closed-loop irrigation systems and innovative water management. Thanks to already improving irrigation management and practices, FAO estimates that the amount of water used by agriculture in developing countries will increase by only 14%. 1. Using closed systems for water irrigation exposes several problems, like agrochemical residues, the balance of ions in the nutrient solution, and pathogens'spread. The latter is particularly pressing in closed-loop irrigation systems, as one single plant can release pathogens (bacteria, moulds, viruses) through the root system into the circulating water, infecting other plants. Some closed-loop irrigation systems use UV disinfection, which is economical but quite susceptible to water turbidity and requires several filters, while others, to a smaller extent, use membrane filtration, which is prone to constant filter cleaning. To address the spread of pathogens in closed-loop and semi-closed-loop irrigation systems, we have researched the possibility of joining two advanced oxidation methods: hydrodynamic cavitation and gaseous plasma. In this sense, we have designed a device that exploits the effect of hydrodynamic cavitation called the "supercavitation regime"that enables a formation of a single stable water bubble filled with water vapour [2]. In this way, we created conditions to ignite a gaseous plasma in water vapour and hence generate oxidizing species and, to a smaller extent, UV radiation. We built and tested two systems, small and medium scale, each with different characteristics for the inactivation of plant viruses. Systematic measurements were performed with MS2 bacteriophage, a surrogate for human enteric viruses, with both systems'best-achieved inactivation rate of 5-log. The method proved to be non-cytotoxic and efficient in inactivating (or even destroying) MS2 bacteriophage and is thus considered an environmentally friendly disinfection method as it uses no chemicals.

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Session Classification: Water Treatment

Track Classification: Water Treatment

Contribution ID: **15** Type: **Invited Oral**

Plant pathogens control using air atmospheric pressure plasmas

Thursday, September 21, 2023 2:45 PM (30 minutes)

Atmospheric pressure plasma (APP) technology, enabling to convert air molecules into multi-functional reactive oxygen and nitrogen species (RONS), has been of great interest and extensively investigated. In particular, air APP devices, working only with air and electricity, can potentially allow for ubiquitous supply of RONS, which can be applied in a wide range of fields such as medical, agricultural, environmental, and biomaterial fields [1-4]. Recently, we have developed a new composite air APP device consisting low and high temperature plasma reactors, enabling to supply RONS [dinitrogen pentoxide (N_2O_5), ozone (O_3), nitric oxides (NO_x), …] with fine control and good reproducibility [5]. In addition, the APP device can utilize room air and renewable energy sources, such as a solar cell, and thus can realize sustainable and ubiquitous RONS supply.
Among the RONS synthesized by the air APP device, N_2O_5 is well known as a powerful oxidizing and nitrating agent and can potentially be bioactive. Since the air APP devices can easily supply N_2O_5 to biomaterials (e.g., amino acid, protein, cells, virus, bacteria, ⋯), we are exploring the inactivation effects of N_2O_5 exposure on pathogen and virus, modification of amino acid, and activation effects of plant immunity by the APP synthesized N_2O_5 gas (APP-N_2O_{5gas}).
First, we have investigated the inactivation effects on C. gloeosporioides (strawberry pathogen) and Qβ phage (RNA virus). The APP-N_2O_{5gas} exposure significantly increased the inactivation effect, which was not only due to pH decrease by HNO_{3aq} transfer into the droplet from N_2O_{5gas}. This indicates that N_2O_{5aq}, $[NO_2^+][NO_3^-]_{aq}$, or ${NO_2^+}_{aq}$ may contribute to the inactivation 1.
Second, we conducted experiments on the modification of amino acids such as tyrosine by APP-N_2O_{5gas}. Tyrosine solution was treated by N_2O_{5gas} together with several reactive species such as O_{3gas} or NO_{2gas}, and it is found that dopachrome and nitrotyrosine were generated by the modification of tyrosine [5]. Interestingly, dopachrome generation rate in N_2O_{5gas} with excess O_{3gas} was most high, and the dopachrome generation was correlated with O_{3gas} density.
Third, activation effects of plant immunity were found in pathogen inoculation test using Arabidopsis thaliana, exposed to APP-N_2O_{5gas} [6]. Gene expression analysis with RNA-seq and qRT-PCR showed that the N_2O_{5gas} exposure activated the signaling pathways for jasmonic acid (JA) and ethylene (ET), which are important phytohormones for plant immunity. These results indicate that N_2O_{5gas} can be used as a plant activator and also indicates that those N_2O_5 effects were pronounced when the plants were placed in high humidity conditions.
In the presentation, the details of the various biomaterial APP processes and APP-N_2O_{5gas} reaction pathway in the gas and liquid phase will be discussed.

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Session Classification: Agriculture

Track Classification: Agriculture

Contribution ID: **16** Type: **Invited Oral**

Plasma applications for smart and sustainable agriculture-possibilities and challenges

Thursday, September 21, 2023 4:05 PM (30 minutes)

The population growth represents a serious challenge for humankind due to the continuous increase in demand for food. The climate change is also presenting a significant factor on food production due to the change in weather patterns, pest appearance, water availability etc. Therefore it is necessary to develop new and efficient technologies that can enhance productivity while maintaining food quality and safety. One of these technologies are non-equilibrium (non-thermal plasmas) plasmas that are considered as a green alternative to conventional fertilizers in agriculture to improve yields, increase size and robustness of plants, to reduce (or eliminate) the need for pesticides and in the case of final products treatments of food and its packaging. The reason for this is their rich plasma chemistry that is created in gas phase (at room temperature) and can be easily transferred to liquid samples. Plasma chemistry is rich in Reactive Oxygen Nitrogen Species (RONS) 1 and it was shown that low pressure and atmospheric pressure plasmas can be successfully used in stimulation of the seed growth, increase of germination percentage and decontamination, breaking of dormancy or lengthening of the seed sprout [2, 3]. In direct plasma treatments (gas phase plasma is in contact with sample surface) of seeds the surface is activated and different functional groups can be attached resulting in increased wettability, coating with desired compounds or just decontaminated from pathogens [4]. Another successful approach is in treatment of water for production of Plasma Activated Water (PAW) rich in long living RONS [5]. Here we will present some of the recent results in the field of Plasma Agriculture and address future challenges of plasma applications in this field.

