Charge Transfer Process in DBD

Essential Defference between DBD and RF Discharge and Glow Discharge

Mase. H
Email:maseh@vc.ibaraki.ac.jp.

In the DBD (Dielectric Barrier Discharge), the discharge is quenched after a very short time from the beginning of the discharge, because the dielectrics surface is charged up to near apply voltage. In order to continue the short pulse discharge, it is necessary to apply an AC voltage.
We discuss the charge transfer process in DBD and also clarify the essential difference between DBD and other discharges.

Abstract

In the DBD (Dielectric Barrier Discharge), the surface of the dielectrics on the electrodes are charged up nearly applied voltage after a very short time from the beginning of the discharge and then the discharge is quenched, The electrons, which are charged up on the surface of dielectrics, play a role of the initial electrons in electron avalanche, when the gap is applied a high voltage of inverse polarity opposite to the preceding discharge, The discharge is never sustained in steady state. In order to continue the short pulse discharge, it is necessary to apply an AC voltage. While the discharge is happening, only the displacement current flows due to the charge transfer process.

We discuss the charge transfer process in DBD and also clarify the essential difference between DBD and other discharges.

DBD is distinguished from the RF discharge by the operating frequency range. DBD in which the charge transfer by ion drift is to operate in much lowerfrequency than that of RF discharge.

The essential difference between DBD and glow discharge is the presence or absence of the effect of electron emission by ion bombardment on the negative electrode. In DBD the electron emission from the electrode is never required. Even if the DBD might look like an apparent glow discharge, it would not be referred to as a glow discharge.

Typical DBD Configuration

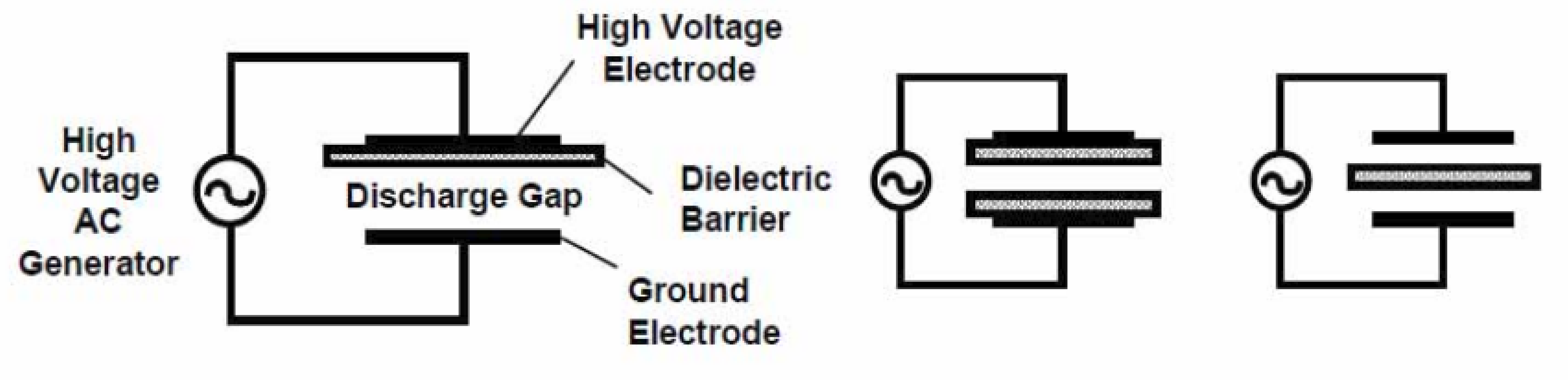


Fig. 1: Typical barrier discharge configurations

DBD device is considered a system that is parallel-connected with a lot of capacitive coupled diode discharge elements (CCMD, Capacitive Coupled Multi-Discharge). Each capacitive coupled diode discharge element generates a micro-discharge. DBD could be considered to be the integrated micro-discharge [Mase.H et al : Appl. Phys. Lett. 83, 5392 (2003)]..

