Development of Pulsed Surface Dielectric Barrier Discharge and Its Application for Ignition Initiation

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1   Temperature Measurements

To initiate sliding discharge we used magnetic compression generator with pulse amplitude up to 50 kV, rise time 7 ns, duration 25 ns. The high-voltage pulses were transferred from the pulse generator to the high-voltage electrode by means of 50-Ohm coaxial RC-50-11-11 cable.
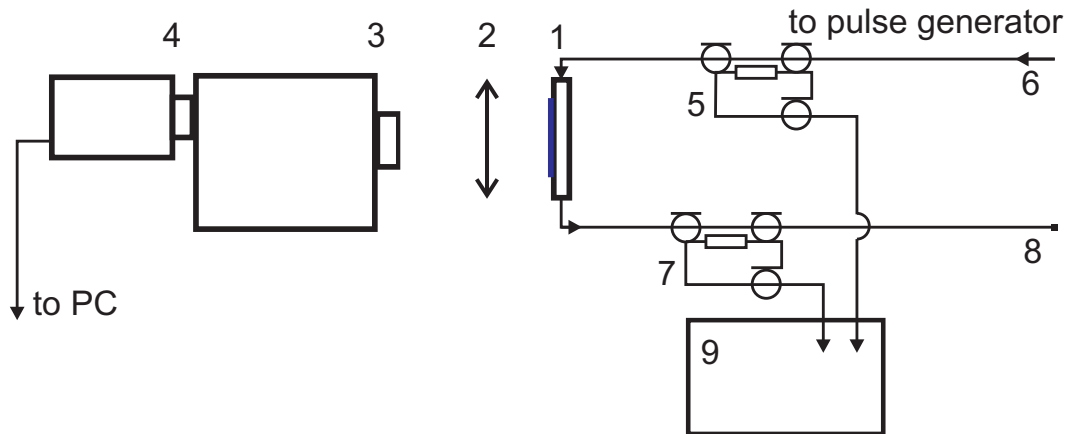

Figure 1: Scheme of experimental setup for temperature measurements. 1) actuator, 2) focus system, 3) monochromator MDR23, 4) high speed ICCD camera PicoStar HR12, 5) back current shunt, 6) coaxial cable from the HV generator, 7) back current shunt, 8) coaxial cable, 9) oscilloscope Tektronix TDS 3054.

The energy input in the discharge was calculated as the difference between the energy stored in the incident pulse measured by back-current shunt and the energy in the pulse after the actuator measured by back-current shunt (Fig.1 (7)). Typically, the value of energy input was within the range of 3 to 10 mJ per pulse for HV pulse amplitude from 13 to 18 kV on the discharge gap.

Gas temperature was measured using emission spectra of $0 \rightarrow 0$ transition of 2^+ system of Nitrogen molecule with unresolved rotational structure. The scheme of experimental setup is shown in Fig. 1.
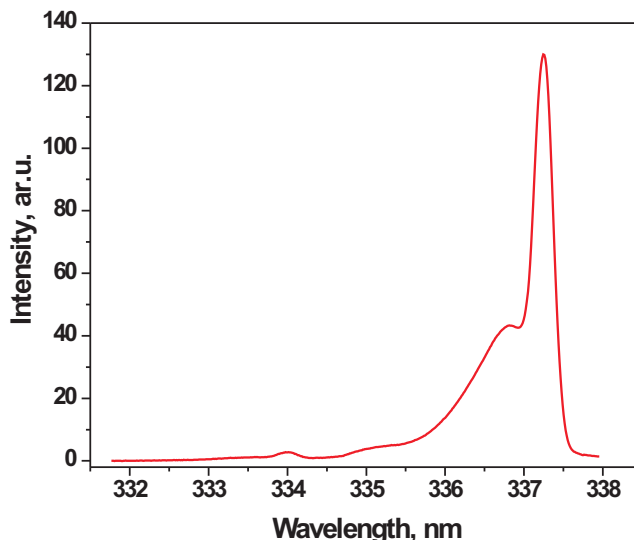

Figure 2: Spectra of 2^+ system of Nitrogen is obtained during the discharge phase. U=18 kV on the discharge gap. $\triangle\lambda = 0.25$ nm.

