Development of a coaxial-stacked trielectrode plasma curtain

D. Grondona, P. Allen, and H. Kelly

***Abstract*— The development of a plasma curtain discharge with a cylindrical geometry is presented. The discharge is generated at atmospheric pressure, by combining a dielectric barrier discharge (DBD) with a *dc* corona discharge (CD). The DBD is established between two aluminum ring-shape electrodes separated by a circular dielectric plate and the CD discharge is generated with a third electrode consisting in a cylindrical mesh positioned coaxially with respect to the DBD electrodes. Between the DBD electrodes and the CD electrode there is a 23 mm large air-gap. The discharge is composed of a train of streamers crossing the air-gap, with a repetition frequency of about 100 kHz and carrying an average current of 0.3 – 0.4 mA, that can be sustained for large time periods. Also, a stacked arrangement was studied by placing a second set of DBD electrodes parallel to the first one, along the CD electrode axis. It was found that in this parallel configuration the discharge is well established, showing that an extended stacked configuration can be achieved without difficulty. This result is useful for gas processing applications in which the gas to be treated flows through the discharge.**

***Index Terms*— Gas Discharges, Non-thermal Plasma, Plasma curtain.**

I. Introduction

Plasma processing based on non-thermal plasma sources at a high pressure (typically, atmospheric pressure) presents considerable practical interest, since it avoids expensive vacuum systems and batch processing of work-pieces. These plasmas include corona discharges (CD) [1], dielectric barrier discharges (DBD) [2], and atmospheric pressure glow discharge (OAUGDPTM [3]). In practice, these sources have been employed in microelectronics [4], surface modifications [5], light sources [6], surface sterilization [7], gas decontamination [8] and flow control [9].

Devices based on *dc* CD discharges with two active electrodes allow establishing ionized regions with extended air gaps but they present some drawbacks, such as problems related to spark transition and non-uniform distribution of the discharge along the electrodes side length. The *ac* DBD devices [2] can overcome some of the quoted CD difficulties, but the ionization in these kinds of devices has been in general restricted to the vicinity of the electrodes resulting in ionized air gaps of a few millimeters length.

In previous works [10],[11], it was presented the development of a so call trielectrode plasma curtain discharge (TPC) that could be long time sustained, over inter-electrode air gaps up to 20-25 mm, and with electrodes length of ~ 15 cm in the transversal direction. The discharge was based on the combination of a DBD with a CD in a three electrode system, and basically it resulted from the ‘stretching’ of a pure DBD discharge by the action of a CD discharge generated between the active electrode of the DBD and a remote third electrode. The TPC was an extension of a previously developed sliding discharge [12]–[14], in which a considerable part of the dielectric surface was replaced by an air gap. It was found that this relatively large TPC discharge was generated during the positive cycle of the DBD discharge, and besides it had a pulsed and filamentary nature, being composed of repetitive streamers that were uniformly distributed along the whole electrode length.

Energetic electrons are produced at the streamer head. They can excite, ionize and dissociate gas molecules forming radicals that are highly reactive. These radicals readily react with other existing species reducing the pollutant's concentration.

Considering an application in which a gas flow passing through the discharge is involved, the main disadvantage of the TPC discharge is its plane geometry, which requires the use of additional walls for guiding that gas flow.

In this work we present the development of a coaxial trielectrode plasma curtain discharge (TPCC) that avoids the above mentioned drawbacks of the TPC discharge, since the coaxial geometry provides a natural boundary to conduct a gas flow. The electrical and some plasma characteristics of this discharge are presented. Also, results on the parallel operation of two TPCC discharges show that an extended stacked configuration can be achieved without difficulty, thus allowing an improved gas processing efficiency.

