Characteristics of PT-Driven Plasma Discharge at Atmospheric Pressure

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Abstract: This study uses experiments and simulations to investigate the spatial and temporal characteristics of a piezoelectric transformer (PT)- driven plasma with a secondary electrode. Findings reveal distinct plasma-surface interactions initiated by heavy species reactions and influenced by polarity. Comprehensive insights into PT-driven plasma discharges will unlock their full potential, enabling more efficient and versatile applications in plasma generation.

1. Introduction

Piezoelectric transformers (PTs) have emerged as compact high-voltage sources capable of generating various atmospheric pressure plasma discharges, such as corona, glow, and dielectric barrier discharges [1]. Unlike conventional atmospheric pressure plasma sources, PT-driven plasmas can operate with low power consumption (~5–8 W), making them ideal for designing portable and handheld devices [2]. While previous studies have focused on free plasma jets generated from PT [3], the behavior of surface plasma on PTs remains underexplored. This study aims to address this gap by investigating PT-driven plasma's spatial and temporal discharge characteristics using a combination of experimental measurements and numerical simulations.

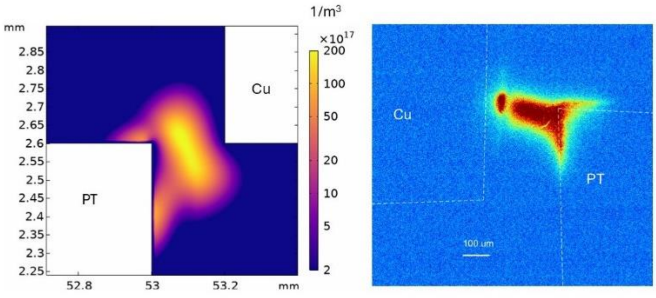
2. Methods

A Rosen-type PT made of lead zirconate titanate (PZT) with dimensions 53×7.5×2.6 mm^3 was used. The primary side was driven at 80–200 V (peak to peak) with an input frequency of 67.8 kHz (resonant frequency), while a grounded copper electrode positioned at a 250 µm distance served as the secondary electrode. Experimental diagnostics included time-resolved imaging of plasma discharges and measurements of voltage and current signals. In addition, a 2D model has been developed combining piezoelectricity and plasma dynamics to investigate physicochemical processes observed during the experiment.

3. Results and Discussion

Experimental data revealed the importance of added impedance on both the PT and Cu electrodes as it impacts the operating resonant frequency and the discharge current dynamics. Apart from signal characteristics, time-resolved images showed a high-current spike with intense plasma discharge that gradually converted into a moderate-intensity plasma regime. Plasma discharges during the negative polarity exhibited lower current spikes than those during the positive polarity while maintaining distinct surface behavior on the PT.

The mathematical model that resolves the PT and plasma dynamics predicts discharge dynamics that agree with the experimental observations. The predictions confirm the asymmetrical surface behaviors between positive and negative cycles. During the positive cycle, the charge transport properties at the PT surface drive the formation of surface plasmas and show higher current density. The surface plasma is strongly dictated by the lifetime of the charged and excited states and the PT response time. In addition, heavy species reactions close to the surface showed a noteworthy impact on the voltage and current profiles.



(a) **(b)**

Fig 1. (a) Predicted number density of excited species during positive polarity (b) Time-averaged image of plasma discharge during positive polarity

4. Conclusion

This study highlights PT-driven plasma discharges' distinct spatial and temporal behaviors influenced by impedance and polarity. Experimental and numerical findings demonstrate asymmetrical surface dynamics and the significant role of heavy species reactions near the surface. These findings contribute to a deeper understanding of PT-driven plasma discharges, paving the way for optimized designs in low-power plasma devices.

Acknowledgment

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References

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