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Session Classification: Agriculture

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **17** Type: **Invited Oral**

Atmospheric Pressure Plasma jet for Biomedical Applications

Wednesday, September 20, 2023 11:50 AM (30 minutes)

Atmospheric pressure non-thermal (i.e., cold) plasmas especially atmospheric pressure plasma jets are widely studied in plasma medicine and used for various therapeutic applications. These cold plasmas for tumor treatment or for skin infection etc. is promising and emerging field. Recently, the use of plasma in dermatology, cancer research and oncology are of particular interest. In this talk, an overview will be given about the activities performed in this field at Institute for Plasma Research in collaboration with different medical Institutes in India.
A low temperature atmospheric pressure plasmas like atmospheric pressure plasma jets (APPJ) operating with Helium/Argon gas as well as volume and surface dielectric barrier discharge (DBD) air plasmas are developed at Institute for Plasma Research (IPR). These atmospheric pressure plasmas have been explored for various applications like surface sterilization, cancer cell treatment, skin treatment, blood coagulation etc.
The treatment modality of oral cancers comprises of surgical resection of the tumor in conjunction with chemotherapy or radiation therapy which have limitations, such as, free flap reconstruction post-surgery, high radiation dose in radiotherapy and chemo-resistance in chemotherapy. To address these limitations, we have explored the effect of non-thermal / cold atmospheric plasma (CAP) in treatment of oral cancer cells lines. Here, CAP has shown to induce cancer cell death. We firstly established the in vitro efficacy of plasma treatment on GB-SCC, MCF7 and HEK293 cell lines using MTT assay. We observed a time dependent decrease in the cell viability on treatment with plasma jet. We further analysed its effect on in vivo hamster buccal pouch (HBP) model. Tumor was induced in hamsters and direct CAP treatment was initiated to observe CAP induced tumor regression over period of time.

Further helium-based CAP was applied on resected tumor specimens obtained from patients with glioma. The results show that CAP was effective in generating enhanced levels of RONS in glioma samples and CAP jet is more effective in thinner samples as compared to thick tumor samples. Our findings suggests that CAP could lead to RONS-mediated tumor cell death and can be potentially used as an adjunct therapy for treatment on the tumor bed, post resection of tumor in patients with glioma. The atmospheric pressure DBD air plasma was also used for sterilization and decontamination of the surfaces. The results showed that the air plasma effectively kills microbes likes bacteria, Fungus and virus on the different surfaces after treatment of few minutes.

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Session Classification: Medicine

Track Classification: Medicine

Contribution ID: **18** Type: **Contributed Oral**

Commercialisation pathways for plasma-activated coatings, plasma immersion ion implantation and plasma-polymerised nanoparticles in biomedical science

Tuesday, September 19, 2023 2:10 PM (15 minutes)

Globally, biomedical researchers are hampered in reagent, consumable and product development by the inability of functional biomolecules to bind to polystyrene, glass and other important materials. Functional biomolecules - used in products ranging from diagnostics to cell culture to drug delivery systems - are most often physisorbed to the surface, meaning their attachment is relatively weak and that they may be washed off during use. To overcome this, linker chemistry is frequently used, however this is typically performed on an individual biomolecule basis, often involves toxic chemicals and is largely focused on the attachment of proteins to specific surfaces. The development of plasma-based systems to embed or coat surfaces with radicals capable of covalently binding to biomolecules offers a significant step forward in overcoming the poor biomolecule-surface attachment hurdle. Crucially, these plasma processes also make the surfaces hydrophilic enabling immobilised biomolecules to maintain function. We have recently developed plasma-activated coatings (PAC) on flat glass and non-flat geometry cell culture polystyrene consumables as well as plasma ion immersion implantation (PIII) of paramagnetic microparticles. During the plasma treatment for PAC, plasma-polymerised nanoparticles can also be generated. All four of these plasma applications result in surfaces which can rapidly and covalently bind to biomolecules including proteins, carbohydrates, lipids, DNA, RNA, vitamins, drugs and fluorescent molecules, all with a simple incubation of the biomolecule and the surface. Within an hour of incubation, functional biomolecules are covalently bound without the need for other reagents or wet chemistry. This technology is now in various stages of commercialisation including: the manufacturing of PAC-treated cell culture plates for cellular immunotherapy and cellular agriculture; PAC-treated bioassay and immunoassay plates to improve diagnostics; PAC-treated borosilicate glass for improving cell culture on surfaces optimal for microscopy; PIII-treated magnetic microparticles for intracellular cell sorting; and plasma-polymerised nanoparticles for flow cytometry, vaccine development and drug delivery. This presentation will focus on the application of these plasma technologies in the design and manufacturing of novel, superior products driven by the needs of biomedical industry partners.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **19** Type: **Invited Oral**

Scientific approach to plasma technologies

Tuesday, September 19, 2023 10:15 AM (30 minutes)

The basic principle of plasma technologies is the modification of surface properties of solid materials by treatment with species of high potential and/or kinetic energy. The surface finish usually depends on the dose of plasma species (charged particles, neutral radicals, and radiation) and sometimes also on the fluxes of plasma species. Scientific literature, however, rarely reports the fluxes or doses. Instead, it reports the peculiarities of the experimental system, the discharge coupling and power, the gas pressures and flows, and the treatment time. The lack of information about the fluxes and doses disables the upscaling of the scientific results to the industrial level. The scientific approach to plasma functionalization and wettability of organic materials will be presented. It will be shown that the evolution of the surface wettability of numerous polymers depends only on the dose of neutral atoms and marginally on other parameters such as the discharge power, gas pressure, and treatment time. Knowing the required dose for a desired wettability thus enables upscaling, which is merely a technological, and not a scientific challenge. The desired surface finish of many polymers is achieved by treatment with oxygen plasma, while a two-step process should treat some polymers (especially fluorinated). First, the polymer is exposed to plasma which is a significant source of vacuum ultraviolet radiation, and then to a mild oxygen plasma or its afterglow. The first step enables bond breakage in the surface film and the second functionalization with polar functional groups. The two-step process allows a super-hydrophilic surface finish of many polymers, including Teflon.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **21** Type: **Invited Oral**