II. Experimental arrangement

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A schematic of the electrode layout is shown in Fig. 1. The first TPCC discharge was generated by using an electrode arrangement consisting in two circular flat foils (electrodes 1 and 2) made of 50μm adhesive aluminum tape with 34 (1) and 38 (2) mm of diameters, flush mounted on the top and bottom surfaces of a poly-methyl methacrylate dielectric disk with 40 mm diameter and 5.6 mm width. The whole structure was sustained by a cylindrical insulating tube (9 mm in diameter) piercing the dielectric disk and also electrodes 1 and 2 through a central hole. The tube was fixed to a base insulating plate. On the same base plate was also fixed another insulating tube with 86 mm inner diameter, 80 mm height and with a wall thickness of 2 mm. On the inner wall of this insulating tube was fixed a steel mesh that acted as the electrode 3. Electrode 1 was air-exposed, while electrode 2 was completely covered with an epoxy resin (not air-exposed). The distance between the edges of electrodes 1 and 3 was 26 mm, allowing for an 23 mm air gap. To investigate a stacked configuration, another TPCC discharge was produced between another electrode arrangement similar to that corresponding to electrodes 1 and 2 (located parallel to the original and separated by 30 mm, electrodes 1´and 2´, see Fig. 1) and the same electrode 3.

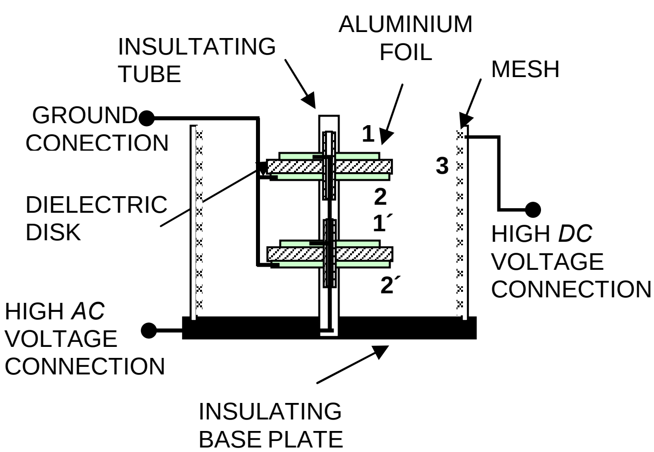


Fig. 1. Schematic of the electrode layout.

In Fig. 2 the electrical block diagram of the experimental set-up is presented. The electric circuit consisted of a negative variable *dc* power supply (continuous voltage V_{DC} in the range 0 – -20 kV) and *ac* power supply (alternating peak-to-peak voltage V_{AC} in the range 0–35 kV). The *ac* supply was connected between electrode 1 and ground, while the negative terminal of the *dc* supply was connected to electrode 3. For the stacked operation electrodes 1 and 1´ were electrically connected in parallel to the same *ac* source.

The *ac* power supply consisted in a function generator coupled to an audio-amplifier (power of 700 W) that fed a high voltage transformer [15]. In practice, there was an optimal matching frequency, corresponding to the resonance between the transformer inductance and the stray capacity of the electrode arrangement, including the wire connections. For our circuit geometry, the optimum excitation *a-c* frequency was f_{ac} = 8.8 kHz. The instantaneous alternating voltage applied to electrode 1, *V(t)*, was measured with a HV probe (1000 X / 3.0 pF/100MΩ). These electrical signals were registered by using a four-channel digitizing oscilloscope with an analog bandwidth of 60 MHz and 1 Gs/s of sampling rate. Current measurements were performed by inserting 50 Ω resistances between both power supplies and ground (see Fig.2), and registering the voltage drop on these resistances. Thus, the current circulating between electrode 2 and ground corresponds to the DBD current (I_{DBD}) while that circulating between electrode 3 and ground corresponds to the TPCC current (I_{TPC}).

The light emitted from the discharge was detected by an optical system consisting in a converging lens and a quartz optical fiber coupled to a photo-multiplier tube (*pmt*). The *pmt* was able to detect light in the wavelength range 185–650 nm, with a response time of about 5 ns. The focal distance of the converging lens was 5 cm and the optical fiber radius was 1 mm. The lens was covered with opaque masks with rectangular slits of different widths. Hence, it was possible to select several plasma emitting regions differing in their length.

