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EUV spectroscopy of Nitrogen filled capillary discharge plasma

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We are reporting spectroscopy studies of Nitrogen filled capillary discharge. Identification procedure of spectra was done with use of extreme ultraviolet (EUV) grazing incidence spectrometer with torroidal grating. The source of radiation and the object under study is a pinching alumina capillary discharge in Nitrogen, where stimulated emission in 13.4 nm wavelength region is expected. To simplify alignment of spectrometer during experiment the off Rowland circle registration scheme is used. In this scheme, spectra are recorded in a single plane and thus exact focusing of the input slit takes place only for one single wavelength, which corresponds to the intersection of the plane of registration with the Rowland circle. An appropriate image processing must be applied to reconstruct the spectrum and to calibrate wavelength positions. The cooled EUV-sensitive CCD camera was used in role of planar detector. It has 512×512 elements matrix with 24 μm square pixels. 16-bit dynamic range together with very low-noise provide good data source for image post-processing.

1. Distortion elimination

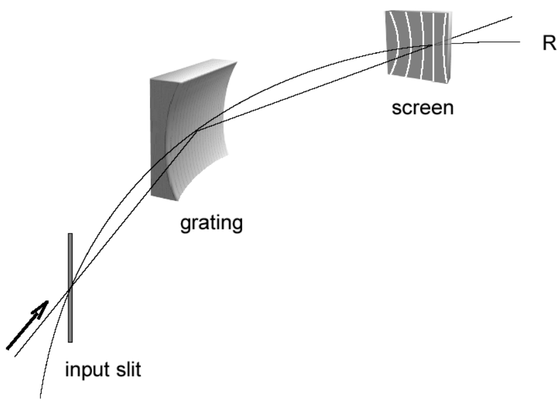

Figure 1: The spatial configuration of the spectrometer with toroidal grating. The input slit is imaging to the screen. The cross section of the screen with the Rowland circle defines on preferred wavelength. Its line is imaged without any astigmatism. All others line are distorted in correlation with the distance between the screen and the Rowland circle.

The spatial configuration of the spectrometer with toroidal grating [1] is schematically drawn in Fig. 1. To eliminate geometrical distortion of spectra the following method is used. Several horizontal profiles are taken on the image with good contrast line pattern. From the line pattern several well-defined lines are selected. Each horizontal profile is separately fitted by multiple Gaussian peaks at selected lines. Positions of their centers define a matrix of distortion. Each column of this matrix is fitted by a parabola. The generated matrix can be used for distortion elimination after its smoothing by the parabola fit. For distortion elimination – image warping – we are using open source program xmorph [2] with sophisticated wavelet amplitude correction to ensure the photometric data from original spectra. The result of these steps is an image with parallel spectral lines over entire screen.

2. Calibration

A spectrum identified in this work is generated by a capillary discharge in nitrogen pre-filled alumina capillary (nitrogen pre-fill pressure 0,49 torr), capillary dimensions were 297 mm long, 3.0 mm in diameter and current form is damped sinus with quarter period t_1=87.5 ns, damping time t_2=600 ns and I_0=22 kA. For comparison we have two independently calibrated spectra [3, 4]. The first one is a spectrum of capillary discharge in nitrogen pre-filled alumina capillary (nitrogen pre-fill pressure 0.9 torr). Capillary

