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Experimental study of fast gas heating in a capillary nanosecond discharge

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A capillary nanosecond discharge is used to produce electronically excited species in synthetic air. The relaxation of the energy of the excited species into gas thermal energy (so-called fast gas heating) is studied experimentally. It is shown that the discharge under study exhibits at the same time a strong gas heating (1000-5000°K), a relative homogeneity, and a strong reduced electric field, sustained during the energy deposition phase. Such parameters allow for a comparison with kinetic models describing fast gas heating at high E/N.

1. Introduction

So-called fast gas heating is the fast relaxation of the electronic degrees of freedom of a gas causing a sharp increase in its translational temperature. It has been experimentally observed in [1], and the detailed kinetic mechanisms [2] have been validated for E/N<400Td [3]. Although recent experimental evidence [4,5] shows heating of up to several thousand degrees in tens of nanoseconds, the kinetic models describing such a fast and strong heating are not well validated yet. Our goal is to achieve a fast gas heating experiment showing a high and uniform E/N to help this validation.

2. Experimental setup

A scheme of the experimental setup is presented in Fig.1. The discharge is realized in a 1.4 mm diameter and 85 mm long quartz tube, closed at both ends by semi-conical needle electrodes, and surrounded by 2 waveguide metal plates. A FID FPG 10-MKS20 high voltage pulse generator produces 11 kV, 4 ns rise time, 28 ns FWHM pulses at 3 Hz frequency; these pulses then propagate in a 25 m RG213 coaxial cable to the discharge. When each pulse arrives at the high voltage electrode of the discharge, it divides into a transmitted and reflected pulse, the discharge assembly being as coaxial as the cable. The transmitted pulse causes the formation of a fast ionization wave (FIW) in the tube that crosses the gap in a few nanoseconds, creating the plasma [6]. The reflected pulse goes back and forth between the generator and the discharge 2 more times before beeing dissipated in the generator. Each reflection at the discharge causes one more breakdown, 240 and 480 ns after the first pulse. The transmitted pulse does the same in a delay cable connected to the low voltage electrode of the discharge tube, and returns to the dicharge at t=1 and 2 µs. All these additional breakdowns are used to measure the gas temperature by recording the profile of the $N_2(C\,^3\Pi_u,v=0)\rightarrow N_2(B\,^3\Pi_g,v=0)$transition at t=0, 0.24, 0.48, 1 and 2 µs. The current profile of each pulse was measured by two back current shunts, BCS1 and BCS2, soldered to the cable shielding, 12.5 m before and after the discharge. The dynamics of the potential drop along the discharge tube, over a distance of 55 mm, was measured in 1 mm increment by a capacitive gauge inserted over the discharge in a slit in its shielding. The reduced electric field E/N(t) was derived from these measurements using a procedure described in [7].

A gas flow of 20-50 sccm was used to renew the gas between subsequent HV pulses; the gas used was synthetic air of purity 99.999%, it was pumped using a XDS5 rotary pump. Gas pressure varied between 2 and 900 mbar.

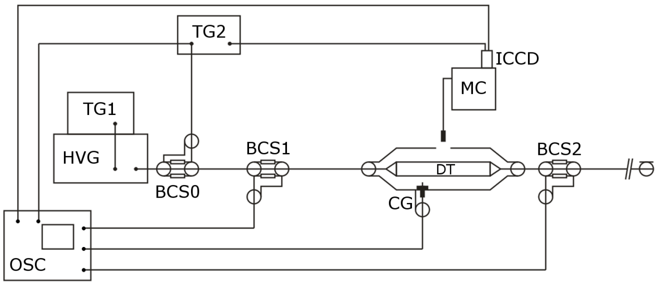

Fig.1: Scheme of the experimental setup

Finally, the ICCD was also used to obtain nanosecond-resolved pictures of the discharge to measure the homogeneity of its visible and close UV radiation. BCS1, BCS2, the ICCD gate monitor and the capacitive gauge (CG), were all connected to a LeCroy WR44Xi Oscilloscope with 0.2 ns resolution.

