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MASS SPECTROMETRY OF DIFFUSE COPLANAR SURFACE BARRIER DISCHARGE

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Abstract. In this paper we present some of the results obtained in non-equilibrium low-temperature diffuse coplanar surface barrier discharge by using Molecular Beam Mass Spectrometer. In order to understand the process of treatment by this type of plasma, knowledge of the composition of plasma, i.e. of the active species, is needed. In this work we present mass spectrometric studies on chemical products and active species in the plasma generated by the DCSBD at atmospheric pressure in the ambient air. Neutral chemistry and nitric oxide production are discussed.

1. INTRODUCTION

In many areas of industry, plasma processing of materials is a vital technology. Nonequilibrium plasmas have proved to be capable of producing chemically reactive species at low gas temperature while maintaining highly uniform reaction rates over relatively large areas. Their action is versatile, the effects include changing of surface properties (wettability, dyeability etc.), surface activation to improve germination, adhesion of coatings, etching and many more (Puač et al. 2006, Radetić et al. 2007).

Mass spectrometry is a popular method to analyse chemical composition of gases and plasmas. The results are particularly relevant for surface treatment, because the mass spectrometer samples the species which arrive at and potentially interact with the surface. Mass spectrometry of radical species is well established in low-pressure discharges (Sugai et al. 1992), but its applications to atmospheric plasmas are relatively new (Stoffels et al. 2006, Aranda-Gonzalvo et al. 2006).

In this work attention is given to atomic nitrogen and oxygen and to nitrogen monoxide (NO). We will present mass spectrometric studies on gas conversion in the plasma generated by the diffuse coplanar surface barrier discharge. Neutral chemistry and nitric oxide production are discussed.

2. EXPERIMENT

Coplanar barrier discharge - DCSBD (diffuse coplanar surface barrier discharge) was developed to provide functionality of a non-equilibrium low-temperature plasma at atmospheric pressure in ambient air. The DCSBD electrodes, consisting of 15 pairs of silver strip electrodes embedded 0.5 mm below the surface of 96% Al_2O_3 ceramics, was energized by 14 kHz sinusoidal voltage, supplied by HV generator LIFETECH VF700. The mutual distance of the 200 mm long and 2 mm wide silver strip electrodes was 1 mm.

The MBMS(Molecular Beam Mass Spectrometer) system incorporates a Hiden EQP mass/ energy analyzer. Species created in the discharge are sampled using a triple stage differentially pumped molecular beam inlet system. The mass spectrometer can be operated in two different modes: the SIMS mode to extract positive ions and record their energy spectra or in the RGA mode to detect neutrals. In order to detect neutrals the mass spectrometer is equipped with an internal electron source with variable electron energy, which allows ionization of species (positive RGA). Since our main interest are radicals created in the plasma we have used RGA mode in all our measurements.

The surface of the discharge created by DCSBD was positioned against the orifice of a HIDEN EQP mass/energy analyzer system at the distance of 5 mm. Experiments were performed using the ambient air of the laboratory at atmospheric pressure and ambient temperature. Measurements by the mass-energy analyser were performed for two different powers of 300 and 400 W.

3. RESULTS AND DISCUSSION

When presenting the results we have used 'yields' of specific masses instead of counts per second obtained directly from the detector. Yield was calculated as percentage of a certain signal in the total signal summed over a range of masses in order to cancel out the fluctuations:

$$Y = \frac{Y^i_{mass}}{\Sigma_i Y^i_{mass}}[\%] \tag{1}$$

where Y_i is the count of specific positive ion (like N+, O+, etc.) and this was divided by sum of all recorded masses (1-100 amu).

In Fig. 1 mass spectra for the power of 400 W is shown. We can see that $N_2{}^+$ and $O_2{}^+$ have the largest yields followed by H_2O^+, N^+ and O^+. One should bear in mind that, N_2O^+ has mass of 44 amu, which coincides with the persistent $CO_2{}^+$ peak and this causes some problems in the analysis of the recorded spectra.

Main radical species of our interest are N^+, O^+ and NO^+ and in Fig. 2 their yields are shown for two different powers (300 and 400 W). The distance between the electrodes and the mass analyser was 5 mm.

As we can see, in case when applied power was 300 W, yields for N^+ and O^+ are somewhat smaller then in the case when applied power was 400 W. On the other hand, yields for NO^+ decrease with the increase of the applied power.

