Influence of voltage waveform and repetition frequency on atmospheric-pressure barrier discharges in argon

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Gas discharges operated at atmospheric pressure are an established method for generating non-thermal plasmas and are used in a wide range of applications. These include, for example, air and water purification, food processing and wound treatment [1]. Barrier discharges in particular are widely utilised atmospheric pressure plasma sources due to their robustness and scalability, and ongoing research aims to control the discharge properties in order to enhance the effectiveness and efficiency of applications [2]. A very important physical quantity is the electric field, which is influenced by the geometry, external power supply and space charge in the plasma. For this reason, research activities are currently focused on determining the electric field in atmospheric pressure discharges by means of experiments, simulations and a coupling of both [3]. For a correct interpretation of experimentally determined electric field strengths and – depending on the method used – for its determination, it is important to know to what extent space charge and shielding effects caused by charge carriers in the plasma influence the electric field for different operation conditions.

In order to provide a basis for this and to support data analysis and method development, this paper presents the results of a systematic study of the influence of waveform and repetition frequency of the applied voltage in a single filament barrier discharge in argon at atmospheric pressure. A time-dependent and spatially one-dimensional fluid Poisson model was used to simulate the spatiotemporal evolution of the discharge for sinusoidal voltages, bipolar rectangular pulses and positive nanosecond pulses in the frequency range from 5 kHz to 1 MHz (see Figure 1). It was investigated how the spatiotemporal distribution of the electric field and essential plasma parameters change under the influence of the applied voltage in the given parameter range. In addition, the gain and loss processes of excited argon atoms in the 2p states (in Paschen notation), which can be used and are recently investigated to determine the electric field using the so-called intensity ratio method [4], were analysed.

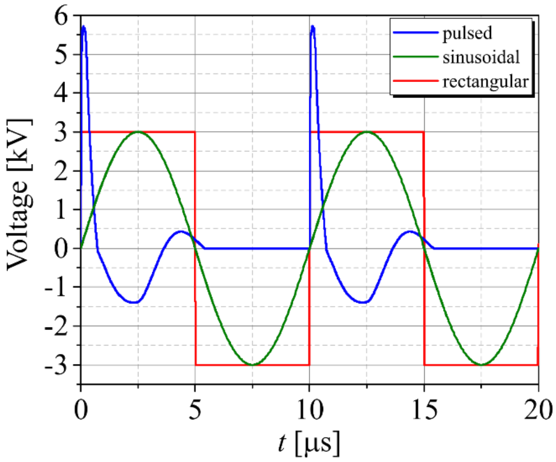

Fig. 1: Voltage waveforms used in the modelling for the example of $f = 100$ kHz.

The results show that for voltage repetition frequencies above 5 kHz, preionisation effects influence the discharge dynamics and lead to a weakening of the electric field during the streamer-driven discharge breakdown. In the case of a sinusoidal power supply, a mode transition to a discharge with low field strength and electron density in the discharge volume occurs at frequencies above 100 kHz (see Figure 2), with a periodic discharge only observed in the cathode layer (transition from typical barrier discharge mode with transient glow discharge to a mode with continuous plasma bulk). In general, it can be observed that the population processes of the 2p argon levels become more complex with increasing repetition frequency, i.e. stepwise processes, superelastic collisions and quenching of higher levels increasingly contribute to their population. The results thus represent an essential basis for the further development of the intensity ratio method for determination of the electric field in transient atmospheric pressure discharges.

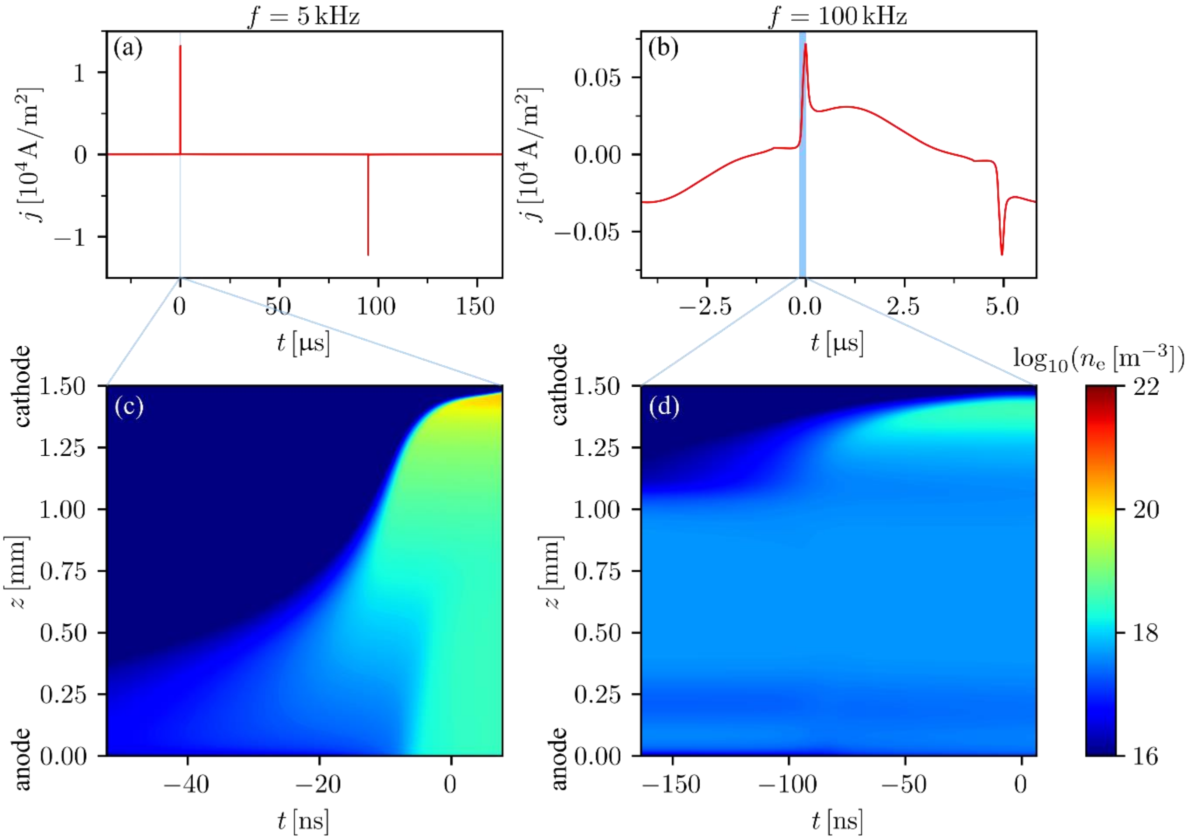

Fig. 2: Temporal evolution of the discharge current density during one period (a, b), and spatiotemporal evolution of the electron number density during the breakdown (c, d) for sinusoidal voltages with $f = 5$ kHz (a, c) and $f = 100$ kHz (b, d). The blue-coloured areas in (a) and (b) represent the time ranges shown in panels (c) and (d). The time $t = 0$ is set to the respective moment of maximum current.

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