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Pulsed nanosecond discharges and their applications

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Review of nanosecond discharges in the pressure range 10 mbar – 15 bar will be presented. The discharges will be classified by specific delivered energy, increasing from 0.001 eV per molecule in the moderate pressure fast ionization waves (FIWs) to 5-7 eV per molecule in high pressure filamentary nanosecond surface dielectric barrier discharges (nSDBD). Peculiarities of experimental study and peculiarities of kinetics will be underlined for each case. Potential applications of nanosecond discharges will be discussed.

1. Introduction

Recent progress in solid-state high power electronics was a reason for increased, during last decades, interest to nanosecond discharges: modern companies suggest compact and reliable high voltage nanosecond generators allowing operation both in laboratories and in the extreme conditions of industrial applications. High-voltage pulses 5-10 kV in amplitude and a few tens of nanoseconds in duration are capable to produce low temperature

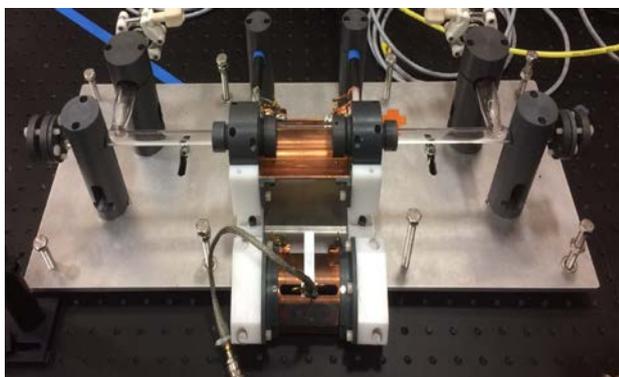


Fig. 1. Discharge tube for laser diagnostics in 20-100 mbar fast ionization waves

plasma in a wide pressure range, from 0.1 Torr to 15 bar. 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.

2. Experiment and diagnostics

The fact that nanosecond discharges are uniform at low and moderate gas densities, and are naturally synchronized within 0.1 ns in time in the case of a

multi-streamer configuration at high gas densities, is extremely attractive for laboratory-scale research.

Three discharges will be discussed: a “classical” fast ionization wave (FIW) discharge at moderate pressures (units-tens of mbar), a capillary nanosecond discharge at the same pressures and a nanosecond surface dielectric barrier discharge (nSDBD) at elevated pressures, 1-15 bar. 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.

Two examples of the discharge setups are shown in Figures 1-2. Figure 1 presents a discharge tube to study kinetics in the fast ionization wave by advanced laser diagnostics. The side tubes provides connexion to the vacuum system and optical access; the electrodes are the cone-shape electrodes with a 5 mm

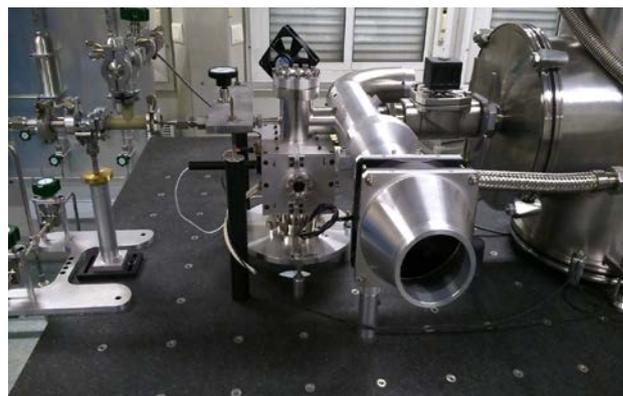


Fig. 2. Discharge cell for high pressure ($P < 15$ bar) high temperature ($T < 700$ K) nanosecond SDBD

diameter opening. The diameter of the tube is 2 cm, the distance between the electrodes is 8 cm. In the case of a capillary discharge, the distance between the electrodes is the same and the diameter of the capillary is 1.5-2 mm. Figure 2 shows a photo of high pressure high temperature (HPHT) discharge cell

with mounted system of SDBD electrodes in cylindrically symmetrical configuration. The electrode system is compatible with the combustion chamber of a rapid compression machine (RCM).

