Optical emission spectroscopy for plasma diagnostics

A. Meiners, HAWK Göttingen (August 2010)

Application Note

Introduction

Nowadays, plasmas can be found in a variety of applications. Plasma treatment, for example, is one of the most efficient ways to clean, activate or coat surfaces. To create and utilize perfect plasma, it is necessary to know all processes that take place within the plasma and its properties. One of the most important methods to get to know these processes is optical emission spectroscopy (OES). As it does not interfere with the plasma itself, information on the undisturbed plasma can be obtained. In OES, the spectrum of the radiation emitted by the plasma is sliced and its intensity measured as function of the wavelength. These spectra allow conclusions on the type and number of the excited particles in the plasma and the rotation and vibration temperatures. For equilibrium plasmas the electron temperature can be derived, in case of non-equilibrium plasmas the so-called excitation temperature is gained. More detailed information on the theoretical background can be found in [1].

Experiment

For the experiment, we examined the plasma of a dielectrically hampered discharge (DBE). A DBE is cold so-called non-equilibrium plasma under atmospheric pressure. It is characterized by the fact that only the electrons have a temperature of approx. 10000 K. The temperature of the ions and neutrons is just above room temperature, which means the plasma stays cold. A dielectric between the electrodes prevents current between them in form of breakdowns and provides homogenous and cold plasma.

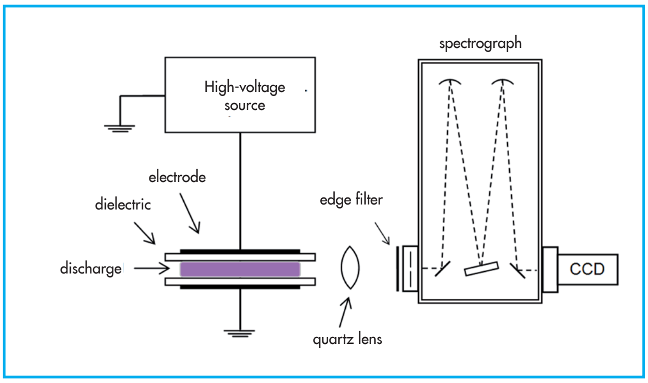

Fig. 1: Experimental set-up to record emission spectra

The DBE plasma source was specially created for spectroscopic examinations and can easily be integrated into the set-up with an optical bank (fig. 2). The two Al_2O_3 dielectrics are 10 mm x 10 mm in size and 1 mm thick. The gas-discharge gap is 1 mm wide. The electrodes consist of a copper foil 6 mm x 6 mm in size. The processing gas is ambient air with a volume flow rate of 1.3 l/min. The high-voltage source produces an ac voltage of about 15 kHz and an amplitude of up to 10 kV.

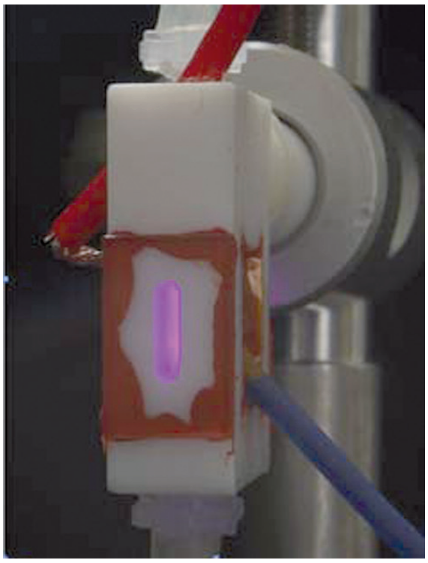

Fig. 2: DBE plasma source in operation

The light emitted by the plasma source was imaged onto the entrance slit of the spectrograph with a quartz lens (f= 25.4 mm, d= 22 mm). The spectrograph (SR-303i-B by Andor Technology) has a relative aperture of f/4. To make optimal use of the grating, it is necessary to completely illuminate the entrance mirror and the connected grating. The necessary image distance can be calculated from the product of the relative aperture and lens diameter. The corresponding object distance can be derived from the focal length of the lens using the Gaussian lens equations. In our experiment, the distance from the lens to the entrance slit was 88 mm; the distance of the plasma source to the lens was 36 mm. We used a grating of 2400 lines/mm and a blaze wavelength of 300 nm to record the spectra from 200 nm to 500 nm, and a 1200 line/mm grating and blaze wavelength of 500 nm for the spectra above 500 nm.

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To avoid recording diffraction maxima of higher orders, an edge filter is used additionally for measurements above 500 nm. The size of the entrance slit was 10 µm.

