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RESEARCH INTO A NEON SPECTRAL LINE PROFILE OF DUSTY PLASMA

Ordered dusty structures influence plasma conditions. This influence can be revealed, when plasma spectral characteristics change, as dusty particles are injected. For example, a variation in the atomic temperature leads to a variation in the profiles of spectral lines. We studied the profile of a 585 nm neon spectral line in the dusty structures. The structures levitated in a positive column of a glow discharge at a pressure of 50–150 Pa and with a current of 1–9 mA. We scanned the profile with the use of a Fabry–Perot interferometer, by changing the air pressure between the interferometer mirrors. To process the data, a special algorithm was developed. The algorithm is resistant to a noise and a scanning speed instability. We have found an upper bound of the impact of dusty structures on the profile width. The appearance of macroparticles changes the atomic plasma temperature less than by 10 K.

Keywords: spectral line profile, dusty plasma, dusty structure, Fabry–Perot interferometer.

1. Introduction

Charged macroparticles levitating in plasma can form ordered dusty structures. Properties of the structures are determined by plasma conditions and *vice versa.* Electrons and ions recombinate on the surface of macroparticles. Having an electrical charge, the grains disturb an electrical field around themselves. Changing the plasma spectral characteristics, as dusty particles are injected, is well studied (see, e.g., [1]).

The impact of dusty structures on the profiles of spectral lines is not studied enough. In [2], the spectral line profile H_β was modeled, and it was shown that an electric field around dusty particles leads to the Stark broadening.

Elementary processes can also be reflected in spectral line profiles. The spectral line profile H_α in an Ar–C_2H_2 RF discharge was investigated in [3]. In plasma without particles, there are hot H atoms with energies more than 10 eV. They are reflected in the wings of a spectral line profile H_α. The hot atoms disappear, when dusty grains appear.

Gas heating is one more way for the dusty particles to change the profiles of spectral lines. Changing the atomic temperature leads to changing the profiles of spectral lines due to the Doppler broadening. Electrons and ions recombine on the surfaces of particles. Hence, an electric field increases to compensate charge losses [4]. The surfaces of particles are by tens Kelvins hotter than the gas around [5] and heat up the gas in the center of a tube where the light emission is the most intensive.

We tried to detect the influence of dusty structures on the 585-nm neon spectral line in a glow discharge positive column.

2. Setup

To conduct the experiment, we constructed a setup consisting of a complex plasma-creating system [1], a Fabry–Perot interferometer, a monochromator, and a photoregistration system based on a photomultiplier. Light from a discharge tube passed through the interferometer. An objective (focus length $F = 10$ cm) formed rings on a monochromator input slit. A 0.15-mm aperture detached a central part of the rings. Scanning was performed by changing the pressure in a camera with the interferometer. The experimental data were obtained with a special computer program.

A DC glow discharge was in the tube 3 cm in diameter. After injections of (1–10)-μm Zn particles, a dusty structure levitated over a special narrowing of the positive column of the discharge. The typical structure had a diameter of 3–5 mm and a length

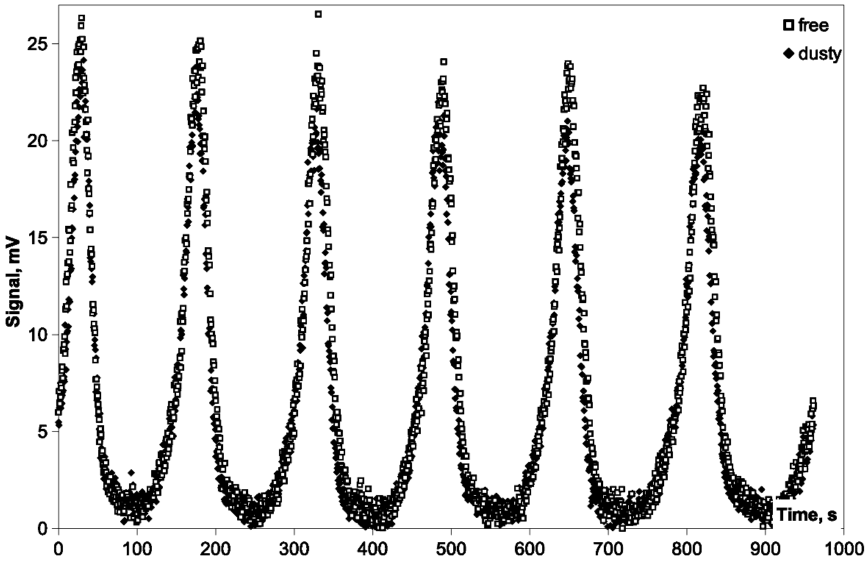

Fig. 1. Raw interferograms. $p = 50$ Pa, $I = 3$ mA

of 7–10 mm. The width of the interferometer was 14 mm. The objective and a lens between the tube and the interferometer drew the discharge image on the slit. The central part of the rings coincided with the dusty structure image. The monochromator detached the 585.2-nm neon spectral line.