Pros and Cons of Plasma Agriculture: A Current View

Thursday, September 21, 2023 1:45 PM (30 minutes)

Plasma agriculture is an emerging research field that involves the use of low-temperature plasma to enhance agricultural productivities [1-4]. Based on some examples, we discuss some potential pros and cons associated with plasma agriculture.
Seven Pros of Plasma Agriculture:
1. Increased crop yields: Plasma agriculture has the potential to enhance plant growth and increase crop yields. Plasma treatments can stimulate seed germination, improve nutrient absorption, and enhance photosynthesis, leading to healthier and more productive plants.
2. Pest and disease control: Plasma can be effective in eliminating pests, pathogens, and weeds. Plasma treatments can help reduce the reliance on chemical pesticides and herbicides, potentially resulting in reduced environmental contamination and lower health risks for farmers and consumers.
3. Water and soil improvement: Plasma treatments have the potential to improve water and soil quality. Plasma can remove contaminants and toxins from water, making it safer for irrigation. It can also break down organic matter and improve nutrient availability in the soil.
4. Reduced chemical inputs: Plasma agriculture has the potential to reduce the need for synthetic fertilizers and pesticides. This can lead to lower costs for farmers and reduced environmental impact, including less pollution of water bodies and reduced soil degradation.
5. Extended shelf life: Plasma treatments can help extend the shelf life of fruits and vegetables. By reducing the growth of spoilage-causing microorganisms, plasma can help preserve the freshness and quality of produce, reducing food waste.
6. Cost and infrastructure: Implementing plasma agriculture can be inexpensive,. The rental or co-ownership of the plasma equipments may be cost-effective for many farmers even in developing regions.
7. Energy consumption: Plasma generation requires energy, and the energy consumption associated with plasma agriculture is evaluated below 3% of the energy of whole agricultural processes. The use of electricity from on-site renewable energy sources may contribute to sustain plasma.
Three Cons of Plasma Agriculture:
1. Lack of long-term studies: Plasma agriculture is still a relatively new field, and there is limited long-term research on its effects. More studies are needed to fully understand the potential environmental and health impacts associated with plasma treatments.
2. Potential unintended consequences: While plasma treatments can target pests and pathogens, there is a risk of unintended effects on beneficial organisms. It is crucial to study and minimize any potential harm to beneficial insects, pollinators, and other organisms in the ecosystem.
3. Regulatory challenges: The adoption of plasma agriculture may face regulatory hurdles, as the technology is still emerging and may not fit within existing regulatory frameworks. This could slow down its widespread implementation and commercialization.
It's important to note that plasma agriculture is an evolving field, and further research and development are necessary to fully understand its potential benefits and drawbacks.

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Session Classification: Agriculture

Track Classification: Agriculture

Contribution ID: **22** Type: **Invited Oral**

Non-thermal plasma catalytic dry reforming of methane over Ni-Co3O4 supported modified-titania catalysts: Effect of process conditions on syngas production

Wednesday, September 20, 2023 3:20 PM (30 minutes)

The dry reforming of methane has been studied over modified TiO_2-supported 10%Ni-5%Co_3O_4 composite catalysts using a non-thermal plasma dielectric barrier discharge fixed-bed reactor. The 10%Ni-Co_3O_4/modified-TiO_2 nanorods (NR) have been synthesized by hydrothermal method. Physicochemical characterizations of the composite catalysts have been conducted by X-ray diffraction (XRD), H_2 temperature-programmed reduction (H_2-TPR), CO_2 temperature-programmed desorption (CO_2-TPD), high-resolution transmission electron microscopy (HRTEM) and N_2 adsorption-desorption (BET) analysis. Incorporation of cubic-structured Co_3O_4 into Ni/TiO_2 attributes to the enhancement of basicity, reducibility and metal-support interaction. Consequently,the catalytic activity of 10%Ni-5%Co_3O_4/TiO_2 NR increases and confer CH_4 and CO_2 conversions at 86.4% and 84.9%, respectively. Meanwhile, the H_2 and CO selectivity are reported as 50.1% and 49.0% respectively. Higher syngas ratio (H_2/CO) from 0.84 to 1.01 and 26% increment in overall energy efficiency compared to plasma DRM alone have been observed. The superior plasma DRM performance is correlated to the greater basicity properties and the synergistic effect of non-thermal plasma with the 10%Ni-5%Co_3O_4/modified-TiO_2 catalyst composite.

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Session Classification: Catalysis

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **24** Type: **Invited Oral**

PLASMA MEDICINE: CURRENT STATUS AND PERSPECTIVES

Wednesday, September 20, 2023 10:00 AM (30 minutes)

Plasma medicine, defined as the application of non-equilibrium plasmas for therapeutic purposes, has made tremendous progress over the last decade, becoming a lively transdisciplinary research field where expertises from life sciences and medicine are combined with plasma physics, chemistry and engineering. Plasma application in wound healing is well on its way into clinical routine and several other avenues are being currently pursued, chief among which cancer treatment.
A large number of devices is now in experimental or clinical application, but two architectures are dominating: dielectric barrier discharges (DBD) and plasma jets (PJ); these devices work in ambient air conditions or using ambient air as the working gas for plasma generation, resulting in the production of reactive oxygen and nitrogen species (ROS, RNS). The composition and quantity of ROS and RNS, currently identified as the principal plasma agents inducing specific biological effects, depends on the plasma device, operating conditions, ambient conditions and, if present, plasma contact with other media beyond atmospheric air (e.g. liquid phases).
Given the role of ROS and RNS in plasma treatment, redox biology is serving as a scientific basis to understand molecular mechanisms of the biological effects of plasmas; among the most important results of current studies, mutagenic and genotoxic effects can be excluded given proper application of plasma devices.
Four major challenges have been recently identified for plasma medicine: 1) regulatory aspects, 2) the treatment of internal cavities of the bodies, 3) the definition of a concept of dose for medical applications of plasmas and 4) ensuring repeatability of plasma treatments in clinical settings 1.