For detection, we used a 16-bit CCD camera (DV401-BV, 1024 x 128 pixels) by Andor Technolgy. The used camera detects photons in the wavelength range 200 – 1000 nm. As neither the camera's sensitivity nor the reflectivity of the grating are uniform over the entire range, a calibration of the intensity is necessary. This was done with a quartz-tungsten halogen lamp.

Results

Fig. 3 and 4 show typical emission spectra of the plasma in the range of 200 nm to 500 nm and 500 to 900 nm. The intensive bands in the range 270 nm to 540 nm come from the transfer of the N_2 molecule of the second positive system $(C^3\Pi_u \rightarrow B^3\Pi_g)$. Both the bands of the N_2 molecule of the first positive system $(B^3\Pi_g \rightarrow A^3\Sigma_u+)$ from 500 nm on and those of the Herman infrared system $(C''^5\Pi_u \rightarrow A'^5\Sigma_u^+)$ from 700 nm on are a lot less intensive. Also, weak bands of the N_2+ ion of the first negative system $(B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+)$ in the range of 390 nm to 440 nm are detected (see magnified section on the right side of fig. 3). The small bands in the range around 800 nm are transfers of O or Ar atoms.

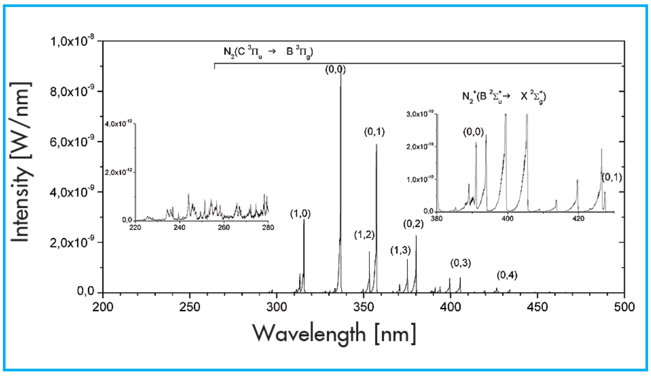

Fig 3: Typical DBE emission spectrum in the range of 200 nm to 500 nm

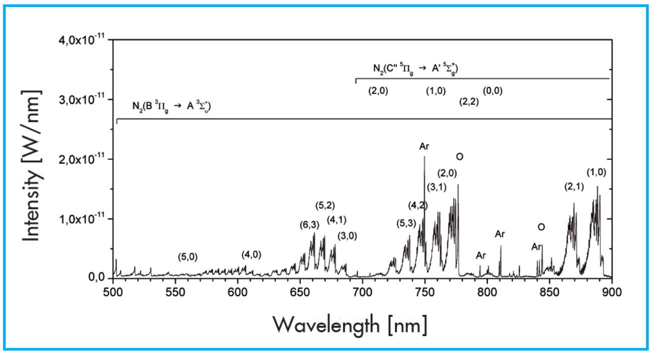

Fig 4: Typical DBE emission spectrum in the range of 500 nm to 900 nm

The spectra were analyzed with Excel. The vibration and excitation temperature were determined by using Boltzmann's application. As the individual rotational bands are not resolved, the synthetic spectrum has to be calculated and compared with the experimental spectrum to determine the rotational temperature. The following table shows typical values for the examined DBD plasma source (plasma power 10 W):

Rotational temperature:	430 K
Vibration temperature:	2870 K
Excitation temperature:	9800 K
Population density of second positive system	$6 \cdot 10^9$ cm^{-3}

The calculated temperatures clearly show the non-equilibrium of the DBD. The concentration of the electronically excited species is in the ppb level.

Conclusion

Optical emission spectroscopy is a suitable tool to detect plasmas and activity within the plasmas. Due to its high dynamic range, its sensitivity and its spectral resolution, the spectrograph with CCD camera used for this experiment is perfectly suited for the detection of the spectra. The included spectrometer software allows easy and intuitive control of the system. For a more detailed analysis of the spectra, additional software like Excel or Origin may be used. When setting up the experiment, all components must be very carefully adjusted, as this has a direct influence on the width of the measured bands. The bandwidth as one of the instrument constants is a determining factor in the calculation of the rotational temperature

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References

[1] A. Meiners, M. Leck and B. Abel, Multiple parameter optimization and spectroscopic characterization of a dielectric barrier discharge in N_2, Plasma Sources Sci. Technol. 18 (2009) 045015

Contact

Annette Meiners
HAWK
Hochschule für angewandte Wissenschaft und Kunst
Fachhochschule Hildesheim/Holzminden/Göttingen
Fakultät Naturwissenschaften und Technik
Von-Ossietzky-Straße 99
37085 Göttingen
Germany

Phone: +49 (551) 508378-13
E-mail: meiners@hawk-hhg.de
Web: http://natec.hawk-hhg.de