PROPERTIES OF DIELECTRIC BARRIER DISCHARGES IN DIFFERENT ARRANGEMENTS

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1 Introduction

Dielectric barrier discharges (DBDs) occur in arrangements where at least one dielectric is positioned in a gas space in between conducting electrodes. When breakdown field strength is reached in such a device, charge carriers are created in the gas region, accelerated, multiplied and finally collected on the surface(s) of the dielectric(s). The charge accumulation on the dielectric creates a counter field to that resulting from the power supply and as all of these processes are rather fast, the discharge quenches rapidly.

The dielectric has two tasks, it limits the transferred charge and by this the energy conversion and distributes the discharge over the electrode area. That is why DBDs are non-thermal discharges which exist even at atmospheric pressure.

2 DBD arrangements

2.1 Volume discharge arrangement

There exist a lot of different possibilities to realise DBD arrangements. The classical one is using plane metal electrodes from which one or both are covered by a dielectric layer. In the remaining gas gap normally in the range of a few millimetres microdischarges occur, which consist at atmospheric pressure in general of tiny discharge columns and surface discharges on the dielectric(s). This type of discharge will be named volume discharge (VD) below. In Fig. 1 a) a sketch of the VD arrangement is given.

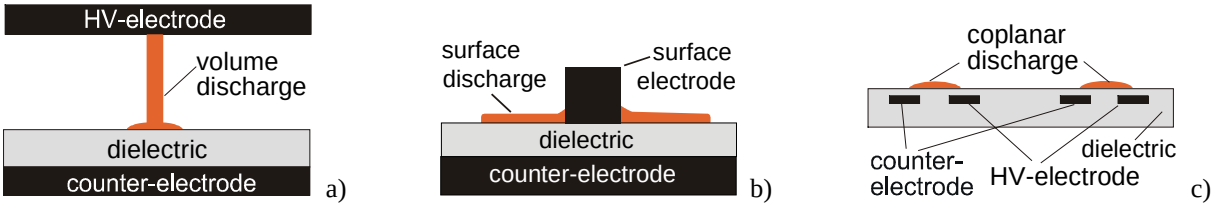


Fig 1: Basic configurations of DBDs, a) volume discharge (VD), b) surface discharge (SD) and c) coplanar discharge (CD) arrangement

2.2 Surface discharge arrangement

The discharges created in an arrangement like in Fig. 1b) consist of pure surface discharges (SDs). At critical field strength on the surface the discharge starts with a short discharge step. After a certain time delay (and voltage rise) further steps occur up to voltage peak. The duration of such a step is comparable to those of a microdischarge in the VD case. This has been proved experimentally by measuring the radiation of the discharge (Fig. 2, [1]).

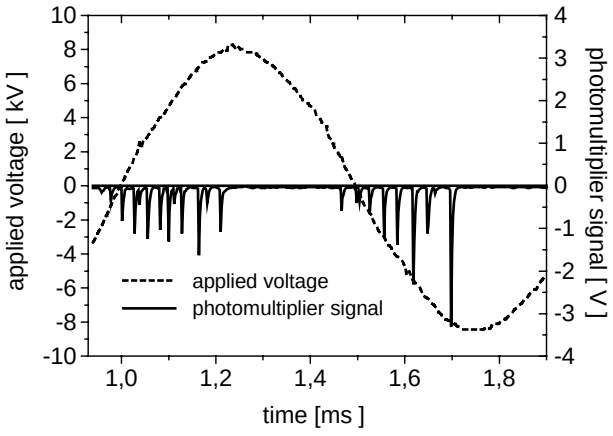


Fig. 2: Photomultiplier signal of the radiation of a SD during a period of the applied voltage

The patterns of SDs depend on polarity and are comparable to those on the surface of the dielectric of the VD configuration. The extension of the discharge depends on voltage amplitude. In order to get enhanced energy densities most often a lot of parallel extended surface electrodes with optimised inter-electrode distances are used and the frequency of the applied voltage is increased, respectively.

