Measurement of Breakdown Characteristics for Negatively Pulsed Plasma

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Abstract

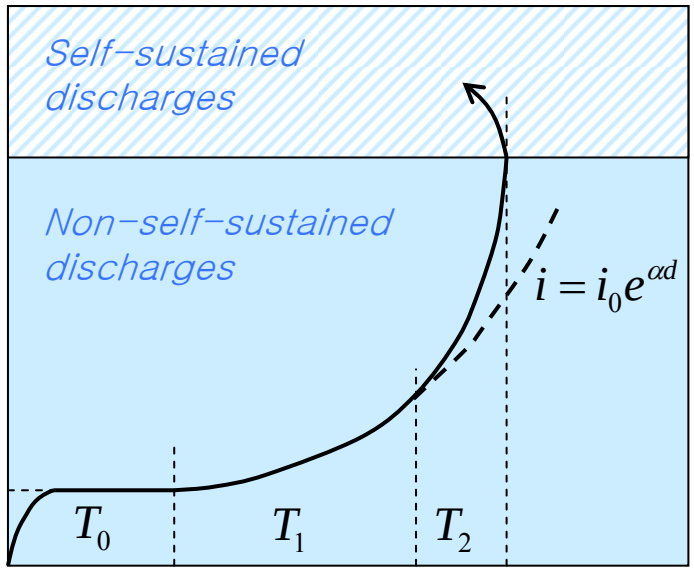
The transient discharge currents are measured for the negatively pulsed plasmas. A current transformer and a shunt resistor are used to measure discharge current. During pulses or between pulses, discharge currents and plasma parameters are affected by gas pressure, pulse voltage, electrode distance, electrode material and others. It is observed that the secondary electron emission by ion bombardments affects the plasma discharge characteristics.

This experiment describes the observational result of the discharge current rising-time characteristics for neutral gas filling density, bias voltage, gap distance.

Criteria for electric breakdown

Breakdown

Nonself-sustaining Discharge → Self-sustaining Discharge

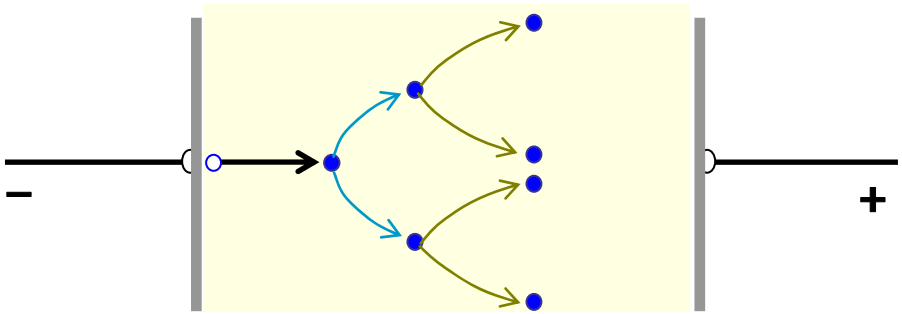


The condition for the discharge to be self-sustained,

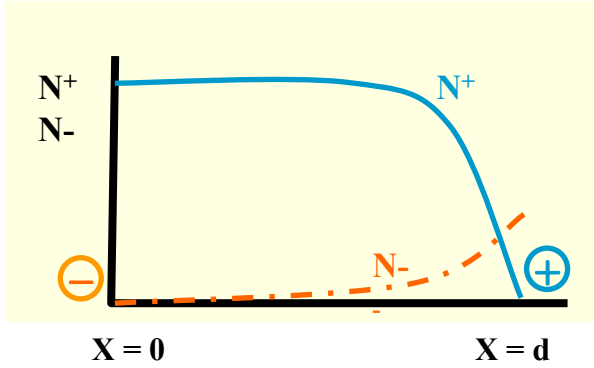
$$\mu = \gamma\left(e^{\alpha d} - 1\right) \geq 1$$

The sense of this condition is that when a single electron avalanche develops, as a result of secondary processes characterized by a coefficient γ, a secondary electron, if only one, appears at the cathode to give to give rise to a new electron avalanche.

α - Discharge (Townsend Process)



Multiplication of charges in an electric field



Distribution in the gap of the number density of electrons N- and ions N^+ in the steady state

The increase in the number of ion pairs along an element of length dx is αdx per electron, and for N_x electrons at x we obtain

$$dN = N_x \alpha dx$$

By integrating between x=0 and x=d we obtain for the number of electron N at d or the current *i* at d

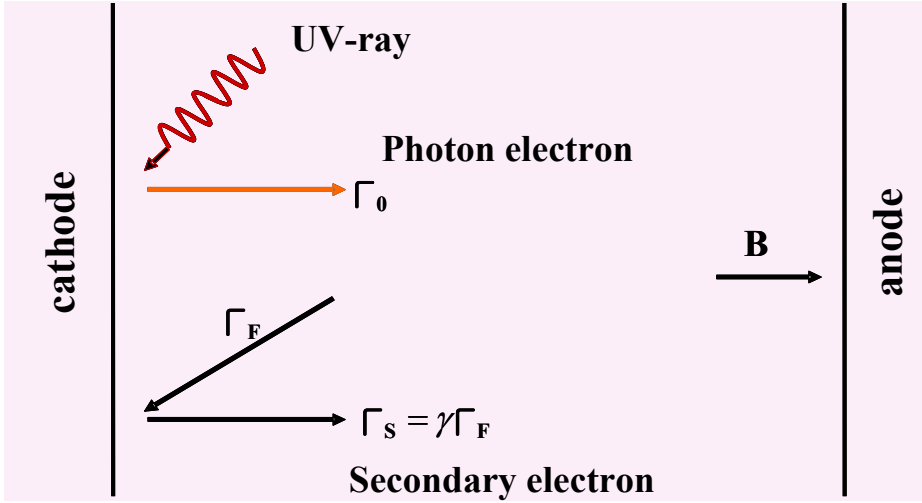
$$N/N_0 = i/i_0 = e^{\alpha d}$$

$$n = \int_0^d N_0 e^{\alpha d}\, dx = (N_0/\alpha)(e^{\alpha d} - 1) \qquad i/i_0 = n/(N_0 d) = (1/\alpha d)(e^{\alpha d} - 1)$$