A signal from the photomultiplier was measured with a rate of 2×10^4 samples per second. Every experimental point was obtained by averaging the samples in 600 ms. The typical interferogram registration took 1000 s.

To compensate the floating of discharge conditions, we were changing the registration order. If we registered the profiles of the free plasma before the profiles of the plasma with particles for one day, we worked for the next day under the same conditions, but in the reverse order.

3. Data Processing Algorithm

The discharge current must be low to let the self-organization of dusty structures. Hence, the light intensity is weak, and a registration system noise is significant. One more problem is a scanning speed instability. To compare the spectral line profiles, we need to transform them. A special algorithm was developed to solve the problems.

First of all, a dark signal was measured before and after every interferogram registration and was subtracted, considering a linear change of the dark signal. The next step was to divide the interferogram into individual profiles. Then we had to find the maxima of profiles. A simple maximum of the signal could not be used because of the noise. We approximated 15% of the profile top with a parabola and used its vertex as the profile maximum.

After that, we transformed abscissas. The interferometer constant $\Delta\lambda = \frac{\lambda_0^2}{2d} = 12.2$ pm ($\lambda_0 = 585.2$ nm – a center of the spectral line, $d = 14$ cm – a distance between the interferometer mirrors) is scanned in time between 2 neighbor interferogram maxima. The scanning speed was not constant. We used fractions of $\Delta\lambda$ as new coordinates x:

$$x = c_0 + c_1 t + c_2 t^2.$$

The coefficients c were calculated for a current profile to have $x = 0$ for its maximum, $x = -1$ for its left neighbor maximum and $x = 1$ for its right neighbor maximum. The profile must have neighbors, that is why we could not transform coordinates of the first and last profiles in each interferogram. Then we normalized the ordinates of the profiles to their maxima taking a slight intensity change into account.

Then we tried 2 ways of calculations.

– To determine the profile width, we approximated points with ordinates from 0.43 to 0.57 with straight lines and used abscissas of the points of lines with ordinates of 0.5.

