Study of X-ray emission in long sparks combined with ns-fast photography.

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This work is focused on X-ray emission from meter-scale laboratory sparks. There is ongoing discussion in the scientific community about the source and the mechanism behind this high-energetic radiation produced during a spark discharge. In this work we will show that the presence of negative streamers is a necessary condition for X-ray emission to occur. Some basic physical properties of this radiation like energy spectra, timing, attenuation curves have been obtained. According to detailed ns-fast imaging of positive polarity discharge, X-rays were detected in close approximation of the bridging of the positive and negative streamers. This was also confirmed by current measurements on both electrodes.

1. Introduction

X-ray have been observed in long spark discharges in the laboratory [1], rocket-triggered [2] and natural lightning [3]. Large gamma bursts observed from space are strong correlated with lightning [4]. There is an ongoing debate about the mechanism behind this energetic phenomenon.

Currently there are two main theories explaining this phenomenon 1) A process called `positive feedback' [5] for providing the necessary seed electrons if the total field region is large enough (with U > 100 MV). 2) The generation of seed electrons in streamer and leader heads [6-7].

The aim of this poster is to present detailed pictures of positive and negative coronas and link them with current measurements in X-ray generation time.

2. Experiment

2.1. Setup description

All measurements were done at High-Voltage laboratory at Eindhoven University of Technology.
A 2MV Marx generator with a 1.2/52µs pulse shape when unloaded is used to generate more than 3000 surges of positive and negative polarities. The distances between floating high-voltage (HV) and grounded (GND) point electrodes varied from 100 cm to 150 cm in different series. Such distance is small enough to get detailed pictures and large enough to allow the pre-discharge phenomena to appear over appreciable time. Breakdown voltage between electrodes was about 1MV. The currents through the grounded electrode and through the high-voltage electrode are recorded separately and simultaneously with the voltage and the X-ray signal. A high-speed camera 4Picos with exposure time down to 200 ps is located at 4 m distance from the gap and operated in a frame mode.

X-rays are registered by two LaBr3(Ce+) scintillation detectors in different positions with respect to the forming discharge channel. In some series we used two plastic scintillation detectors in addition.

2.2. Results

Up to now we have collected some 5 GB mostly text data of meter-scale discharge parameters. This data includes voltage, currents, x-rays, magnetic field measurements and nanosecond long exposure and intensified photographs of positive and negative coronas.

Typical positive polarity discharge data is shown in Figure 1. Out of this data we have obtained important characteristics of high-energetic radiation like registration rates, spectra, timing, attenuation curves, generation area. We found consistent coincidence of X-rays with the cathode current. No X-rays were observed before the cathode current start. Most of X-rays appeared simultaneously with first cathode current. All subsequent X-rays were registered in coincidence with cathode current HF oscillations (magenta line in Figure 1).

Lead attenuation curves of initial radiation allow us make an assumption that common single-photon energy lie around 200 keV. The fact we saw events with energies up to several MeV in one discharge can be interpreted by signal pile up.

Series of experiments with 2 cm thick lead collimators around X-ray detectors have shown that X-ray initiation area is located close to cathode.

Picture of ionization processes in the gap at the moment of X-ray generation (blue vertical bar in Figure 1) is shown in Figure 2. X-ray generation time coincides with connection between positive corona from HV-electrode and negative streamers, emitted by GND-electrode. Connection usually occurs at 10-20 cm distance from GND-electrode, which is perfectly confirmed by experiments with lead collimators.

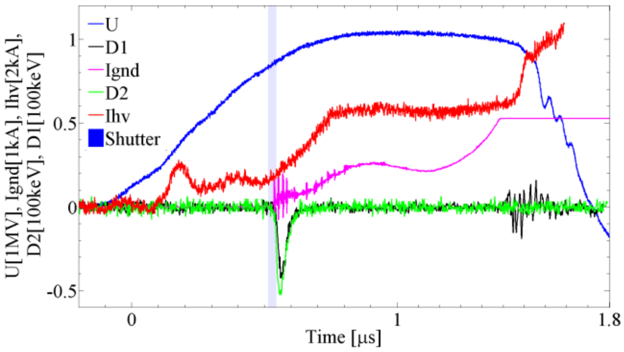

Figure 1. Voltage on the gap U, currents through grounded and high-voltage electrode Ignd and Ihv, signals from two $LaBr_3$(Ce) detectors and camera shutter opening time (50 ns) have shown. All probes were calibrated before measuring.

Out of the pictures we can identify the following phenomena: positive and negative streamers, leaders, coronas, space stems [8] and some other poorly investigated objects. Some numerical properties of streamers like amount, velocity, density, width are estimated from photographs and will be presented at the workshop.

The photographs with various exposure times (from 200 ps up to 1 μs) of corona development processes are obtained. Some pseudo-movies (time-resolved and time-integrated) of predischarge development processes of both polarities are compiled and will be shown.

3. Conclusions

The current measurements on both electrodes combined with the ns-fast photography indicate that negative streamers are necessary for the emission of X-rays during the spark formation.

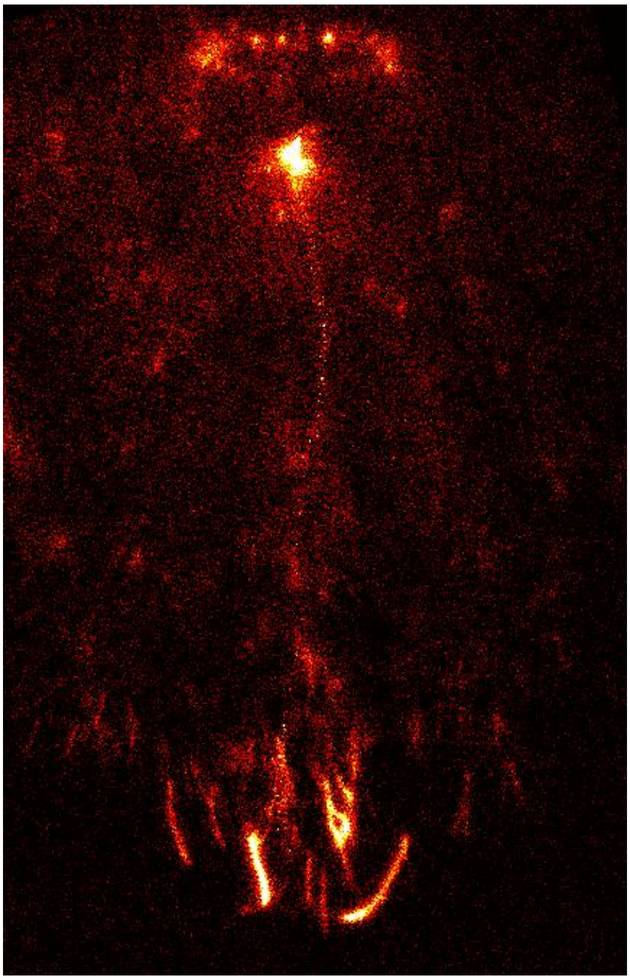

Figure 2. Ionization processes in the gap in X-ray generation time. Exposure time is 30 ns.

4. References

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