γ - Discharge (Secondary effect)

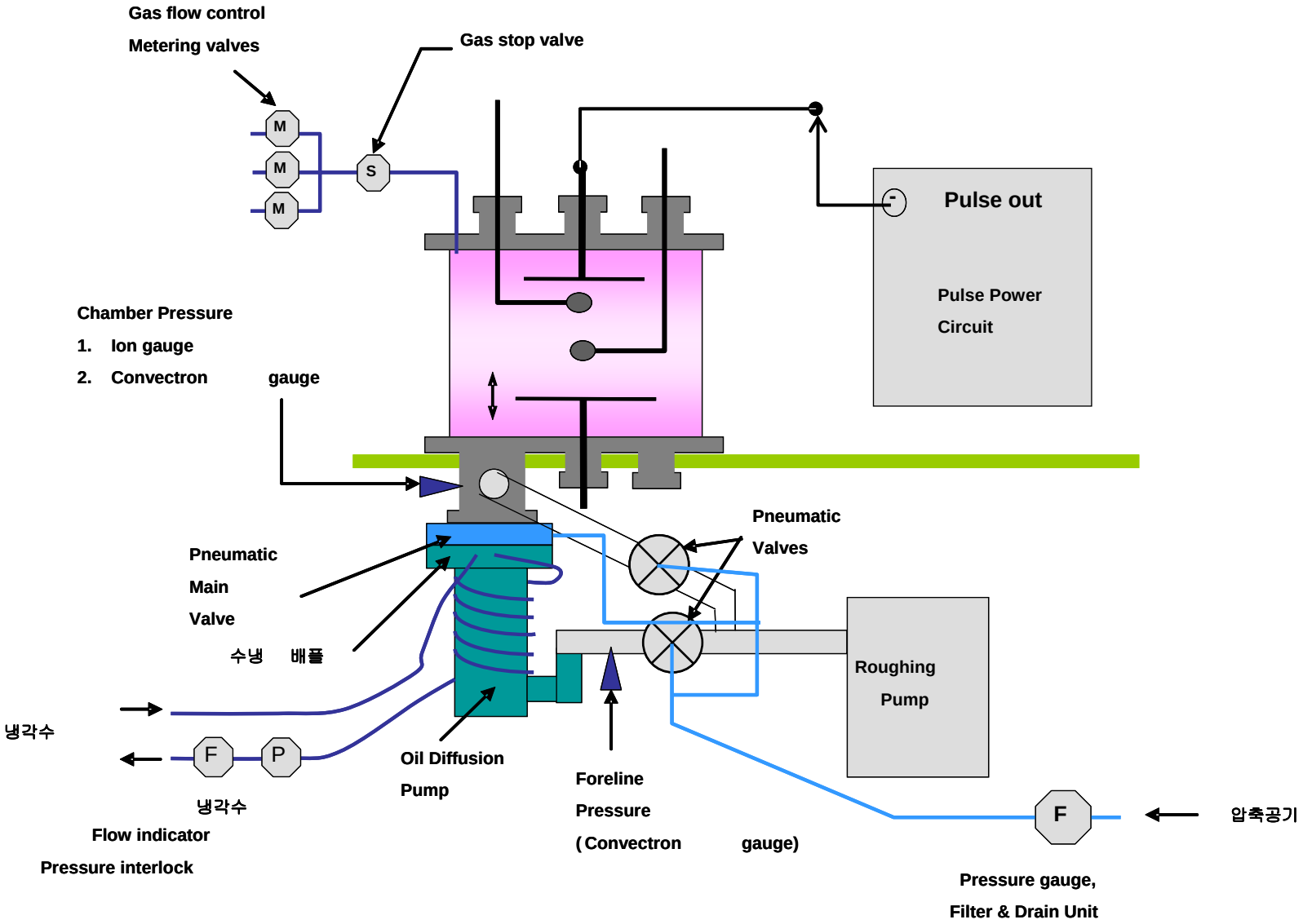
With n_0 primary electron/sec released at the cathode, ionization by electron collisions in the gas, and secondary electron emission by positive ions arriving at the cathode, the current at d is

