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Editorial

The Applications of Plasma Techniques

Mariusz Jasiński

Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-231 Gdańsk, Poland; mj@imp.gda.pl

1. Introduction

This Special Issue "The Applications of Plasma Techniques" in the section "Optics and Lasers" of the journal *Applied Sciences* intends to provide a description of plasmas, plasma devices and processes related to plasma applications in a broad sense. Plasma is called the fourth state of matter because its properties differ significantly from those of a neutral gas. Plasma is a conductive medium generated by the ionization of gases; thus, it occurs as a mixture of photons, electrons, and ions, but it can also contain neutral atoms and molecules. The concept of plasma includes media with very different properties. Plasma can be generated in different gases, at different pressures, and using different techniques. The densities and kinetic energies of various types of plasma components differ by several or even more orders of magnitude. Plasmas can also have very different applications; for example, plasma is used in areas as diverse as gas purification, chemical compound production, surface treatment of materials, synthesis of nanoparticles, and deactivation of bacteria, viruses, and cancer cells. Readers interested in this modern field of science and technology are invited to enjoy this collection of articles, which will excite the curiosity of scientists, engineers, and entrepreneurs interested in plasma applications. As a guest editor of this Special Issue, I wish you pleasant reading.

2. Results

As a guest editor of this Special Issue of "The Applications of Plasma Techniques" in the "Optics and Lasers" section of the journal "*Applied Sciences*" invited to write this Editorial, I briefly discuss below the results of all articles published in this Special Issue.

2.1. Numerical 3D Modelling: Microwave Plasma Torch at Intermediate Pressure

Qinghao Shen et al. in [1] presented the temporal and spatial variations in electron density during the excitation of a microwave-induced argon plasma, which were studied by simulations based on a self-consistent 3D fluid plasma model with Maxwell equations at intermediate pressures (between 1000 and 5000 Pa). The model was established using the finite element method to analyze the effects of time–space characteristics—the variation of plasma parameters with time and the 3D spatial distribution of plasma parameters in the plasma torch at various times. The numerical modeling was demonstrated in three different stages, where the growth of electron density is associated with time. The analysis of microwave plasma parameters indicated that intermediate pressure is useful for modeling and plasma source designing, especially for carbon dioxide conversion.

2.2. Probing Collisional Plasmas with MCRS: Opportunities and Challenges

Bart Platier et al. in [2] presented a review article on Microwave Cavity Resonance Spectroscopy (MCRS) and the technique's ability to diagnose both low-pressure and atmospheric-pressure plasmas. The working area of this diagnostic method has only recently been extended to atmospheric pressure plasma. This review discusses the advancements required for this transition and the implications of studying highly collisional plasmas with respect to the probing frequencies. These developments and implications call for a redefinition of the limitations of MCRS, which also impact studies of low-pressure

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plasmas using the diagnostic method. The discussed topics might be able to help to further develop the diagnostic method and explain unexpected results.

2.3. Axial Plasma Spraying of Mixed Suspensions: A Case Study on Processing, Characteristics, and Tribological Behavior of Al_2O_3-YSZ Coatings

Sneha Goel et al. in [3] proposed thermal spraying deploying liquid feedstock (specifically Suspension Plasma Spraying—SPS), which offers an opportunity to obtain coatings with characteristics that are vastly different from those produced using conventional spray-grade powders. As a case study, the presented research concerns axial plasma-sprayed coatings produced using a mixed suspension of fine (submicron or nano-sized) powders of Al_2O_3 and YSZ. Evaluation of the surface morphology, microstructure, and hardness of the coatings reveals that the axial SPS of mixed suspensions provides an exciting pathway to realize finely structured multi-constituent coatings using suspensions with as high as 40 wt.% solid loading. The study of scratch, dry sliding wear, and erosion behavior also shows that the addition of YSZ into the Al_2O_3 matrix can improve the tribological properties of the coating.