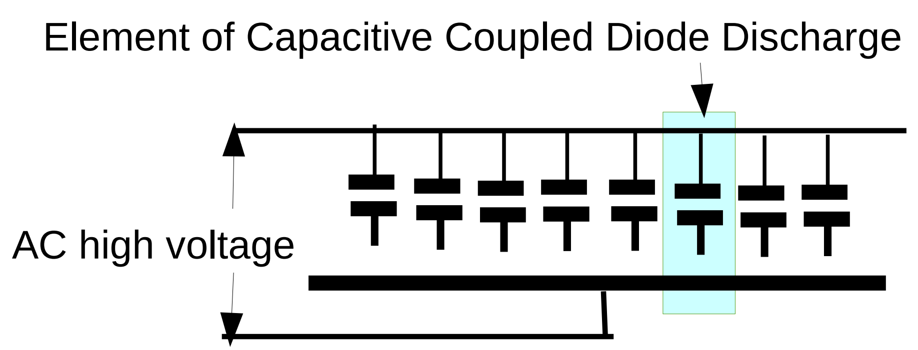
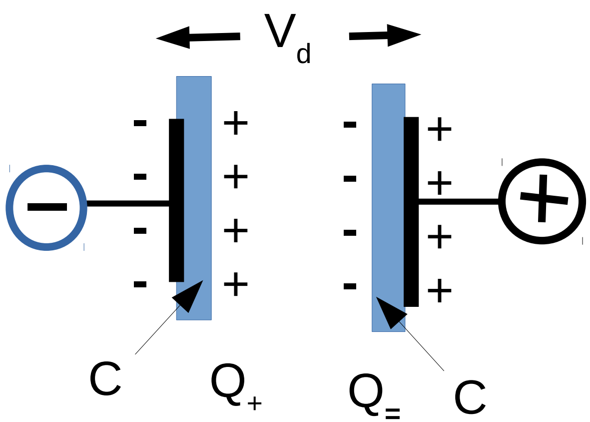


Fig.2 CCMD model

Charged Particles on Surface of Dielectric Barrier after Quenching of Discharge

We consider the amount of charged particles on surface of dielectric barrier after quenching of discharge in well used DVD with both electrodes covered by dielectric barrier. (The case of DBD consisting of metal electrode and dielectric barrier electrode is described in the appendix)



$$Q_i = Q_e \sim \frac{1}{2} \cdot CV_d \qquad N_i = N_e \equiv N \sim \frac{1}{2e} \cdot CV_d$$

input energy W $$W \sim \frac{1}{4} \cdot CV_d^2 = \frac{1}{2} \cdot eNV_d$$

where C is capacitance asociated with an integarated micro-discharges

Total Amount of Electron-Ion Pairs Generated in Discharge after Quenching Preciding Discharge

Since the negative and positive charges on the dielectric barrier caused by previous discharge is neutralized and furthermore the dielectric barrier is charged up near applied voltage, the total amount of electron ion pairs are required to generate N_0 pairs in a single pulse discharge in DBD (gap length d and electrode area S) .

Time t_g is required for generation of N_0 electron-ion pairs

$$\frac{d\,n_e}{dt} dS = \frac{v_e}{\lambda_i} n_e dS \qquad \frac{n_e dS}{N_0} = \frac{2\,N_0}{N_0} = \exp\left(\frac{v_e}{\lambda_i} \cdot t_g\right)$$