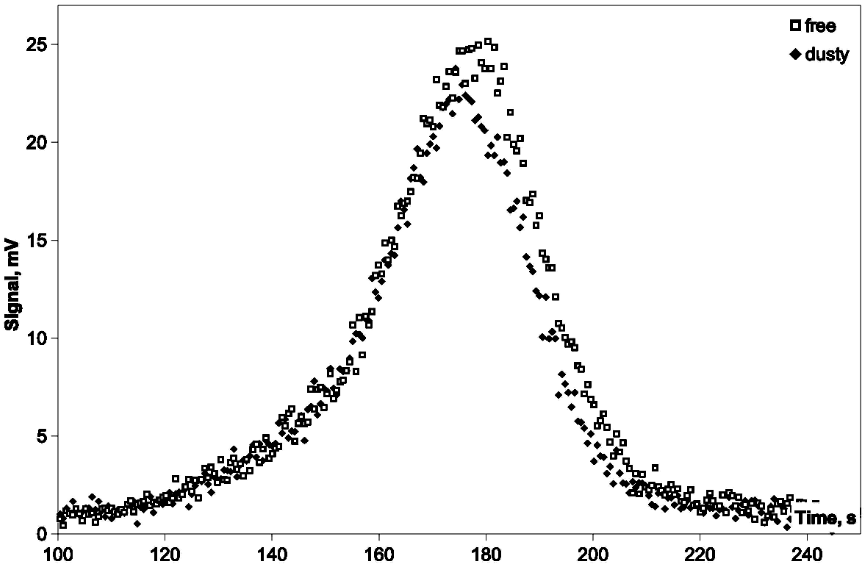

Fig. 2. One peak of the interferograms presented in Fig. 1

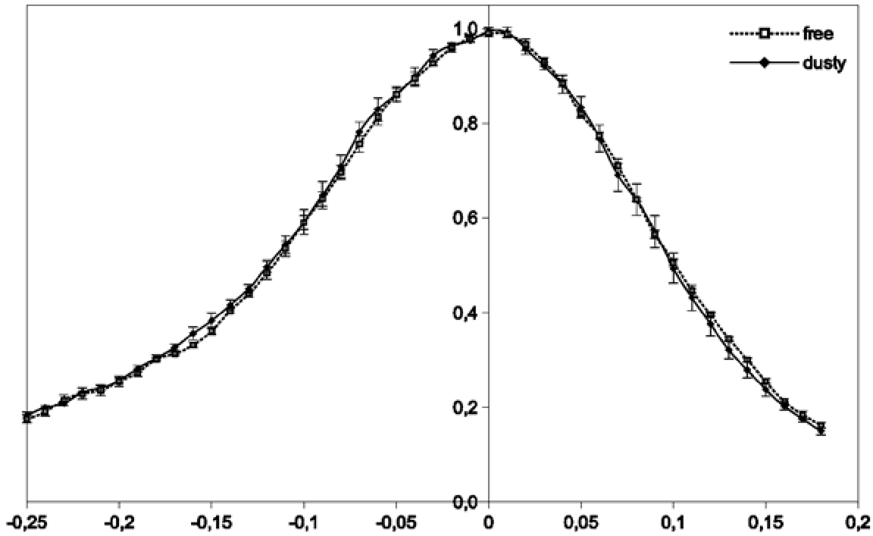

Fig. 3. Averaged profiles obtained from the interferograms shown in Fig. 1. Abscissas are in fractions of the interferometer constant

– To compare the shapes of profiles, we calculated the averaged profile for every interferogram. Every averaged profile consisted of points with a step of $0.01\Delta\lambda$.

4. Results

An example of raw interferograms is shown in Figs. 1–2. These interferograms after transformation are presented in Fig. 3. The difference between the original interferograms is caused by variations of the scanning speed and the start moment. No changes in the shapes of profiles caused by particles can be detected. The profiles are asymmetric due to an isotopic structure.

To detect changes in the widths of profiles, we calculated differences of the widths of profiles with and

Difference between the widths of profiles with and without particles

Conditions	Number of the profiles pairs	Average difference of the widths, pm	Confidence interval for 90% probability, pm
50 Pa, 1 mA	19	–0.019	0.032
50 Pa, 3 mA	16	–0.012	0.038
50 Pa, 6 mA	21	0.003	0.019
50 Pa, 9 mA	18	0.013	0.018
60 Pa, 3 mA	10	–0.031	0.044
100 Pa, 1 mA	18	–0.012	0.033
100 Pa, 3 mA	37	0.007	0.031
100 Pa, 6 mA	18	–0.010	0.026
150 Pa, 3 mA	19	–0.008	0.042

without dusty particles. After that, we checked a hypothesis that the difference is equal to zero. The results are presented in Table. It can be seen that zero is in the confidence interval for every investigated condition.

The confidence interval value is the upper bound of the dusty influence on the profile. A simulation with a program [6] showed that the gas temperature change by 10 K leads to the profile width change by 0.029 pm. For the simulation, we used the Doppler profile shape and an ideal Fabry–Perot apparatus function for the mirrors reflectivity $R = 0.8$.

If no change in profiles was detected, one can use gas temperature data obtained for a discharge without particles for dusty plasma studies. The presented algorithm will be useful for processing the interferograms in a further research.

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ДОСЛІДЖЕННЯ КОНТУРА СПЕКТРАЛЬНОЇ ЛІНІЇ НЕОНА У ПИЛОВІЙ ПЛАЗМІ

Резюме

Впорядковані плазмово-пилові структури впливають на властивості плазми. Цей вплив проявляється у зміні спектральних характеристик плазми при внесенні частинок. Наприклад, зміна атомної температури приводить до зміни контурів спектральних ліній. Ми досліджували контур спектральної лінії неону 585,2 нм. Пилова структура зависала в позитивному стовпі тліючого розряду при тиску 50–150 Па і струмі 1–9 мА. Сканування контуру проводилося за допомогою інтерферометра Фабрі–Перо шляхом зміни тиску повітря між дзеркалами. Для обробки даних було розроблено алгоритм, стійкий до шумів і непостійності швидкості сканування. Було знайдено верхню межу впливу пилових структур на ширину контуру спектральної лінії в досліджених умовах. Поява пилу змінює температуру газу менше ніж на 10 К.