Study of Gaseous Products Generated by Coplanar Barrier Discharge in Air and N_2/O_2 Mixtures by FTIR spectroscopy

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Abstract: Absolute densities of gaseous products generated by coplanar dielectric barrier discharge in N_2/O_2 mixtures and in ambient air were determined using Fourier transform infrared (FTIR) spectroscopy. The product densities were determined for a wide range of applied input powers (100 – 400 W). Ozone (O_3) and nitrogen oxides (N_2O, NO, NO_2 and N_2O_5) were identified as the stable products of the discharge in N_2/O_2 mixtures, HNO_2, HNO_3 and CO_2 were steadily present in the gas coming from the discharge in ambient air. At a specific input power (and the gas temperature) O_3 disappeared, while NO_2 density started to increase steeply.

Keywords: coplanar barrier discharge, ozone, nitrogen oxides, FTIR.

1. Introduction

Low-temperature plasma (LTP) at atmospheric pressure is currently widely studied as a tool for plasma treatment of the surfaces of various materials. The reason for the wide interest is the potential of plasma applications associated with low costs and environmentally friendly technologies. Plasma interaction with the surfaces of materials depends on plasma composition. Therefore, plasma diagnostics plays the important role in the study of the effect of the plasma treatment.

Reactive oxygen and nitrogen species (RONS) are produced in LTP. These significant particles in plasma play an important role in the positive plasma effect on materials. In the case of bio-medicine, RONS are active in many intercellular and intracellular processes, which can have a positive effect in dermatology, on wound healing, cancer treatment or in therapies involving the cardiovascular system [1,2]. In the area of agriculture, RONS are important in terms of plasma disinfection effect [3] or in plant physiology [4].

Currently, there is increasing interest in the use of LTP generated by different types of dielectric barrier discharges, widely used are surface dielectric barrier discharges (SDBDs) of various electrode configurations. In our work, we focus on the diagnostics of coplanar surface barrier discharge plasma, which is often used in the surface treatment of various materials, in order to better elucidate the key components affecting the treated (for example biomaterial) surfaces.

2. Experimental set-up

The coplanar dielectric barrier discharge (CBD) is a type of dielectric barrier discharge operated typically in air at atmospheric pressure. The coplanar electrode arrangement contains both electrodes on one side of the dielectric barrier. In the used set-up, 19 parallel electrode pairs, connected alternately in parallel, were deposited on 0.7 mm thick Al_2O_3 ceramics with dimensions 20 cm × 8 cm. The electrodes (1.5 mm wide with 1 mm gap) were immersed in oil and cooled by the oil cooling circuit. The electrode system was placed in a box with dimensions 16 cm × 30 cm × 8 cm made of plastics. The electrodes were supplied with AC high voltage (20 kV peak-to-peak, frequency 14 kHz). The input power to high voltage power supply was measured by FK Technics power meter. The ratio of the power delivered to the plasma and to the high voltage power supply input power is then 0.95. In this work, the CBD plasma source was operated in closed reactor. The discharge was generated in an ambient air, oxygen, nitrogen and in mixtures of nitrogen and oxygen in ratio of 80:20, 60:40 and 40:60. The gas flow rate was kept at 3 l/min in all cases. The ambient air was first compressed to ensure the gas flow. The relative humidity of the air was approximately 50 %.

FTIR spectra of the stable gaseous products of the CBD plasma were measured by FTIR spectrometer Bruker Vertex 80v (3 mm detector RT-DLaTGS, KBr beamsplitter). Gaseous products coming out of the reactor chamber passed through the vacuum-resistant stainless steel cuvette (germanium windows, optical path 20 cm), situated in the spectrometer. The tube between the chamber and the spectrometer was 1 m long and 8 mm in inner diameter. The spectra were measured in the wavenumber range of 4000-500 cm^{-1} with 2 cm^{-1} spectral resolution. The densities of the gaseous plasma products were determined by fitting the measured spectra in homemade software H-fit. The rovibrational spectra of N_2O, NO, NO_2, O_3, HNO_3 and CO_2 were simulated using the molecular line data taken from the Hitran 2016 database [5]. The absorption cross sections of these molecules were reconstructed on a wavenumber scale using Voigt lineshape function; mechanisms as pressure broadening by air, pressure self-broadening and Doppler broadening were taken into account.