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Session Classification: Medicine

Track Classification: Medicine

Contribution ID: **25** Type: **Contributed Oral**

Material modifications due to the plasma irradiation

Tuesday, September 19, 2023 2:25 PM (15 minutes)

In many areas of energy production and application, materials with superb thermal and mechanical properties are required. In particular in fusion devices, first wall materials are exposed to extreme heat, neutron and particle fluxes, leading to material degradation. In solar tower power plants the exposure to highly concentrated and alternating solar fluxes, leading to cyclic thermal loads, and operating in humid air environment combined with high operational temperatures of above 1000℃ required for commercially competitive electricity production imposes comparably challenging requirements on materials for solar receivers. New production methods, material combinations and complex materials concepts are investigated to develop new materials with improved properties, reduced production costs and larger flexibility with respect to manufacturing of final components, as well as increasing the overall efficiency of energy systems. We produce material modifications due to plasma for several applications.
1. Deposition of antifriction and antisintering coatings of solid lubricants (MoS2) that are very effective at high loads close to the yield stress of contacting materials, at low sliding speed. In aerospace field, such coatings are used to prevent friction in friction units; in the oil and gas industry, threads are coated to prevent sticking; in nuclear fusion facilities they are used to protect fixing articles in construction elements of tokamaks (ITER, France; JET, England) and stellarators (Wendelstein 7-X, Germany). The coatings underwent tests at high temperature (250℃) in vacuum environment.
2. Plasma nitriding in an inductively coupled plasma (ICP) source facility, and ICP combined with plasma immersion ion implantation (PIII) method for material surface hardening. Duplex treatment of surfaces by first-stage plasma nitriding followed by magnetron sputter deposition of hard and/or wear-resistant coatings. Duplex treatment allows drastic improvement of surface parameters without compromising the coating adhesion. Coating materials include CrN, CrAlN, TiN. These technologies are being used for improving performance of cutting tools in machining industries.
3. He plasma interaction with advanced W-Cr-Y alloy for production of nearly black body to prevent loss of heat for solar tower power plants.
4. Developing plasma-based technology for titanium implant surface engineering. For this purpose, ion flux from ICP source is used to bombard the surface of the implant and to produce the anticipated topology. Technology allows preparing surface topologies with nanometer features for improving the antibacterial properties and those with micrometer features for improving the proliferation of osteoblasts. Combined laser and plasma technology for controlled surface patterning as an eco-friendly wasteless method for preparation of surfaces of a wide range of bone integrated materials.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **26** Type: **Invited Oral**

Plasma electrochemistry for organic synthesis: Pinacol coupling as proof-of-concept

Thursday, September 21, 2023 9:00 AM (30 minutes)

Low-temperature, atmospheric-pressure plasmas in contact with liquids have attracted interest for various chemical applications including the synthesis of colloidal nanoparticles, degradation of organic pollutants, and conversion of abundant feedstocks. Compared to other chemical approaches, plasma-liquid chemistry does not require a catalyst material, is electrified, and produces unique reactive species such as solvated electrons, one of the strongest chemical reducing species.

Here, we present an application of plasma-liquid chemistry to organic synthesis using the example of the pinacol coupling reaction to demonstrate the potential to forge new carbon-carbon bonds. Our study was performed using a direct-current (DC) powered plasma formed between a metal electrode and liquid methanol surface. Parametric studies were focused on methyl-4-formylbenzoate (MFB) as the substrate. The experimental results were supported by a reaction-diffusion model. In addition to the pinacol product, nuclear magnetic resonance (NMR) spectroscopy also indicated methyl 4-(dimethoxymethyl)benzoate, methyl 4-(hydroxymethyl)benzoate, and 4-(methoxycarbonyl)benzoic acid as side products. By varying process conditions such as the initial MFB concentration and the addition of water to the reaction, the faradaic efficiency of the pinacol product is increased up to 80%, and the yield is as high as 46% after 12 h. Scavenger control experiments reveal that the vicinal diol is produced by solvated electron reduction while the side products are formed by reactions with other radicals or the solvent. The generality of the approach is demonstrated by extending to several other aromatic aldehydes and ketones.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **27** Type: **Invited Oral**

Adaptive Plasmas for Biomedical Applications

Wednesday, September 20, 2023 9:00 AM (30 minutes)

The uniqueness of low-temperature plasma is in its ability to change composition in situ. Plasma self-organization could lead to formation of coherent plasma structures. These coherent structures tend to modulate plasma chemistry and composition, including reactive species, the electric field and charged particles. Formation of coherent plasma structures allows the plasma to adapt to external boundary conditions, such as different cells types and their contextual tissues. In this talk we will explore possibilities and opportunities that the adaptive plasma therapeutic system might offer. We shall define such an adaptive system as a plasma device that is able to adjust the plasma composition to obtain optimal desirable outcomes through its interaction with cells and tissues.

Various approaches for plasma therapy based on plasma adaptation to target conditions will be reviewed. These approaches are based on the ability of measuring the cellular response to plasma immediately after treatment and modifying the composition and power of plasma via a feedback mechanism. Plasma self-adaptation might be feasible due to self-organization and pattern formation when plasma interacts with targets. Plasma effect on biological targets is influenced by various factors including the plasma jet discharge voltage, gas composition, humidity and cancer cell type. To address this, we present an optimal feedback control scheme to adjust treatment conditions responsive to the biological response.

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Session Classification: Medicine

Track Classification: Medicine

Contribution ID: **28** Type: **Invited Oral**

Methane as a feedstock in plasma-liquid processes

Thursday, September 21, 2023 11:05 AM (30 minutes)

Natural gas is one of the abundant fossil fuels, and probably the most flexible considering its relatively simple composition. The primary constituent is methane, and methane is used in several industrially crucial processes, such as steam-methane reforming and partial oxidation for the production of hydrogen and syngas, respectively. However, there are still plenty of other reactions that involve methane, which have not yet been established in any scale. The most important examples are dry reforming, oligomerization of methane, organic synthesis of cyanides and methanol synthesis. The common problem in these reactions is either the stability of the catalyst or low conversion levels.

