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SELF-PULSING DC DRIVEN DISCHARGES IN PREHEATED AIR AIMED FOR PLASMA ASSISTED COMBUSTION

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***Abstract**. We studied electrical and optical properties of DC driven self-pulsing discharges with kHz repetition frequency and short current pulse duration (~ns) in atmospheric pressure air preheated up to 1000 K. The goal was to find a low cost repetitively pulsed discharge operating at high temperatures usable for stabilization of lean flames. The utilization of obtained discharge regimes for the plasma assisted combustion is the next step in this research.*

Keywords: self-pulsing discharges, preheated air, plasma assisted combustion

Introduction

Nanosecond repetitively pulsed (NRD) discharge operating at frequency above 10 kHz was shown to be able to stabilize lean flames, while consuming only ~70 W [1]. Using lean combustion mixtures leads to decrease of NO generation thanks to lower combustion temperature. The plasma assisted combustion has therefore significant environmental benefits. However, the disadvantage of NRP discharge could be relatively expensive high voltage (HV) high frequency pulse generators. We therefore plan to test for stabilization of lean flames another type of repetitively pulsed discharge named transient spark (TS) [2]. Despite the pulsed character, TS is driven by a simpler and cheaper DC HV power supply, and it already proved to be usable for several environmental and bio-medical applications [3]. However, for purposes of plasma assisted combustion, we first had to test and optimize the behaviour of TS in preheated air, since we studied it only at laboratory temperature till now.

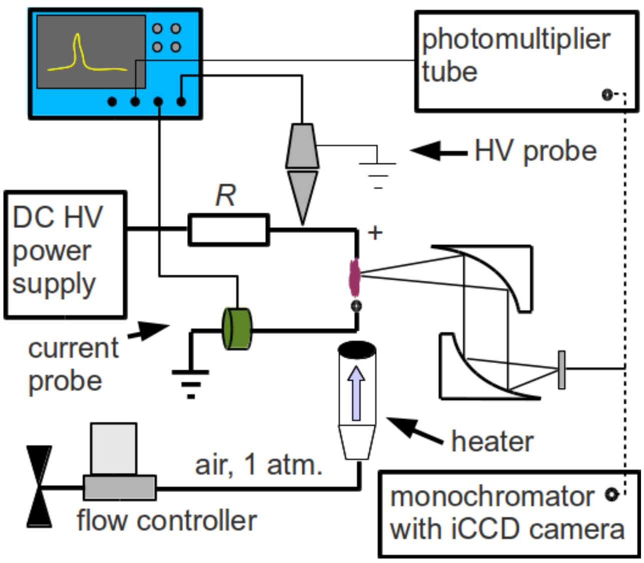

Fig.1. Schematic of the experimental set-up.

Experimental set-up

Experiments were carried out in atmospheric pressure air preheated with controlled ohmic heater to 300–973 K, with an axial flow with velocity 2 m/s. The distance between the stainless steel needle electrodes (point-to-plain configuration with anode at the top) was 5 mm. A positive polarity DC HV power supply HCL 14-20000 connected via a series resistor (R = 10 MΩ) was used to generate a discharge. The discharge voltage was measured by a HV probe LeCroy PMK-14kVAC and the discharge current was measured using a Pearson Electronics 2877 (1V/A) current probe linked to a 350 MHz digitizing oscilloscope LeCroy Waverunner 434 (maximum 2GS/s).

The UV-VIS spectra were obtained using a monochromator (Acton SpectraPro 2500i) fitted with an intensified CCD camera (Princeton Instruments PI-MAX). For time-resolved optical emission measurements, a photomultiplier tube (PMT) module with a 1.4-ns rise time (Hamamatsu H9305-3) was used. Besides the total emission, we monitored emission of N_2 2nd positive system by inserting a bandpass interference filter transparent at 337 nm (3nm width) into the optical path. The experimental set-up is depicted on Fig. 1.

Results and Discussion

Our previous studies of TS at input gas temperature (T_g) 300 K showed that it is initiated by a streamer, which creates a relatively conductive plasma bridge between the electrodes. After this, during the streamer-to-spark transition phase, the temperature inside this channel grows due to the joule heating. A transition to the short (~ns) high current (~A) spark pulse occurs at ~1000 K [4]. During the spark, the discharge voltage U drops almost to zero and the whole energy accumulated in the internal capacity C of used electrical circuit (~10-40 pF) is delivered to the gap. This small value of C is responsible for short duration of TS current pulses and therefore also for characteristics of generated plasma, which remains non-thermal. After the conductivity of plasma generated by TS decreases enough, charging of C and a growth of U start again. As U exceeds certain threshold value, we observe streamer corona discharge. Further increase of U above certain threshold value U_{TS} leads to the generation of 'stronger' streamers, capable to initiate another TS pulse. TS discharge is thus based on charging and discharging of C, with a typical frequency f from given approximately by:

$$f \approx \frac{1}{RC\ln\left(\frac{U_o}{U_o - U_{TS}}\right)} \quad (1)$$

where U_o is the onset voltage delivered by power supply.

