On the similarities between nitrogen impurities and trapped gas effects under the atmospheric pulsed barrier discharge in helium

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This contribution presents the experimental results on the comparative characterization of dielectric barrier discharge (DBD) plasma produced in stationary helium gas and flowing helium-nitrogen gas mixture using electrical measurements and spectral diagnosis through time and space resolved imaging of spectral light radiated/absorbed by plasma system. The study focuses on the effects induced by trapped helium gas on the space-time distribution of its excited species in pulsed DBD using symmetrical electrode configuration.

1. Introduction

Several potential applications of atmospheric-pressure plasma produced in recirculated working gas and trapped gas (when the discharge gap is filled with stationary gas) have been reported so far [1-5]. Among these there have to be mentioned: disinfection of medical instruments [2], surface modifications of closed plastic bags for biomedical applications [3], food processing in order to reduce the risk of microbial infections [4, 5]. One of the discharges, with high potential for applications, is dielectric barrier discharge (DBD). These motivate the importance of studying atmospheric-pressure plasma produced by DBD in stationary gas.

2. Experimental Setup

The DBD plasma was generated in helium and mixture of helium with nitrogen using a symmetrical electrode configuration with fixed gas gap [6]. Positive voltage pulses with 2 kHz repetition frequency, 30 μs pulse width and 3.2 kV amplitude were used to excite the discharge. The energy transferred to the discharge system during one pulse was maximum 1 mJ. The DBD cell was equipped with a gas inlet and outlet controlled by valves in order to investigate the discharges operating in trapped (TGA) or flowing gas atmosphere (FGA) in the same set-up. All experiments were performed at atmospheric pressure, after outgases by vacuum pumping.

The high-speed camera technique combined with band-pass filters was used in order to acquire time and space distribution of some excited species (He, O, NO, N_2, N_2^+) of the DBD plasma. Also, optical emission spectroscopy (OES) and tunable diode laser (at 777.194 nm) absorption spectroscopy (TDLAS) techniques were used to quantify the density of different excited species, including metastable oxygen atoms.

3. Experimental Results

The electrical measurements show important differences in the number of the current pulses between discharges operating in stationary and flowing helium gas atmosphere. One single current peak is observed per rising (or falling) flank of the voltage pulse for the He-DBD in FGA mode of operation. While, more current peaks per increasing (or decreasing) phase of each voltage pulse were obtained for He-DBD in TGA mode [6] and He+N_2 – DBD in FGA mode (Figure 1). Moreover, detailed analyses emphases important similarities between current oscillograms of the He–DBD in TGA mode [6] and the He+0.4%N_2–DBD in FGA mode. Therefore, a complex comparative characterization of the DBD system working in these two modes was performed.

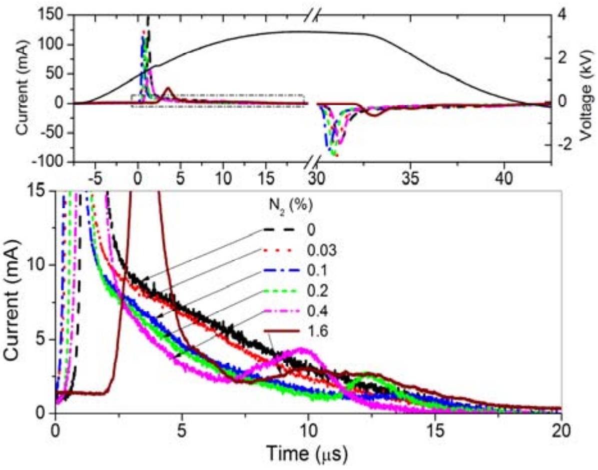

Figure 1. Typical temporal evolution of the applied voltage and discharge current at different nitrogen percentage added to flowing helium in DBD system.

Furthermore, the temporal evolution of the representative excited species' densities show also important differences between discharges operating in stationary (Figure 2b) and flowing (Figure 2a) helium gas atmosphere. On the other hand, the temporal behaviour of the excited species from the He-DBD working in TGA mode is very similar with those presented in Figure 2c, for He+0.4% N_2–DBD working in FGA mode. This fact strongly suggests that the absence of the gas flow in TGA mode leads to the accumulation in the gas volume of nitrogen molecules desorbed and/or etched from the barriers surfaces, which change the proportion of various components of the trapped gas. Therefore, the dynamic of DBD plasma produced in TGA mode is expected to be influenced by the formation of supplementary source of seed electrons generated by desorption of electrons due to excited nitrogen molecules, originated from barriers surfaces [6].

