plasma

MDPI

Editorial

Special Issue on Low Temperature Plasma Jets

Mounir Laroussi

Electrical & Computer Engineering Department, Old Dominion University, Norfolk, VA 23529, USA; mlarouss@odu.edu; Tel.: 757-683-6369

Received: 12 July 2019; Accepted: 30 July 2019; Published: 31 July 2019

Low temperature plasma jets are unique plasma sources capable of delivering plasma outside of the confinement of electrodes and away from gas enclosures/chambers. With these jets plasma can be easily delivered to a target located at some distance from the plasma generation region [1]. Various power driving methods have been used to ignite and sustain low temperature plasma jets. These include direct current (DC), pulsed DC, Radio Frequency (RF), and microwave power [1]. In particular, low temperature plasma jets that are generated at atmospheric pressure are playing an ever increasing role in many plasma processing applications, including surface treatment and in biomedicine. This is because they provide interesting reactive chemistry that can be exploited in various processing applications. Reactive oxygen and nitrogen species (RONS), such as O, OH, O_2^-, $^1O_2$, H_2O_2, NO, NO_2, which are generated by these plasma jets, have been shown to play a central role in their interactions with solids surfaces, liquids, and soft matter (including cells and tissues).

The discovery that atmospheric pressure, low temperature plasma jets are in fact not continuous plasma plumes but fast propagating discrete small volumes of plasma (known as "plasma bullets") makes the physics of these jets particularly interesting [2,3]. This led to numerous experimental and modeling works which aimed at elucidating their mechanisms of ignition and propagation [4–8]. Today, it is well established that these jets are enabled by guided ionization waves where photoionization and the electric field at the head of the ionization front play important roles [9]. The magnitude of the electric field was measured by several investigators and was found to be in the 10–30 kV/cm range [10–13].

Low temperature plasma jets have been used in various applications. For example, in material processing, using various operating conditions and gases, they were found to increase the wettability of Polypropylene (PP) and Polyethylene terephthalate (PET) films [14], degrade aromatic rings of dies such methyl violet [15], etch silicon, Si (100), ash photoresist at a rate greater than 1.2 μm/min [16], deposit silicon dioxide, SiO_2, films on various substrates at deposition rates greater than 10 nm/s, etc. However, and by far, the most interesting and emerging applications of low temperature plasma jets are in biomedicine. In this field of research, intense investigations of their various biomedical applications surged ever since the first "bio-tolerant" plasma jets were reported in the mid-2000s [17,18]. Today these plasma jets are being extensively researched for medical applications ranging from wound healing, to dentistry, and to cancer therapy [19–21].

This special issue contains articles discussing the latest works which cover both fundamental studies and applications of low temperature plasma jets. The guest editor would like to thank the authors for their valuable contributions and the reviewers for their time and efforts.

References

1. Laroussi, M.; Akan, T. Arc-free Atmospheric Pressure Cold Plasma Jets: A Review. *Plasma Process. Polym.* **2007**, *4*, 777. [CrossRef]
2. Teschke, M.; Kedzierski, J.; Finantu-Dinu, E.G.; Korzec, D.; Engemann, J. High-Speed Photographs of a Dielectric Barrier Atmospheric Pressure Plasma Jet. *IEEE Trans. Plasma Sci.* **2005**, *33*, 310. [CrossRef]