$$j = j_{em} \frac{e^{\alpha d}}{1-\gamma\left(e^{\alpha d}-1\right)}$$

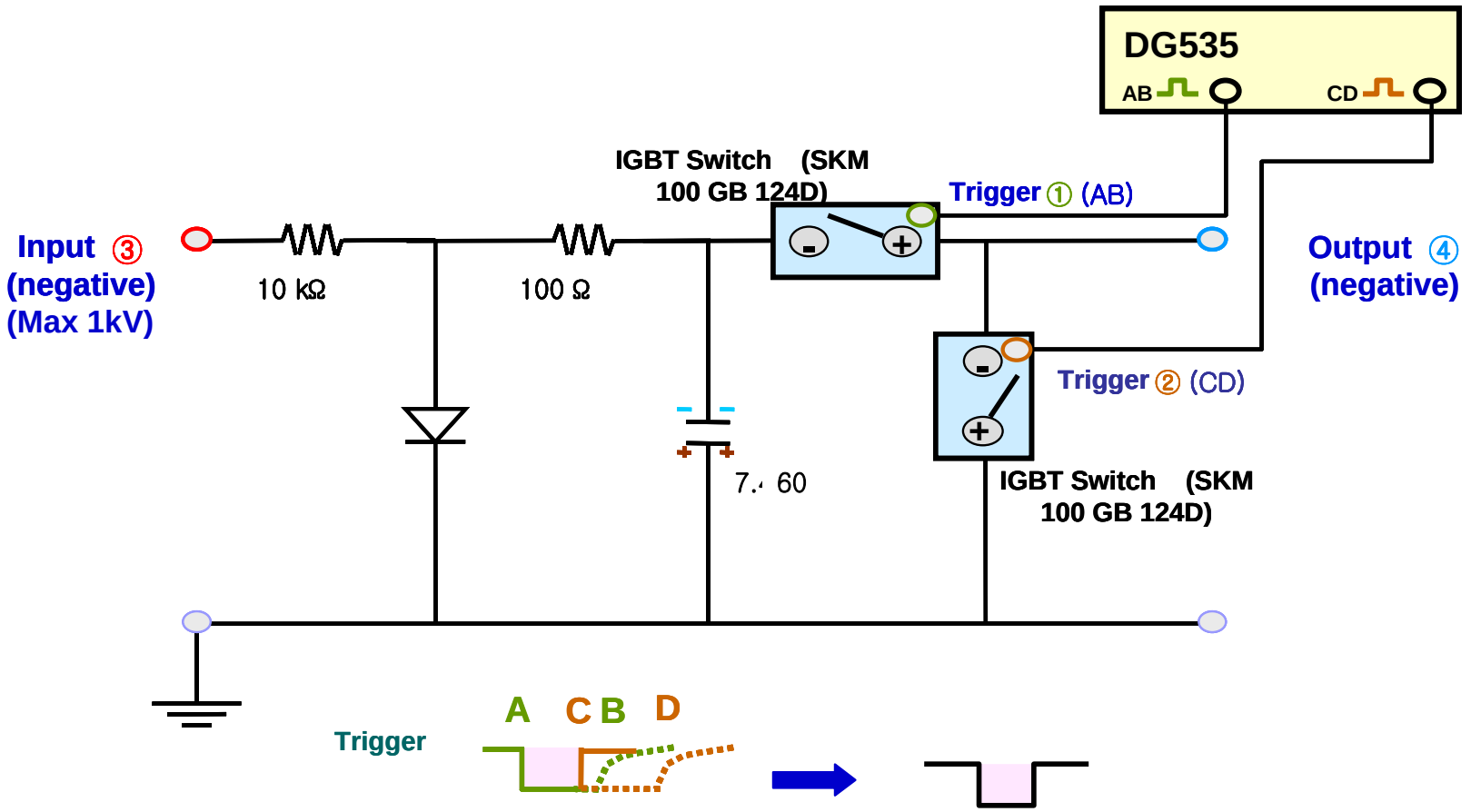


Cathode	Gas	Anode
Cycle I 1 electron starts	$(e^{\alpha d}-1)$ ion pairs produced	$e^{\alpha d}$ electrons enter
Cycle II $(e^{\alpha d}-1)$ ions arrive and $\gamma(e^{\alpha d}-1)$ electrons start	$\gamma(e^{\alpha d}-1)^2$ ion pairs produced	$\gamma(e^{\alpha d}-1)e^{\alpha d}$ electrons enter
Cycle III $(e^{\alpha d}-1)^2$ ions arrive and $\gamma(e^{\alpha d}-1)^2$ electrons start	$\gamma^2(e^{\alpha d}-1)^3$ ion pairs produced	$\gamma^2(e^{\alpha d}-1)^2 e^{\alpha d}$ electrons enter

Experimental setup

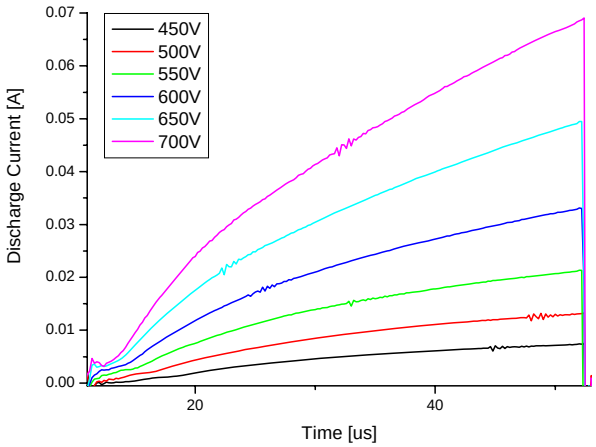


Circuit for negatively pulse

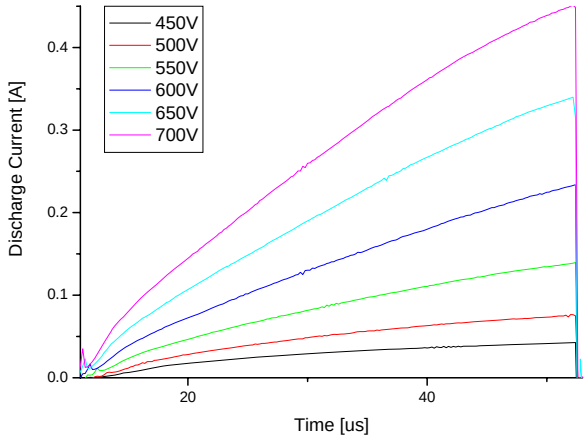


Time characteristic of discharge current -1

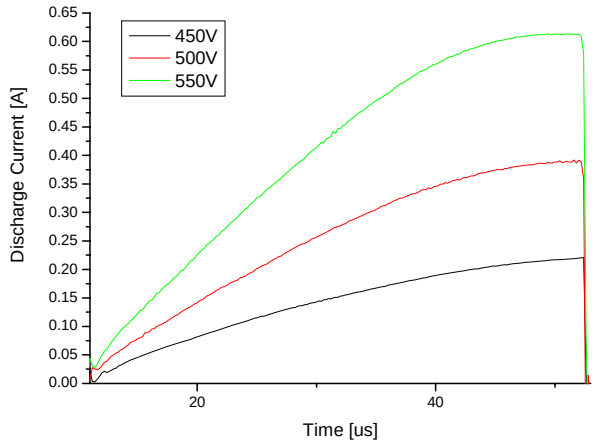
Base Pre: 5.5mTorr Gap distance: 2cm Rep. rate: 10Hz, Plate's diameter: 10cm