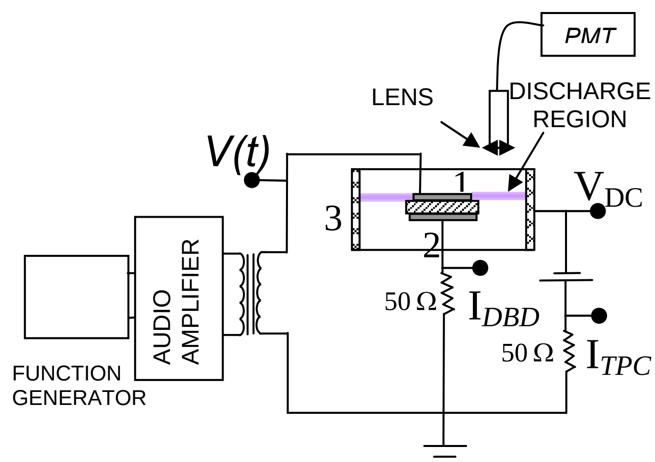
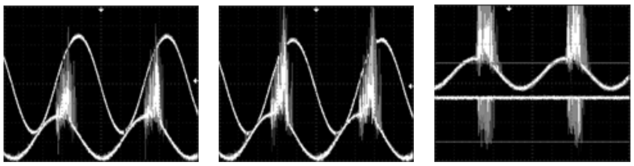


Fig. 2. Electrical block diagram of the experimental set-up.

III. RESULTS

In Figs. 3 typical waveforms of *V(t)*, I_{TPC} , and the photo-multiplier signal (V_{pmt}) are presented for V_{AC} = 21 kV and V_{DC} = 11 kV. Fig. 3a) shows *V(t)* and I_{TPC} for a single plasma curtain, whereas Fig. 3b) shows *V(t)* and I_{TPC} for the stacked configuration and Fig.3c) shows V_{pmt} and I_{TPC} for the single configuration. The photo-multiplier was pointing to a region located between electrodes 1 and 3 (around the middle of the air-gap, so the DBD discharge was outside its field of view). The electrical signals are completely similar to those registered in previous works with the TPC discharge in plane geometry [10],[11]. Following these quoted works, it was concluded that this discharge is again composed of a train of streamers.



a) b) c)

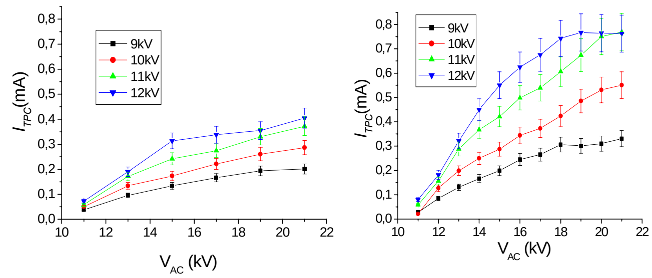
Fig. 3. Typical waveforms: a) *V(t)* and I_{TPC} single curtain, b) *V(t)* and I_{TPC} double curtain and c) I_{TPC} and V_{pmt} single curtain for V_{AC} = 21 kV and V_{DC} = 11 kV.

Fig. 4 shows a photograph of the discharge under the same operating voltage values presented in Fig.3 and for the stacked configuration. It can be seen from this picture that the discharge takes the form of annular plasma curtains and has also a filamentary nature.

Fig. 4. Photograph of the discharge.

Assuming that the electron density profile that originates the *pmt* signal is steep and corresponds to a streamer head [12], the transit time of a filament will be simply equal to the temporal width of the light signal. Several transit times were measured for slits of different widths. From these measurements it was derived an average velocity of (1.2 ± 0.2) 10^5 m/s.