While all the reactions mentioned above are generally studied in gas phase utilizing heterogeneous catalysts, methanol synthesis can be conducted catalyst-free in liquid phase, if a plasma is utilized. Since methane can easily be broken into methyl and hydrogen radicals by the free electrons of the plasma, both oligomerization and methane pyrolysis are feasible. In other words, the degree of methane dehydrogenation is expected to dictate the product spectrum in a methane plasma. In the presence of water and its vapor, methanol synthesis is expected to occur only if dehydrogenation is limited, which requires control over the electron population, electron energy distribution and residence time. Increasing the extent of dehydrogenation would favor carbon formation, whereas decreasing it is hypothesized to improve the yield of larger alcohols. Therefore, a combined approach of methane plasma kinetics and chemical reaction engineering is needed to tune the product spectrum.

This talk will focus on the use of plasma-liquid interaction for direct methane conversion into alcohols. We will first critically review previous work on the combination of water and methane in a plasma. Following that, a reaction kinetics model and computational fluid dynamics calculations will be presented with the aim of assessing the impact of plasma operation and residence time on the products. Results of the preliminary experiments obtained in a pin-to-plane setup consisting of pure methane and water will also be discussed.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **29** Type: **Invited Oral**

Microwave and RF Plasma Enhanced Synthesis of Nanomaterials

Thursday, September 21, 2023 11:35 AM (30 minutes)

Microwave Plasma and Radio Frequency (RF) Plasma are widely utilized plasma techniques for fabricating nano materials with tailored properties to suit specific applications. RF Plasma Enhanced Chemical Vapor Deposition (PECVD) is commonly employed for producing carbon nanomaterials, such as vertical graphene, which possesses desired defects for specific applications. By adopting PECVD, significant reductions in fabrication temperature can be achieved, although external heating and vacuum conditions are still necessary. On the other hand, Microwave Plasma enable graphene fabrication under ambient conditions and in larger quantities. Moreover, Microwave Plasma simplifies the complex multi-step processes involved in producing graphene oxide or doped graphene. These plasma techniques not only reduce energy consumption and costs compared to traditional methods but also offer the flexibility to utilize various carbon sources and substrates, broadening the potential applications of plasma-assisted graphene fabrication. The unique properties of graphene produced through microwave and RF plasma techniques open up numerous opportunities for diverse and high-value applications in electronics, energy storage, sensors, and other fields.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **30** Type: **Invited Oral**

Plasma for space applications

Wednesday, September 20, 2023 3:50 PM (15 minutes)

Among established and emerging plasma technologies for space applications are electric propulsion for satellites, plasma contactors for preventing charge accumulation on spacecraft and electrodynamic tethers. This talk will be focused mainly on electric propulsion which utilizes electric power to ionize and accelerate propellant, thereby generating thrust. The main advantage of using electric propulsion for spacecraft orbit control over chemical rockets is the larger jet velocity (˜10–100 km/s), which enables significant savings in the propellant mass. By 2021, about 3000 electrically propelled satellites have been launched 1. The most common form of electric propulsion technology on these satellites is the Hall thruster, which generates thrust by electrostatically accelerating ions in crossed electric and magnetic fields (ExB), which are applied in a quasineutral. Over the last 60 years, research and development efforts have been focused on 0.5-10 kW power level Hall thrusters. The on-going rise of higher power capabilities onboard satellites and the miniaturization of components open the possibility for new electrically propelled space missions including, for example, constellations of miniaturized satellites (e.g. CubeSats) and high power interplanetary missions. These new space missions and applications require Hall thrusters scaled down in size and up in power to operate efficiently with a high thrust density (thrust-to-thruster frontal area) at lower (<100 W) and higher (>100 kW) power levels, respectively. Most of the existing Hall thrusters operate with thrust densities of ˜ 10 N/mˆ2. In a recent theoretical study, the fundamental limit of Hall thrusters was predicted to be at least 10 times higher [2]. This would imply much more compact thrusters suitable to the above applications are possible. In order to achieve this predicted limit, there is a strong need to address a number of plasma science challenges associated with cross-field transport and instabilities, plasma-wall interactions, and ionization relevant to high thrust density operation. Alternative ExB thruster configurations may be needed to operate in these extreme regimes. This talk will briefly discuss these challenges and their potential solutions.

References:
1 B. R. Frongello et al., "Spacecraft Electric Propulsion at an Inflection Point", ASCEND 2021, Las Vegas, ND/Virtual, November 2021
[2] J. Simmonds, Y. Raitses, and A. Smolyakov, "A theoretical thrust density limit for Hall thrusters" , J. Electric Propul. 2, 12 (2023)

Acknowledgement: Drs. Jacob Simmonds, Andrei Smolyakov and Michael Keidar for fruitful discussions.
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Session Classification: Space

Track Classification: Space

Contribution ID: **31** Type: **Invited Oral**

Perspectives on atmospheric pressure air plasma for chemical and microbial decontamination across the food production sector.

Thursday, September 21, 2023 2:15 PM (30 minutes)

Microbial contamination is one of the greatest challenges faced by the food industry. Biological contaminants, such as bacteria and fungi, cause significant food waste, economic losses to food producers, and serious illnesses to over 2 billion people each year. Low temperature plasmas have shown great promise for the decontamination of microorganism and other contaminants, yet uptake of the technology across the food production sector has been limited due in part to the complexity of the underpinning physicochemical processes at play.

This contribution will focus on recent efforts to develop plasma technology for use across the food production sector, focusing on the decontamination of food contact surfaces and food products. Results from the application of advanced experimental diagnostic techniques, such as laser induced fluorescence, and computational modelling, are used to shed light on the transport of key plasma-generated Reactive Oxygen and Nitrogen Species (RONS) to a downstream target. It will be show that the composition and concentration of RONS arriving at a target are heavily dependent on the specific design parameters of the plasma generating source, opening the possibility to enhance mass transport and therefore increase application efficacy.

Several topical examples of where the technology has shown promise across the sector will be discussed, including the continuous and in-line decontamination of conveyor belts and the elimination of fungal species, including their toxic secondary metabolites. Ultimately it is shown that plasma technology is capable of meeting industry requirements in terms of both efficacy and treatment time.