Gas pre: 110mTorr

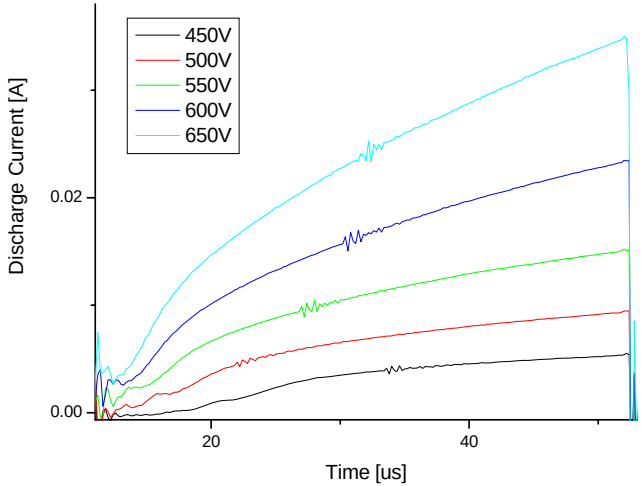


Gas pre: 300mTorr

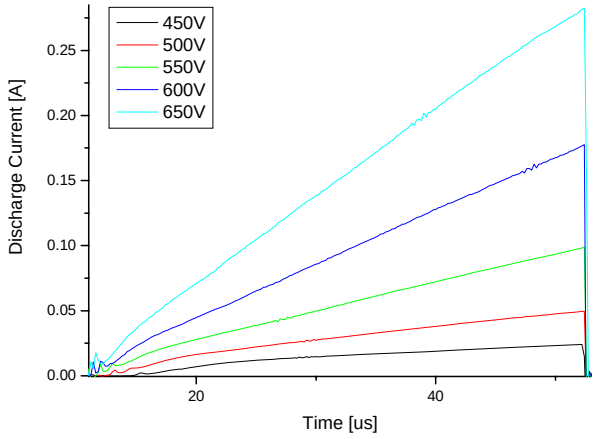


Gas pre: 500mTorr

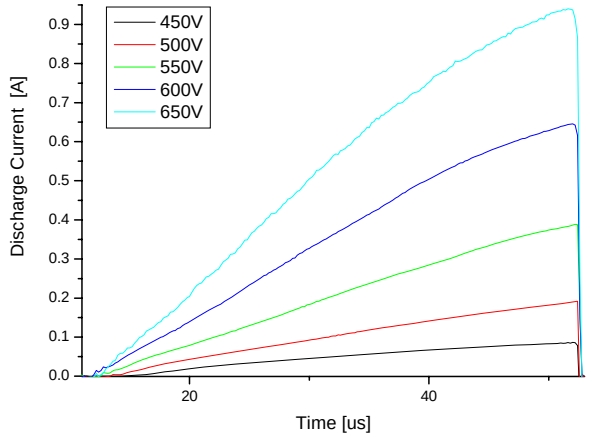
Base Pre: 5.5mTorr Gap distance: 8cm Rep. rate: 10Hz, Plate's diameter: 10cm



Gas pre: 110mTorr



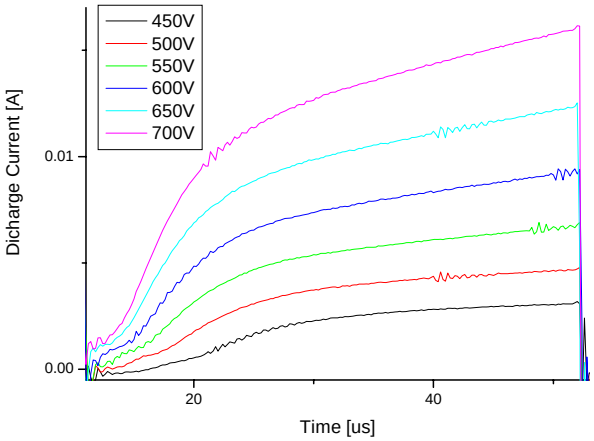
Gas pre: 300mTorr



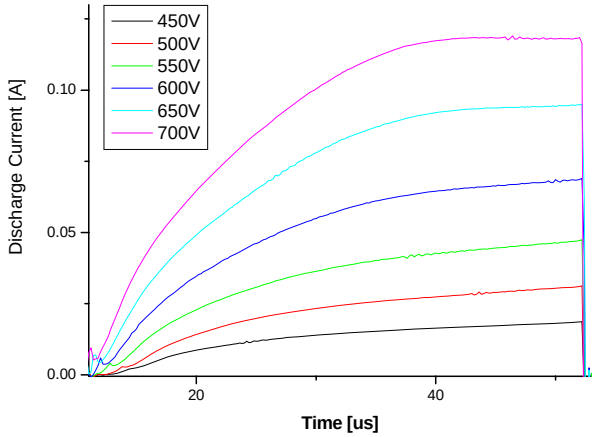
Gas pre: 500mTorr

Time characteristic of discharge current -2

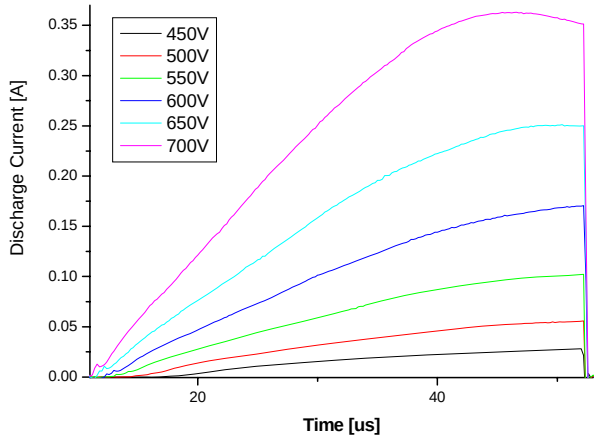
Base Pre: 5.5mTorr Gap distance: 2cm Rep. rate: 10Hz, Plate's diameter: 5cm



