Analysis of Discharge Parameters and Optimization Study of Coaxial DBDs for Efficient Excimer Light Sources

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Abstract: In this work, xenon and argon filled coaxial DBD cells have been studied with two different geometries at different operating conditions. An equivalent electrical model representing the DBD phenomenon has been developed which validates the characteristics of the discharge parameters. From the experimental results and equivalent electrical circuit, the dynamic nature of equivalent capacitance has also been reported. The relative intensity analysis of the Xe continuum peak at wavelength 172 nm in the optical emission spectra of VUV region has been carried out for different discharge conditions. Approximately three times increment in radiation is observed in pulse excitation than that of sinusoidal excitation which infers pulsed excitation of DBD sources are advantageous for excimer light sources.

I. Introduction

DBDs have been used for number of industrial applications starting from ozone generation, surface modification, flat plasma display panels, biology and medical field [1]-[7]. Dielectric barrier based discharges are traditionally driven by sinusoidal wave voltages with magnitudes in the kilovolt range and frequencies in the kilohertz range. To improve the energy transfer efficiency, voltage pulses with submicrosecond rise and fall times have been proposed by several investigators [8]-[9]. Here, we performed the experiment with the unipolar pulse and sinusoidal applied waveforms for a xenon and argon filled coaxial DBD tubes. For electrical diagnostics of the discharge, a temporally dynamic model for diffuse DBDs is developed [10]. From this model, further equations were derived which allow the calculation of internal electrical quantities in the discharge gap from measured external electrical quantities. The relative intensity analysis of the Xe intensity peaks in the optical emission spectra has also been carried out and around three times larger VUV radiations of peak wavelength at 172 nm are observed in pulse excitation than that of sinusoidal excitation.

II. Equivalent Electrical Model for DBD Discharge

An analogous electrical circuit model has been developed for coaxial DBD tubes to calculate the internal electrical quantities, which was extensively discussed in the references [10]-[12]. The schematic diagram of the circuit is shown in Figure 2 (a). The equivalent electrical model of the DBD tube consists of three capacitors in series connection.

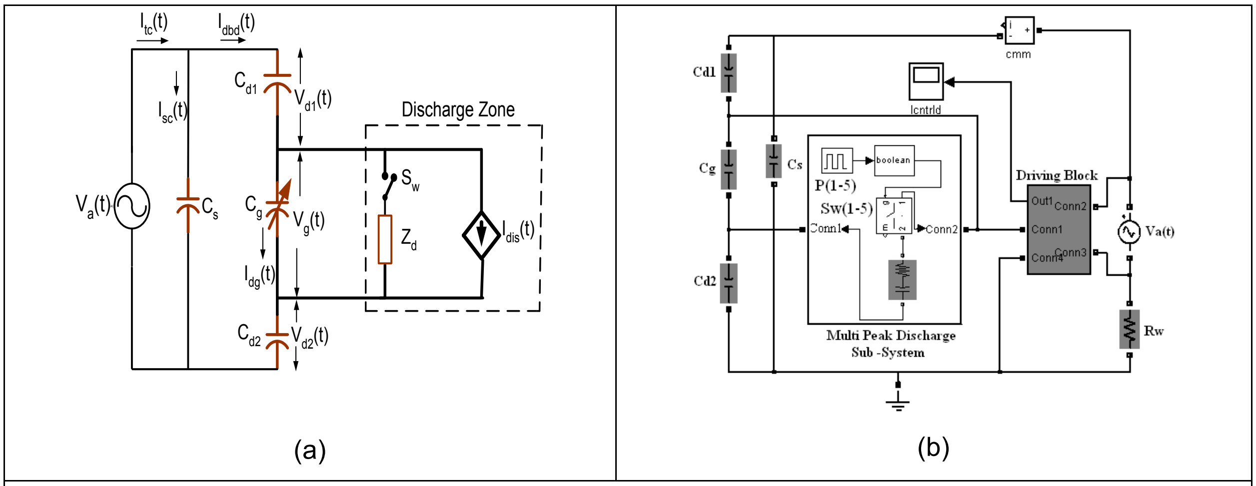


Figure 2. (a) Equivalent electrical circuit of coaxial DBD cell. (b) Proposed Simulink Model for DBD cell.

