

# POSITIVE AND NEGATIVE PULSED CORONA IN ARGON

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**Abstract:** Photographs are obtained of corona discharges in argon at atmospheric pressure using a high resolution, intensified CCD camera. Positive and negative polarity is applied at the curved electrode in a point-plane gap and a plane-plane gap with a protruding point. Branching is observed in the positive point-plane gap but it is much less pronounced than in air probably due to the much lower energy input. The positive point-protrusion case does not show branching and it very rapidly develops into a spark breakdown. The negative corona in argon requires roughly a two times higher average applied field to develop a discharge. Its appearance is diffuse in the point-plane as well as in the plane-protrusion case. Since the inception voltage and the breakdown voltage in argon are quite close to each other it is not possible using the present set-up to obtain experimental results at the very high field condition where a new theory predicts streamer formation and branching in negative corona.

## 1. INTRODUCTION

Corona discharges have fascinated people for a long time. Physical research on these phenomena already started early in the twentieth century [1, 2]. In the last two decades of this century possible applications of (pulsed) corona discharge have been subject of intense research [3]. Pulsed corona here implies that the power source which creates the discharge is switched on and off on a (sub-)microsecond time scale to obtain high electric fields without sparking. Recently power supplies have become available that will enable large scale application while having a high efficiency, good reliability and acceptable investment cost [4]. A great effort is put into advanced diagnostics and detailed simulations of the streamers which are created by the corona discharge [3]. Simulations have concentrated up to now on the single streamer discharge. In reality often strong branching is observed [1] and this will have a large impact on the distribution of active particles that are created and probably also on the energy efficiency with which they are formed. Recently this branching phenomenon is studied for positive corona in air with the use of a CCD camera with a high resolution in space and time [5, 6]. Modeling of branching has been done occasionally on the basis of stochastic processes [7-9], but the results are very limited upto now. Recently a completely different branching mechanism of streamers is found in a fully deterministic fluid model [10]. This model is derived, for the moment, for the case of negative streamers in a homogeneous electric field where photoionization can be neglected and no negative ions are present. This case is quite different from positive streamers in air. For this reason an investigation of pulsed corona in argon is made with positive polarity to compare them with previous results obtained in air, and with negative polarity to approach the predictions of the deterministic branching model.

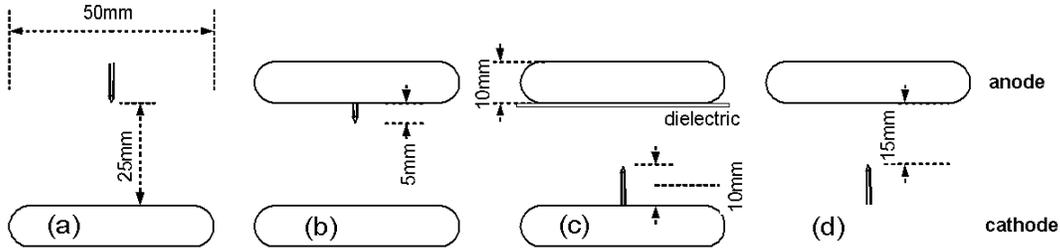
## 2. EXPERIMENTAL SET-UP

The electrodes of the corona discharge are contained in an aluminium cube which is evacuated before filling it with argon of 99.999% purity. A flow of ~30 sccm is maintained, this gives a residence time of roughly 30 minutes. Figure 1 shows schematically the gap configurations that have been used for the

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experiments. Configuration (a) is a point-plane gap having a stainless steel cathode and a tungsten pin of 1 mm diameter which has a tip with a radius of  $\sim 15 \mu\text{m}$ . The same tip is used in all other configurations. In gap (b) two identical stainless steel electrodes are used but the top one contains the needle with a protrusion of 5 mm length. Corona inception is very rare with smaller protrusions. The field distribution becomes much closer to homogeneous by the introduction of the second plate as is shown in [11]. In gaps (c) and (d) a negative corona is created and the gap is made smaller to have better corona inception.