In Figs. 5 the TPCC discharge current-voltage characteristic in terms of the V_{AC} values (with V_{DC} as a parameter) is presented, for both the cases of a single TPCC (Fig.5a) and a double TPCC (Fig 5b) discharge. Following previous works [10]-[12], the TPCC current is presented as an average value (I_{TPC} ^{m}), obtained by setting the oscilloscope in the average acquisition mode, and acquiring an average waveform of the current signal over 128 samples. To ignore the reactive component of the current (that is present even without the discharge), this statistical-averaged signal was time-averaged over one period of the *a-c* voltage to finally obtain I_{TPC} ^{m}. The relative uncertainty in the average current values was estimated to be ~ 10%. The coaxial TPCC discharge remains quite stable for the range of V_{AC} and V_{DC} values shown in Fig. 5. Voltage values below those presented in the quoted figure correspond to non-uniform discharges, while larger voltage values lead to sparking. It can also be seen from Figs. 5 that the double TPCC discharge produces almost double average current than that corresponding to the single one (for the same voltage values), a result indicating that in the stacked arrangement both TPCC discharges develop independently. Typical average currents for a well-developed single discharge amount to 0.3 – 0.4 mA. It is worth noting that the appearance of stable TPCC discharges requires some accuracy in preserving the axial symmetry of the arrangement (the circular symmetry must be preserved with a tolerance shorter than 1 mm).



a) b)

Fig. 5. TPCC discharge current-voltage characteristic in terms of the V_{AC} values (with V_{DC} as a parameter), a) single TPCC and b) double TPCC discharge.

From the *pmt* waveform, by measuring directly the trigger frequency of the oscilloscope, the pulse frequency f_{pmt}, was obtained. Since it fluctuated somewhat in time (the spikes were not purely periodic), several oscilloscope frequency values (around 20 values) during a large time interval (~ 100 s) were registered, and finally the statistical average value was calculated. The associated statistical uncertainties in f_{pmt} were not larger than 20%. It is important to mention that the f_{pmt} value depended on the selected amplitude of the pulses, which in turn were controlled by the trigger level of the oscilloscope. We thus decided to select a medium-amplitude trigger level, so as to register most of the pulses produced, but rejecting low amplitude pulses that could be confused with the electrical noise of the discharge. Comparing Figs. 5 and 6, it can be seen that f_{pmt} is well correlated with I_{TPC} ^{m}, which indicates that a discharge current increase is related to an increase in the streamer frequency rather than a change in the characteristics of each individual streamer.

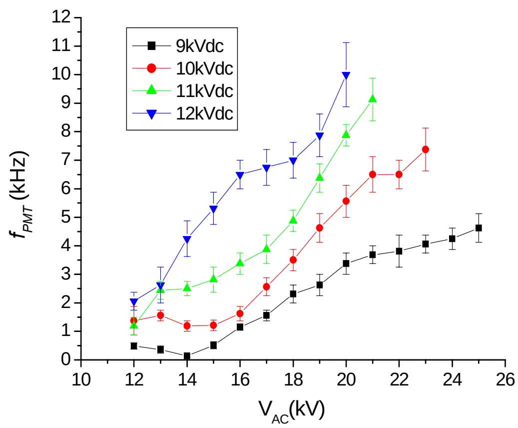


Fig.6. The pulse frequency as a function of V_{AC} (with V_{DC} as a parameter).

IV. Final Remarks

It has been developed an atmospheric non-equilibrium discharge in a coaxial geometry that remains stable during relatively large periods of time (several tenths of minutes). An attractive point of this discharge is the use of simple, non-expensive power sources. This discharge requires good accuracy in the axial symmetry of the arrangement, and takes the form of an annular plasma curtain. The discharge is composed of a train of streamers with a repetition frequency around 100 kHz and carrying an average current of 0.3 – 0.4 mA. The discharge can be parallel operated (stacked configuration) without difficulty provided that the power source can support the total current required. The electrode geometry and the discharge characteristics should be useful for studies about treatment of polluted air streams.

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