Analysis of homogenous nanosecond discharge at moderate pressure: dissociation of oxygen for plasma assisted detonation.

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Abstract: The present study is a preliminary step toward producing a non-equilibrium plasma capable of enhancing deflagration and detonation processes. Experiments show that single shot nanosecond discharges can produce an homogeneous plasma in O_2:Ar:Air mixtures. The measurement of the deposited energy was used as an input to ZDplaskin calculation of the O/O_2 dissociation ratio. The result indicates that these ratio are very small compared with those that are achived by shock processes in non-dissociated mixtures.

Keywords: Cold plasma, nanosecond discharge, oxygen dissociation, detonation.

1. Introduction

Combustion of a fuel-oxidizer mixture in a pulsed detonation engine (PDE) is characterized by significantly higher thermodynamic efficiency than the conventional constant pressure combustion. A detonation wave may be formed by a direct initiation or through a deflagration to detonation transition (DDT) process. The typical DDT length amounts to several tens of tube diameters. DDT length and time are crucial parameters for PDE applications. Detonation significantly depends on the parameters of the gas, in particular – on gas composition. Plasma community has been intensively working on the problem of plasma assisted ignition [1,2], that is reduction of delay time of ignition of combustible mixtures with the help of non-equilibrium low-temperature plasma, and plasma assisted combustion [3] where gas mixture is prepared by the action of plasma right before combustion demonstrating significant extension of combustion limits and capacity to burn lean mixture in a stable regime.

2. Experimental set-up and results

The aim of the experiments is to produce a spatially-uniform plasma with large O/O_2 dissociation ratio, and to measure the necessary deposited energy. **Figure 1** shows a schematic of the experimental set-up.

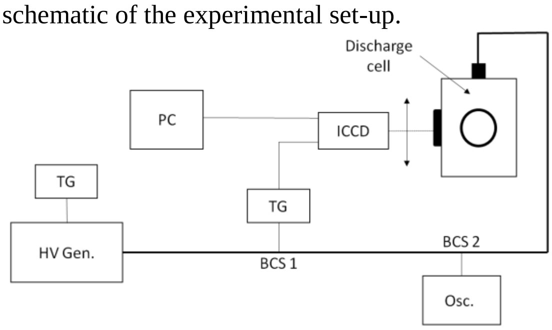

Fig. 1. Experimental setup. HV Gen. = High voltage generator. TG = Trigger generator. BCS = Back current shunt. Osc. = Oscilloscope. ICCD = Camera. PC = Personal Computer.

The discharges were made in the O_2:Ar:Air (50:40:10) mixture with pressure ranging between 50 and 200 mbar. The mixture was contained in a rectangular-parallelepiped cell made of Plexiglas, with inner lenth and squared section 200 mm and 50x50 mm², respectively. The visualizations were made by means of and ICCD camera, through a quartz window positioned at the long wall.

A high-voltage generator provided voltages up to 30 kV with pulses of 20-ns duration and 2-to-3-ns rise times. The high-voltage cable was 30-m long with two back current shunts used to trigger the camera and the oscilloscope.

Breakdown was found to occur for all pressures in the considered range. Homogeneous plasma was obtained for all pressures. **Figure 2** shows a typical discharge recording for 200mbar.

The propagation of the ionization wave was captured by reducing the camera gate to 1ns. The discharge fills the gap within 4ns. The fast ionization wave speed was found 1.2 cm/ns.

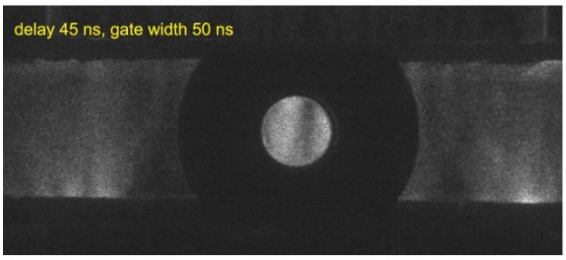

Fig. 2. Image of the discharge in O2:Ar:Air (50:40:10) at 200 mbar. For 50 ns camera gate width and trigger delay of 45 ns.

Electrical diagnostics were made using classic back current shunt techniques. The energy deposited to the plasma was measured for several pressures and two generator tensions 25 kV and 30 kV. **Figure 3** shows that energy deposition increases with increasing pressure and reaches the maximum 180 mJ at 120 mbar for 25 kV, and 300 mJ at 170 mbar for 30 kV.

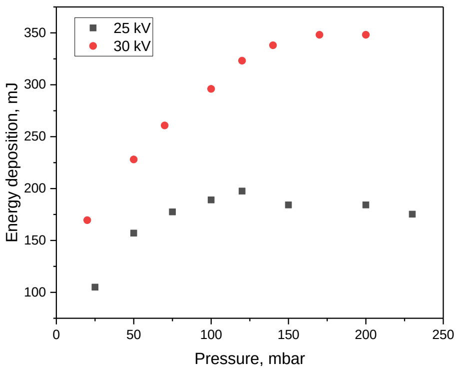

Fig. 3. Energy deposition versus pressure for 25 and 30 kV. Maximum is observed for 120 and 170 mbar

3. Discussion and conclusions

These measured values of the deposited energy were key parameters for oxygen dissociation. Numerical calculations were made using a ZDPlaskin code with experimental electric field as an input and using kinetic schemes for O_2:Ar:Air mixtures [5-7]. **Figure 4** shows the O_2 and O density levels as a function of time for the case 25 kV-120 mbar for: (1) The single nanosecond pulse (20 ns + 180 ns afterglow) obtained with experimental electric field. The O_2/O ratio is 0.1%, the level of dissociation is small compared to what we need for DDT [1,2]. Therefore, the present nanosecond single pulse is likely not supplying enough energy to dissociate more than 0.1% oxygen in our conditions. Using a repetitive nanosecond discharge appears to be necessary and was investigated in numerical calculation. The (2) region was obtained with extrapolation of electric field for repetitive pulses (decreasing by 10% for each pulses)

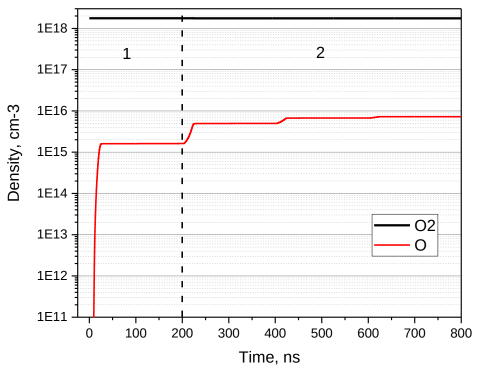

Fig. 4. Numerical modeling of the dissociation ratio of oxygen for 120 mbar and 25 kV for: (1) experimental electric field for the nanosecond pulse; (2) extrapolated electric field for 3 pulses (decrease of 10% for each pulses)

4. Acknoledgments

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The experimental discharge cell was designed and made by Ali Majoub and Bruno Katra.

5. Reference

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