**FIGURE 1.** Gap configuration to create positive (a, b) and negative (c, d) corona discharges.

The pulsed power supply is similar to the one used in [5] and [6]. Its main features are a 1nF coupling capacitor which is discharged by a fast switch giving a pulse rise time of 20 ns. The semiconductor switch (Behlke HTS-301) is used for the case of argon because at the relatively low voltages required here the available spark gap did not function reliable while the semiconductor switch retains its 0.1 ns jitter.

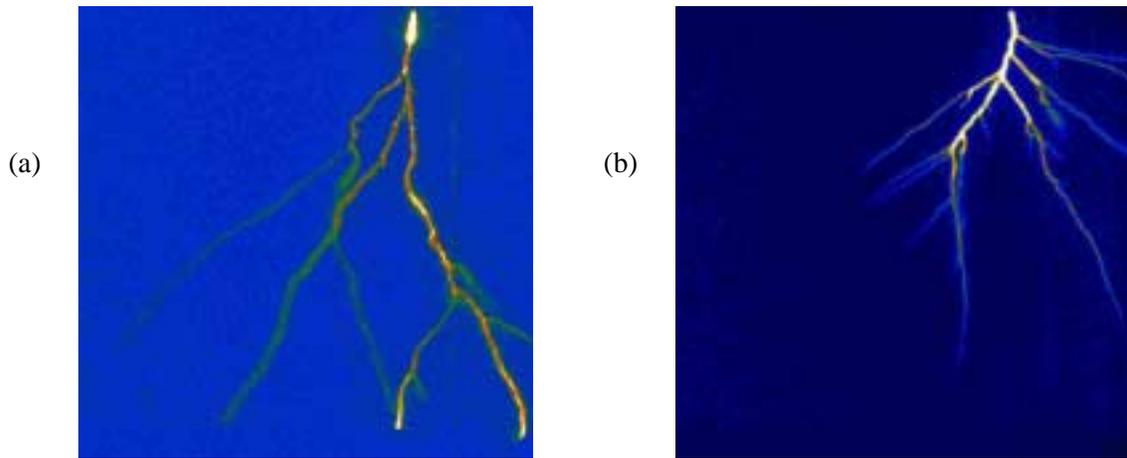
Photographs of the corona discharges are taken using an intensified CCD camera (Andor Technology ICCD-452). This camera has a spatial resolution of  $20 \mu\text{m}$ , a minimum optical gate time of 0.8 ns and photon counting sensitivity. The complete gap is always imaged on the CCD with a 2:1 magnification using a quartz lens. The photos in this paper are taken with optical gates of several microseconds. Examples of the 0.8 ns optical gate can be found in [5] and [6].

The photographs of the CCD camera are digitized with 16 bits resolution so values from 0 to 64535 (a.u.) are possible. In reality the intensity saturates at 45000. Peltier cooling to  $-10^\circ\text{C}$  is always used, this gives a uniform background of  $\sim 880$  with a fluctuation of not more than 10. Background subtraction is not performed because it increases the noise. An intensity difference of  $\sim 10$  can already be differentiated from the background. So the measurement has a very large dynamic range which cannot be represented on a printed version. In all photos the highest intensity of the optical emission is at the sharp tip and the intensity of the discharges in the gap are 10 to 1000 times lower in intensity. Breakdown channels have  $\sim 100$  times higher intensity than this anode spot. Images can be reproduced in grey scale, as printed in this proceedings, or in false color pictures, as given on the Internet version of this proceedings or several other papers [5-6, 10]. The color pictures give more information because it can show more levels of intensity.