2.3 Coplanar discharge arrangement

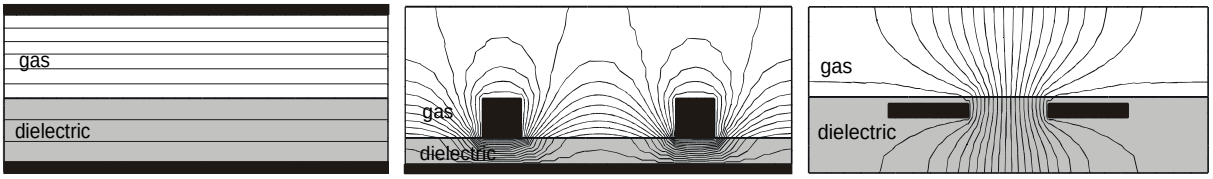
The coplanar discharge (CD) arrangement is characterised by pairs of extended electrodes with opposite polarity, which are imbedded within a dielectric bulk nearby a surface (Fig. 1 c). As such strips can be produced with high accuracy and easily be coated with a dielectric layer by technologies well introduced in the semiconductor industry, short inter-electrode gaps in the range of 100 µm and below can be realised.

At short inter-electrode gaps the discharge behaves similar to VDs. Short "microdischarge channels" bridge the region on the dielectric surface above the electrodes. The discharge pattern are of cause independent on polarity. The width of the channel is basically fixed and in the range of the inter-electrode gap. The number of the channels depend on the voltage amplitude as well.

High energy densities on small surface areas are possible at small inter-electrode gaps.

3 Discharge dynamics

The discharge dynamics is determined by the initial field strength distribution and the influence of the volume and surface charge development. In Fig. 3 the initial potential distributions of the basic configurations are compared [1]. While in the VD configuration the potential distribution is homogeneous, it is rather non-homogeneous in the SD case. Because in CD arrangements the electrodes are covered by a dielectric layer the initial potential distribution is more homogeneous than in SD arrangements.



a) VD b) SD c) CD

Fig. 3: Initial potential distribution in different configurations a) to c)

The VD is characterised by initially burning in an uniform field. In general cathode directed streamers as well as distinct cathode layers are formed rapidly at least in electronegative gases. The field strength drops in the discharge channel to a value where the effective ionisation coefficient is about zero. The energy density in the channel defines the level of the field strength [2].

The SD propagates in a strongly non-uniform field. A cathode layer development (and a cathode directed streamer) has not been observed. The discharge current as well as the corresponding charging of the surface is presented in Fig. 4 for a halve period of the voltage. In the outer region of the discharged area the field strength rises to a value nearby the breakdown value. This field strength peak moves along the surface (Fig. 5) [3].

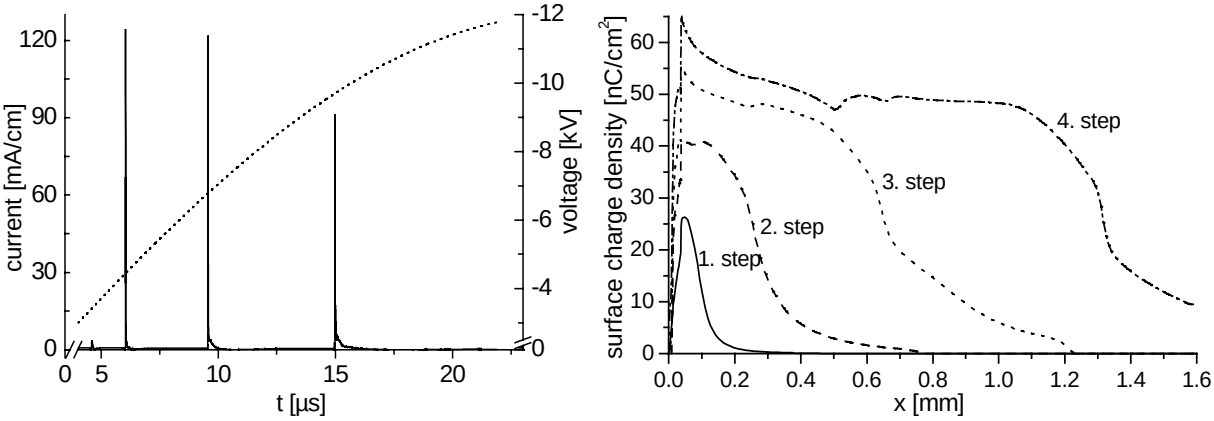


Fig. 4: Simulated discharge currents during voltage rise and surface charge density after each discharge step