Gas pre: 110mTorr

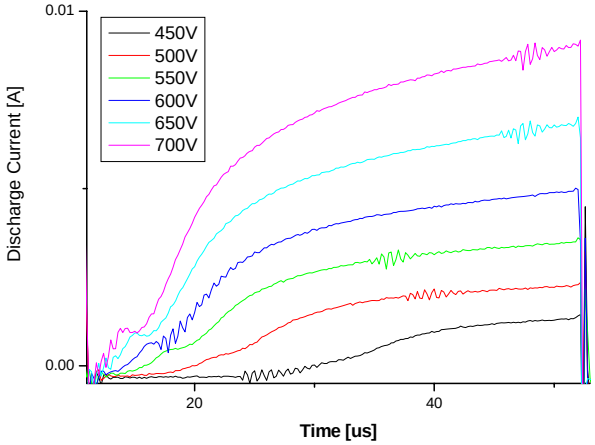


Gas pre: 300mTorr

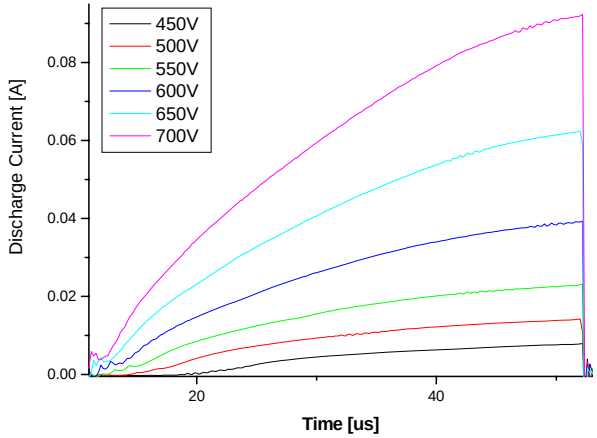


Gas pre: 500mTorr

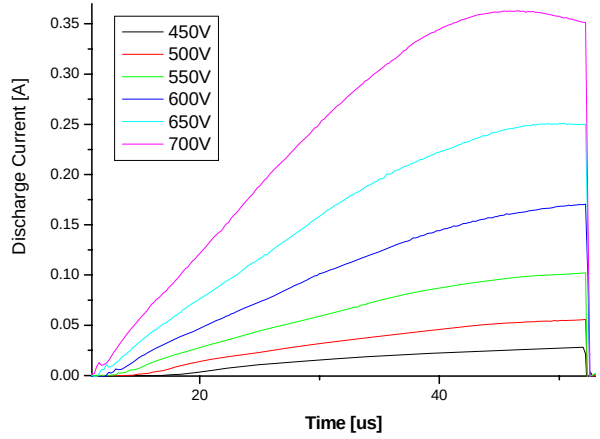
Base Pre: 5.5mTorr Gap distance: 8cm Rep. rate: 10Hz, Plate's diameter: 5cm