2.4. Chosen Aspects of the Electromagnetic Compatibility of Plasma Reactors with Gliding Arc Discharges

Paweł Mazurek in [4] presented an analysis of electromagnetic disturbance interactions inside the three-phase gliding arc plasma generation installation. This constitutes the main part of the electromagnetic compatibility analysis of the reactor installation. All elements of the nonthermal plasma installation are described from the perspective of disturbance generation and its influence on the power supply system. The analysis is based on the results of tests carried out in accordance with the guidelines of the electromagnetic compatibility (EMC) directive and harmonized standards. The disturbances measured are large—over 20 dB above the limits—and allow for valid conclusions to be reached in relation to this type of installation. This implies a need for plasma reactors to be designed with elements that reduce radiated and conducted interference.

2.5. A Gliding Arc Microreactor Power Supply System Based on Push–Pull Converter Topology

Piotr Krupski and Henryka Danuta Stryczewska in [5] presented the use of an inverter power supply for a miniaturized GlidArc (gliding arc). It demonstrates the use of a push–pull topology in an unusual application. A special part is devoted to parasitic phenomena in the inverter and the switching over of voltages as a way to improve the ignition parameters of the power supply. The results of the tests with a plasma reactor in air conditions as a process gas are also presented. The authors stated that the designed and constructed power supply has the desired utility features required from the power electronic source of the plasma reactor. It also has numerous features that place it at an advantage over devices in which energy is transformed using a transformer with a network frequency, such as good control parameters, a good power-to-volume ratio of the power supply, and a high susceptibility to modifications.

2.6. Operating Problems of Arc Plasma Reactors Powered by AC/DC/AC Converters

Grzegorz Komarzyniec and Michał Aftyka in [6] reported the results of research on the cooperation of three-electrode plasma reactors with gliding arc discharge powered from multi-phase AC/DC/AC converters. To achieve the scientific and practical goal of the project, a test stand was designed and built which included: a multi-electrode GlidArc type plasma reactor; a power-electronic AC/DC/AC converter working as a source of voltage or current with regulated parameters of energy transferred to the discharge space; a reactor operation diagnostics systems; and a process gas feeding and flow control system. The GlidArc Plasma Reactor demonstrated high sensitivity to changes in many electrical, gas chemical, gas-dynamic, and mechanical parameters. The AC/DC/AC converter system was sensitive to interference generated by the plasma reactor. It was found that the operation of the reactor in certain conditions causes larger interferences on the converter.

However, it is difficult to systematize the influence of specific parameters of the reactor's operation on the operation of the AC/DC/AC converter and vice versa due to mutual correlations of many parameters. On the one hand, the correct operation of a plasma reactor depends on the characteristics of the power supply system; on the other, the power supply system reacts to such an untypical receiver as a plasma reactor.

2.7. Supply Systems of Non-Thermal Plasma Reactors. Construction Review with Examples of Applications

Henryka Danuta Stryczewska in [7] performed a review of the power supply systems of non-thermal plasma reactors (NTPR) with dielectric barrier discharge (DBD), atmospheric pressure plasma jets (APPJ), and gliding arc discharge (GAD). This choice is due to the following reasons: these types of electrical discharge produce non-thermal plasmas at atmospheric pressure; the reactor design is well developed and relatively simple; the potential area of application is large, especially in environmental protection processes and biotechnologies currently under development; and these reactors can be powered from similar sources using non-linear transformer magnetic circuits and power electronics systems. The author stated that research on the properties and applications of non-thermal and non-equilibrium plasmas at atmospheric pressure requires the interdisciplinary cooperation of scientists who represent both basic and applied sciences, namely: plasma chemistry and physics, biochemistry, microbiology, medicine, chemical technology, environmental engineering, material engineering, agricultural engineering, bioengineering, metrology, and electrical engineering. The latter is represented by the author of this review, who, together with a team from the Department of Electrical Engineering and Electrotechnology of the Lublin University of Technology, has conducted research for over 30 years on the generation of non-thermal plasma by means of electrical discharges. In particular, the author's research has focused on the power supply systems of these special energy receivers in cooperation with the above-mentioned representatives of the basic and applied sciences. The research has resulted in many monographs, publications, doctorates, and patents, most of which are cited in this review.