3. Results and discussion

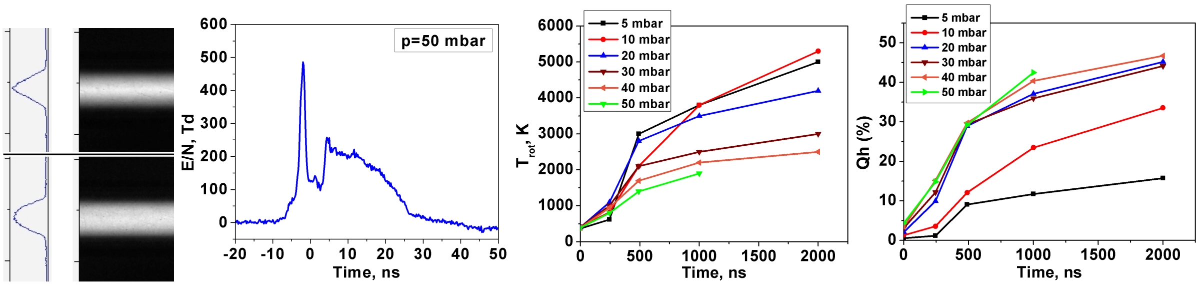

Fig.2: from left to right: a) pictures of the discharge. Up: 10 mbar, 5 ns exposure; down: 50 mbar, 10 ns exposure; left: relative intensity of the radiation in arbitrary units on a typical cross section. b) reduced electric field, 50 mbar, 50 mm from the HV electrode; c) temperature of the gas vs time; d) ratio of gas thermal energy to the energy of the first incident pulse, assuming that the gas composition remains unchanged

As can be seen in Fig.2.a, the discharge seems uniform in both cases; to explain the profile of the luminosity, the thickness of the quartz tube walls (1mm, compared to its radius of 0.7 mm) and their refracting effet, have to be taken into account. In Fig.2.b, the initial burst in the electric field corresponds to the FIW bridging the discharge gap. The second increase of the field, 5 ns later, is due to the establishment of the electrical current in the delay cable. The potential at the low voltage electrode drops, and due to the fact that the potential of the high voltage electrode keeps constant, the field increases. Finally, it can be seen on Fig.2.c and d that, for all 6 working pressures, the heating is over 1000°K, and reaches 5000°K for 5 mbar; and starting from 20 mbar, more than 40% of the initial pulse energy is spent to heating after 2 μs.

4. Conclusions

Fast gas heating in the afterglow of a high voltage pulsed nanosecond discharge has been characterized experimentally, and its parameters have been measured. A gas heating of a few thousand degrees was observed, while an electric field of a few hundred Townsend was maintained during the energy deposition phase (after the discharge gap has been bridged, and a high current started to flow). Finally, preliminary ICCD imaging show that the discharge seems to be fairly uniform. These parameters seem to allow that the experimental data obtained now and in the future from this experiment, be used as a basis to test kinetic models describing fast gas heating at high E/N.

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References

[1] A.Yu. Starikovskii, A.A. Nikipelov, M.M. Nudnova, D.V. Roupassov, *Plasma Sources Sci. Technol.* **18** (2009) 034015 (17pp)

[2] N.A. Popov, *Plasma Physics Reports* **27**/10 (2001) 886-896

[3] E.I. Mintoussov, S.J. Pendleton, F.G. Gerbault, N.A. Popov and S.M. Starikovskaia, *J. Phys. D: Appl. Phys.* **44** (2011) 000000 (13pp)

[4] N.L. Aleksandrov, S.V. Kindusheva, M.M. Nudnova and A.Yu. Starikovskii, *J. Phys. D: Appl. Phys.* **43** (2010) 255201 (19pp)

[5] G. Stancu, F Kaddouri, D. Lacoste and C.O. Laux, *J. Phys. D: Appl. Phys.* **43** (2010) 124002

[6] S.M. Starikovskaia, N.B. Anikin, S.V. Pancheschnyi, D.V. Zatsepin, A.Yu. Starikovskii *Plasma Sources Sci. Technol.* **10** (2001) 344

[7] N.B. Anikin, S.M. Starikovskaia, A.Yu. Starikovskii *J. Phys. D: Appl. Phys.* **35** (2002) 2785