This behavior can be explained by reaction kinetics in the discharge. In case of nitrogen monoxide (NO) one of the possible reactions is forming NO by dissociation of N_2 and O_2 and then by three-body recombination $N + O + M \rightarrow NO + M$. The

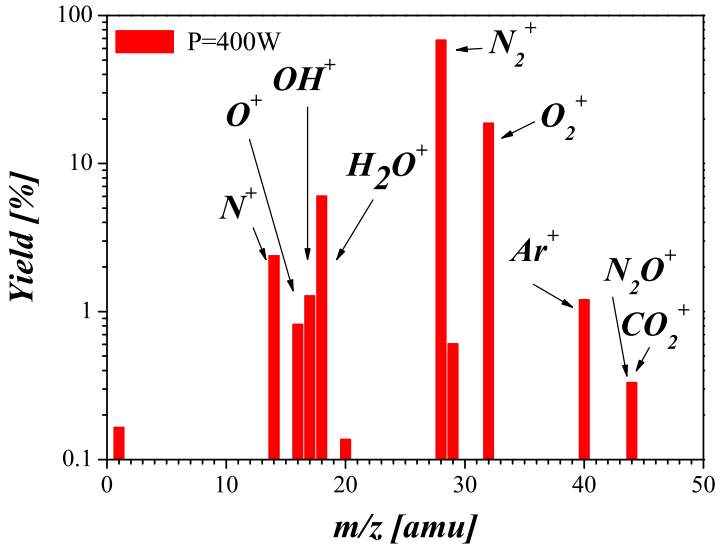

Figure 1: Mass to charge spectra for power of 400 W. Distance from the electrode from the mass analyzer was 5 mm.

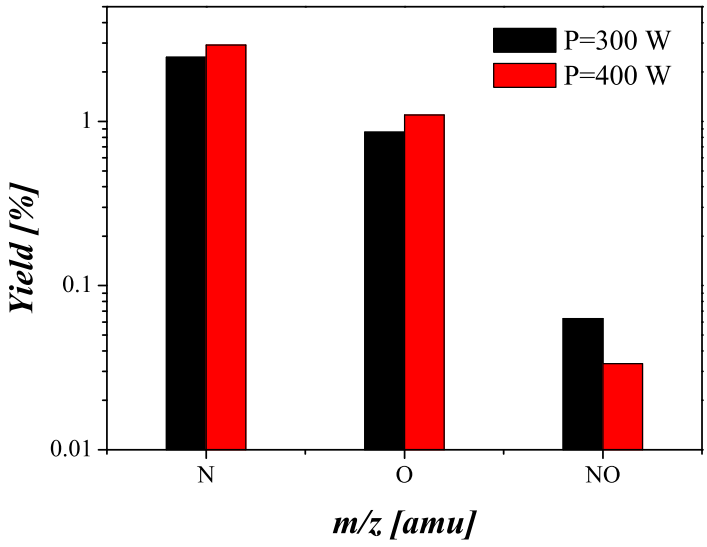

Figure 2: Yields for three different radicals are shown. Distance from the electrode to the mass analyzer was 5 mm and applied powers were 300 and 400 W.

recombination rate at close to the ambient temperature for this reaction is about $10^{-45}m^6s^{-1}$ (http://kinetics.nist.gov). Another possibility is the reaction $N + O_2 \rightarrow NO + O$ which has rate coefficient about $10^{-21}m^3s^{-1}$ at 400 K (Hewson et al. 1999).

Nitric oxide plays an important role in various treatments involving living tissues and organisms and its concentration should be significant in order for the treatment to be successful. On the other hand, nitrogen oxide (NO_2) and ozone (O_3) are quite toxic and its concentrations should be minimized. In our DCSBD discharge concentration of NO_2 and O_3 are very small and this makes this discharge eligible for different types of treatments in ambient air without worrying about pollution.

4. CONCLUSION

We have made mass spectrometry measurements of the diffuse coplanar surface barrier discharge by using HIDEN HPR60 mass spectrum analyzer. DCSBD works in ambient air at atmospheric pressure. Main radicals of our interest were N^+, O^+ and NO^+ since nitric oxide plays important role in various treatments. Significant amount of NO radical is created in plasma and we can say that atmospheric plasma can be an efficient source of nitric oxide. In addition, concentrations of toxic NO_2 and O_3 are very small so this type of discharge may be safe to be used for treatment of living tissues.

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