Finally, the future perspectives on the implementation of plasma technology across the food supply chain will be discussed; highlighting the remaining challenges that must be overcome to realise its full potential across the sector.

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Session Classification: Agriculture

Track Classification: Agriculture

Contribution ID: **32** Type: **Invited Oral**

Plasma Catalysis: Opportunities and Challenges in Gas Conversion

Wednesday, September 20, 2023 1:30 PM (30 minutes)

The conversion of inert molecules (e.g., CO2, CH4, and N2) with strong chemical bonds for the synthesis of value-added synthetic fuels and platform chemicals has attracted significant interest. However, the activation of these molecules remains a great challenge due to their thermodynamical stable, requiring a substantial amount of energy for activation. Non-thermal plasma (NTP) has emerged as a promising technology for gas conversions under ambient conditions. The combination of NTP with heterogeneous catalysis has great potential for achieving a synergistic effect through the interactions between the plasma and catalysts, which can activate catalysts at low temperatures, improve their activity and stability, and lead to a notable increase in conversion, selectivity, and yield of end-products, as well as enhance the energy efficiency of the process. Furthermore, plasma processes can be switched on and off instantly, offering great flexibility in decentralised fuel and chemical production using renewable energy sources, particularly intermittent renewable energy. This presentation will discuss the opportunities and challenges in plasma-catalytic gas conversion to fuels and chemicals, including various chemical processes such as CH4 activation, CO2 conversion, and ammonia synthesis.

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Session Classification: Catalysis

Track Classification: Catalysis

Contribution ID: **39** Type: **Invited Oral**

Applied potential of cold plasmas for seed processing

Thursday, September 21, 2023 3:35 PM (30 minutes)

In the context of rapid population growth, climate change, and resource constraints, sustainable and smart agriculture has become essential. Obtaining high yields in agricultural production starts with planting seeds that germinate in high percentages and produce robust plants with minimal delay. The potential of seed irradiation with low temperature plasmas (cold plasmas, CP) for application in agriculture is under intensive investigation, as a green alternative to conventional chemicals (fertilizers, pesticides and herbicides). It has been demonstrated on numerous crop species that short term seed irradiation with low-pressure or atmospheric CP devices can decrease microbial seed contamination, improve yields and increase robustness of plants through complex wide-scale changes evolving at the epigenomic, transcriptomic, proteomic and metabolic levels. In the last decade, many important aspects at the molecular level have been revealed, and the knowledge of such mechanisms has an immense potential for applications in agriculture.

The accumulated body of evidence indicates to the high complexity of seed response to CP treatment on the molecular level. Increased amount of photosynthetic pigments and upregulated photosynthesis, improved root development results in enhanced growth, while the stimulated secondary metabolism leads to better plant establishment, fitness and stress resistance. The most important novel findings on such response induced in dry seeds are changes in EPR signal, DNA methylation, balance of phytohormones, expression of genes and proteins, enzyme activities, modified seed microbiome. CP-induced changes in reactive oxygen species production were reported in the germinating seeds. The events of seed response to the CP stress signal are further developed in the growing plant. This is manifested as multiple interrelated changes in gene expression due to DNA methylation, changes in protein expression, activities of numerous enzymes important for photosynthetic system, secondary metabolism and antioxidant defense. Modulation of secondary metabolism and capacity of the antioxidant system is associated with an increased plant fitness and resistance to biotic and abiotic stress, as well as modified plant communication with microorganisms - both pathogens and plant growth promoting microorganisms, e.g. N-fixating rhizobacteria. Thus, seed treatments with CP induce mobilization of the molecular mechanisms leading to improved chances for plant survival, including better establishment, stress resistance and productivity.

Understanding the complex interactions between seeds and CP remains challenging due to the intricacy of seed structure and yet unidentified molecular systems involved in signal perception and transduction. Further, reproducing observed effects poses reliability concerns for these technologies. A better grasp of the dependence on factors such as species, cultivar, genetic lineage, plant gender, and seed polymorphism could enhance reproducibility and reliability. Furthermore, the development of strategies for the technology transfer from the laboratory practice for medium and large scale application in cooperation with the industry is required.

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Session Classification: Agriculture

Track Classification: Agriculture

Contribution ID: **40** Type: **Invited Oral**

Plasma Bubbles: A path to Green Chemistry

Tuesday, September 19, 2023 9:45 AM (30 minutes)

The interface between plasma and liquid plays an important role in the generation and transfer of reactive species. Plasma bubbles offers the means of providing energy efficiency and enhanced mass transfer facilitating effective and competitive scaling of plasma systems for energy applications. A number of green chemistry examples will be presented including; Example One will focus on the plasma bubbles-enabled water purification, which will emphasize the significance of plasma bubble characteristics for transferring oxygen reactive species, particularly superoxides; Example Two will focus on the plasma bubbles for ROS production (H2O2), with the further improvement of H2O2 yield by photocatalysis; Example Three will focus on the plasma bubbles for RNS production (NOx) and the combination of electrochemical catalysis for ammonia production. The potential of combining plasma bubbles with catalysts will be outlined.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications

Contribution ID: **42** Type: **Invited Oral**

Catalysis and plasma processing: The tip of the iceberg

Wednesday, September 20, 2023 2:00 PM (30 minutes)