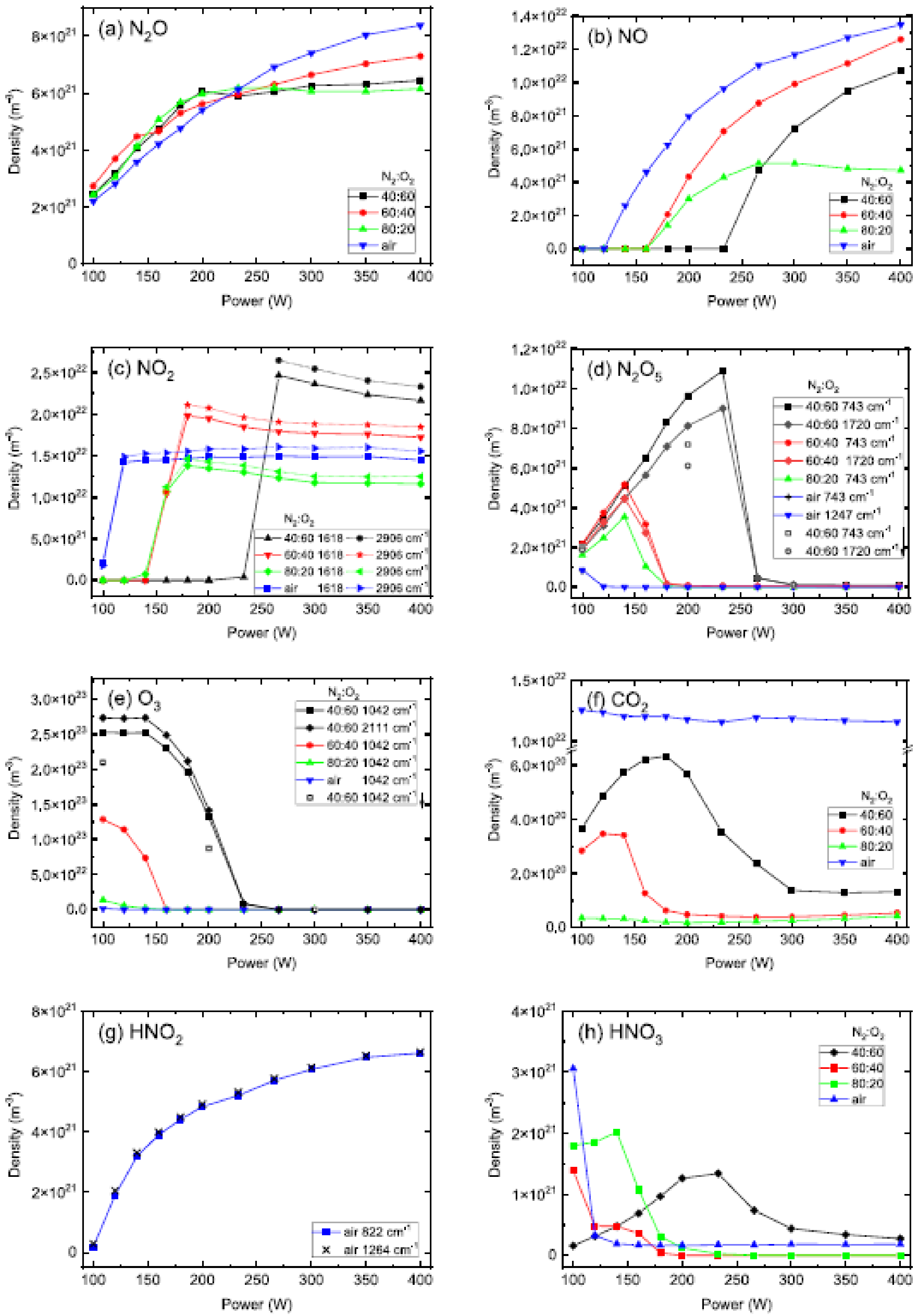

Fig.1: Power dependencies of gaseous plasma product densities measured by FTIR spectroscopy. (a) N_2O, (b) NO, (c) NO_2, (d) N_2O_5, e) O_3, (f) CO_2, (g) HNO_2 and (h) HNO_3

3. Results and discussion

The molecule densities, obtained from the best fits of the theoretical spectra to those measured by FTIR, are displayed as functions of discharge input power in figures 7(a)–(h). O_3 density was high and nearly constant at low input powers (see figure 7(e)). When O_3 was present, the density of NO and NO_2 was very low or even below the limit of detection. After the O_3 disappearance, NO started increasing gradually, while NO_2 increased steeply first and then it decreased only slightly (see figures 7(b) and (c)).

An interesting behaviour was observed in case of N_2O_5 (figure 7(d)). A gradual density increase, observed at low input powers, was followed by a fast N_2O_5 extinction. The extinction occurred at the power of O_3 disappearance and therefore depended on the gas mixture. A similar behaviour was observed in case of CO_2 (figure 7(f)). Since the CO_2 density was still considerably below the concentration of CO_2 in ambient laboratory air, this suggests, that the CO_2 was produced in the discharge from carbon-containing contamination. On the other hand, N_2O density development exhibited only a slope change during the O_3 removal (see figure 7(a)).

HNO_2 did not appear among the products of synthetic mixtures and was observed only as the product of humid ambient air plasma (figure 7(g)). HNO_3 could be monitore in synthetic mixtures based on three curve fitting of 1400-1180 cm^{-1} spectral region. The observed dependencies varied, probably with the water impurity in the plasma reactor (see figure 7(h)). As mentioned earlier, the HNO_2 clearly replaced HNO_3 above 100 W in humid air plasma (watch the blue curves in figures 7(g) and (h)).

4. Conclusion

The absolute densities of stable gaseous products generated by the coplanar dielectric barrier discharge in N_2/O_2 mixtures and in ambient air were determined by FTIR spectroscopy. Ozone (O_3) and nitrogen oxides (N_2O, NO, NO_2 and N_2O_5) were identified as the stable products of the discharge in N_2/O_2 mixtures. Besides, HNO_2 and HNO_3 were abundant in the discharge in ambient air. The product densities were determined for a wide range of applied input powers (100–400 W). More details can be found in [6].

5. Acknowledgment

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6. References

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