ABOUT UNREALIZATION OF TUNGSTEN LINES UP TO THE GROUND STATE IN THE NONIDEAL PLASMA OF PULSE DISCHARGES IN WATER

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The paper considers the dynamics of tungsten impurity absorption line appearance in the plasma channel of the pulse discharge in water (PDW) during the plasma relaxation process. In the initial stage of discharge (3 μs) any tungsten and hydrogen absorption line is not observed in the spectrum. The optical gap width ΔE in the nonideal plasma exceeds 5.5 eV. After 20 μs in the process of plasma relaxation, the absorption lines appear in the spectrum. They correspond to transitions from the ground level to the levels with higher energies, not exceeding 3.24 eV, i.e. the gap width is 4.74 eV. After 53 μs the gap width decreases down to 2.22 eV. The estimations of the electron concentration in the plasma, obtained on the basis of the gap width, and on the plasma frequency, are in a good agreement.
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1. INTRODUCTION

At present time one cannot practically meet in the literature any data on investigations of metal atom radiation and absorption spectra in the case of high plasma densities (except for mercury [1]). The authors of [2] only noticed that the number of lines corresponding to the material of conductor, which initiates the pulse discharge in water (PDW), increases with time, however the dynamics of their appearance during the plasma relaxation process was not investigated. Not too many experimental results on unrealizable levels of metal atoms can be found also in the review [3]. At the same time in theoretical works [4-6] a possibility of optical gap presence in the nonideal plasma with the high degrees of nonideality is validated.

Thus, there are not enough regular experimental researches in the given field and, therefore, the task has been set to investigate the dynamics of the metal line absorption spectrum with decreasing the degree of PDW plasma nonideality when impurity metallic atoms are introduced into the plasma channel.

2.THE MAIN PART

We have carried out investigations using the equipment with a capacity of discharge batteries of 14.6 μF and a discharge period of 15.5 μs. The diameter of a tungsten conductor electrode initiating the discharge was 320 μm, initial voltage 20 Kv, interval between electrodes 40 mm. In this case the plasma consists, for the most part, of tungsten atoms and ions.

Let us consider the dynamics of absorption tungsten line appearance in the spectral range from 488 to 561 nm. In Figs. 1-3 presented are the microphotograms of the photometric density distributions of a photofilm in this range. The microphotogram (Fig. 1) shows that after 3±2 μs of the discharge it is not possible to reveal any line of tungsten absorption or radiation.

In the ideal plasma in this range of wavelengths there are observed the tungsten lines with a minimal excitation potentials, i.e., 2.66 eV (λ = 551.47 nm), gf = 0.0039 (transition from 3326 to 2145 cm^{-1}); 2.48 eV (λ = 543.5 nm), gf = 0.00063 (transition from 1670 to 20064 cm^{-1}); 2.48 eV (λ = 498.26 nm), gf = 0.0019, (transition from 0 to 20064 cm^{-1}) and others [7] (gf is the product of statistical weights and oscillator strengths at the absorption). The optical gap width is the difference between the atom ionization potential value (E_i) and the higher energy excitation of the observable transition with the greatest excitation potential (E_B): $\Delta E = E_i - E_B$. However, it is not possible to observe them in the absorption spectrum during these moments of time. Even the transitions from the ground state are not observed. This fact unambiguously proves the existence of an optical gap effect, and the optical gap width is equal to $\Delta E \geq 5.5$ eV.

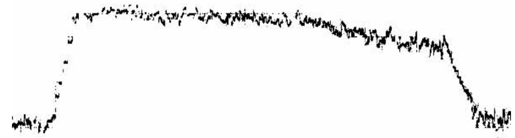

Fig. 1. Microphotogram of the photofilm photometric density distribution in the spectrum range Δλ =488-561 nm, t=3±2 μs

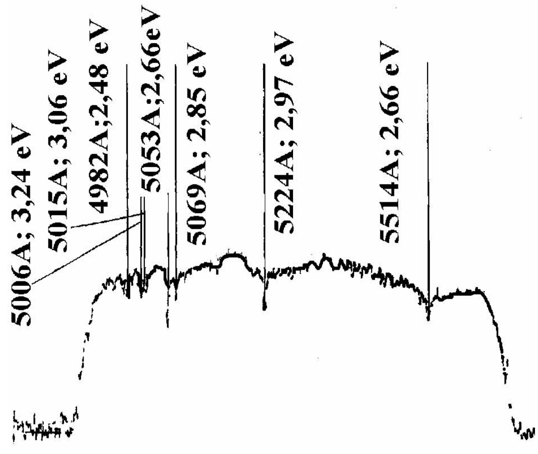

Fig. 2. Microphotogram of photofilm photometric density distribution in the spectrum range Δλ =488-561 nm, t=23±2 μs. Absorption lines of tungsten atoms are marked (the wavelengths are in Å and the excitation potentials are in eV)

In the process of pressure decreasing and slight increase of brightness temperatures (t = 23 μs), against the background of continuous spectrum, very broadened tungsten absorption lines do appear, which belong to the lower spectral levels with an excitation potential not higher than 3 eV (Fig. 2). The lower the excitation potentials, the deeper the downward excursion of tungsten absorption lines. No line with a higher excitation potential at this moment of time is observed, the fact testifying about unrealisation of the upper levels in the microfields of strongly nonideal plasma. The gap in the absorption spectrum in this case is equal to ΔE = 4.7 eV.