The system (2) focus the emission of sliding discharge to the input monochromator's slit. The monochromator MDR23 with the diffracting grid with 1200 lines/mm was used. The spectral dispersion of monochromator was 0.6 nm/mm. Real spectral resolution of the system was limited by micro channel Intensifier of ICCD camera and was about 0.25 nm. The output monochromator's optical plane was adjusted to the photocathode of the high speed camera. The high speed camera was synchronized with the HV pulses. The camera gate was started when the HV pulse reached the plasma actuator. The exposure time was equal to 100 ns. During one experiment we obtained the full spectra of $0 \rightarrow 0$ transition of 2^+ system of Nitrogen molecule. To increase a signal to noise ratio we collected 2000 spectra in one regime and summed them. The example of the spectra measured is shown in Fig. 2.

We have compared this spectra with calculated one at a given temperature. The theoretical spectra was obtained with the help of code [1]. The comparison of experimental and theoretical spectra is shown in Fig. 3. Two theoretical curves are demonstrated: with spectral resolution $\triangle\lambda = 0.001$ nm and with spectral function corresponded to real system resolution ($\triangle\lambda = 0.25$ nm on the half-width). Calculated spectra demonstrates very good agreement with the measured one. The gas temperature was 330K. That is mean that the gas temperature increase during discharge phase is 40 K.

To obtain the gas temperature dynamic we used the additional coaxial cable connected with the actuator (Fig. **??**(8)). The length of the additional cable was varied from 0 to 100 m. The HV pulse comes through the cable (6) to the actuator and starts to propagate trough the additional coaxial line (8). It reaches the end of the line in 500 ns. After that it reflects and propagates back to the actuator another 500 ns. We synchronized the camera gate with the HV pulse reaching the actuator after this additional delay ($1\mu s$). This pulse initiates weak discharge with the energy input about 0.1 of the first HV pulse. We obtained 2000 spectrums for summing. The final profile is shown in Fig. 4 (2).

It clearly seen that the slope of intensity distribution at high j numbers decreases after $1\mu s$. We have found that the temperature increase is 40 K ($290\rightarrow330$ K) during the discharge phase and additional
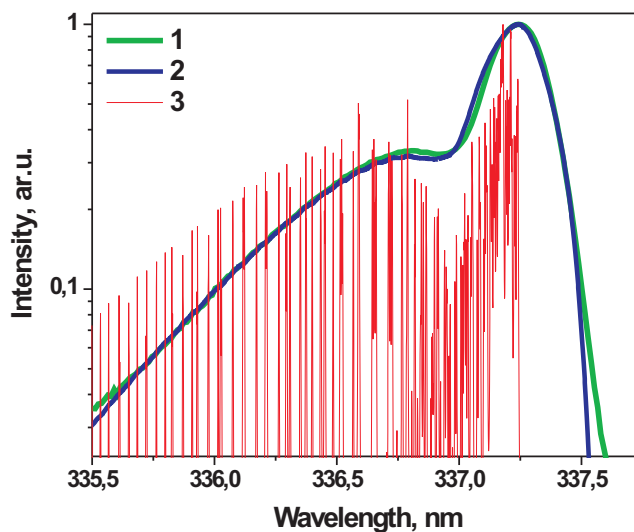
Figure 3: Spectra of 2^+ system of Nitrogen, $\triangle\lambda$=0.25 nm. 1) experiment spectra, camera gate t=0-30 ns, 2) calculations with given temperature T=330 K, $\triangle\lambda$=0.25 nm, 3) calculations with given temperature T=330 K, $\triangle\lambda$=0.001 nm. U=14 kV on the discharge gap.
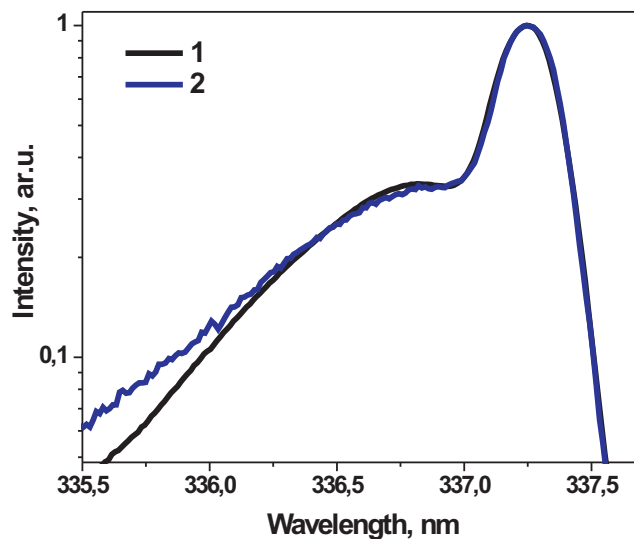