3. Lu, X.; Laroussi, M. Dynamics of an Atmospheric Pressure Plasma Plume Generated by Submicrosecond Voltage Pulses. *J. Appl. Phys.* **2006**, *100*, 063302. [CrossRef]
4. Sands, B.L.; Ganguly, B.N.; Tachibana, K.A. Streamer-like Atmospheric Pressure Plasma Jet. *Appl. Phys. Lett.* **2008**, *92*, 151503. [CrossRef]
5. Mericam-Bourdet, N.; Laroussi, M.; Begum, A.; Karakas, E. Experimental Investigations of Plasma Bullets. *J. Phys. D Appl. Phys.* **2009**, *42*, 055207. [CrossRef]
6. Naidis, G.V. Modeling of Plasma Bullet Propagation along a Helium Jet in Ambient Air. *J. Phys. D Appl. Phys.* **2011**, *44*, 215203. [CrossRef]
7. Yousfi, M.; Eichwald, O.; Merbahi, N.; Jomma, N. Analysis of ionization wave dynamics in low-temperature plasma jets from fluid modeling supported by experimental investigations. *Plasma Sources Sci. Technol.* **2012**, *21*, 045003. [CrossRef]
8. Boeuf, J.-P.; Yang, L.; Pitchford, L. Dynamics of guided streamer (plasma bullet) in a helium jet in air at atmospheric pressure. *J. Phys. D Appl. Phys.* **2013**, *46*, 015201. [CrossRef]
9. Lu, X.; Naidis, G.; Laroussi, M.; Ostrikov, K. Guided Ionization Waves: Theory and Experiments. *Phys. Rep.* **2014**, *540*, 123. [CrossRef]
10. Begum, A.; Laroussi, M.; Pervez, M.R. Atmospheric Pressure helium/air plasma Jet: Breakdown Processes and Propagation Phenomenon. *AIP Adv.* **2013**, *3*, 062117. [CrossRef]
11. Stretenovic, G.B.; Krstic, I.B.; Kovacevic, V.V.; Obradovic, A.M.; Kuraica, M.M. Spatio-temporally resolved electric field measurements in helium plasma jet. *J. Phys. D Appl. Phys.* **2014**, *47*, 102001. [CrossRef]
12. Sobota, A.; Guaitella, O.; Garcia-Caurel, E. Experimentally obtained values of electric field of an atmospheric pressure plasma jet impinging on a dielectric surface. *J. Phys. D Appl. Phys.* **2013**, *46*, 372001. [CrossRef]
13. Darny, T.; Pouvesle, J.-M.; Puech, V.; Douat, C.; Dozias, S.; Robert, E. Analysis of conductive target influence in plasma jet experiments through helium metastable and electric field measurements. *Plasma Sources Sci. Technol.* **2017**, *26*, 045008. [CrossRef]
14. Cheng, C.; Liye, Z.; Zhan, R. Surface Modification of Polymer Fiber by the New Atmospheric Pressure Cold Plasma Jet. *Surface Coat. Technol.* **2006**, *200*, 6659. [CrossRef]
15. Chen, G.; Chen, S.; Zhou, M.; Feng, W.; Gu, W.; Yang, S. The Preliminary Discharging Characterization of a Novel APGD Plume and its Application in Organic Contaminant Degradation. *Plasma Sources Sci. Technol.* **2006**, *15*, 603. [CrossRef]
16. Inomata, K.; Koinuma, H.; Oikawa, Y.; Shiraishi, T. Open Air Photoresist Ashing by Cold Plasma Torch: Catalytic effect of Cathode material. *Appl. Phys. Lett.* **1995**, *66*, 2188. [CrossRef]
17. Laroussi, M.; Lu, X. Room Temperature Atmospheric Pressure Plasma Plume for Biomedical Applications. *Appl. Phys. Lett.* **2005**, *87*, 113902. [CrossRef]
18. Brandenburg, R.; Ehlbeck, J.; Stieber, M.V.; von Woedtke, T.; Zeymer, J.; Schluter, O.; Weltmann, K.-D. Antimicrobial Treatment of Heat Sensitive Materials by Means of Atmospheric Pressure rf-driven Plasma Jet. *Contrib. Plasma Phys.* **2007**, *47*, 72. [CrossRef]
19. Keidar, M.; Shashurin, A.; Volotskova, O.; Stepp, M.A.; Srinivasan, P.; Sandler, A.; Trink, B. Cold atmospheric plasma in cancer therapy. *Phys. Plasmas* **2013**, *20*, 057101. [CrossRef]
20. Gherardi, M.; Tonini, R.; Colombo, V. Plasma in Dentistry: Brief History and Current Status. *Trends Biotechnol.* **2017**, *36*, 583. [CrossRef] [PubMed]
21. Lu, X.; Reuter, S.; Laroussi, M.; Liu, D. *Non-Equilibrium Atmospheric Pressure Plasma Jets: Fundamentals, Diagnostics, and Medical Applications*; CRC Press: Boca Raton, FL, USA, 2019; ISBN 9781498743631.