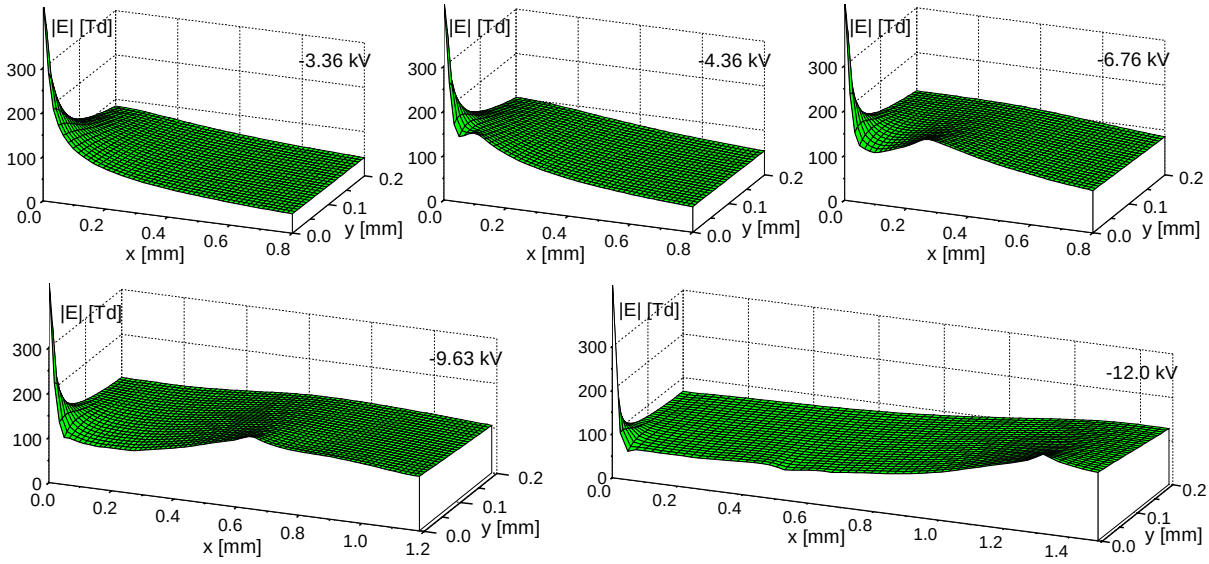


Fig. 5: Initial field strength distributions before each discharge step and after the last one at maximum voltage