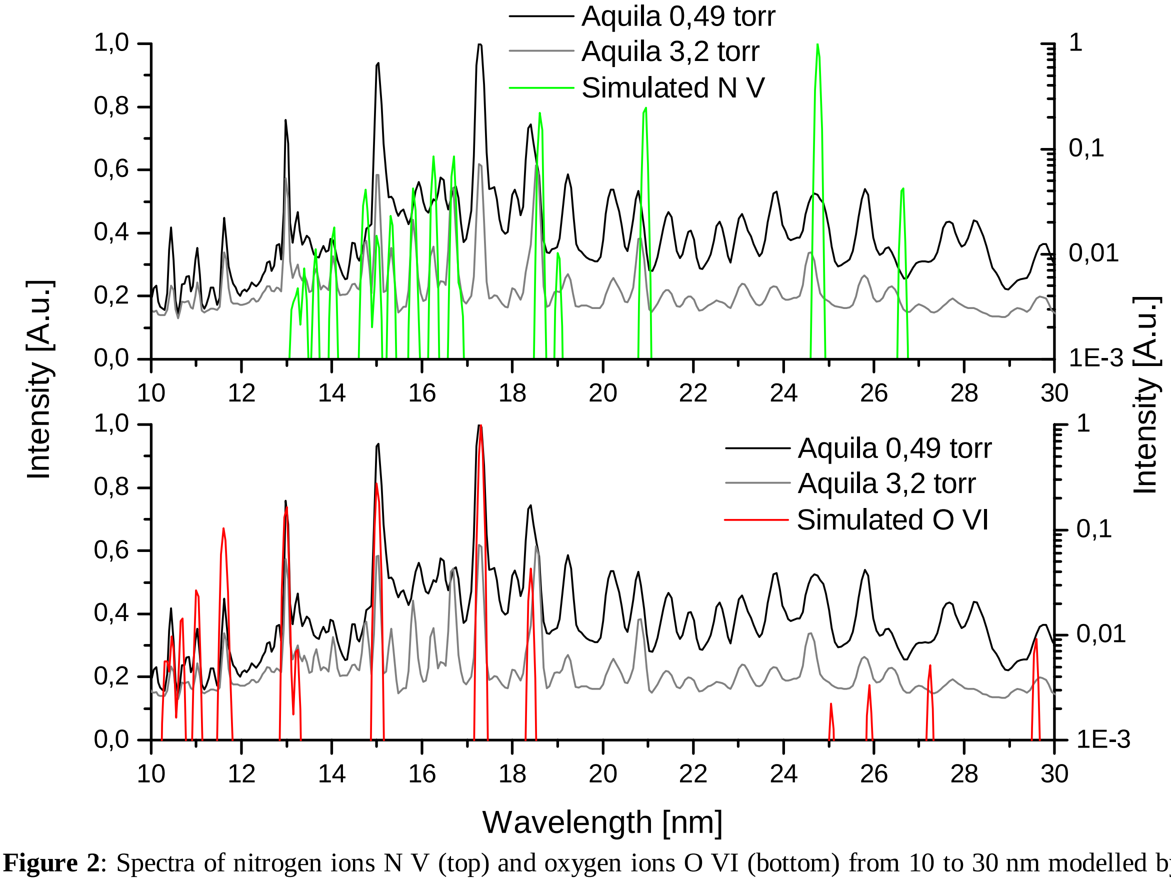

Figure 2: Spectra of nitrogen ions N V (top) and oxygen ions O VI (bottom) from 10 to 30 nm modelled by Sapphire software in logarithmic scale together with measured data at two different pre-fill pressures.

dimensions were 56 mm length and 3 mm diameter, current form is damped sinus with quarter period t_1=150 ns, damping time t_2=600 ns and I_0=15.5 kA. And the second one is a spectrum of ablative capillary discharge in POM capillary. Capillary dimensions were 56 mm length and 1.1 mm initial diameter, current form is damped sinus with quarter period t_1=65 ns, damping time t_2=150 ns and I_0=12 kA. We have identified a strong resemblance between three spectra. Considering that only common element present in every discharge is oxygen, there is a strong indication to assign the most intense lines to oxygen ions. By comparing the simulated spectra of different ions made by Sapphire software [5] with measured values (see Fig. 2) we decided to identify the most intense lines around 13 nm, 15 nm and 17.4 nm as lines belonging to helium like oxygen. Modifying the spectra accordingly we could further identify minor peaks from their absolute wavelength position.