### 3. RESULTS

#### 3.1 Positive corona in argon

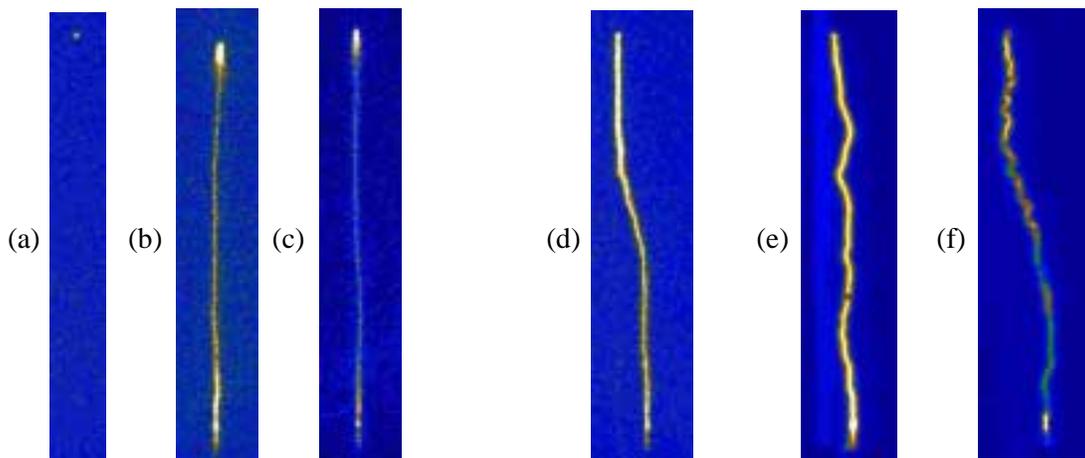
The discharge in argon has been studied first with the point-plane gap as indicated in fig. 1a. The lowest voltage at which optical emission is detected is 3.5 kV. An example is shown in fig. 2a. One interesting feature of this picture is that it shows that the streamers bridge the whole gap. In air the first discharge is detected at 5 kV but only as a very small spot at the anode. The first, short streamers are observed at 6 kV and the lowest voltage at which the streamers reach the cathode is 12.5 kV [6]. Another interesting difference with air is that branching is less pronounced in argon. An increase of emission is seen near the cathode in the case of the two streamers that hit the cathode at the right side of the photo. This looks somewhat similar to the return stroke of lightning. The energy content of this corona pulse could not be determined because the current pulse was too weak to be detected with the equipment used. It can be remarked that the optical diameter of positive streamers in argon is more or less the same as in air [5].



**FIGURE 2.** Positive corona in argon at 1 bar using electrode geometry A, voltage 3.5 kV in (a) and 5 kV in (b).

A picture as fig. 2a is a very rare occasion at the voltage of 3.5 kV. At this voltage level it was necessary, on average, to take 50 to 100 shots to obtain one photo with streamer channels. On some photos the streamers propagate only a fraction of the gap. Again this is different from air where at a certain voltage the length of the streamers is proportional to the voltage in the range of 5 to 12.5 kV. Fig. 2b shows the positive corona in argon using a pulse amplitude of 5 kV. This picture shows more branching than fig. 2a but the streamers do not reach the cathode. The central streamer attached to the anode is more intense than the other branches. Again the energy content of the pulse cannot be detected. At this voltage level one photo is obtained with on average ten high voltage pulses. At 6 kV spark breakdown occurs which is easily seen by eye.

The pictures taken with the plane-protrusion gap of fig. 1b look very different. Now the lowest voltage at which, occasionally, optical emission is observed is 4 kV. This emission is seen either as only a very small spot at the anode, fig. 3a, or as one streamer bridging the whole gap, fig. 3b-c. Intermediate shapes have not been observed. At 4.5 kV a more intense streamer is observed as shown in fig. 3d. At this same voltage also a spark breakdown can occur, examples are given in fig. 3e-f. Branching has never been observed in this geometry using argon gas, this is also very different from corona in air [11].

