Influence of electrode temperature on plasma parameters of diffuse coplanar surface discharge

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The diffuse coplanar surface barrier discharge (DCSBD) has unique properties among others dielectric barrier discharges such as the generation of thin layer of non-equilibrium atmospheric pressure plasma with high power densities (up to $100 W/cm^3$). Among various parameters, which influence properties of the DCSBD, the temperature of electrodes can play a crucial role not only for intensive cooling of the electrode system. But the temperature could also influence significantly processes running during numerous possible technical applications. The electrodes of the DCSBD were cooled/heated by means of Peltiere cells and the discharge spectra were recorded. Using optical emission spectroscopy the variation of plasma parameters was studied. It was found, that the vibrational temperature as well as rotational temperature changes significantly even for relatively narrow electrode temperature range.

1. Introduction

During several last years dielectric barrier discharges (DBDs) became very useful in the field of in-line plasma processing at atmospheric pressure. DBDs can be used as sources of low temperature plasma for a variety of technical applications like surface modification, plasma deposition, sterilization, etc. [1,2].

The diffuse coplanar surface barrier discharge (DCSBD) has following unique properties among others DBDs. The DCSBD generates a thin layer of non-equilibrium atmospheric pressure plasma being not in contact with metal electrodes. That results in an increased lifetime of electrode system and decreased contamination of plasma from electrodes. Moreover, high power densities (up to $100 W/cm^3$) can be achieved and noble gases such as helium, argon, etc. are not needed for DCSBD stabilisation. The least but not last DCSBD has a unique structure where the diffuse part of the discharge can be emphasised while the filamentary part can be suppressed. This unique property can reduce one disadvantage of majority of barrier discharges, their inhomogeneity [3,4].

Among various parameters [5,6], which influence properties of the DCSBD, temperature of electrodes can play a crucial role not only in necessary cooling of the electrode system but also the temperature could influence significantly processes running there.

2. Experimental set-up

The experimental apparatus is shown in Fig.1. It consisted of discharge electrode system (DES) with reaction chamber, power supply unit, cooling/heating unit and diagnostic instruments. The DES was made of alumina plate (Al_2O_3) of 96 % purity 0.5 mm thick, replaceable mounted to the system of coplanar brass electrodes. The electrodes had semi-circle cross-section with the distance between the electrodes 0.7 mm. Contrary to industrial DCSBD [3,4] the electrode system consisted of one electrode pair, in order to better determine the temperature influence. The space between the electrodes was filled with electro-insulating oil bath. The grounded electrode was controllably heated/cooled using series of Peltiere cells connected with external cooler. Through the quartz window in the reaction chamber the emission spectra and the pictures of the discharge were taken. Over the window the slit could be mounted in order to obtain the spectra asymmetrically from above the powered or grounded electrode (without the inter-electrode filamentary part).

The discharge chamber's dimensions were 30x30 mm (diameter x height). The flow rate of 2 slpm of nitrogen (5.3 purity) was kept in all experiments. The discharge was powered by high voltage power supply unit with frequency 34.5 kHz. The voltage amplitude was in the range of 12 to 18 kV and the estimated discharge power of the order of 16 to 42 W.

Electrical parameters were measured by digital oscilloscope LeCroy WaveRunner 6100A (1GHz). Dissipated discharge power was then estimated from the HV voltage and current time evolution measurements. The spectra were recorded with monochromator Jobin-Yvon Triax 550 with 1200 gr/mm and liquid nitrogen cooled CCD detector. The vibrational temperature was then calculated from the bands of second positive system of nitrogen $C\,^3\Pi \rightarrow B\,^3\Pi$ ($\Delta v = -2$, heads 0–2, 1–3, 2–4).

To estimate rotational temperature a quick procedure based on low resolution emission spectroscopy was used [7]. It was found that ratio of maximal and minimal value of emitted light is very sensitive on the rotational temperature, which can be evaluated from the course of specific nitrogen band (individual rotational lines must be not resolved).

Discharge pictures were taken by digital camera Olympus SP500UZ.