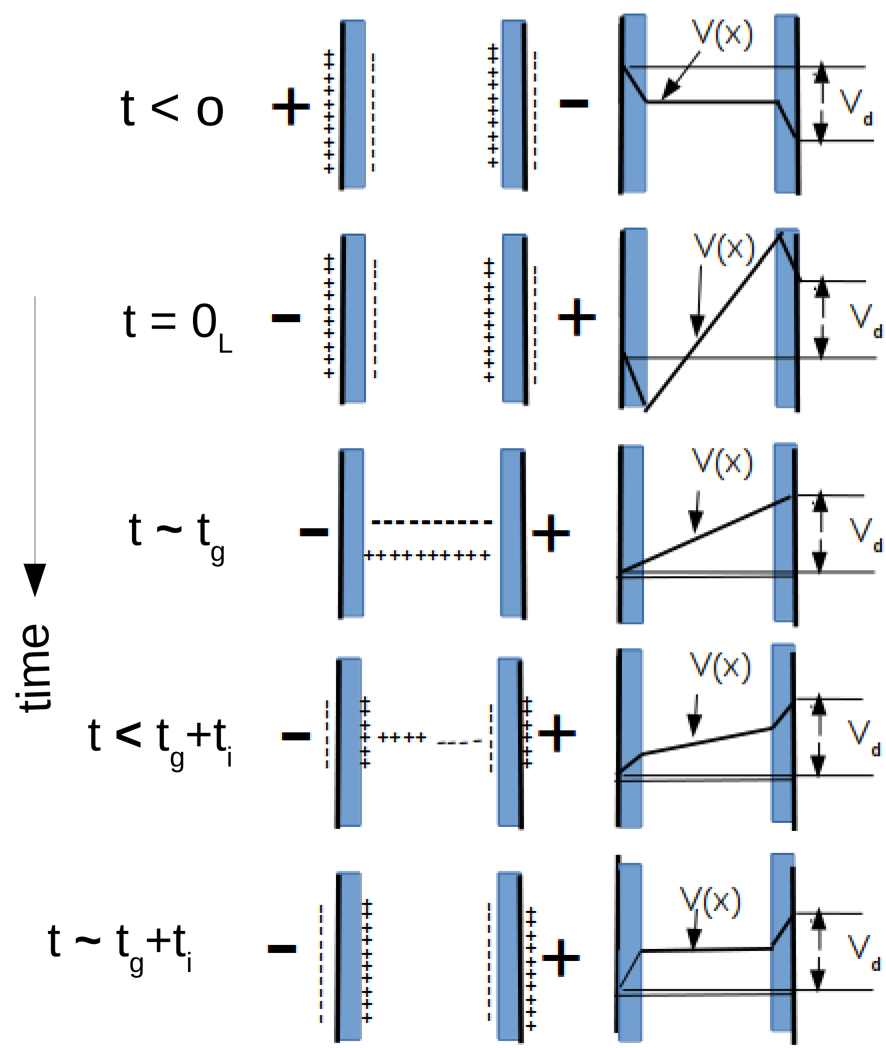
$$t_g = \frac{\lambda_i}{v_e} \cdot \ln(2)$$

where v_e and λ_ι are the electron drift velocity and mean ionization length, respectively. Here the particle losses due to recombination preocess etc are negelected.

t_g is determined from the ionization frequency v_e/λ_ι and never depends on other parameters,

Charge Transfer Process

Neutralization and Charge up on Dielectric Barrier
and
Temporal Variation of Potetial Structure across Electorodes



after quenching of the preciding discharge.
surfaces of dielectric barrier charged up to ~(1/2)V_d .

