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To cite this version:

Tat Loon Chng, Inna Orel, Chenyang Ding, Nikita Lepikhin, Yifei Zhu, et al.. Diagnostics of nanosecond discharges at high electric field and high specific delivered energy. 18th International Workshop on Magneto-Plasma Aerodynamics, Apr 2019, Moscow, Russia. hal-02407643

HAL Id: hal-02407643

https://hal.science/hal-02407643v1

Submitted on 5 Feb 2024

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Diagnostics of nanosecond discharges at high electric field and high specific delivered energy

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Recent progress in solid-state high power electronics is a reason for increased, during last decades, interest to nanosecond discharges: compact and reliable high voltage generators allows operation both in laboratories and in industrial applications. High electric fields, up to kTd, are typical for discharge front, a few nanoseconds in duration. Behind the front the electric field stays high, hundreds of Td, providing high densities of electronically excited states, high dissociation degree and so high efficiency of nanosecond discharge as a trigger for various chemically active systems. Review of experimental techniques used in our group to get better knowledge of kinetics in nanosecond discharges, will be presented.

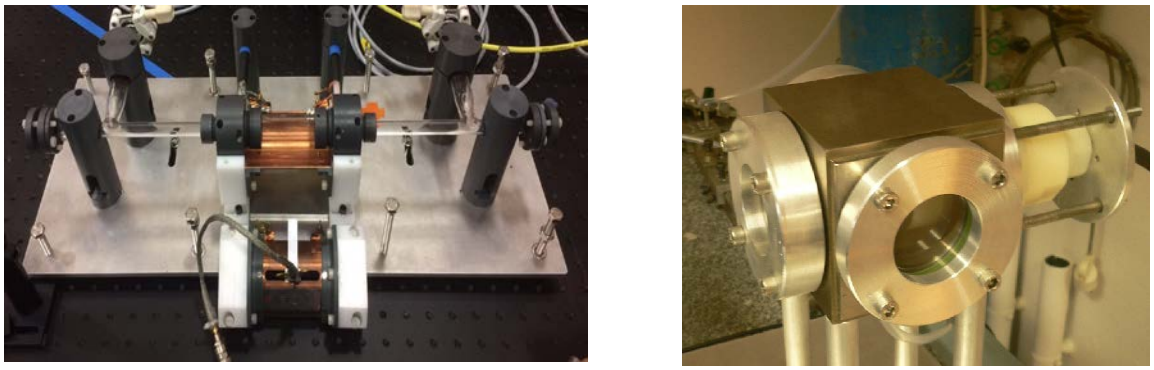

Figure 1. *Photos of typical discharge cells: left – discharge tube for laser diagnostics in 20-100 mbar FIWs; right – high pressure (P<15 bar) constant volume discharge cell.*

High-voltage pulses 5-30 kV in amplitude and a few tens of nanoseconds in duration are capable to produce low temperature plasma in a wide pressure range, from 0.1 mbar to 15 bar. Three discharges will be discussed: a “classical” fast ionization wave (FIW) discharge at moderate pressures (units-tens of mbar), capillary nanosecond discharge at the same pressures and nanosecond surface dielectric barrier discharge (nSDBD) at 1-15 bar. A spatial uniformity of plasma was controlled by ICCD imaging of short-lived electronically excited states. The waveforms of total current through the discharge cell and of total delivered energy were obtained with the help of custom-made calibrated back current shunts taking into account, for the case of nSDBD, a current for charging the constructive capacitance of the electrode

system. The longitudinal electric field in the FIW and in the capillary discharge, after closing the discharge gap, was measured by custom-made calibratied capacitive probe. Recently developed picosecond laser E-FISH technique [1] was applied to measure the E-field in the peak of the FIW. O/Xe and N/Kr TALIF were used to get the knowledge about absolute densities of O- and N-atoms in the FIW and in the nanosecond capillary discharge in early (nanoseconds) and late (up to miliseconds) afterglow of the discharges.

Selected discharges provide a wide range of specific delivered energies: from 0.001 eV/molecule for FIW to 5-7 eV/molecule for filamentary form of the nSDBD [2]. High electric fields, a few hundreds of Td, provide active excitation of high-energy electronic levels, efficient collisional kinetics and energy transfer from electronically excited levels or even transition to local thermal equilibrium during a few nanoseconds, depending upon gas pressure and specific delivered energy. A few typical results are presented in Figure 2. Reduced electric field in the fast ionization wave in nitrogen was measured for the pressure range 20-100 mbar (Figure 2a); absolute values higher than 2000 Td were obtained for the discharge front at 20 mbar nitrogen. Energy per filament per mm was measured experimentally (Figure 2b) on the basis of total energy measurements and spatial distribution of recombination radiation in near UV and visible range.

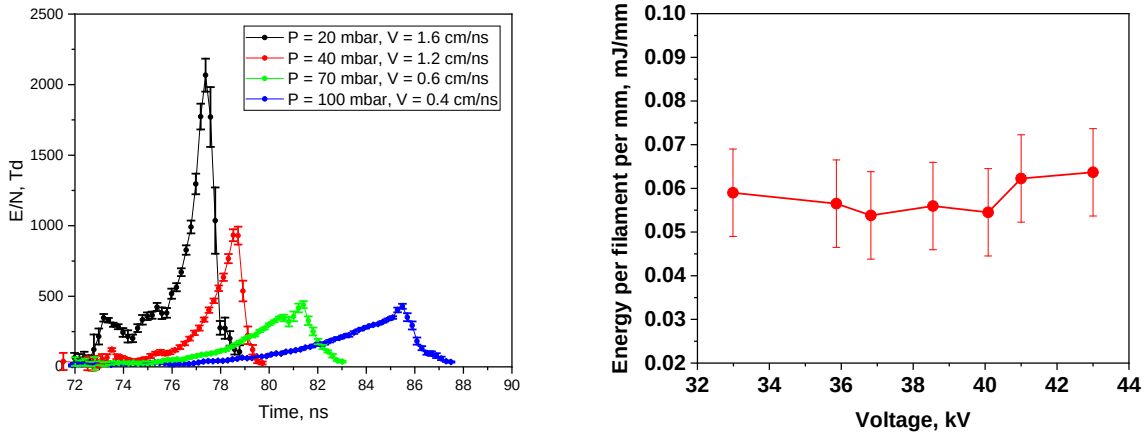

Figure 2. *Left – reduced electric field in the front of the FIW in nitrogen (U=+18 kV on the high-voltage electride) at 20-100 mbar measured by E-FISH technique [2]; right – experimentally measured energy per mm of filament as a function of the voltage amplitude in nSDBD in 7 bar* N_2*, U<0 [3].*

The work was partially supported by LabEx Plas@Par, French National Research Agency (ASPEN Project, ANR-16-CE30-0004-01) and the French-Russian international laboratory LIA KaPPA "Kinetics and physics of pulsed plasmas and their afterglow" (RFBR project 17-52-16001 and CNRS financial and organization support). The support of Prof. Adamovich by the Ecole Polytechnique Gaspard Monge Visiting Professor Program and the support of Chenyang Ding by China Scholarship Council (CSC) are gratefully acknowledged.

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