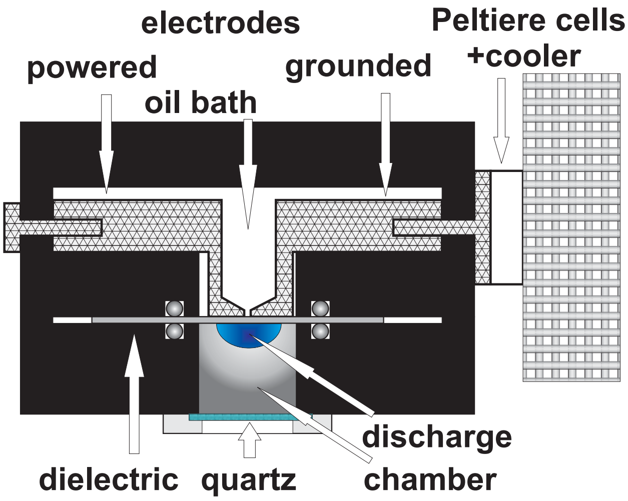


Fig. 1: Schematic drawing of the experimental set-up. The temperature of grounded electrode was controlled by means of Peltiere cells.

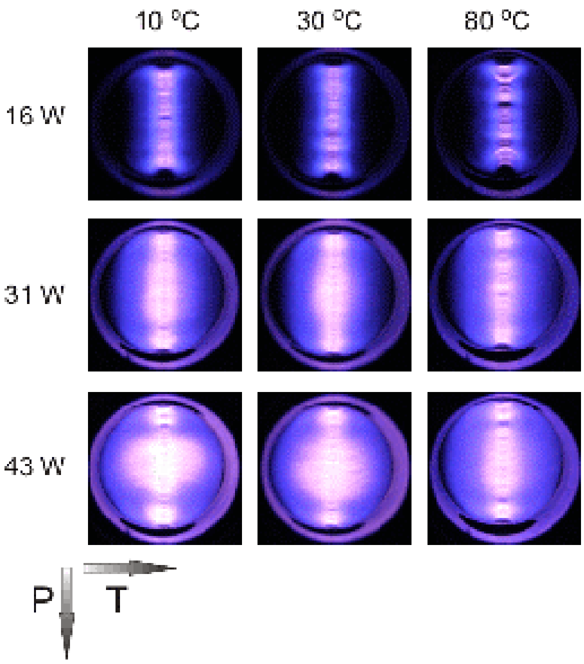
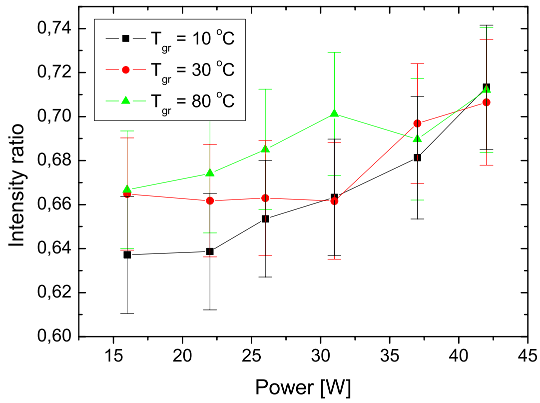


Fig. 2: Typical set of images, where the changing character of the DCSBD vs. the input power as well as the electrode temperature is presented (τ=1/50 s).

3. Results and discussion

A typical set of images is given in Fig. 2 where an influence of input power as well as temperature of the grounded electrode is manifested.The powered electrode was kept at about 30 °C for 10 and 30 °C grounded electrode. For 80 °C grounded electrode, the powered electrode had temperature 60 °C.

For different electrode temperature it was presented the maximal and minimal value in the vibrational band 2-0 (the ratio is proportional to the rotational temperature see theory [7]) vs. input power. One can see that the difference is not negligible each other but it appears to be significant even for relative narrow electrode temperature range (the maximal difference is about 70 °C) and vanishes at high input power. The corresponding values of rotational temperature were about 350 K for ratio 0.6 and 550 K for ratio 0.8.



