Optical Emission Spectroscopy of Diffuse Coplanar Surface Barrier Discharge

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Abstract. Diffuse coplanar surface barrier discharge (DCSBD) as the source of non-equilibrium plasma is widely used nowadays for surface modification of different materials. DCSBD plasma consists of many microdischarges which are moving along the planar dielectric plate and create a thin layer of macroscopically homogeneous plasma above dielectric. The influences of humidity in carrier gas at atmospheric pressure studied by optical emission spectroscopy (OES) and of the electrode width studied by space resolved OES of one DCSBD microdischarge were investigated.

Introduction

DCSBD generates a plasma with a high rate of diffuse plasma at atmospheric pressure. The conspicuous volume density of electric power in the plasma [Kováčik 2006; Černák et al., 2011; Černák et al., 2009] makes DCSBD attractive for the industrial applications such as surface modification of different materials e.g. aluminium [Bónová et al., 2012], glass [Homola et al., 2012], foils, nonwoven fabrics [Černák et al., 2011], artificial and natural fibres [Černák et al., 2009], and also plant seeds [Henselová et al., 2012].

DCSBD plasma consists of many microdischarges which are moving along the planar dielectric plate and create the thin layer (≈ 0.3 mm) of macroscopically homogeneous plasma practically in any gas at atmospheric pressure (Fig. 1). Our investigation was performed to estimate the applicable conditions for the plasma surface modification made by the DCSBD.

Experimental

In this contribution the influence of humidity in carrier gas (nitrogen and synthetic air) at atmospheric pressure studied by OES and the influence of the electrode width studied by space resolved OES of one DCSBD microdischarge were investigated.

The measurements of emission spectra with the dominant 2nd positive system N2 (N2 SPS) were performed by spectrometer Avantes 2048 TEC with spectral range 300–400 nm. The electrode systems with the active plasma area of 200 x 80 mm were formed of silver strip electrodes firstly 1.5 mm and secondly 3 mm wide with 1mm electrode gap placed on the planar ceramics (Al2O3, 96 % purity). The fact, that DCSBD consists of the electrode system situated on dielectric plate results in the requirement of AC feeding voltage (20 kV – peak to peak, 14 kHz).

The spatial distribution of intensity of N2 SPS (380.49 nm) was measured through one microdischarge generated by two types of DCSBD electrode system at input power 350 W in ambient air (Fig. 2). Movement of the microdischarge was stopped by glycerol-silicon emulsion located on the edges of surrounding discharges. The space resolution was optimized by positioning optical components (lens and adjustable shutter) and the spectrum was taken from the circular surface with a diameter of 0.35 ± 0.05 mm. Optical bench was connected to the 3D translation system with micrometer drives and the step of translation along the X and Y axes was set to 0.3 mm.

The emission spectra of the plasma generated by DCSBD with the electrodes 1.5 mm wide at input power 400 W in synthetic air (80 % nitrogen and 20 % oxygen) and nitrogen (the gas purity of 99.99 volume percent, 4.0) with different concentration of water vapour (Fig. 3) were measured in the reactor chamber with the quartz glass window. The flow of the carrier gases was kept at 5 l/min during the experiments and concentration of water vapour was adjusted by temperature of distilled water in the bubbler (20 °C and 80 °C).
Figure 1. Image of the plasma layer generated by the DCSBD (left) and images of an elementary \( H \)-shaped microdischarge of the DCSBD taken in air and nitrogen (right). Electrodes 1.8 mm wide with 0.4 mm electrode gap are indicated by the white lines \([\text{Černák et al.}, 2009]\).

Figure 2. Scheme of the spatially resolved OES measurement of one microdischarge of DCSBD: 1 — mirror, 2 — 3D translation system, 3 — lens, 4 — shutter, 5 — fiber holder, 6 — optical fiber, 7 — spectrometer, 8 — computer.

Figure 3. Scheme of OES measurement: 1 — carrier gas, 2 — bubbler, 3 — gas input, 4 — gas output, 5 — quartz window, 6 — optical fiber, 7 — spectrometer, 8 — computer.

The values of vibrational temperature were estimated from \( \text{N}_2 \) SPS (\( \Delta \nu = -2 \), heads 0–2, 1–3, 2–4 starting at 380.5 nm) by Spectrum Analyser \([\text{Navrátil et al.}, 2006]\). The rotational temperatures were obtained by simulation of \( \text{N}_2 \) SPS (head 0–1 at 357.42 nm) using program Specair \([\text{Laux}, 2007–2009]\).

Results and discussion

The spatial distribution of \( \text{N}_2 \) SPS intensity in one microdischarge generated by the different DCSBD electrode systems in air (Figs. 4–5), and vibrational (\( T_V \)) and rotational (\( T_R \)) temperatures in diffuse (edges of microdischarge) and filamentary (channel) part of the microdischarge (Tab. 1) were measured. The spectra were accumulated over number of discharge periods for 1 s. Values of \( T_V \) and \( T_R \) (Tab. 2) were calculated from spectra of \( \text{N}_2 \) SPS emitted in synthetic air and nitrogen with different concentration of water vapour.
The measurement of the spatial distribution of intensity has shown the similar distribution of integral intensity of N₂ SPS in both microdischarges generated by DCSBD with the different width of electrodes. In Figs. 4 and 5, the structure of two distinct regions of the DCSBD microdischarge can be clearly seen: the filamentary part (channel) and the diffuse part of the microdischarge with the integral intensity one order of magnitude lower than in channel (for both electrode geometries), however, the values of maximum and minimum integral intensity of the emitted spectra are different for these DCSBD electrode systems.

