Slow decay of radiation after a pulsed streamer discharge in pure nitrogen

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Abstract

Light emission and electrical characteristics in the early post-discharge of a high purity nitrogen streamer have been investigated. Up to the *milli*second regime, both light emission and current are significant, while the voltage has decayed after several tens of *micro*seconds. The corresponding decay time constants are 240 μs and 580 μs for the current and radiance, respectively, versus 3.8 μs for the voltage decay. This suggests that energy transfer to high vibrational levels of $N_2(X^1\Sigma, \nu)$ and high population of metastable $N_2(A^3\Sigma_u^+)$ species are important in sustaining the discharge.

Though nitrogen afterglow has been much investigated for microwave plasmas [1, 2, 3], not much is known about the post-discharge dynamics of streamer discharges [4]. Up to five milliseconds after the discharge event, radiance and current of streamer were found in discharges in nitrogen. Here we present measurements of positive (or cathode directed) streamer discharges in pure nitrogen (less than 1 ppm impurities) at 100 mbar in a 16 cm point-plane gap. The discharges are driven by a 130 ns long positive voltage pulse produced by a Blumlein pulser. Images are taken with an ICCD camera. More details about the set-up, pulser and camera are given in [5, 6].

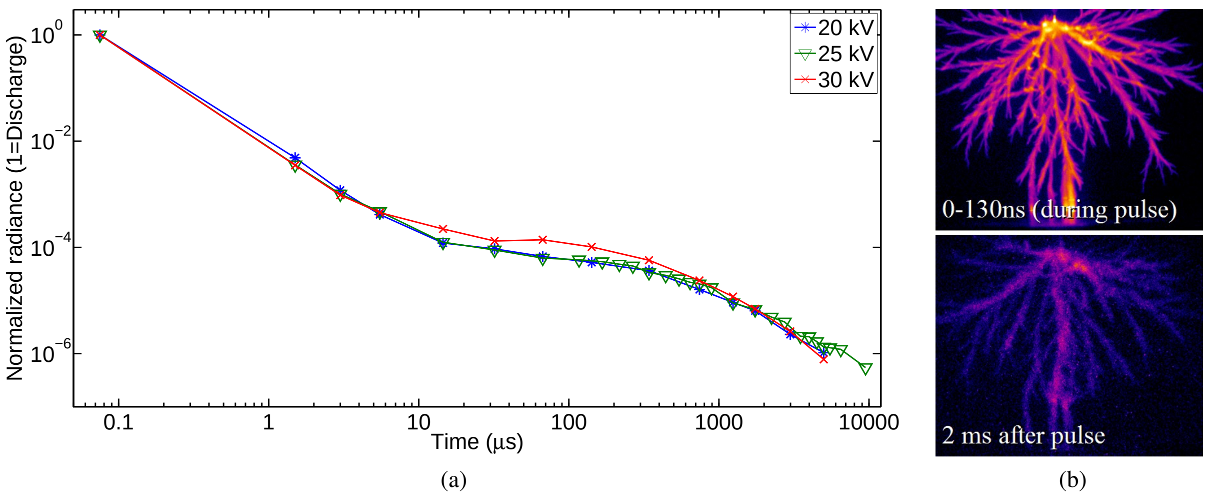

Figure 1: (a) Post-discharge radiance of a streamer discharge in nitrogen 6.0 for different voltage pulses at 1 Hz repetition rate. Data points are connected to visualize the trend. The radiance value is normalized to the average radiance during the discharge formation. (b) Discharge images measured during and 2 ms after the voltage pulse.

The post-discharge radiance is investigated by taking images for different delay times with respect to the voltage pulse. The delay time is varied from about 1 μs up to $5-10$ ms. For voltage pulses of 20, 25, and 30 kV, the *relative* radiance dynamics are shown on a log-log scale in figure 1a. The radiance of the discharge is determined using the pixel counts of the central region of the discharge images. The range of six orders of magnitude in radiance measurements is measured by varying the gate time and intensifier gain of the ICCD camera. Figure 1b shows examples of these images during the voltage pulse (top) and after 2 ms (bottom). It is important to realize that these are images of *different* discharge pulses. The morphology, but not the precise shape of the discharges are the same because the discharge parameters are the same. What is also clear, is that diffusion of ionization is not significant at this time

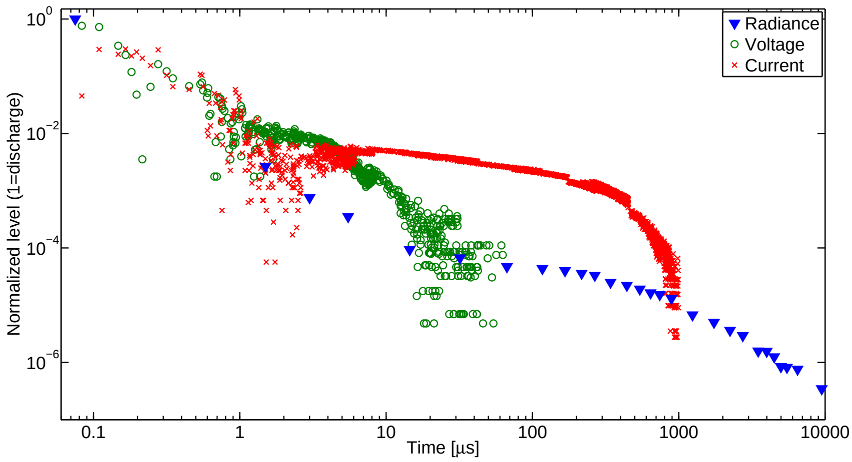

Figure 2: Relative decay of radiance, (absolute) voltage and (absolute) current of discharges in 100 mbar nitrogen 6.0 using 25 kV pulses at 1 Hz repetition rate. All are normalized to their value during the discharge formation.

scale, as the channels have not broadened much. The three voltages have been chosen to cover both bridging and non-bridging discharges. At 20 kV, the discharge does not bridge the 16 cm gap, whereas at 30 kV it bridges after about $100-110$ ns. At 25 kV, the discharge just bridges around the end of the voltage pulse ($t \approx 130$ ns).

The relative decay of radiance in the afterglow shows similar trends for the three applied voltages. A clear stagnation is visible after about 5 μs. The square-root behavior of the radiance represents exponential decay (as the plot is on log-log scale). For the 25 kV pulse, the decay time is estimated as $\tau \approx 580\,\mu$s for the time span after 5 μs, while for the early post-discharge (up to $t = 5\,\mu$s) the decay time is estimated as $\tau_{\leq 5\mu s} \approx 1\,\mu$s.

Figure 2 shows the development of radiance and absolute values of the tip voltage and current through the cathode plate of discharges at 25 kV. The graph shows that the voltage decays to the level of volts within 20 microseconds. The current, however, is sustained significantly longer by the discharge. Two decay times are present: up to $t = 2\,\mu$s, the decay time is approximately $\tau_1 \approx 0.3\,\mu$s, whereas for $t = 2\,\mu s - 1$ ms, there is a much longer decay time of $\tau_2 \approx 240\,\mu$s.

It can be concluded that both the current and the radiance are sustained much longer than the applied voltage. This can be explained by energy pooling processes of vibrational levels of $N_2(X^1\Sigma, \nu)$ and Penning ionization of $N_2(A^3\Sigma_u^+)$ metastables; it supports the theoretical expectations by Simek *et al.* [4] and Guerra *et al.* [3]. Such charge transfer and ionization processes sustain the presence of charge carriers and can therefore explain the sustained current. Our short voltage pulse with a relatively short rise *and* fall time is particularly convenient in the observation of this decay time difference.

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