Several renewable energy harvesting technologies have matured and become affordable and the main output, renewable electricity, is becoming a commodity. The new challenges are short and low-term storage, as well as its conversion into dense, easily transportable forms. Gases and liquids are energy-dense storage media, and the handling infrastructures are already well established for several important chemicals. Renewable electricity-to-chemical conversion processes are not common and are rarely deployed at scale. Plasma processes are uniquely poised to play a significant role in this transition. Near-equilibrium (thermal) plasmas (e.g. plasma torches, electric arc furnaces) have been used for decades for niche gas conversion applications and not only for highly endothermic reactions (e.g. dry reforming of methane, hydrogen production from methane). Transitional (warm) plasmas (e.g. gliding discharges) are already used with lesser endothermic reactions, such as hydrogen production from hydrogen sulfide. Historically, there has been less interest to use non-equilibrium (cold) plasmas (e.g. dielectric barrier discharges, atmospheric pressure glow discharges) for gas conversion, mostly because of their much lower power densities. There are also additional challenges associated with high-throughput requirements which, traditionally, require pressures far above atmospheric where non-thermal plasma generation and maintenance is uneasy. Times are changing though, and new design criteria appear, such as small scale, on-demand, and/or distributed electricity conversion and storage which open the paths to non-thermal plasma processes. There is hope that the non-thermal plasma will compensate for the loss of activity associated with the lower temperatures by locally producing active radicals by electronic impacts, and that cheaper and greener catalysts will be developed thanks to the milder conditions. Nowadays, non-thermal plasma catalysis rapidly gains interest in the plasma processing community. The premise is that the catalyst plays its usual role of lowering the energy requirement/providing the kinetics, while the non-thermal plasma provides the activation energy, excited and dissociated species, photons, electric field, and localized heating. Recent studies highlighted the vast realm of possible applications, plasma-catalyst interactions and complexity, as well as the limited knowledge we gained thus far. Unfortunately, most research work has thus far been heavily inspired by conventional thermal catalysis. As recently stated, "the largest potential benefits of plasma-driven catalysis are in regions of operating parameters space far from that where conventional thermal catalysis is most optimal 1". This tells us that "standard"catalyst materials may no longer work as well due to favorable plasma-catalyst interactions. Furthermore, contrarily to thermal processes with their characteristically large inertia and time constants, plasma excitation and dissociation processes occur on a sub-ns time scale, fast reactions and localized catalyst particle heating in the µs, slow reactions and bulk heating in the ms to s range. The temporal aspects have thus far not been exploited. Finally, plasma processes offer unique environments for the synthesis on non-conventional catalysts such as highly energetic phases, mixed and high-confined metal nanostructures, and catalyst reactivation. These are all vastly unexplored territories. In this talk, I will review the latest work in plasma catalysis and highlight several opportunities for fundamental research and technology development.

1: https://doi.org/10.1021/acsenergylett.9b00263

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Session Classification: Catalysis

Track Classification: Catalysis

Contribution ID: **43** Type: **Contributed Oral**

Irradiation Applications on Agriculture in Maejo University, Chiang Mai, Thailand

Abstract

This abstract provides an overview of the applications of irradiation in agriculture conducted at Maejo University, with a focus on Plants and animals breeding, Plant growth promotion, and Sterilization in field processes and postharvest stages. The university utilizes gamma radiation from the conventional source Gamma-cell 220, which features a Co-60 source with a radiation rate of 400 Gy/hr, to enhance food safety, extend shelf life, and effectively control pests in various agricultural products.
The studies investigate optimal dosage levels, techniques, and irradiation types to assess their impact on the quality and nutritional value of agricultural products. The results demonstrate the effectiveness of irradiation in inducing new characteristics in chili pepper and turmeric (1,2), as well as enhancing the germination rate and seedling growth of okra, cucumber, tomato, and cannabis (3–5).
The atmospheric pressure cold plasma is utilized to study the germination rate, surviving rate, and mutation of plants and fish through the use of plasma-activated water (PAW), offering various applications such as reducing pathogens, extending shelf life, and replacing chemical treatments.
Maejo University aims to contribute to sustainable and safe agricultural practices through the implementation of irradiation technology.

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Presenter: Dr JANPONG, Keratiya (Maejo University)

Session Classification: Agriculture

Track Classification: Agriculture

Contribution ID: **44** Type: **Invited Oral**

Low temperature plasma life innovations: Functional reaction networks of radical chemistry

Wednesday, September 20, 2023 9:30 AM (30 minutes)

Plasma processing technologies involve physical processes induced by electron collisions with precursors to produce unstable, short-lived reactive species that subsequently react with other species to generate various products. As an example, discharges in air with water vapor, a hydroxyl and nitrosyl radicals is first generated, following which chain growth occurs via initiation and propagation, in conjunction with termination reactions. Typically, the reaction is terminated by the addition of radical inhibitors, and this process tends to provide nonlinear growth of the chemical chains. The initiation step is dependent on the initial concentration of radicals, and the propagation reaction is controlled kinetically in conjunction with a continuously changing nonequilibrium state. This paper stressed the importance of understanding the dynamics of complex networks based on kinetically-driven reactions in nonequilibrium states, using empirical data. On this basis, it should be possible to control the functionalization of living organisms by employing common principles associated with the spatiotemporal atomic scale localization of reactive species.

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Session Classification: Medicine

Track Classification: Medicine

Contribution ID: **45** Type: **Invited Oral**

Low Temperature Carbon/Nitrogen Plasma Engineered High-performance Electrode Materials for Energy Storage and Conversion

Wednesday, September 20, 2023 2:30 PM (30 minutes)

The focus of this presentation will be on fabrication of cost-, time- and energy-efficient 3-D nanostructured electrode materials for high-performance energy storage (Li/Na ion batteries) and energy conversion (half/full cell) devices using low-temperature carbon/nitrogen plasmas. For energy storage devices, the electrode materials, particularly the anode materials, significantly influence the performance and efficiency of energy storage batterie as the anode is responsible for storing and releasing ions (e.g., lithium or sodium) during charge and discharge cycles. Similarly, for applications in electrochemical energy conversion processes such as hydrogen and oxygen evolution reactions, the research on electrode materials drives advancements in catalyst activity, electrochemical efficiency, stability and durability, cost and abundance, scalability, and integration. The exploitation of new materials and modification of existing materials at the atomic level are two prime strategies to increase the performance of these devices. Innovative and environmentally friendly synthesis and processing technologies, other than wet chemistry approaches, for development of new materials with desired structural, morphological, physical and chemical properties are actively being explored to achieve improved performance of energy materials. Low-temperature non-thermal carbon/nitrogen-plasma-based synthesis and processing strategies have been actively explored by us to demonstrate that it indeed serves as a promising tool for the preparation of advanced porous 3-D nanoassemblies that provide electrode materials with excellent capacity, capacity retention, cycling, charge transport, low overpotential, and high-stability. In this proposed talk I will provide the overview of the work done on using low temperature carbon/nitrogen plasma in RF-PECVD system to process, dope and synthesize energy storage and conversion materials with significantly improved electrochemical performances.

