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OPTICAL EMISSION SPECTROSCOPY OF ATMOSPHERIC PRESSURE PLASMAS FOR BIO-MEDICAL, ENVIRONMENTAL, AND INDUSTRIAL APPLICATIONS

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Introduction

Atmospheric pressure plasmas in air and nitrogen present considerable interest for a wide range of environmental, bio-medical and industrial applications, such as air pollution control, waste water cleaning, bio-chemical decontamination and sterilization, material and surface treatment, electromagnetic wave shielding, carbon beneficiation and nanotube growth, and trace element analysis. Besides electrical oscilloscopic measurements and photo-documentation, optical emission spectroscopy (OES) in UV-VIS regions is widely used for plasma diagnostics. It provides valuable information on excited atomic and molecular states, enables to determine the rotational and vibrational temperatures of the plasma and thus the level of nonequilibrium and the gas temperature. In addition, it gives insight in the ongoing plasma chemistry [1]. The excited states are produced mostly by collisions with energetic electrons or by thermal collisions, and therefore it is often assumed that optical emission can provide a measurement of the plasma active size, which is of special importance in plasma shielding and other applications.

Experiment

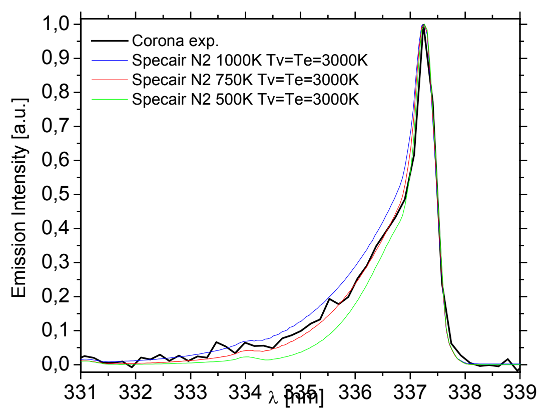
We present emission spectra of three types of DC electrical discharges generating non-thermal plasmas in atmospheric air or nitrogen. The discharges under study are: streamer corona, transient spark, and glow discharge, and they are in more detail described elsewhere [2]. We also investigate emission spectra of atmospheric pressure microwave torch plasma Litmas Red (2.45 GHz, 3 kW) [3] in nitrogen without/with admixtures, which can be used for various industrial and analytical applications. The spectra were obtained by a compact fiber optic emission spectrometer Ocean Optics SD2000 (200-1100 nm, resolution 0.4-1.7 nm).

Results and discussion

Spectra of the N_2 2nd positive system ($C^3\Pi_u$-$B^3\Pi_g$) emitted both in air and nitrogen are the most convenient for plasma diagnostics, since they enable to determine vibrational T_v and rotational T_r (i.e. gas) temperatures by fitting the experimental spectra with the simulated ones (we use Lifbase [4] and Specair [5] simulation programs). Other radiative excited species can be used for this purpose as well, e.g. OH or CN. Fitting experimental spectra with simulated ones is shown in Fig. 1, left.

Owing to fast collisional relaxation at atmospheric pressure, the gas temperature $T_g \approx T_r$. $T_v >> T_r$ indicates the nonequilibrium in the plasma. The preliminary results of temperature measurements are the following:

Streamer corona	$T_g \approx T_r = 500 \pm 200$ K,	$T_v = 6000 \pm 1000$ K
Transient spark	$T_g \approx T_r = 1000 \pm 500$ K,	$T_v = 8000 \pm 1000$ K
Glow discharge	$T_g \approx T_r = 2000 \pm 500$ K,	$T_v = 4000 \pm 1000$ K



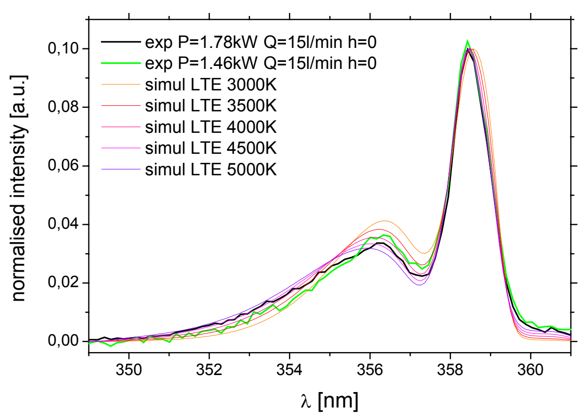
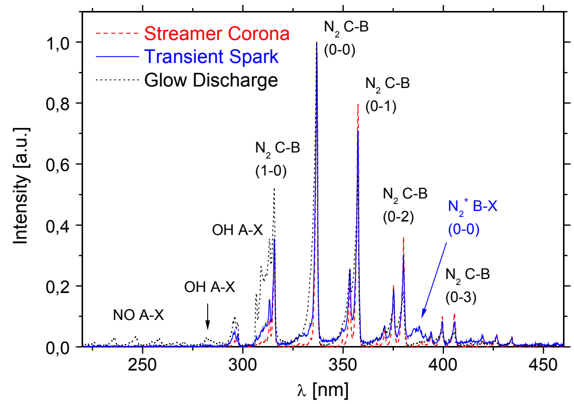


Fig.1. Determination of rotational and vibrational temperatures from N_2 second positive (left) and CN violet (right) spectral bands.