Gas pre: 110mTorr



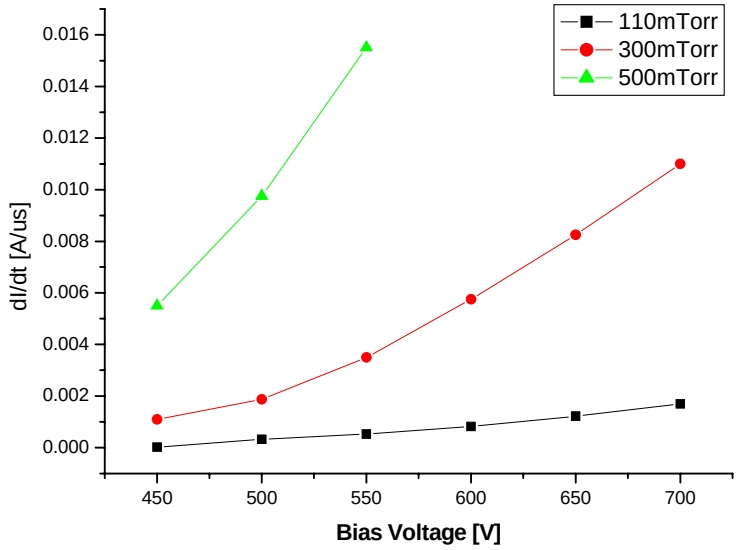
Gas pre: 300mTorr



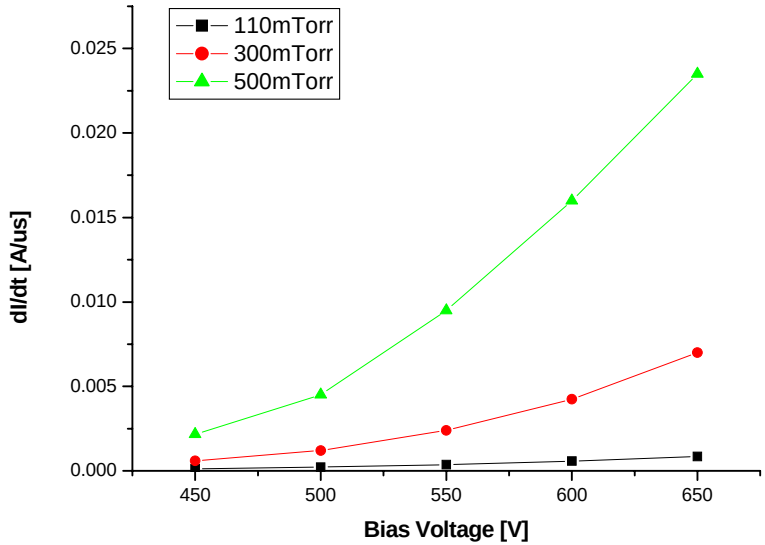
Gas pre: 500mTorr

dI/dt characteristic for neutral filling density

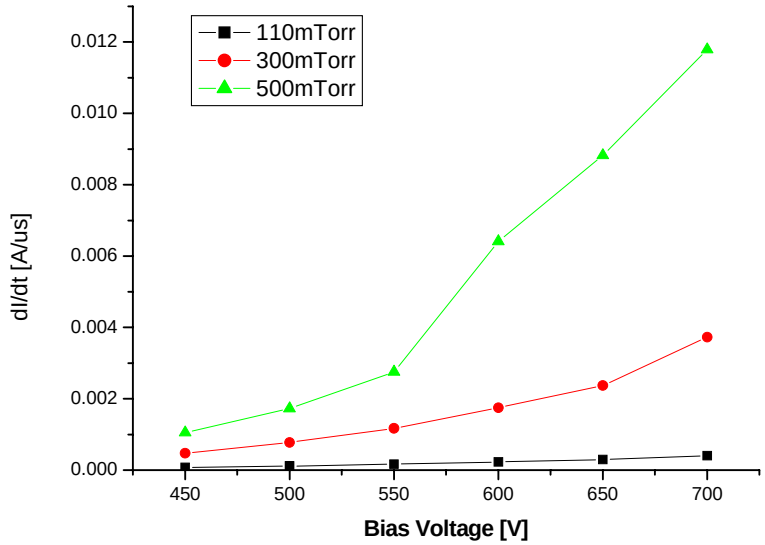
Base Pre: 5.5mTorr Gap: 2cm Rep. rate: 10Hz , Plate's diameter: 10cm



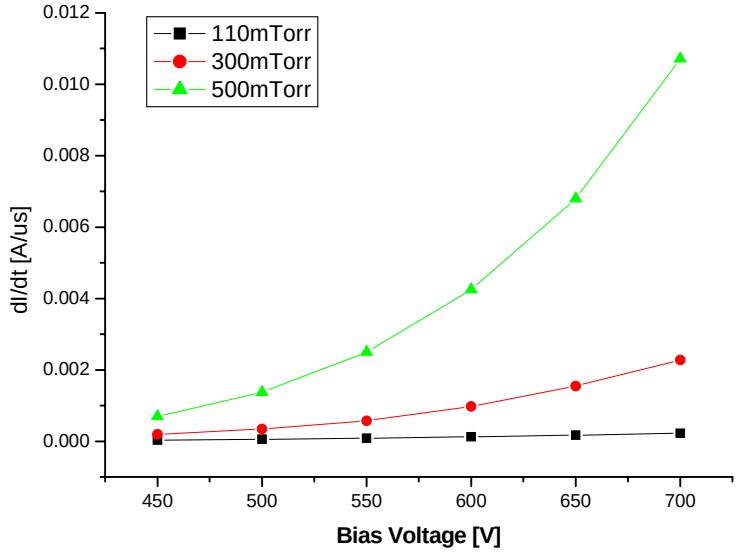
Base Pre: 5.5mTorr Gap: 8cm Rep. rate: 10Hz , Plate's diameter: 10cm



Base Pre: 5.5mTorr Gap: 2cm Rep. rate: 10Hz , Plate's diameter: 5cm

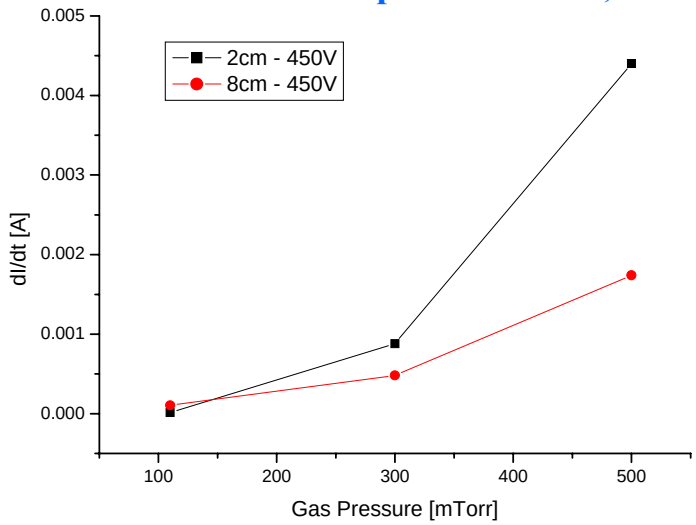


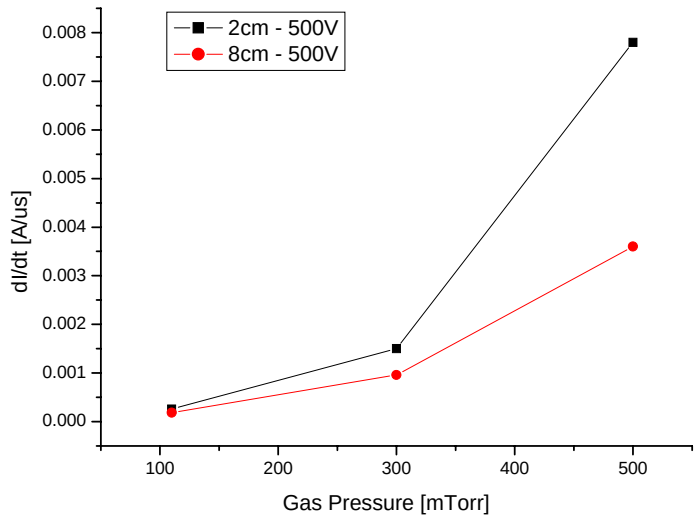
Base Pre: 5.5mTorr Gap: 2cm Rep. rate: 10Hz , Plate's diameter: 5cm