2.8. Structural Tunable Plasma Photonic Crystals in Dielectric Barrier Discharge

Kuangya Gao et al. in [8] presented a kind of structural tunable plasma photonic crystal in a dielectric barrier discharge by self-organization of the plasma filaments. The symmetry, the lattice constant, and the orientations of different plasma photonic crystals can be deliberately controlled by changing the applied voltage. The plasma structures can be tuned from a square lattice to a triangular lattice, the lattice constant is reduced, and the crystal orientation varies $\pi 6/$ when the applied voltage is increased. The band diagrams of the plasma photonic crystals under a transverse magnetic wave have been studied, and show that the positions and sizes of the band gaps change significantly for different plasma structures. The authors suggest a flexible model for the fabrication of tunable plasma photonic crystals, which could be widely applied in the manipulation of microwaves or terahertz waves.

2.9. Tar Removal by Nanosecond-Pulsed Dielectric Barrier Discharge

Mirosław Dors and Daria Kurzyńska in [9] presented results about plasma-catalytic reforming of simulated biomass tar composed of naphthalene, toluene, and benzene in a coaxial plasma reactor supplied with nanosecond high-voltage pulses. The study evaluated the effect of Rh-$LaCoO_3/Al_2O_3$ and Ni/Al_2O_3 catalysts covering high-voltage electrodes on tar conversion efficiency. Compared to the plasma reaction without a catalyst, the combination of plasma with the catalyst significantly enhanced the conversion of all three tar components, achieving complete conversion when a Rh-based catalyst was used. Apart from gaseous and liquid samples, char samples collected from five locations inside the reactor were also analyzed for their chemical composition. The authors stated that char was not formed when the Rh-based catalyst was used. Different by-products were detected

for the plasma reactor without a catalyst or with the Ni- and Rh-based catalysts. A possible reaction pathway in the plasma-catalytic process for naphthalene, as the most complex compound, was proposed through the combined analysis of liquid and solid products.

2.10. Plasma Electrolysis Spraying Al_2O_3 Coating onto Quartz Fiber Fabric for Enhanced Thermal Conductivity and Stability

Aiming Bu et al. in [10] reported the synthesis of Al_2O_3 coating onto quartz fiber fabric by plasma electrolysis spraying for enhanced thermal conductivity and stability. The nano- and micro-sized clusters were partially observed on the coating, while most of the coating was relatively smooth. It was suggested that the formation of a ceramic coating was followed as the nucleation-growth raw; that is, the formation of the coating clusters was partially dependent on the fast growth, implying an inhomogeneous energy distribution in the electrolysis plasma. The deposition of the Al_2O_3 coating increased the tensile strength from 19.2 to 58.1 MPa. The thermal conductivity of the coated quartz fiber was measured to be 1.17 W m^{-1} K^{-1}, increased by ~45% compared to the bare fiber. The formation mechanism of the Al_2O_3 coating was preliminarily discussed. The authors state that the thermally conductive quartz fiber with high thermal stability by plasma electrolysis spray will be widely used in flexible thermal shielding and insulation materials.

3. Conclusions

The collection of articles discussed above covers various types of discharges (including modelling), various processes, and various supply systems of plasma reactors. The discharges presented include, for example, microwave, gliding arc, and dielectric barrier discharges. The characterizations of the plasmas and plasma sources, the diagnostic methods of plasmas, as well as the applications of these plasmas are discussed. The applications include, for example, the synthesis of Al_2O_3 coatings or tar removal. I hope that the presented articles will be valuable for readers representing the world of science, technology, and industry.

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