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MECHANISM OF FAST GAS HEATING IN A NON-EQUILIBRIUM WEAKLY-IONIZED AIR DISCHARGE PLASMA IN HIGH ELECTRIC FIELDS

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In discharge plasmas, electrons gain energy from an external electric field and transfer this energy through collisions into the various degrees of freedom of other particles; most of this energy is eventually released as heat. Problems concerning the mechanisms of fast (< 1 μs for 1 atm) gas heating in molecular gas discharges have attracted considerable attention in the last few decades due to their importance to many discharge applications including plasma-assisted ignition and flow control.

In this work, observations [1] of a shock wave propagating through a uniform decaying plasma in the afterglow of an impulse high-voltage nanosecond discharge in air at 20 Torr and observations [2, 3] of a nanosecond surface dielectric barrier discharge in atmospheric-pressure air were analyzed. The main purpose of this analysis was to determine the fractional electron power quickly transferred into heat in air plasmas in high electric fields. Under the conditions considered, the values of reduced electric field E/N (N is the gas number density) in which the plasma was generated were as large as 10^3 Td. Measurements of shock-wave velocity were used to extract an increase in the gas temperature, ΔT, in the discharge afterglow (by t = 50 μs), whereas energy input was determined from the measurements of discharge current and electric field in the discharge. The observed acceleration of the shock wave front in the discharge afterglow corresponded to a 36-40% conversion of the discharge energy by t = 50 μs at E/N ~ 600 Td.

The analysis of observations [2, 3] of a nanosecond surface dielectric barrier discharge was more complicated because of plasma inhomogeneity. Here, the values of E/N and ΔT were calculated from the emission profiles of the first negative system of N_2^+ ions and the second positive system of N_2 molecules. Images with a PicoStar HR-12 ICCD camera were used to determine the spatial-temporal characteristics of the discharge and to estimate an “effective” plasma volume. Energy input during the discharge was measured by back-current shunts. Calculation showed that approximately 56-66% of the discharge energy was converted from molecular internal and chemical degrees of freedom into heat during 1 μs at E/N ~ 900 Td. In the discharge phase, the fraction of energy conversion could be estimated as 30-40%.

A kinetic model was developed to describe the processes that contribute towards the fast transfer of electron energy into thermal energy under the conditions considered. This model takes into account previously suggested mechanisms to describe observations of fast heating in moderate (~10^2 Td) reduced electric fields (see [4]) and also considers the processes that become important in the presence of high electric fields. Figures 1(a) and 1(b) compare, respectively, the calculated evolution in time of the fractional electron power transferred into heat under the conditions of observations [1] and [2, 3] and the results of our analysis of these experiments. There is reasonable agreement between these results.

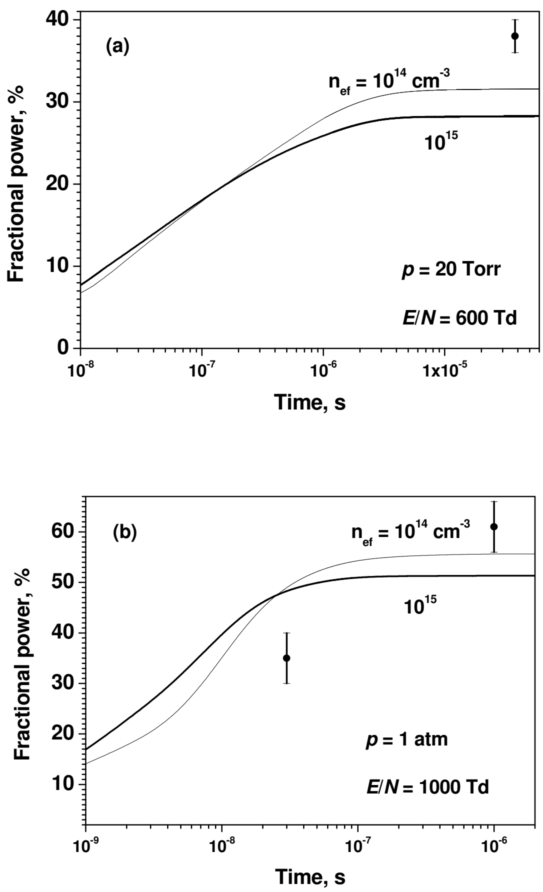

Fig. 1: The calculated evolution in time of the total fractional electron power transferred into heat in dry air (a) under the conditions of observations [1] and (b) under the conditions of observations [2, 3]). The calculations were carried out for various values of electron density at the end of the discharge, n_{ef}. Symbols correspond to our analysis of the measurements.

According to the calculation at 20 Torr, most of electron power was converted into heat through electron-impact dissociation of O_2 and N_2, through excitation of electronic N_2 states followed by their quenching in collisions with O_2 and through electron-ion recombination. At atmospheric pressure, the calculated fractional electron power transferred into heat can be increased by ~20% due to the three-body recombination of positive and negative ions in the discharge afterglow.

References

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