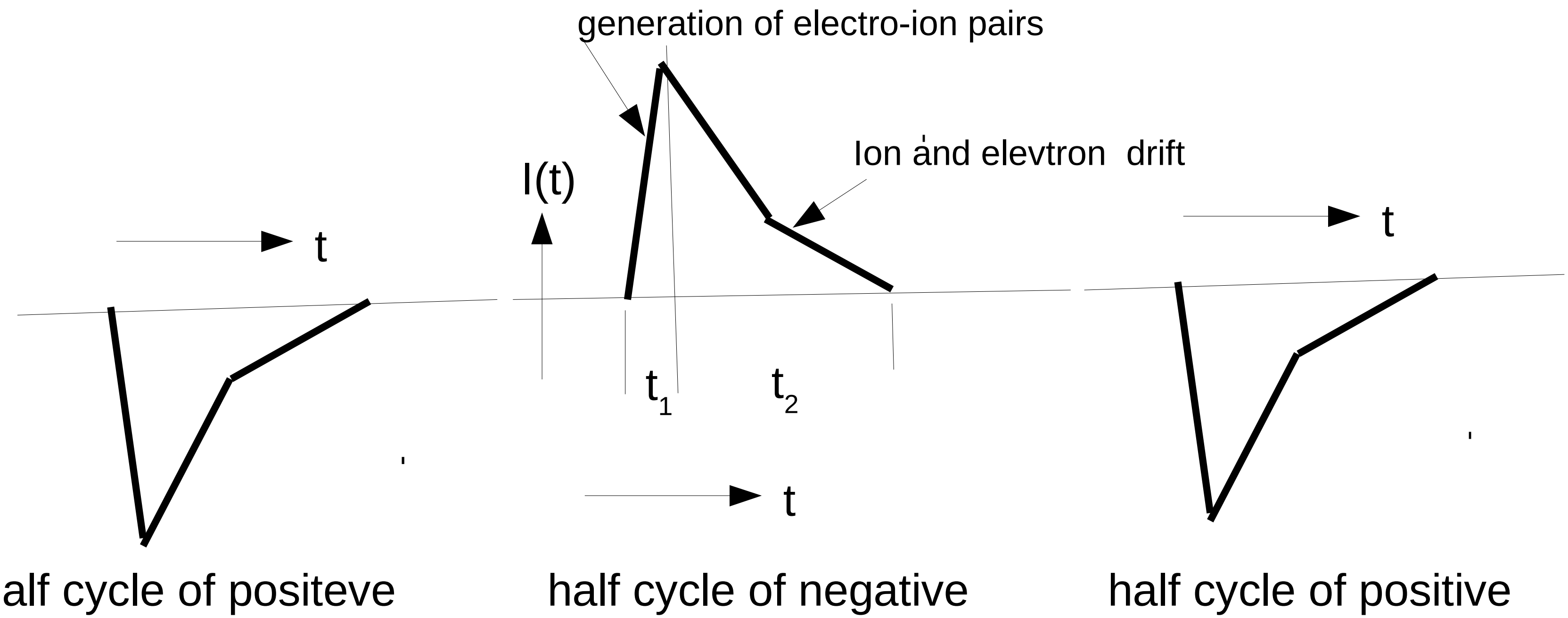
just starting of following discharge

generation of N_0 electron-ion pairs.
N_0 of electrons and ions neutralize the positive and negative charges on dielectric barrier. N_9 electron-ion pairs formed the plasma column.

plasma electrons drift toward the positive electrode and the charge up negatively its dielectric surface.
plasma ions aldo charge up dielectric barrier surface.

each dielectric barrier surface charged up to ~(1/2)V_d and dischare quenched.
ion trasit time t_i ~ d/v_i

Expected Waveform of Discharge Current in DBD



$t_1 \sim (\lambda_e/v_e)\ln(2)$, $t_2 \sim d/v_i$

The discharge current is limited to the displacement current due to charge transfer.

RF discharge

When the frequency of power supply is much higher than 1/te (te;electron transit time te = d/ve), the discharge is maintained without quenching the The discharge is sustained by the ionization due to trapped electrons across the electrodes. Plasma ions are at rest. Such a discharge mode is a RF discharge.

Essential diffrence between DBD and RF and Glow Discharges

DBD

Characteristic features in the DVD are to disappear in a very short time after the start of the discharge, because the surface of dielectric barrier is charged up to near the discharge voltage. The behavior in DBD is due to the charge transfer by both electron and ion drift through the discharge gap. The electrons on the dielectric barrier surface plays important role for the start of discharge. For the continuous operation it is necessary to apply in the frequency range of lower than $1/t_i \sim v_i/d$, that ti is ion transit time. The discharge in DBD is caused by electrons accumulated on the dielectric barrier surface.

RF discharge

When the frequency of power supply is much higher than $1/t_e$ (t_e;electron transit time $t_e = d/v_e$), the discharge is maintained without quenching. The discharge is sustained by the ionization due to trapped electrons across the electrod and the excitation of electron must be less than the plasma frequency. The plasma ions are at rest. Such a discharge mode is a **RF discharge**.

Glow discharge

The glow discharge is sustained due to γ process, that is the secondary electron emission from the cathode by bombardment of accelerated ions through the cathode fall. If the self-sustaining condition is satisfied, it is possible to sustain the steady state discharge in the frequncy range from DC to less than $1/t_{ic}$, that is ion transit time through the cathode sheath.

Summary

Characteristic features of the DVD are to disappear in a very short time after the start of the discharge, because the surface of dielectric barrier is charged up to near the discharge voltage. The behavior in DBD is due to the charge transfer by both electron and ion drift through the discharge gap. The electrons on the dielectric barrier surface plays important role for the start of discharge. For the continuous operation it is necessary to apply in the frequency range of lower than $1/t_i \sim v_i/d$, that t_i is ion transit time.