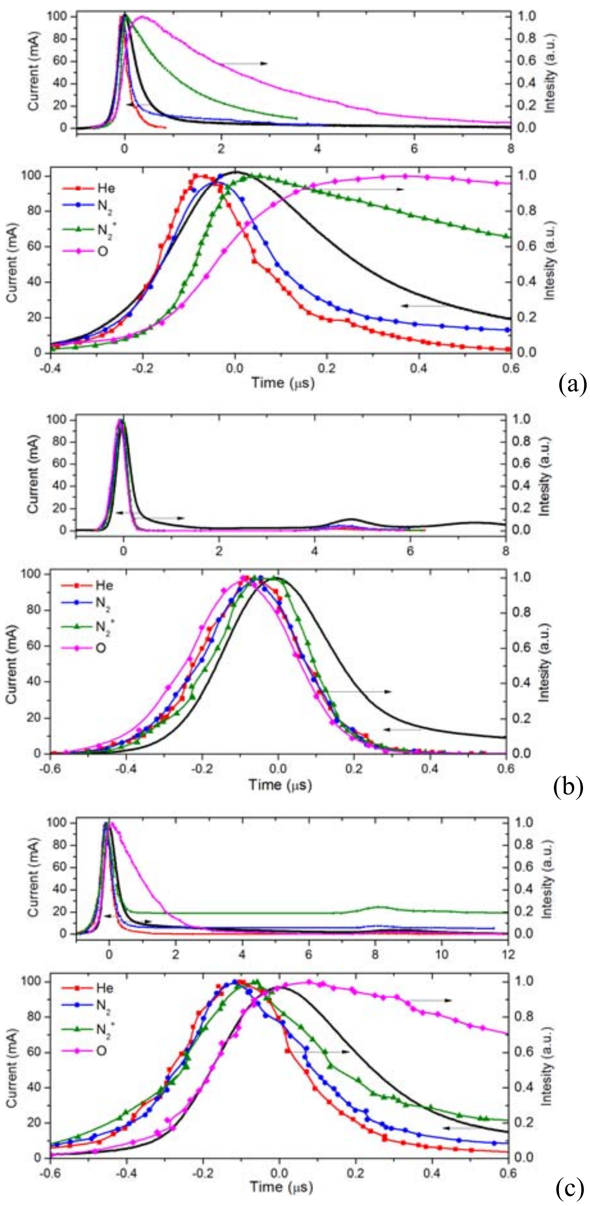

Figure 2. Temporal evolution of the excited species for DBD working in: a) FGA mode in He, b) TGA mode in He, c) FGA mode in He+0.4%N_2.

Similar results were obtained for space normalized intensity distributions of the representative spectral lines (He 706.5 nm and O 777.2 nm) and bands (N_2 337.1 nm, N_2^+ 391.4 nm) in the phase of maximal current of the first positive current pulse (results not shown here). The common feature of the two spatial distributions is the presence of a maximum intensity nearby the dielectric covered cathode.

The similarities between nitrogen impurities and trapped gas effects on the He-DBD are stressed both by the variation of relative density of excited species (He, O, N_2^+, N_2) and by the evolution of the absolute density of oxygen metastable atoms with the helium gas flow rate in comparison with the N_2 percentage added to flowing helium (results not shown here). The experimental results show that the densities of all excited species, except for N_2, sistematically decrease with the reduction of the helium gas flow rate, while the same effect is observed with increasing of the N_2 percentage added to flowing helium.

4. Conclusions

Experimentally was shown that trapped gas effect has a notable impact on the He-DBD mecanism, similar with the influence of nitrogen impurities added to flowing helium. This fact was experimentally demonstrated here by (i) the time-space distribution of the excited species and (ii) the variation of relative density of the excited species (He, O, N_2^+, N_2) and the absolute density of oxygen metastable atoms with the helium gas flow rate in comparison with the N_2 percentage added to flowing helium.

5. References

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