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Session Classification: Catalysis

Track Classification: Catalysis

Contribution ID: **46** Type: **Invited Oral**

Exploring the Interface Between Plasmas and Liquids: Addressing Contemporary Challenges with Innovative Software Tools

Tuesday, September 19, 2023 4:00 PM (30 minutes)

The interaction between low-temperature plasmas and liquid surfaces is a critical problem in many emerging plasma applications including plasma medicine, chemical processing, and water treatment, where precise control over the generation of reactive oxygen and nitrogen species, as well as solvated electrons, is essential. However, comprehensively characterizing the plasma-liquid interface poses significant experimental and computational challenges due to the complex multi-scale and multi-physics nature of the problem. In this talk, we present an overview of recent advancements in modeling techniques for studying plasma-liquid interfaces, introducing (1) a novel open-source software package, Zapdos-CRANE, built upon the MOOSE finite-element framework; (2) RustBCA, a novel software for kinetic treatment of ion-surface interactions; and (2) hPIC2, a Particle-in-Cell for HPC simulations of multi-species chemically reacting plasmas. We demonstrate the code capabilities over several verification and validation problems. We then examine in detail a humid argon DC plasma over a water surface, operating in both cathodic and anodic modes. Within this system, we analyze the chemical pathways involving the formation and dissolution of hydroxide (OH) radicals, leading to subsequent hydrogen peroxide (H2O2) production. The model enables the investigation of key plasma-chemistry reaction mechanisms responsible for peroxide generation. Interestingly, our analysis reveals that anodic plasma treatment leads to an increase in hydrogen peroxide due to elevated water vapor dissociation reactions near the interface. Finally, we discuss the role of solvated electrons generated during cathodic plasma operations, demonstrating their direct degradation of hydrogen peroxide within the first nanolayers of the aqueous phase, consequently inhibiting its accumulation.

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Session Classification: Water Treatment

Track Classification: Water Treatment

Contribution ID: **47** Type: **Invited Oral**

CHEMISTRY ASSOCIATED WITH PLASMA-LIQUID INTERACTIONS: CHALLENGES AND OPPORTUNITIES

Thursday, September 21, 2023 10:35 AM (30 minutes)

Plasma–liquid interactions are important in many applications ranging from environmental remediation to material science and health care. Depending on the type of non-equilibrium electrical discharge plasma, its contact with liquid (i.e., generated either directly in the liquid, in the gas phase over, or in contact with a liquid), and the chemical composition of the surrounding environment, various types of physical processes and plasma-chemical reactions can be initiated. A number of primary and secondary species can be formed by plasma in the liquid either directly or transferred from the gas phase discharge plasma in contact with the liquid. Among these processes, the oxidative properties of reactive oxygen species (OH radical, atomic oxygen, ozone, hydrogen peroxide) and nitrogen species (nitric oxide, nitrogen dioxide radical) are generally accepted to play a central role in the chemical and biological effects of plasma produced in gas-liquid environments. These species can react at or penetrate through the plasma-gas/liquid interface, dissolve into the bulk liquid, and initiate secondary chemical processes in the liquid. Many of these chemical species are not stable in the liquid, and subsequent reactions can take place, giving rise to new transient species such as OH•, O2•-, NO• and NO2• radicals, which have highly cytotoxic properties and cause prolonged chemical and biological activity of plasma-treated solutions after the exposure to the discharge. The properties of such so-called plasma-activated liquids (PAL) and the duration of their activity are affected by many factors which determine the type, quantity, and lifetime of the reactive species being formed in plasma-treated liquid. Great attention is paid to the chemistry and biocidal effects of peroxynitrite and acidified nitrites for aqueous solutions treated by air-liquid-phase plasmas. Formation of reactive oxychlorine species and subsequent Cl-related chemistry and biocidal effects might be initiated by plasma in saline solutions. The composition of cell culture media gives additional complexity to the aqueous chemistry in plasma-activated liquids because of the presence of organic compounds. Therefore, the yield of a total plasma-chemical process is due to the synergistic contributions of numerous different elementary reactions taking place simultaneously. Because of the complexity of the reactions, giving rise to both stable and non-stable intermediates and reactions products, detailed characterization of aqueous chemistry induced by plasma presents one of the challenges in plasma-liquid interactions that need to be addressed to control the chemical processes in the plasma treated liquid and the properties of PAL important for the use of plasma in specific applications. For example, a different approach should be applied when plasma will produce PAL with "stored"chemical/cytotoxic activity, produce fertilizer (i.e., to fixate nitrogen into water), or clean water from organic pollutants. These issues must be considered in the design/optimization of the suitable plasma source, i.e., whether to use a „hot"plasma source of RNS or rather a „cold"plasma source of ROS/RONS. This talk will briefly overview the basic principles of electrical discharge plasmas in liquids, emphasizing the main chemical processes initiated by plasma in treated liquids.

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Session Classification: Atmospheric Pressure Plasma

Track Classification: Atmospheric Pressure Plasma

Contribution ID: **48** Type: **Invited Oral**

Machine learning aided plasma source and process simulation for semiconductor fabrication processes

Tuesday, September 19, 2023 1:10 PM (30 minutes)

The plasma process contributes a high proportion of the semiconductor manufacturing process, and the complexity of the process is gradually increasing. To improve the degree of integration of semiconductor chips, various plasma sources and processes have been developed Furthermore, efforts have been made to design and optimize sources and processes using plasma simulators.

Although various simulators have been developed through the efforts of many research groups, it is still difficult to quickly respond to the needs of field engineers. Therefore, our research group has been conducting research on developing bulk and surface databases as well as simulators for many years to bridge this gap.

Moreover, may researches for plasma source monitoring have also been conducted by developing machine learning-based technologies. Thus, this talk introduces our group's simulator and database development status and the results of applying machine learning technology to plasma source monitoring and simulations.

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Session Classification: Industrial Applications

Track Classification: Industrial Applications