Simulation of Transmission Line Effects on Nanosecond Pulsed Dielectric Barrier Discharge Plasma

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1. Introduction

Nanosecond Pulsed Dielectric Barrier Discharge (NPDBD) plasma has been used for decontamination applications due to its higher conversion efficiency than normal DBD plasma [1]. The maximum removal efficiency is given along with the corresponding energy density (J/L), i.e. the energy deposited per unit volume of process gas [2]. Therefore, accurate energy calculation is essential to determine the efficiency of contaminant removal by NPDBD plasma.

Grundmann et al. [3] and Borcia et al. [4] explained two common ways of calculating the consumed electrical power of an reactor by determining the operating voltage and either the current or the charge by means of a probe resistor or capacitor [5]. To properly apply these methods, it is crucial to accurately measure the voltage and current applied to the plasma. However, unlike the ideal case, the transmission cables and other components used in the actual setup can influence the voltage and current, requiring careful consideration for the measurements [6].

In this study, the transmission line effect, affecting energy transfer to the NPDBD plasma reactor, is considered. The simulation was conducted using PSpice to model these effects, and the results were validated with the experimental data.

2. Methods

The schematic diagram of the experimental setup with NPDBD plasma reactor is shown in Fig. 1. For the NPDBD plasma discharge, the reactor is applied to a voltage of 8 kV with pulse width of 100 ns, and pulse repetition of 1 kHz. Helium (He) gas was injected into the reactor at a rate of 2 L/min. The plasma reactor was a coaxial chamber with a quartz dielectric layer. The repetitive pulses were provided by a commercial pulsed power supply (NSP-60-20-P-250-TG-H, Eagle Harbor Technologies). Electrical measurements were conducted using a current monitor (Model 4100, Pearson) and high voltage probes (P-6015A, Tektronix).

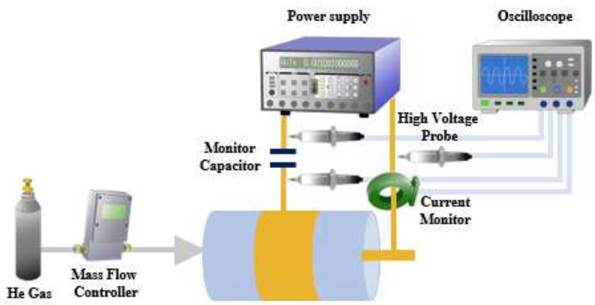


Fig. 1. Schematic diagram of experimental setup with NPDBD plasma reactor.

NPDBD plasma simulation was implemented by constructing equivalent circuit using PSpice. Fig. 2. shows the equivalent circuit of the schematic diagram of NPDBD plasma reactor.

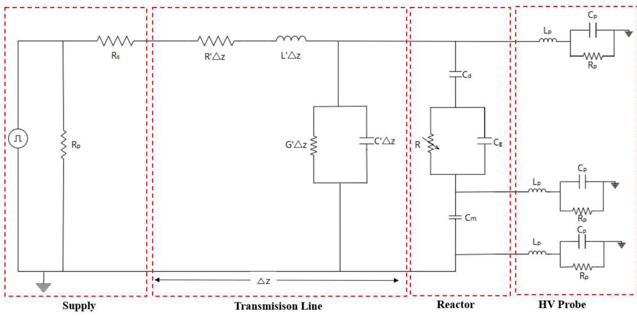


Fig. 2. Equivalent circuit of the experimental setup with NPDBD plasma reactor.

The equivalent circuit is divided into four parts as show in Fig. 2. The supply section and the High Voltage (HV) probe section [7] use the values provided by manufacturers. The impedance of the transmission line is modeled using a formula for two-wire-cable configuration [8] . The values of each components are presented in Table I.

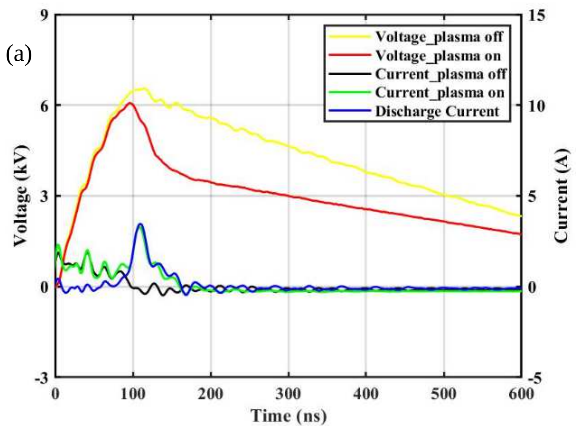
Table I: Circuit parameters of transmission line