A spatial uniformity of plasma is controlled by ICCD imaging of short-lived electronically excited states. The waveforms of total current through the discharge cell and of total delivered energy are obtained with the help of custom-made calibrated

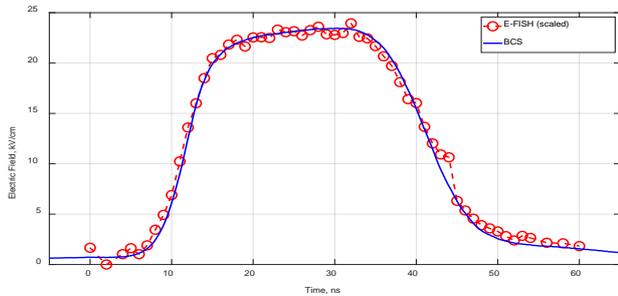


Fig. 3. Time evolution of (square rooted) E-FISH signals (produced by 2.8 ns pulses) appropriately scaled and plotted together with the field evolution measured by the back current shunt (BCS). The time-varying field is imposed by applying 30 ns (FWHM) HV pulses with a rise time of about 8 ns.

back current shunts. The longitudinal electric field in the FIW and in the capillary discharge, after closing the discharge gap, is measured by custom-made calibrated capacitive probe. Recently developed picosecond laser electric field Induced Second

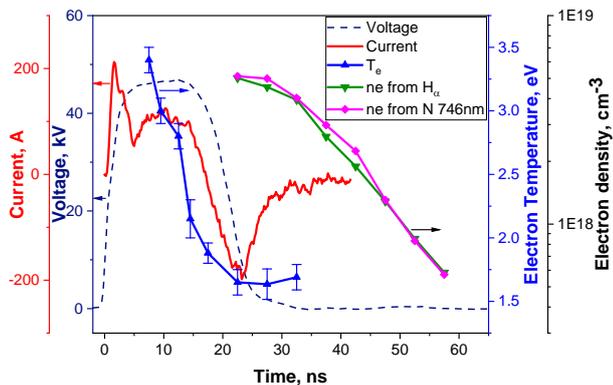


Fig. 4. Synchronized electron density and temperature measurements. Nanosecond SDBD Discharge in 7 bar N_2 at positive polarity of the high-voltage pulse, $U = 47$ kV.

Harmonic (E-FISH) Generation (E-FISH) technique is applied to measure the E-field in the peak of the FIW. Stark broadening of the atomic lines and analysis of distribution of population are used to measure the electron density and the electron temperature respectively. O/Xe and N/Kr TALIF are used to get the knowledge about absolute densities of O- and N-. A new technique suggested by our group and based on the slicing the output laser beam with the external Pockels cell allows adaptation of

existing nanosecond Nd:YAG/dye laser systems to 1-3 ns time resolution. An example of time evolution of E-FISH signals is given by Figure 3.

Figure 4 presents synchronized in time waveform of voltage on the high-voltage electrode, electric current, electron temperature and electron density in the filamentary discharge in nitrogen at $P=8$ bar with trace amount of water giving $H\alpha$ emission line.

Numerical modelling demonstrates that it is possible, within a few nanosecond, to reach local thermal equilibrium (LTE) in the nSDBD at 7 bar. The main responsible processes are stepwise ionization with participation of electronically excited levels of molecular nitrogen with significant energy release to translational degrees of freedom, so-called fast gas heating (FGH), the temperature should reach tens of thousands of K. The LTE explains long, tens of nanoseconds, decay of the electron density: the decay corresponds to gas cooling.

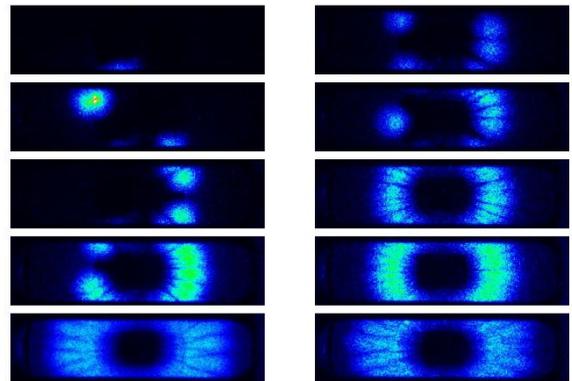


Fig. 5. Combustion waves initiated in 5 bar (left) and 3 bar (right) H_2 :air ($ER=0.6$) near the surface of the dielectric. The high voltage electrode is a disk 20 mm in diameter.

Finally, potential applications of nanosecond discharges will be discussed, underlining possible drawbacks and benefits. Figure 5 presents an example of multiple combustion waves starting from the disk-shape HV electrode. For left and right pictures, the delivered energy increases from top to bottom. The OH emission, presented in the figure, follows the traces of N_2 discharge emission in the discharge. The picture is similar for different fuels (H_2 , CH_4 - nC_7H_{16}) including lean mixtures ($ER=0.3-1$).

2.3. Acknowledgements

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