The growth of f up to ~10 kHz can thus be controlled by the increase of U_o. At higher f, new discharge regime appears – pulse-less high pressure glow discharge (GD) [4] with a constant current starting from ~2 mA. However, due to large external resistor R and U_o limited to maximum 20 kV, the GD regime was not stable in our experiments. The discharge randomly switched between GD and high frequency TS regimes.

When we increase input gas temperature to 400 K and higher, we observed new phenomenon. Even the first streamers, which appear at $U_{STR} \approx 3$ kV (this is well below U_{TS}) are followed by instantaneous partial drop of the voltage to a certain minimal value U_{min}. However, this voltage is drop is not so drastic as in case of TS. It is rather gradual and it takes several μs to reach U_{min}. After this partial discharging event, C is charged again till U_{STR} is reached. As a result, streamer pulses appear with a relatively regular frequency f_{STR}, which is given by a modified version of Eq. 1, where U_{min} is also considered:

$$f_{STR} \approx \frac{1}{RC \ln\left(\frac{U_o - U_{\min}}{U_o - U_{STR}}\right)} \qquad (2)$$

We thus obtained a new self-pulsing discharge regime preliminarily named 'repetitive streamer' (RS) discharge. This regime actually initially inhibits the appearance of TS, because U_{TS} cannot be reached due to relatively significant voltage drop after the streamers. However, we observed that U_{min} tends to decrease and the voltage drop accelerates with increasing T_g and increasing f_{STR}. And as U_{min} approaches ~200 V, we again observed much narrower and higher current pulses attributable to TS discharge. Although, compared to TS pulses at T_g = 300 K, at higher T_g there is no streamer-to-spark transition time, and fast discharging with spark current pulse starts almost instantaneously after the streamer.

At higher T_g, a stable TS discharge was observed only at 1000 K. At lower temperatures, we mostly observed only unstable TS, i. e. the discharge randomly switched between RS and TS regimes, generating current pulses of two types (see Fig. 2 for illustration of RS and TS current pulses obtained both at 900 K). We even observed a situation when discharged randomly switched between all three possible regimes, including GD. A chart describing achievable discharge regimes depending on T_g and U_o is depicted in Fig. 3.

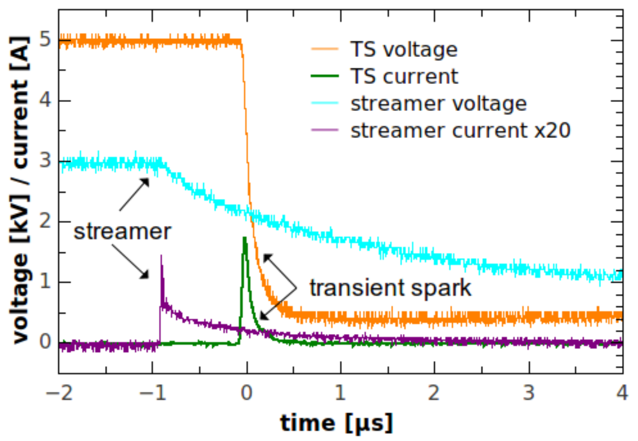

Fig.2. Typical waveforms of streamer regime (current multiplied by 20), compared to current pulse of unstable TS regime, T_g = 900 K.

Optical characteristics of different discharge regimes also changes. In TS, one can see two peaks of the total emission: the first one is produced by the streamer, and the second one by the short spark. The emission during the 'streamer' peak can be mostly attributed to the N_2(C) species, whereas the 'spark' peak is mostly due to the excited atomic species. Compared to TS, the emission from N_2(C) does not change much in RS discharge regime, but the emission of excited atomic species almost completely disappears. In RS regime we also did observe any gas heating as it was in case of TS at T_g = 300 K. No gas heating was observed also in case of TS discharge regime at T_g = 1000 K.

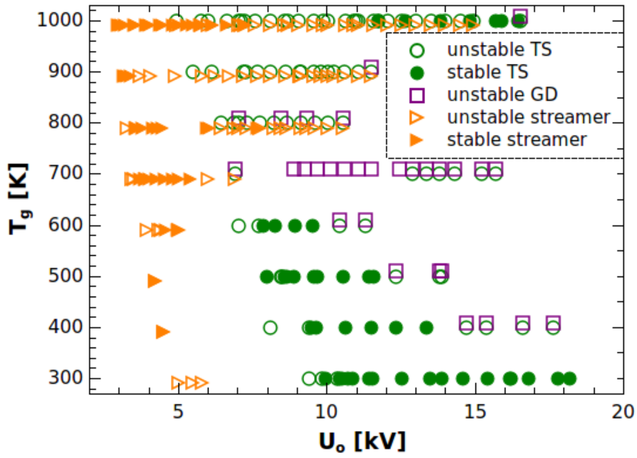

Fig.3. Discharge regimes as function of applied voltage U_o and input gas temperature T_g.

Conclusions

We succeeded to generate high frequency self-pulsing discharges using simple electrical set-up containing a DC power supply in pre-heated up to 1000 K. However, changes of input gas temperature significantly influenced discharge regimes we were able to generate. Properties of generated plasma and amount of produced reactive species might significantly differ from regime to regime, as can be deduced from optical measurements. It is therefore necessary to perform further research to identify the best possible application for observed discharge regimes. As a first step, we will try transient spark for the stabilization of lean flames.

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