Parameter per unit length		Para-meter	△z = 0.15	△z = 1.7	(m)
Resistance (R')	3.58 (μΩ/m)	R'△z	**0.53**	**6.09**	(μΩ)
Inductance (L')	0.52 (μH/m)	L'△z	**0.07**	**0.89**	(μH)
Conductance (G')	0 (S/m)	G'△z	**0**	**0**	(S)
Capacitance (C')	42.2 (pF/m)	C'△z	**6.33**	**71.8**	(pF)

The values for the reactor section were obtained from the experimental data. The capacitance of the dielectric was derived using the Lissajous figures, which are commonly used in NPDBD plasma discharge analysis, based on the Q-V data obtained from the monitor capacitor [5, 9]. The total capacitance of the reactor was determined from measurements taken using an LCR meter. The variable plasma resistance was calculated using Ohm's law. In the plasma discharge period, the plasma resistance averaged around 1.5 kΩ, while in the non-discharge period, the resistance assumed to be infinite.

3. Results and Discussion

The comparison between the simulation and experiment when the current monitor was placed close to the plasma reactor (0.15 meters away from the reactor) is shown in Fig. 3. It shows that in both cases, when the plasma is on, the voltage decreases by 0.5 kV as discharge current flows. Additionally, a significant peak in discharge current is observed.



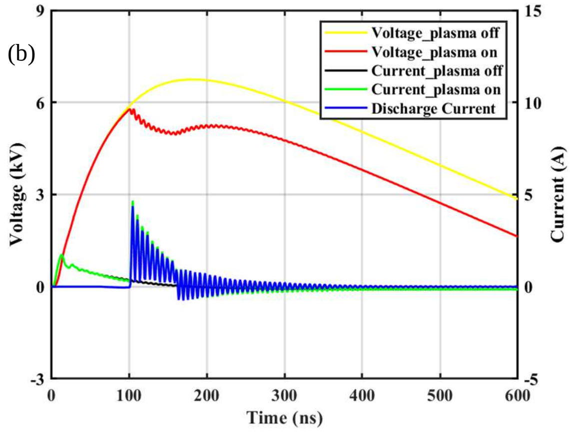


Fig. 3. Voltage and current data when the current monitor is near the NPDBD plasma reactor. (a) Experimental data. (b) Simulation data.

When the current monitor was placed near the power supply (1.7 meters away from the reactor), a voltage drop similar to the previous case is observed as discharge current flowed.

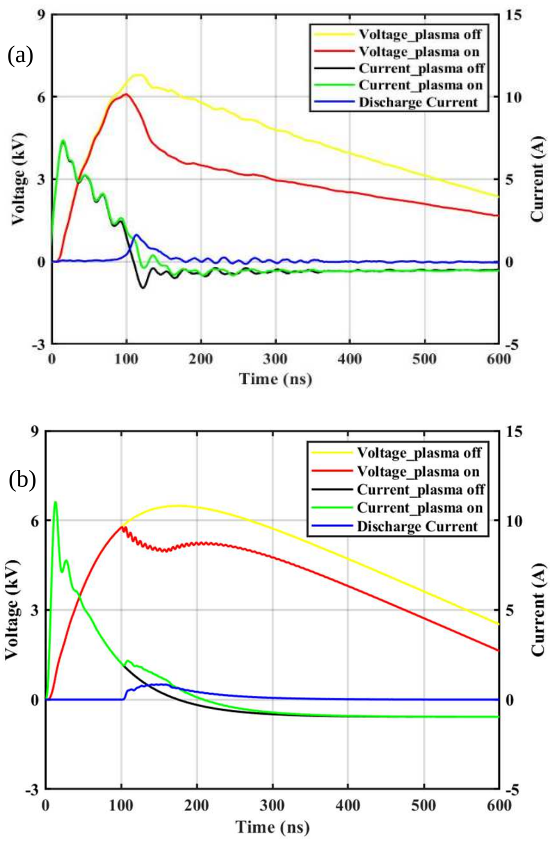


Fig. 4. Voltage and current data when the current monitor is near the power supply. (a) Experimental data. (b) Simulation data.

4. Conclusion

Comparison of the simulation and experimental results presented in this paper confirm that the transmission line effect causes variations in the output data depending on the position of the current monitor. Therefore, to obtain accurate output data in NPDBD plasma without losses, it is necessary to place the current monitor closer to the reactor, minimizing the current absorbed by the transmission line and accurately measuring the discharge current. In addition, a discrepancy is observed in the voltage drop trends after plasma generation between the experimental and simulation data. This is likely due to new resistance or capacitance components forming near the reactor after the plasma is discharged. Further investigations will be conducted in future work to identify the factors influencing this phenomenon.

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