The typical emission spectra of the three types of DC discharge are shown in Fig. 2. Spectrum of N_2 2^{nd} positive system is typically accompanied by the N_2 1^{st} positive system (B^3□$_g$ - $A^3\Sigma_u^+$) in VIS-NIR indicating the formation of N_2 $A^3\Sigma_u^+$ states. These long-lived metastables (energy ~6eV) are very important as reservoirs of energy promoting many plasma chemical reactions leading to harmless condensed products in flue gas cleaning applications. Air plasmas under certain conditions also emit OH ($A^2\Sigma^+$-$X^2\Pi_{3/2}$) and NO □

($A^2\Sigma^+$-$X^2\Pi_r$) systems in UV. OH radical is formed from water vapors present in ambient air, and can be also applied for rotational temperature measurement [1]. NO radical is formed from O_2 and N_2 that dissociate at higher temperatures (>1000 K). NO and OH radicals, detected by means of OES mainly in the glow discharge, play crucial roles in biochemical decontamination, sterilization and water cleaning applications due to their strong bactericidal effect.



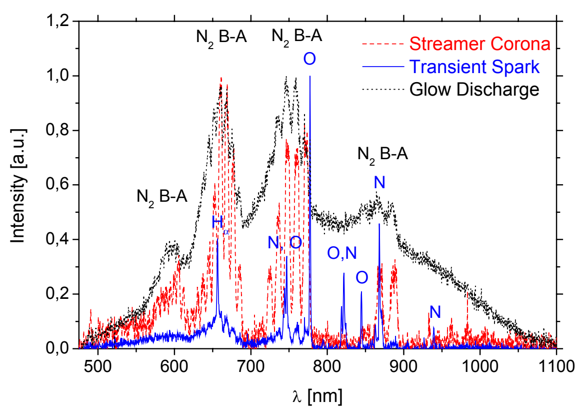
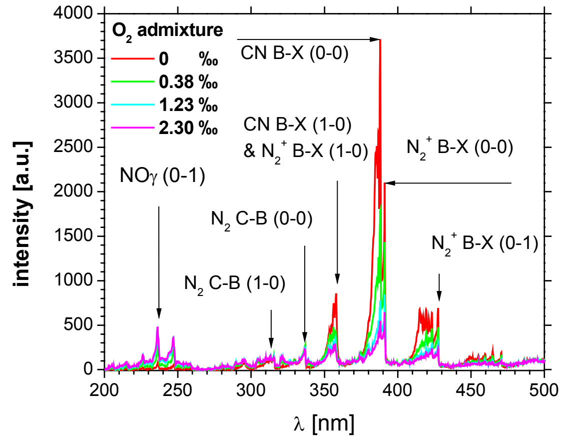


Fig. 2. Typical emission spectra of DC discharges in UV and VIS-NIR regions

Plasmas with high electron temperatures lead to the emission of N_2^+ 1st negative system ($B^2\Sigma_u^+$-$X^2\Sigma_g^+$) in UV and atomic N, O and H lines, as can be observed in the transient spark. These species indicate a high level of nonequilibrium and energetic electrons that are essential in air and water cleaning, as well as in bio-decontamination. This is most likely due to atomic N, O, and H radicals initiating many plasma chemical processes.

Spectroscopic investigations of thermal microwave plasmas generated by a Litmas Red plasma torch (2.45 GHz, 3 kW) in nitrogen revealed that this plasma reaches 3000-4500 K, and is close to LTE conditions. The main emission comes from CN radicals forming in N_2 from carbon-containing impurities. CN violet ($B^2\Sigma^+$ - $X^2\Sigma^+$) system can be used for the plasma temperature measurements in this case, with certain limitations (see Fig. 1, right). A very small admixture of oxygen or water vapor (~100-1000 ppm) dramatically changes the involved plasma chemistry and thus the emitted spectra, strongly decreasing the CN emission and enhancing the emission of NO or NH radicals, as illustrated in Fig. 3.



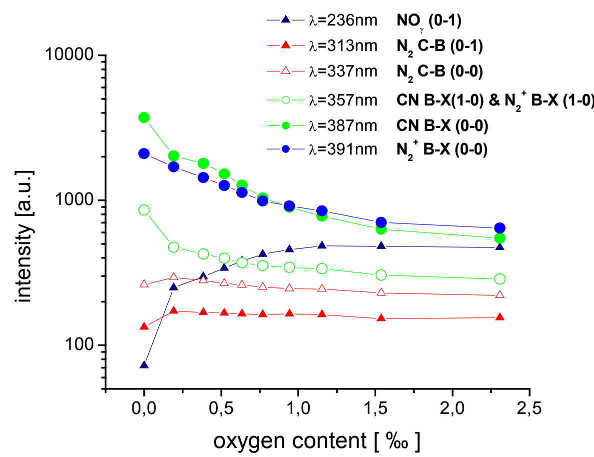


Fig. 3. UV emission spectra of microwave torch plasma in nitrogen with small O_2 admixture (top). The evolution of emission bands with increasing oxygen content (bottom).

Summary

Optical emission spectroscopy in UV-VIS regions is widely used for atmospheric pressure plasma diagnostics. It provides valuable information on excited atomic and molecular states, enables to determine the rotational and vibrational temperatures of the plasma and thus the level of nonequilibrium and the gas temperature, and gives insight in the ongoing plasma chemistry. Optical emission can also provide a measurement of the plasma active size. This technique can be extensively applied to characterize atmospheric pressure plasmas used in bio-medical, environmental, and industrial applications.

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