The values of vibrational temperature (∼ electron kinetic temperature) (Tab. 1) have shown the slight increase of Tᵥ (approx. 300 K in average) in the electrode system with the narrower electrodes. It can be seen that the rotational temperature (∼ gas temperature) in the diffuse part of the microdischarge (Tab. 1) is slightly higher than Tᵣ in the filament and is the same for both electrode systems of DCSBD, but remains sufficiently low for surface treatment of the thermally sensitive samples. The higher Tᵣ in the diffuse part of plasma is rather contraintuitive and does not correspond with results published in [Čech et al., 2009]. However, these data were obtained from spectra emitted by many microdischarges of DCSBD powered by power supply with the higher frequency of 35 to 37 kHz. Therefore, further investigation of the single microdischarge generated in our experimental conditions is needed.

The results of the spatial distribution of intensity and Tᵥ/Tᵣ have shown that these electrode system geometries are usable for the surface treatment of wide scale of materials and the main difference in generated plasma is the rate of diffuse and filamentary plasma in generated discharge.

During the measurement of OES in the atmosphere with different concentration of water vapour a condensation on the chamber walls and on the ceramics of DCSBD and related quenching of the discharge was observed. Therefore we were not able to document the detailed picture of generated discharge. The condensation of water vapour on the quartz glass and on the investigated ceramic surface with generated discharge was eliminated by additional heating.

The values of Tᵥ of N₂ SPS calculated from the spectra measured in nitrogen (Tab. 2) increase with the rising concentration of water vapour. The values of Tᵥ calculated from the measurement in synthetic air have the same tendency, but considering uncertainty, this increase of Tᵥ is ambiguous. The values of Tᵣ are quasi-stable and in average 370 K (considering uncertainty 20 K) in both carrier gasses with changing humidity. However the plasma generated in different gases with high concentration of water vapour preserves its non-thermal condition and DCSBD can be ignited in the atmosphere with high concentration of water vapour.

### Table 1. The vibrational and rotational temperatures of N₂ SPS in two different microdischarge parts (diffuse plasma and filament) generated by different DCSBD electrode systems.

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<tbody>
<tr>
<td>1.5 × 1 mm</td>
<td>Diffuse discharge</td>
<td>3524</td>
<td>491</td>
<td>380</td>
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<tr>
<td></td>
<td>Filamentary discharge</td>
<td>3264</td>
<td>545</td>
<td>350</td>
</tr>
<tr>
<td>3 × 1 mm</td>
<td>Diffuse discharge</td>
<td>3052</td>
<td>265</td>
<td>380</td>
</tr>
<tr>
<td></td>
<td>Filamentary discharge</td>
<td>3066</td>
<td>283</td>
<td>350</td>
</tr>
</tbody>
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### Table 2. The vibrational and rotational temperatures of N₂ SPS in plasma generated by DCSBD in carrier gas (synthetic air and nitrogen) with different humidity.

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<tr>
<td>20 %</td>
<td>Synthetic air</td>
<td>2965</td>
<td>100</td>
<td>350</td>
<td>20</td>
</tr>
<tr>
<td>65 %</td>
<td>3075</td>
<td>260</td>
<td>355</td>
<td>20</td>
<td></td>
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<tr>
<td>86 %</td>
<td>3400</td>
<td>300</td>
<td>380</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>20 %</td>
<td>Nitrogen</td>
<td>2175</td>
<td>116</td>
<td>380</td>
<td>20</td>
</tr>
<tr>
<td>63 %</td>
<td>2542</td>
<td>114</td>
<td>360</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>86 %</td>
<td>2750</td>
<td>344</td>
<td>380</td>
<td>20</td>
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**Figure 4.** Spatial distribution of integral intensity ($N_2$ SPS-380.49 nm) in one microdischarge generated by DCSBD with the electrodes 1.5 mm wide and 1 mm electrode gap.

**Figure 5.** Spatial distribution of integral intensity ($N_2$ SPS-380.49 nm) in one microdischarge generated by DCSBD with the electrodes 3 mm wide and 1 mm electrode gap.
Conclusion

The results obtained via OES of N₂ SPS show that the plasma generated by DCSBD the electrode system of different geometry and in various types of gas with different concentration of water vapour at atmospheric pressure is in non-thermal condition. This attribute is crucial for the industrial plasma modification of low-added-value materials by DCSBD at atmospheric pressure.

This investigation was conducted in order to show the potential plasma application of DCSBD in process of surface treatment executed in pure water vapour atmosphere. The high production of the highly reactive OH radicals, which play an important role in surface treatment of many materials was a motivation for the design and construction of a plasma reactor generating non-thermal plasma in pure water vapour at temperature above 100 °C.

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References