Based on our analysis the internal DBD discharge parameters [9]-[12] can be represented by the expressed below,

$$I_{dis}(t) = (1+\frac{C_g}{C_d})I_{dbd}(t) - C_g\frac{dV_a(t)}{dt} \quad (1)$$

$$V_d(t) = \frac{1}{C_d}\int I_{tc}(t)dt + V_{m0} \quad (2)$$

$$V_g(t) = V_a(t) - \frac{1}{C_d}\int I_{tc}(t)dt - V_{m0} \quad (3)$$

$$V_{m0} = -\frac{1}{2C_d}\int_0^{T/2} I_{dbd}(t)dt \quad (4)$$

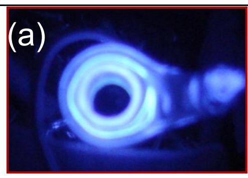
$$P_{sup}(t) = V_a(t).I_{tc}(t) \quad (5)$$

$$P_{dis}(t) = V_g(t).I_{dis}(t) \quad (6)$$

The simulation model made in Simulink is shown in figure 2 (b). This simulation model is based on the equivalent electrical circuit proposed by us as shown in figure 2 (a). The emphasis has been mainly laid on the electrical operating conditions of the circuit. However, parameters governing ignition and extinction of microdischarges in DBDs are taken into account.

III. Results and Discussion

Figure 3(*a*) and 4(a) show the average images of discharges taken with a digital for xenon and argon DBDs. The images indicate that the diffuse discharge covers the entire surface of the electrodes. Figure 3(*b*) and 4(*b*) show the total current trace together with the applied voltages, where the discharge current waveform having a number of current pulses with nanosecond order, which are superimposed on the total current, confirms filamentary discharge [10]-[13].



(b)

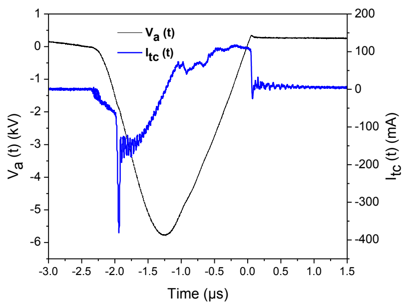
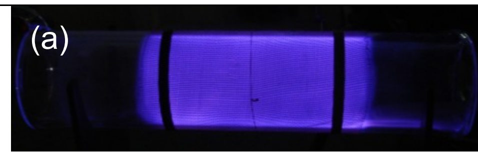


Figure 3. (a) Picture of diffused DBD discharge (pressure: 400 mbar, frequency = 30 kHz). (b) Applied voltage V_a *(t)* and total current I_{tc} *(t)* vs time.



(b)

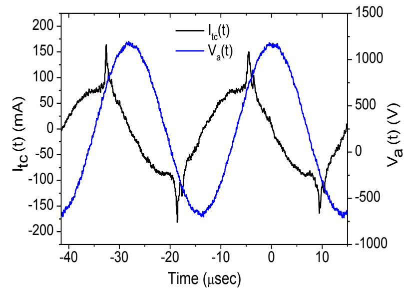
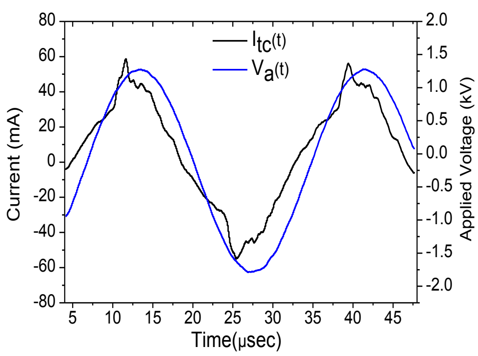
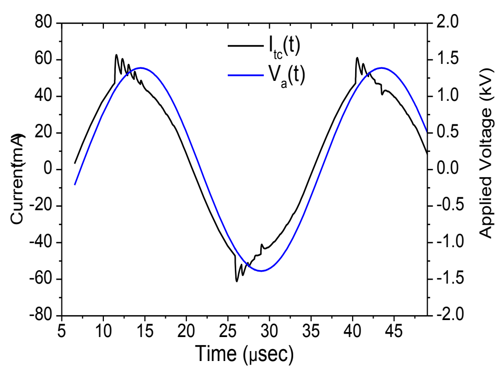


Figure 4 (a) DBD in argon atmosphere (pressure: 600 mbar, frequency = 34.5 kHz). (*a*) Picture of the diffused DBD discharge. (*b*) Applied voltage and total current waveforms.