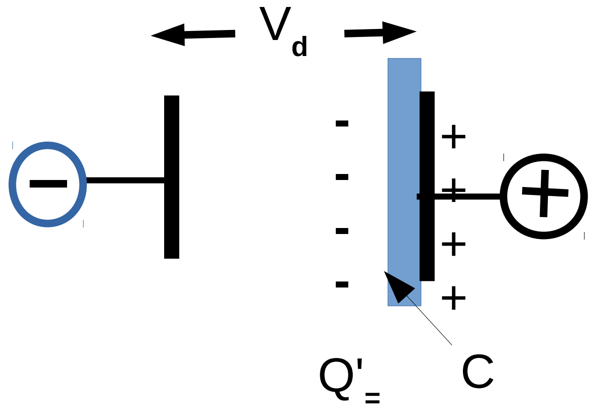
DBD is distinguished from the RF discharge by the operating frequency range. DBD in which the charge transfer by ion drift is to operate in much lower frequecy than that of RF discharge.

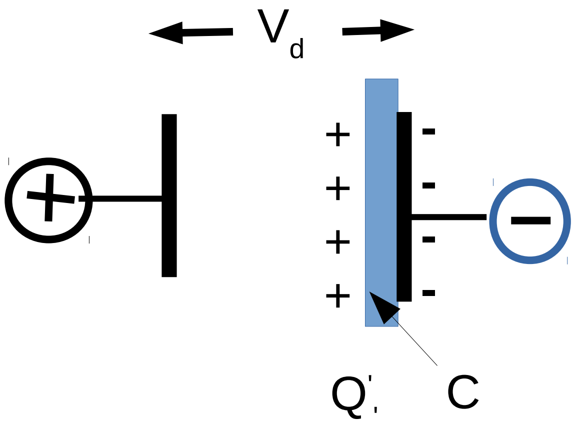
The essential difference between DBD and glow discharge is the presence or absence of the effect of electron emission by ion bombardment on the negative electrode. In DBD the electron emission from the electrode is never required. Even if the DBD might look like an apparent glow discharge, it would not be referred to as a glow discharge.

Appendix

- Charge Transfer Process in DBD consisting of Metale Electrode and Dielectric Barrier Electrode

Charge Transfer in DVD Consisting of Metal Electrode and Dielectric Barrier Electrode (1/3)

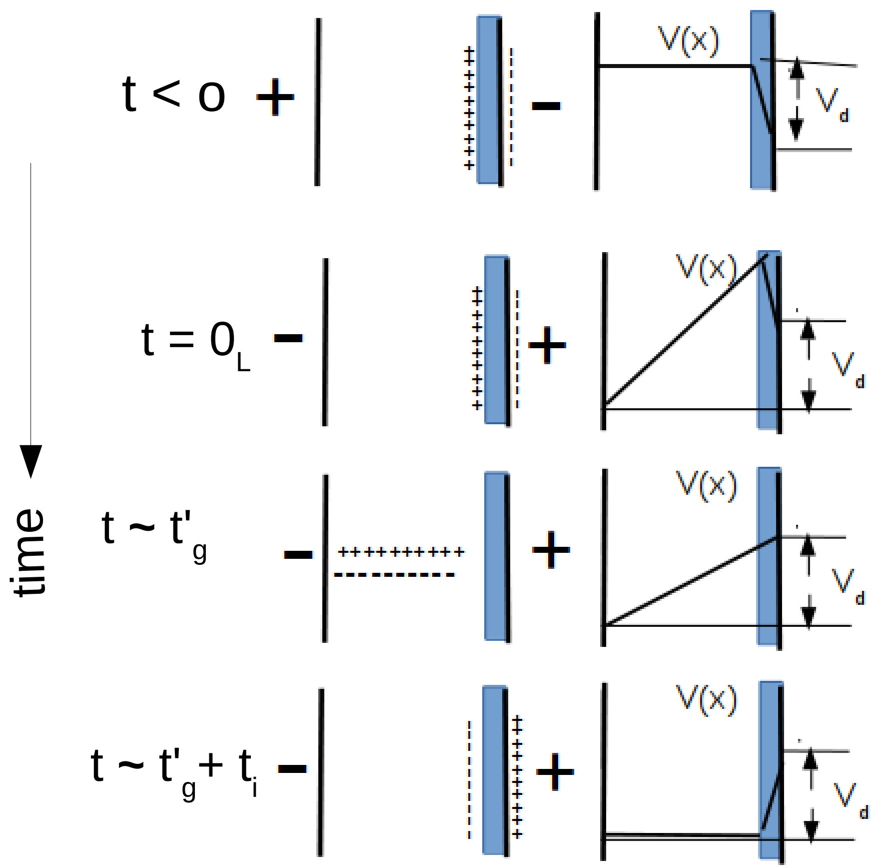




$$Q_i' = Q_e' \sim CV_d \qquad N_i' = N_e' \equiv N' \sim \frac{1}{e}\cdot CV_d$$