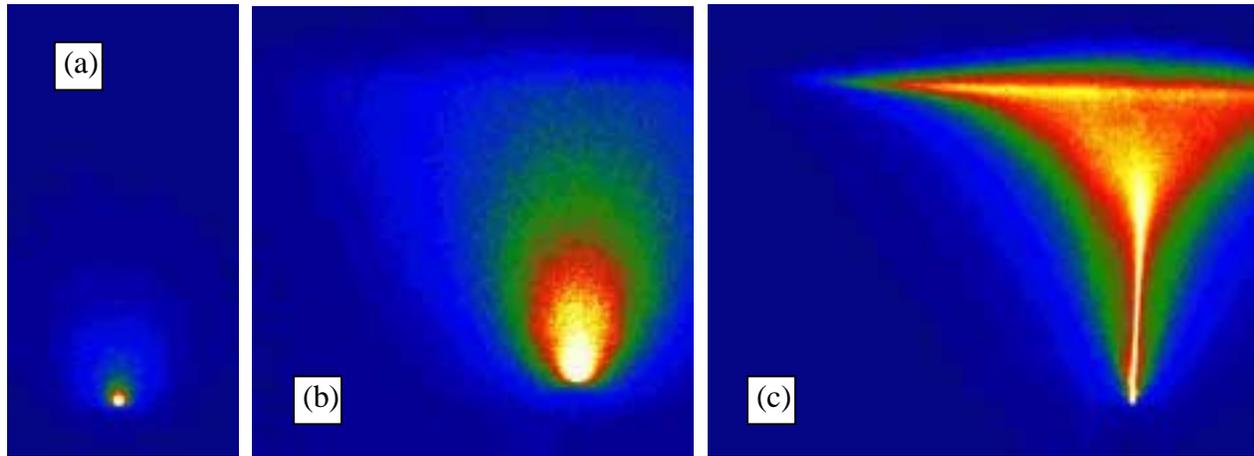


**FIGURE 3.** Positive corona in argon obtained with gap configuration b, a-c are at 4 kV, d-f at 4.5 kV.

### 3.2 Negative corona in argon

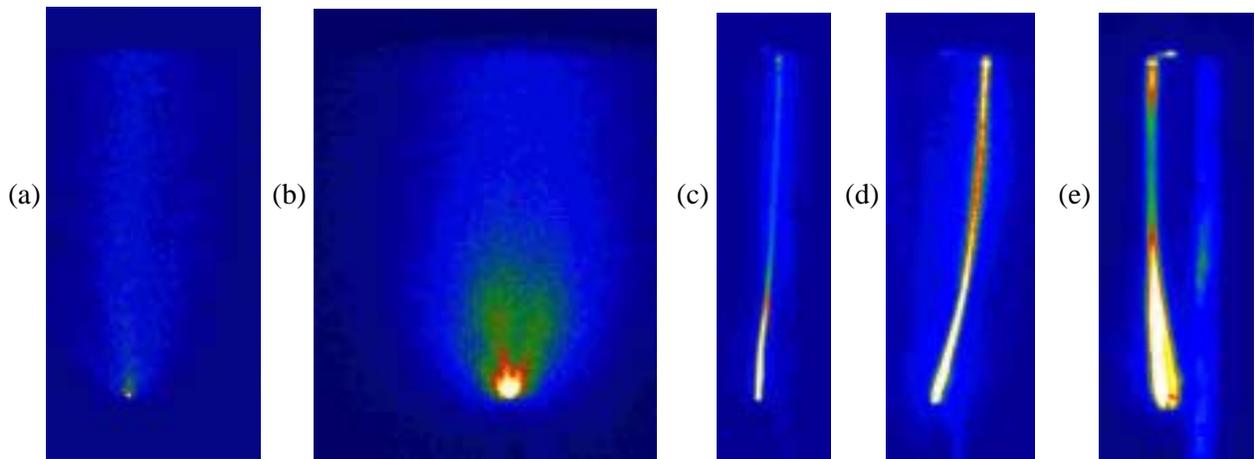
The first tests have been performed with configuration 1c with a small protrusion and an additional dielectric cover of 0.5 mm thickness on the anode since spark breakdown may occur immediately at the inception voltage. Using the larger 10 mm protrusion, optical emission is observed below breakdown voltages. Fig. 4a is obtained at a pulse amplitude of 5 kV, fig. 4b at 7 kV. In both cases the probability of

obtaining a photo is one per five high voltage pulses. The intensity at the tip is again much higher than in the gap. Photos taken with shorter optical gate times, down to 30 ns, also did not reveal any streamerlike structure. Fig. 4c is at 9 kV, but some pictures at this voltage look much more like fig. 4b. It is clear that in this case a surface discharge develops on the dielectric and it appears to be very diffuse. At 10 kV sparking occurs in few thin channels in the gas and also on the surface.