(a)



(b)

Figure 5. Applied voltage and total current waveform (gas: argon at 1000 mbar, f = 47.5 kHz). (a) Experimental result. (b) Simulated result.

Figure 5(*a*) represents the applied voltage V_a*(t)* and the total current I_{tc}*(t)* waveforms measured at 1000 mbar argon atmosphere for 47.5 kHz frequency. The filamentary discharge characteristics are verified by the simulation done using SIMULINK Software as shown in Figure 5(b). The dynamic behaviour of different voltages for the DBD cell is shown in Figure 6(a) & 7(a) for xenon and argon DBDs respectively.

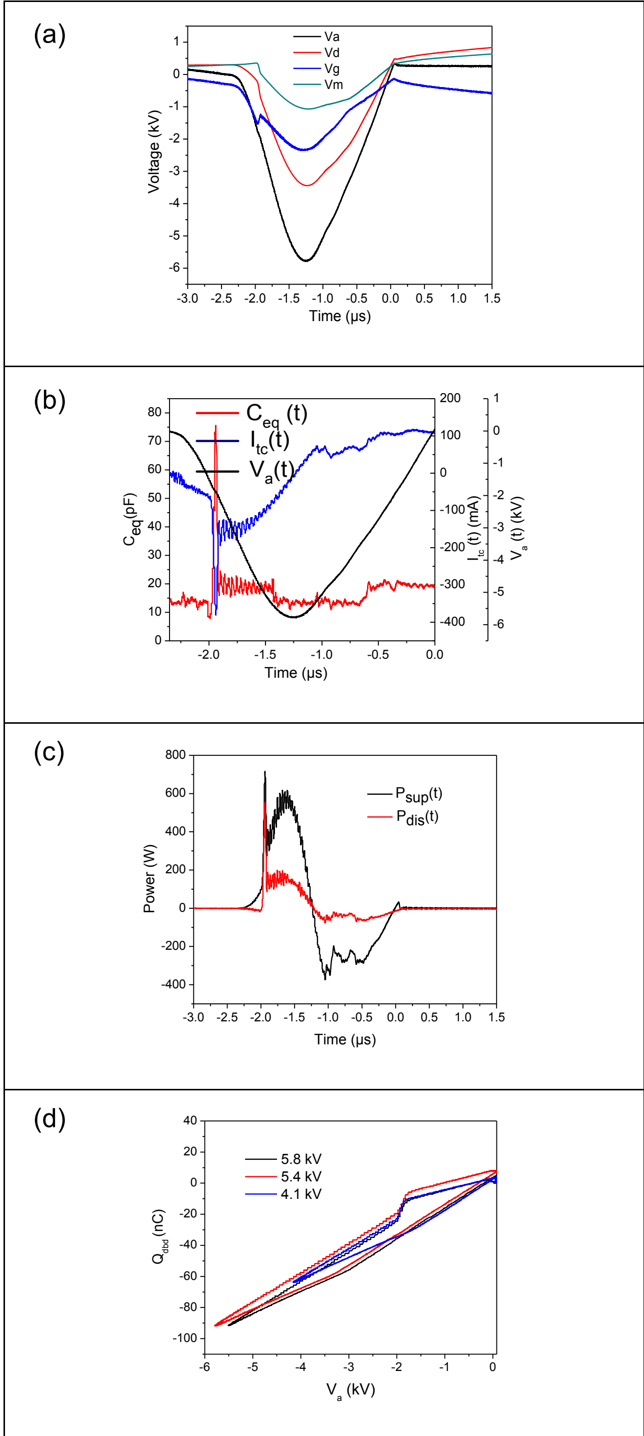


Figure 6. Experimental values for xenon DBD (pressure: 400 mbar, frequency = 30 kHz). (a) Different voltages, (b) Equivalent capacitance, (c) Supplied and discharge power waveform and (d) Lissajous figure.