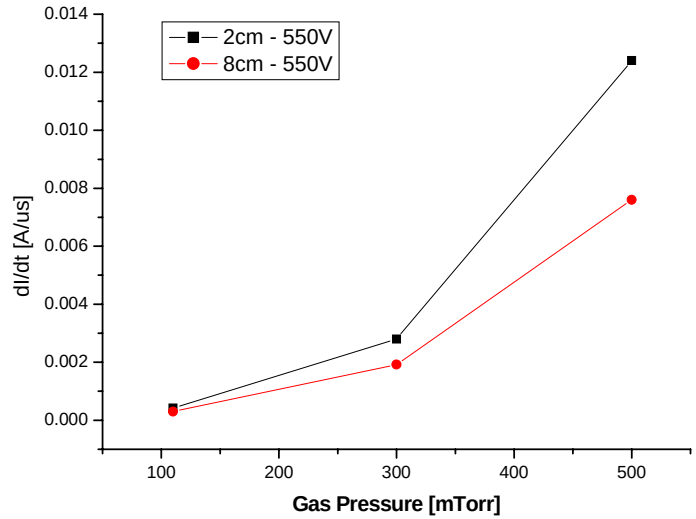


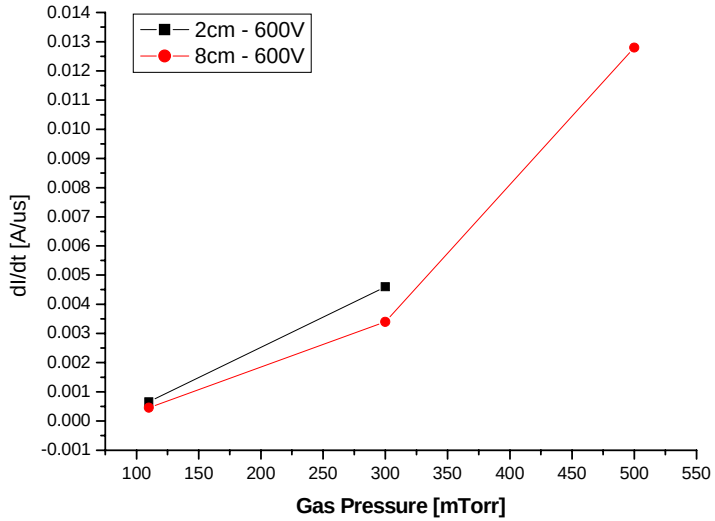
dI/dt characteristic for gap distance–bias voltage

Base Pre: 5.5mTorr Rep. rate: 10Hz , Plate's diameter: 10cm









As gap distance is decrease in same gas pressure, electric field E(t) grow. So dI/dt increase

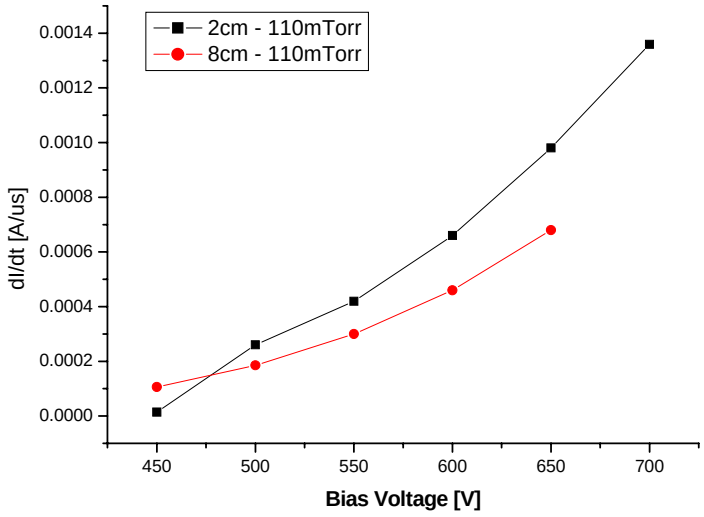
dI/dt characteristic for gap distance-gas pressure

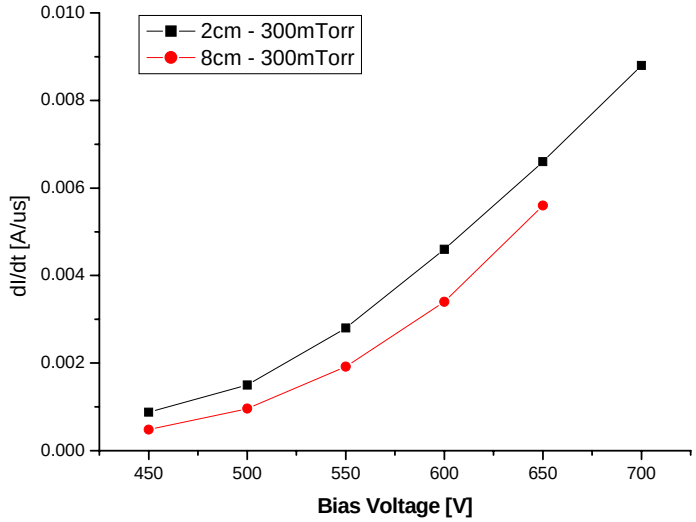
Base Pre: 5.5mTorr Rep. rate: 10Hz ,
Plate's diameter: 10cm