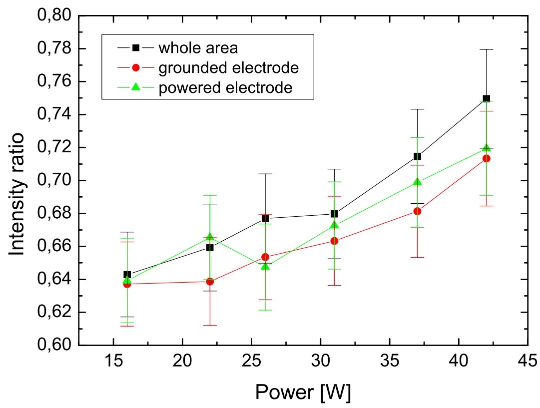


Fig. 3: The ratio of maximal and minimal intensity in the nitrogen band vs. the input power: the temperature of grounded electrode changes (top). In the bottom, the ratio is determined separately near individual electrodes as well as from whole discharge. Based on theory [7] the ratio is proportional to the rotational temperature.

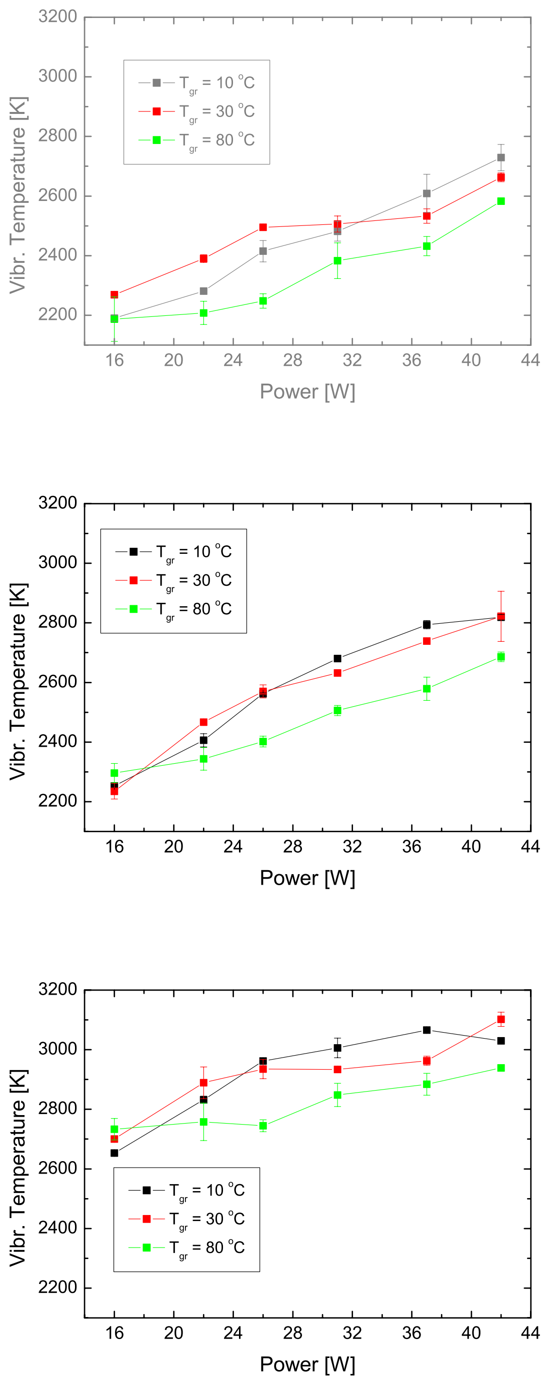


Fig. 4 Vibrational temperature estimated from nitrogen bands vs. input power for different temperature of electrode. The estimated values of vibrational temperature near the grounded (top) and powered electrode (middle) and the mean values from the whole discharge are also presented (bottom).

From the photos of the discharge presented in Fig. 2 on can't deduce whether the discharge distribution is symmetrical or not.

In Fig. 4 one can observe slight temperature asymmetry and the highest temperature is reached for integral measurement where the filamentary part is included in contrast to boundary measurements (where filamentary plasma light emission is shielded).

The vibrational temperature estimated from the band measured across the diameter is always higher contrary to the individual electrodes (grounded and powered) as the filaments are preferable localised between electrodes. Generally, the filamentary discharge is characterised with higher temperature in comparison with boundary parts close to the electrodes. The plasma above electrodes is considered for afterglow as the main contribution is originated from the filaments in the centre.

4. Conclusion

Based on preliminary results presented in this contribution one can deduce that the temperature of electrodes in the DCSBD play important role. It was found that vibrational as well as rotational temperature could be higher more than 10 % even if the temperature electrodes differ only 70 °C. At the same time, the temperature influences significantly the character of the DCSBD.

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