$$W \sim \frac{1}{2}\cdot CV_d^2 = \frac{1}{2}\cdot eN'V_d$$

Charge Transfer in DVD Consisting of Metal Electrod and Dielectric Barrier Electrode (2/3)



after the preciding dischage quenched

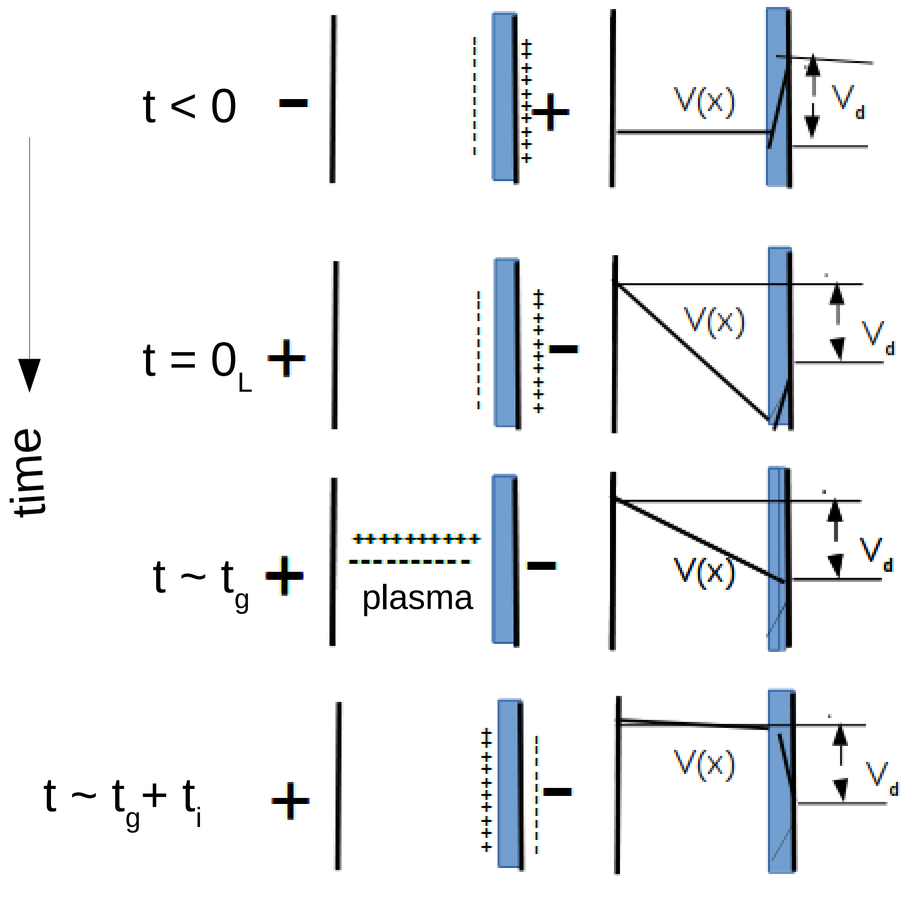
just starting of following discharge
initial electrons is insignificant amount

generation of 2N' electron ion pairs.
ionization growth up to 2N' require more long time than t_g, because initial electrons is insignificant amount

$t'_g.=(\lambda_e/v_e)\ln(2N'/n_{e0}dS) >> ((\lambda_e/v_e)\ln(2)$

surface of dielectric barrier negatively charged up to ~ V_d,
and then discharge quenched.
Ions are neutralized by Auger electrons on surface of metal electrode.

Charge Transfer in DVD Consisting of Metal Electrode and Dielectric Barrier Electrode (3/3)



preciding discharge quenched
surface of dielectric barrier is negatively charged uo ~ V_d

just starting following discharge

gejeration of electron-ion pairs of N_0
initial electrons neutralized positeively charge on electrode

surface of dielectric barrier is positively charged up to ~ V_d and discharge quenched