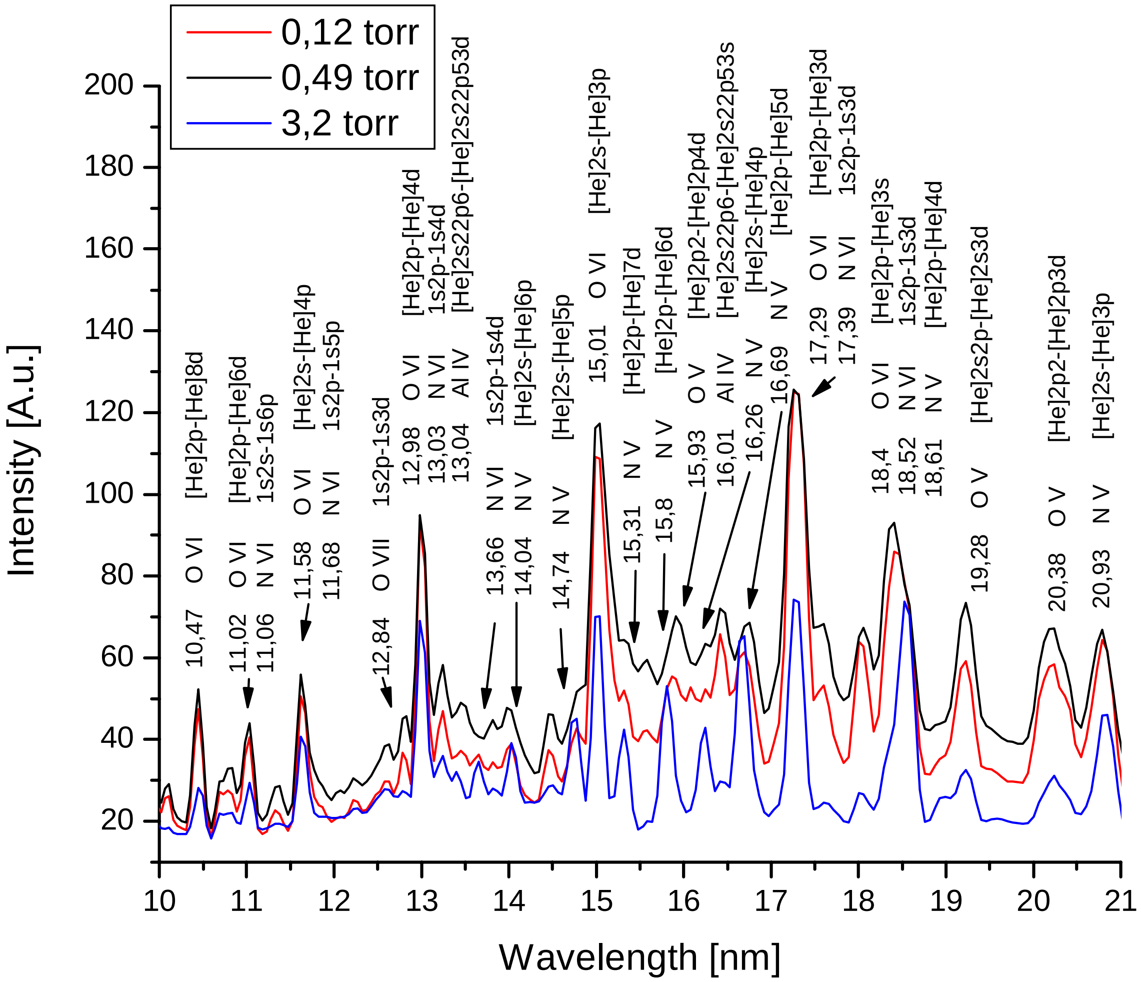

Figure 3: Identification of the spectral lines in region 10 to 21 nm. Measured spectra at three representative pre-fill pressures are displayed.

By assigning the most intense lines to oxygen ions a very good accordance of measurement with simulated lines of He-like oxygen (O VI) was found. Further very good accordance can be seen with simulated lines of He-like nitrogen (N V), especially in experiments with higher nitrogen pre-fill pressure. The Fig. 3 summarizes the identification of the transitions.

From the identification we can see that the lines assigned to the nitrogen ions arise in the measurements with higher pre-fill pressure. This effect comes probably from the fact that with the more dense filling of the capillary the material ablated from the walls (oxygen, aluminum) takes a smaller mass portion of the plasma than before and thus the lines originating from oxygen or aluminum are less intense compared to nitrogen.

3. Conclusion

The experimental impossibility to record simultaneously zeroth order maximum and the first diffraction order spectrum was a crucial problem in presented process. Spectral lines belonging to excited Nitrogen ions N^{4+} and N^{5+} were identified. We may note that we were not able to identify as many lines in the interval above 22 nm then we did in interval 7-22 nm. This may be caused by lower resolution as we are far away off the Rowland circle. The presented methodology can be applied to any experiment using torroidal grating spectrometer.

Acknowledgement

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