Figure 4: Spectra of 2^+ system of Nitrogen $\triangle\lambda$=0.25 nm. 1) experimental spectra, camera gate t=0-30 ns, 2) experimental spectra, camera gate t=1000-1030 ns. U=18 kV on the discharge gap.

100 K (330→430 K) after 1 μs at U=18 kV in the first pulse on the discharge gap (energy input 11 mJ). At lower voltage U=14 kV we obtained the temperature increase is 40 K (290→330 K) during the discharge phase and 50 K (330→380 K) at U=14 kV on the discharge gap (energy input 3 mJ).
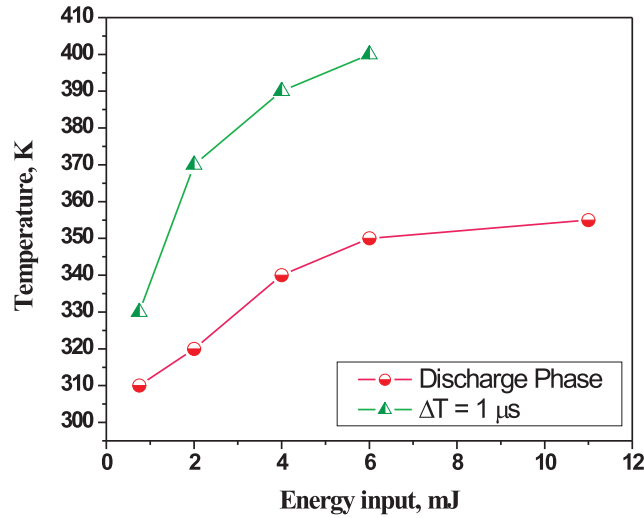
Figure 5: Dynamics of temperature increase in plasma layer. 1) camera gate t=0-30 ns, 2) camera gate t=1000-1030 ns.

Thus the typical values of the energy input are 3-10 mJ. The spectra of $0 \rightarrow 0$ transition of 2^+ system of Nitrogen molecule was obtained with $\triangle\lambda = 0.25$ nm resolution. Gas temperature was restored using emission data (Figure 5). Gas temperature increase during discharge phase (t=0-30 ns) was 40 K ($290\rightarrow330$ K) and additional 100 K ($330\rightarrow430$ K) after 1 μs at voltage U=18 kV (energy input 11 mJ). At lower voltage U=14 kV we obtained the temperature increase is 40 K ($290\rightarrow330$ K) during the discharge phase and 50 K ($330\rightarrow380$ K) at U=14 kV on the discharge gap (energy input 3 mJ).

2   Conclusions

The measurements performed have shown overheating of the discharge region under fast ($\tau \leq 1\mu$s) thermalization of the plasma inputed energy. Independent measurements of the gas translational temperature in the plasma layer by emission diagnostics, measurements of the pressure dynamics near the surface, structure of the flow field demonstrate self-consistent picture of the process development. The measurements have shown that the mean values of such heating for the plasma layer can reach 70, 200, and even 400 K for 7-, 12- and 50-ns pulse durations, respectively. Thus SDBD can be used for effective combustion initiation and stabilization under high-pressure gas conditions.

References

[1] C.O.Laux. Radiation and Nonequilibrium Collisional-Radiative Models. von Karman Institute Lecture Series 2002-07, Physico-Chemical Modeling of High Enthalpy and Plasma Flows, eds. D. Fletcher, J.-M. Charbonnier, G.S.R. Sarma, and T. Magin, Rhode-Saint-Gense, Belgium, 2002.