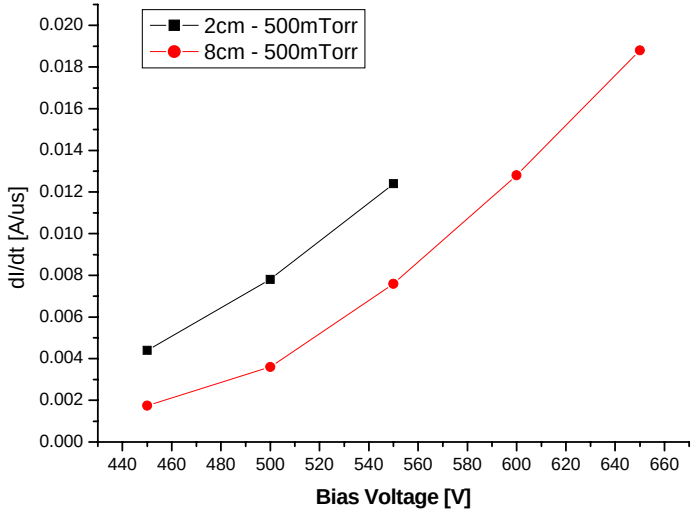
$$E_{2cm} = V / d$$

$$E_{8cm} = V / 4d = E_{2cm}/4$$

Though the bias voltage increase in uniform difference of gap distance, the difference of dI/dt value is sustained.

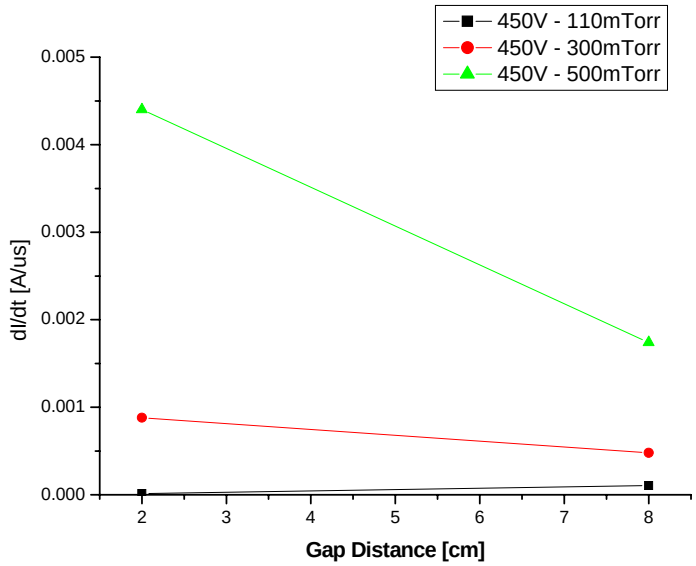


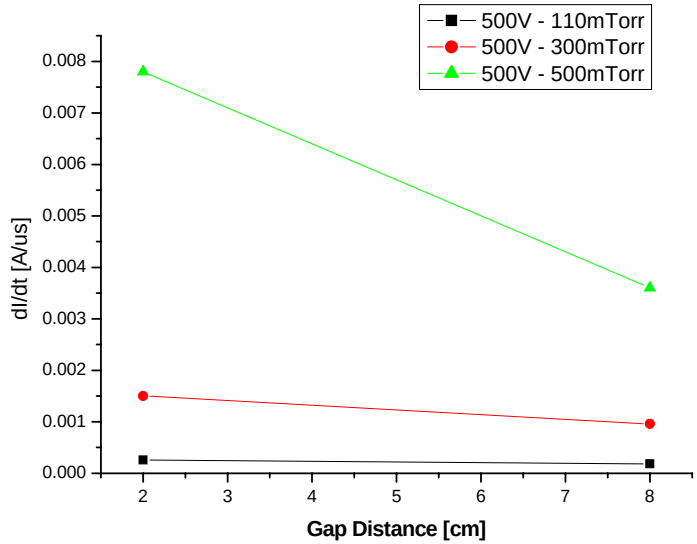


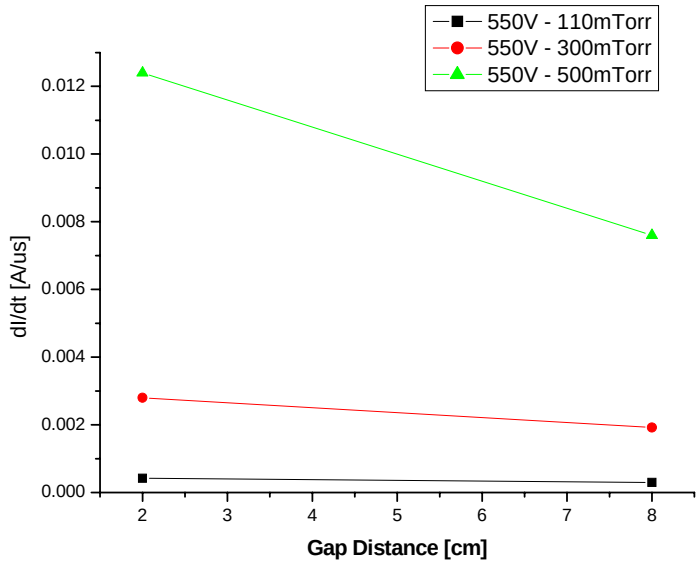


dI/dt characteristic for bias voltage-gas pressure

Base Pre: 5.5mTorr, Rep. rate: 10Hz , Plate's diameter: 10cm







Conclusion and future work

Conclusion

We measured the dI/dt value for several conditions and have studied for characteristics of time-dependent current

- **dI/dt value has two characteristics for neutral gas filling pressure. (two or one slope)**
- **Neutral gas filling pressure and electric field between electrodes are dominant to dI/dt**
- **If gap distance and neutral gas filling pressure are fixed, ion energy (bias voltage) is not dominant to dI/dt.**

Future work

- **Find the α and γ process about pulse's time evolution**
- **Measurement of plasma parameter through micro-interferometer and electric guard ring probe**
- **Measurement the dI/dt characteristics depended on electrode geometry**