**FIGURE 4.** Negative corona in argon obtained with gap configuration c, a is at 5 kV, b at 7 kV and c at 9 kV.

The negative corona in a 15 mm point-plane gap with a metal anode (gap d) ignites much easier than the one between plane electrodes with a protrusion (gap c) which has a dielectric sheet on the anode. This is most likely due to the much higher field strength at the tip in the case of gap d [11]. Optical emission is observed at almost all electrical pulses of 5 kV and more, see fig. 5a-b in comparison with 4a-b. The appearance of the emission is quite similar, a diffuse cloud fills the gap. As is to be expected breakdown occurs at lower voltages now, sometimes already at 6 kV. At 7 kV almost always a breakdown occurs, a few examples are shown in fig. 5c-e.



**FIGURE 5.** Negative corona in argon obtained with gap configuration d, a is at 5 kV, b at 6 kV and c-e at 7 kV.

#### 4. DISCUSSION AND CONCLUSIONS

In the past it has been remarked that discharges in argon do not show prebreakdown effects [12]. In the course of our measurements it became clear that there are two reasons why it is so difficult to observe these effects. In case of the positive corona in a 25 mm point-plane gap the inception voltage in argon is 3.5 kV and in air it is 5 kV. The lowest voltage at which streamers reach the cathode is 3.5 kV in argon and 12.5 kV in air. At 3.5 kV in argon the discharge starts only sporadically, but at 5 kV in argon it starts

almost always. From these figures it can be concluded that the inception is roughly at the same voltage but the propagation in the gap is very different. This is expected from theory which says that streamers can propagate above a threshold, the “stability field” [3]. This field is 5 kV/cm for air and 0.4 kV/cm in argon [13]. This low stability field explains why corona inception and sparking are very close to each other. The second difficulty for the measurements in argon is that already at 5 kV breakdown occurs occasionally and at 6 kV regularly. So the range of voltages in which streamers can be observed is very limited. The combination of stochastic inception and very easy breakdown is probably the reason why streamers in argon could not be detected in the past. In the plane-plane gap with a protrusion these effects are even more pronounced. Inception is sporadic at 4 kV and breakdown occurs quite often at 4.5 kV. Branching is never observed in this geometry at these voltages.

The branching behaviour of positive corona in argon is also quite different from air: much less branches are observed. Since the field strength and the number of ions of a streamer head are limited, so its energy content must also be limited. Therefore one can expect that the number of branches depends on the energy input. The energy content of the corona pulse in argon could not be established but it is estimated to be 10 to 100 times less than in air. The maximum field strength at the streamer head can be estimated from the bending point of the ionization coefficient versus the electric field strength [14] using experimental data. This leads to 100 kV/cm for argon [15] and 150 kV/cm for air [16]. So because these fields are quite similar, a lower number of streamers in argon can indeed be expected.

The discharge behaviour is quite different when the cathode is strongly curved rather than the anode. Roughly 1.5 times higher voltages are required for inception and breakdown in a gap which is 15 mm instead of 25 mm. This factor is the same for argon and air. The discharge appears as a diffuse cloud which can also spread across a dielectric surface, if present. Time resolved measurements, which were possible down to 30 ns optical gate time, did not reveal any difference in shape and the cloud is present for several hundred nanoseconds. This behaviour is very different from the simulations in [10] where a much higher field is applied. In the present experiment such conditions lead to spark breakdown. The measurements can be improved by using a very short high voltage pulse to prevent breakdown, a pre-ionization trigger to overcome inception problems, and lower operating pressures to slow down the evolution so that it can be observed by the CCD camera. Then the parameter range as used in the simulations of [10] may come within reach.

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