Interactions of guided ionization waves

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Abstract: In this contribution, we report preliminary investigations of the interactions of guided ionization waves (IWs) generated using two geometrically identical atmospheric pressure plasma jets (APPJs) which are operated at positive or opposite polarities. In the positive case, the interaction stops the propagation of the IWs, while in the opposite polarity case, 'secondary' discharges appear to increase ionization along the plasma column.

1. Introduction

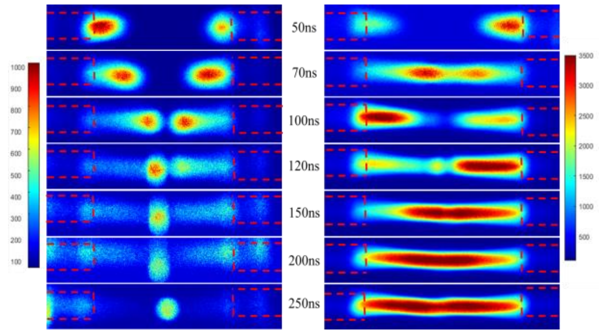
Atmospheric Pressure Plasma Jets (APPJs) are effective sources of chemically active species for biomedicine, agriculture, microelectronics, and pollution control. These applications can involve arrays of APPJs and interactions of IWs that can be utilized to tune the reactive species and plasma properties and, hence, the plasma chemistry and surface treatments. Previous studies have considered two counter-propagating positive streamers that do not merge, and suggest a region of minimum approach between them where ionization growth is limited by the available distance [1]. Controlling the phase difference changes the location of the interaction and can enhance treatment of substrates [2]. Simulations of these interactions show changes in the electric field, electron density, and temperature of the reactive species [3, 4]. Here, we begin an investigation of the interactions of IWs generated from APPJs operated at opposite polarities, which exhibit different interaction phenomena, and hence offer new opportunities to control plasma-surface interactions.

2. Methods

Two identical APPJs are used, each powered by a 3 kV 200 ns DC pulse at 5 kHz repetition rate generated using two high-voltage pulse generators (DEI, PVX-4110) [5]. Ultra-high-purity helium gas (99.999% purity) is provided at 1 standard liters per minute using a mass flow controller. An UV sensitive intensified charge-coupled device (ICCD) (La Vision, IRO) is used to image the interactions between the two jets. A delay generator (SRS, DG645) synchronized to the high voltage pulse is used for direct gating of the ICCD to reduce jitter and achieve 5 ns gate widths.

3. Results and Discussion

Fig.1 shows images acquired by the ICCD at different times after the start of the nanosecond DC pulse. Fig. 1(a) shows the interaction when the APPJs are operated at the same polarity (both positive) and Fig. 1(b) shows the interaction when the AAPJs are operated at opposite polarity (one negative and one positive). In Fig. 1(a), the two plasma bullets approach each other and their interaction stops their propagation. The ionization appears to become concentrated within a spherical region after 120 ns, suggesting the electric field in this region is no longer high enough to propagate the IW. A different behavior is observed in Fig. 1(b) for the case of opposite polarity. A secondary discharges is observed when the positive IW approaches the negative APPJ (at 70ns), and later, the interaction leads to increased ionization along the plasma column connecting the APPJs.



(a) **(b)**

Fig. 1. High-speed images of guided-ionization waves generated from two APPJs at different times after the start of the nanosecond pulse, for the case when, (a) both jets are operated at positive polarity; and (b) left jet is at negative polarity and right jet is at positive polarity. The red dashed lines in the images represent the quartz tube of APPJs.

4. Conclusion

Preliminary investigations of interactions of counter-propagating IWs suggest advantages of operating opposite polarity jets, including continued propagation, uniform discharge regions, and potentially, higher plasma densities.

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References

[1] Douat, Claire, et al. Plasma Sources Science and Technology 21.3 (2012): 034010.
[2] Johnson, Michael J., et al. Journal of Vacuum Science & Technology B 42.3 (2024).
[3] Naidis, G. V." Plasma Sources Science and Technology 21.3 (2012): 034003.
[4] Yan, Wen, et al. Physics of Plasmas 21.6 (2014).
[5] Bentz, Brian Z. Plasma Sources Science and Technology 32.10 (2023): 105003.