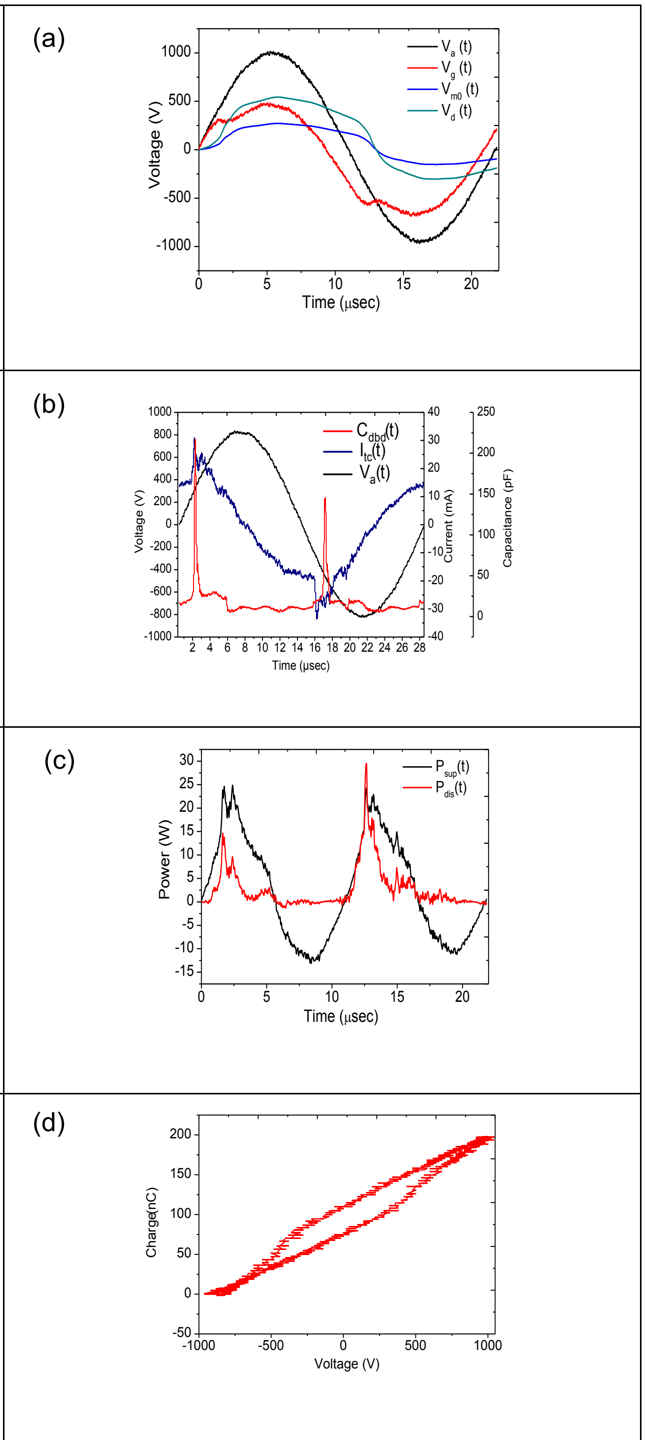


Figure 7. Experimental values for argon DBD (gas: argon at 1000 mbar, f = 47.5 kHz). (a) Different voltages, (b) Equivalent capacitance, (c) Supplied and discharge power waveform and (d) Lissajous figure.

IV. Conclusion

The discharges useful for excimer light sources were examined in the Xe and Ar filled coaxial DBD cells and are found to be filamentary and diffused type. An electrical circuit model has been proposed for the discharge analysis of the DBD cells. For this, equations based on the equivalent electrical circuit have been formulated. The dynamic behaviour of the discharge parameters (barrier voltage, gas gap voltage, discharge current, supplied power, consumed power and the energy stored, etc) and VUV radiation at 172 nm have been studied and investigated.

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