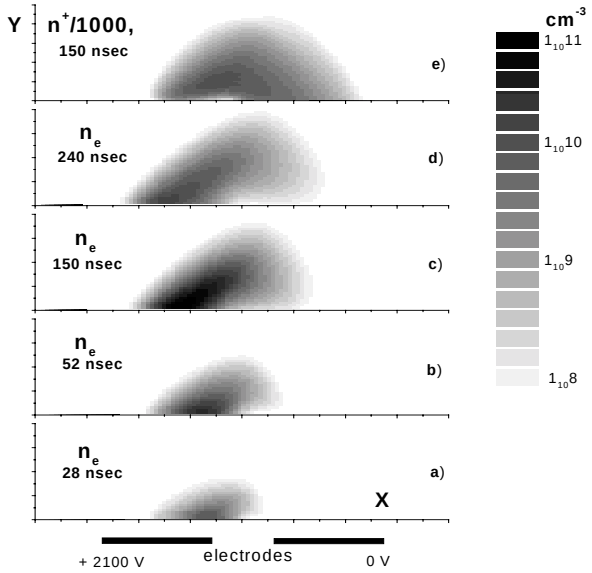


Fig. 6: Electron and positive ion density distributions in a CD arrangement

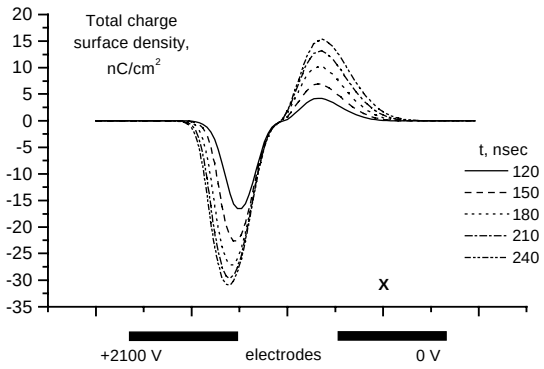


Fig. 7: Temporal development of the surface charge densities

As the dynamic behaviour of CDs at small discharge gaps hardly can be investigated experimentally, preliminary numerical investigations have been performed [4]. As examples of some results the temporal development of the electron and positive ion density distributions (Fig. 6), the temporal development of the distribution of the surface density (Fig. 7) and the temporal development of the power and mean value of field strength (Fig. 8) are presented.

The field strength (averaged along the channel) decreases in time while the power increases. This situation is qualitatively true in all configurations under investigation. Although there are different starting conditions the charge transfer mechanisms are similar.

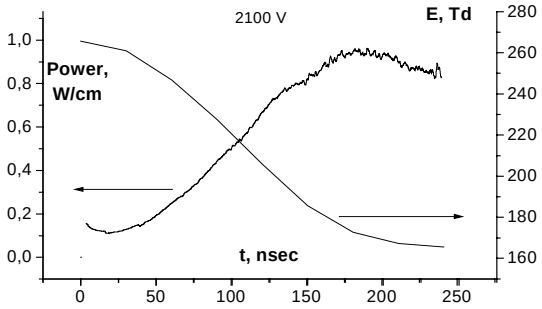


Fig. 8: Temporal development of the power and mean value of field strength in a CD arrangement at 2100 V

4 Peculiarities of VDs, SDs and CDs

The VD is characterised by consisting in general of numerous tiny microdischarges, which develop in a uniform background field strength. The transferred charge of each microdischarge is equal in electronegative gases; in electropositive gases there exist a more broad distribution of the charge values [2]. Their number density is proportional to the applied voltage. The bases of the microdischarges on the dielectric cover the whole discharge area and even more than one time at sufficient high voltage amplitudes and at moderate frequencies of the applied voltage in general. Furthermore the properties of the discharge is rather easy to be tailored for specific applications by changing the transferred charge of the microdischarges. This can be realised by varying the dimensions of the arrangement and/or the properties of the dielectric [1].

The SD develops in an initially decreasing field strength. It propagates stepwise on the surface at rising voltage. The discharged area is proportional to the applied voltage. As there exists not a fixed starting position for the SD on the surface electrode, the Paschen minimum is always reached. That does mean, the SD is characterised by low ignition voltages. This may be partly be supported by an involvement of surface properties in the ignition process as well. The SD can be operated at comparable low applied voltages. A further feature of SD arrangements is that the discharge can be cooled effectively by dielectric materials of high heat conductivity. The most active regions for plasma chemical reactions are directly at the surface electrode (connected with a comparable high stress of the surface electrode) and on the tip of the propagating discharge.

The CD combines somehow the advantages of the VD and SD, especially at short electrode gaps. It develops in a more uniform initial field strength than the SD at a nearly fixed discharge length. The CD consists like the VD of numerous tiny microdischarges; their number density is proportional to the applied voltage as well. Because of the possibility to realise short precise electrode gaps it is possible to enhance the region of tailoring the DBD to high mean field strengths. The accuracy of the distance of a guiding plate to the CD arrangement (for plasma chemical applications) is of less importance. The cooling possibilities are comparable with those of SD arrangements. High power densities, especially at enhanced operating frequencies combined with low applied voltages even at atmospheric pressure are further advantages of this type of discharge. However, there exist some difficulties to find suitable, high field resistant coatings for the electrodes.

5 References

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