Pulsed Electron Heating in Atmospheric Pressure Glow Discharges

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Atmospheric pressure plasmas have gained much interest because of their possible uses as plasma reactors, as light sources, for thin film deposition or surface modification, and as plasma ramparts. For plasma ramparts the electron density needs to be on the order of 10^{13} cm^{-3} at a gas temperature below 2000 K. At equilibrium conditions, where the electron energy distribution (EEDF) is fully determined by the reduced electric field, E/N, the power required to sustain such plasmas is on the order of 5 kW/cm^3 [1]. However, by shifting the EEDF temporarily (on a time scale of less than the time constant for glow-to-arc transition) towards higher energies, and consequently increase the rate coefficient for ionization it is possible to reduce the average sustaining power considerably. This power savings effect has been demonstrated with a single 10 ns pulse applied to a dc glow in atmospheric pressure air [2]. The experimental setup and the pulse form of the 10 ns pulse are shown in Fig. 1. Electrical and optical diagnostics, including high-speed photography was used to study the temporal development of the plasma. An increase in the plasma decay time, which is inversely related to the sustaining power, from several tens of nanoseconds to several microseconds was measured when the pulsed electric field was raised from 10 kV/cm to 40 kV/cm (Fig. 2). Calculations with ELENDIF, a zero-dimensional Boltzmann solver show that use of ns-high voltage pulses can reduce the power budget in atmospheric pressure air discharges by more than two orders in magnitude. Results of this calculation for the temporal range below 20 ns are shown in Fig. 3. Besides allowing power reduction, pulsed electron heating has also the potential to enhance plasma processes, which require elevated electron energies, such as excimer generation for ultra violet lamps. Experiments with double pulse generators, as a first step towards quasi-dc operation of these nonequilibrium plasmas are under way. A pulse generator, with two 10 Ω pulse forming networks, and pulse durations of 10 ns has been constructed and tested up to voltages of 13 kV. The interval between the pulses can be varied continuously between 1 μs and 1 ms. Results of first experiments on the ignition and sustainment phase of pulsed high pressure glow discharges will be reported.

[1] Robert H. Stark and Karl H. Schoenbach, Appl. Phys. Lett. 74, 3770 (1999).
[2] Robert H. Stark and Karl H. Schoenbach "Electron Heating in Pulsed Atmospheric Pressure Glow Discharges", to appear in J. Appl. Phys.

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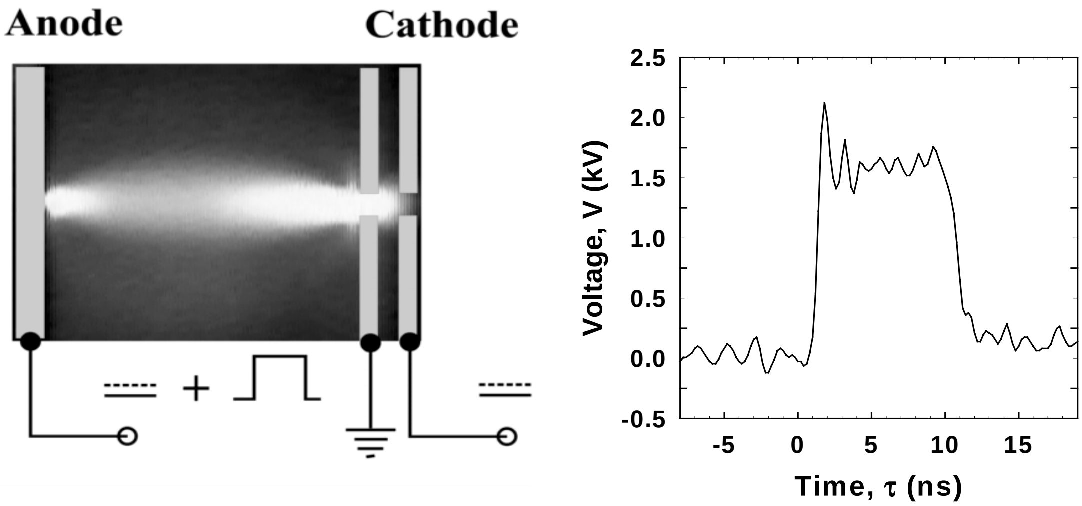

Fig. 1 Experimental setup and temporal development of the 10 ns high voltage pulse (V_{pulse} = 1.6 kV). The microhollow cathode discharge and the MHCD sustained glow are operated in a direct current mode (I = 10 mA). A 10 ns high voltage pulse of variable amplitude is applied at the anode, superimposed to the dc voltage.

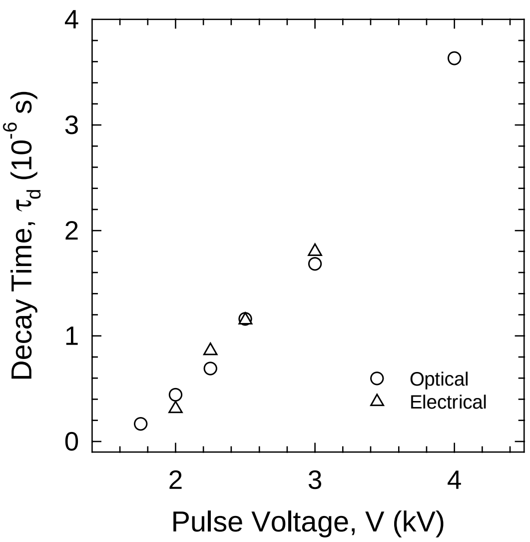

Fig. 2 Decay time versus pulsed electric field, obtained from electrical and optical measurements.

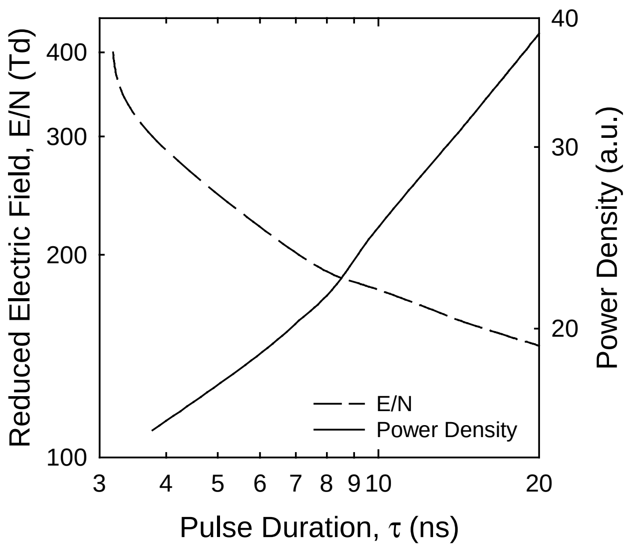

Fig. 3 Pulse duration and electric field amplitude, required to increase the electron density from the dc-value ($n_0 = 10^{13}$ cm^{-3}) to a peak value ($n_p = 5 \cdot 10^{13}$ cm^{-3}), and corresponding electrical power density, $(E/N)^2 \cdot \tau/\tau_d$, where τ is the pulse duration and τ_d is the decay time.