The electron concentration N_e was evaluated by the formulas of [4, 5]

$$\Delta E / kT = (3\text{-}4)\cdot\gamma,$$

which after transformations takes the form

$$\Delta E = (3\text{-}4)\cdot Z_i\cdot e^2\cdot(2N_e)^{1/3}, \qquad (1)$$

and by the formula of [6]:

$$\Delta E / kT = 2.4\cdot\gamma^{3/4}, \qquad (2),$$

where ΔE is the width of the optical gap in the spectrum, N_e – electron concentration, T – plasma temperature, k – Boltzman constant, γ– degree of plasma nonideality.

For t=3 μs and ΔE ≥ 5.5 eV these formulas give, respectively:

$N_e \geq (2\text{-}4)\cdot 10^{21}$ cm^{-3} and $5.5\cdot 10^{21}$ cm^{-3}.

For t=23 μs and ΔE ≥ 4.7 eV we obtain the values $(3\ldots 7)\cdot 10^{20}$ and $3\cdot 10^{21}$ cm^{-3}, and the degree of nonideality $\gamma \approx 2.5$ at $T_e = 10^4$ K. The values N_e found for t = 53 μs and ΔE = 4.54 eV are $1\cdot 10^{21}$ and $3\cdot 10^{21}$ cm^{-3}, correspondingly.

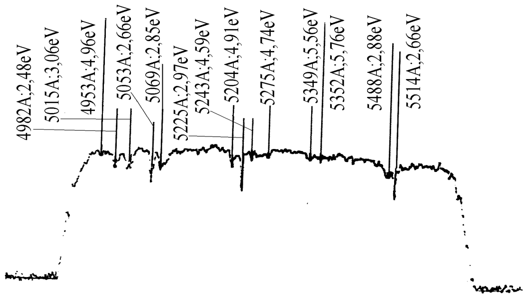

Fig. 3 Microphotogram of photofilm photometric density distribution in the spectrum range Δλ =488-561 nm, t=53±2 μs

Calculations of electron concentration using the plasma frequency, observed in the spectrum, give for N_e the values $\approx 5.0\cdot 10^{21}$ cm^{-3} at t=23 μs and $\approx 4.5\cdot 10^{21}$ cm^{-3} at t=53 μs [9]. Hence the difference between values of N_e, calculated by two independent methods, is no more, than factor three. Therefore, to estimate N_e, one may use the formula given in [6], but for high N_e that formula should be corrected. The similar values of N_e obtained by two methods confirm that the intensity dip observed in the spectrum corresponds to the plasma frequency [8].

To check out the validity of the statement that the lines with high excitation potentials are not realized, let us choose several pairs of tungsten lines with different excitation potentials and very different oscillator strengths [7]. The brightness temperature of plasma is known, thus we shall estimate the intensity ratio (of equivalent widths) for several pairs of lines in the assumption of the Boltzmann distribution of level population by formulas [10]:

$$\frac{W_1}{W_2} = \frac{g_1 f_1 \lambda_1^{-3} e^{\frac{E_2-E_1}{kT}}}{g_2 f_2 \lambda_2^{-3}} \times \frac{1-\exp(-\frac{h\upsilon_1}{kT})}{1-\exp(-\frac{h\upsilon_2}{kT})}, \qquad (3)$$

$$\left(W_1 = \int \Omega(\upsilon)d\upsilon = N_0 f_1 g_1 e^{-E/kT}\right),$$

where E_1, E_2 are the excitation potentials of the upper levels of the first and second lines, T – temperature, W – equivalent line width, **Ω** – dependence of absorption coefficient on frequency, θ – frequency (cm^{-1}). The concentration N_0 of absorbing atoms is absent in the formula because it is reduced in the definition of the line width ratio. In this formula the forced transitions are taken into account also; the gf values are originated from [7]. The calculated results for three pairs of lines are given in the Table.

#	Λ, nm	gf	E, eV	$T\cdot 10^3$K	W_1 / W_2
1	506.9 513.8	0.0045 0.88	2.85 5.9	8…11.5	0.443…0.115
2	522.5 524.9	0.023 1.2	2.97 5.76	8…11.5	0.323…0.137
3	551.4 529.2	0.0039 2	2.66 5.94	8…11.5	0.049…0.0183

These results support the classical consideration of spectra, according to which the lines with a high gf value should appear in the absorption spectrum without fail, because their equivalent widths are larger than the width of lines with small gf value but with low excitation potentials. This result is an experimental confirmation of theoretical assumption about disappearance of upper levels in the strong plasma microfields due to the increase of the degree of plasma nonideality [5, 6].

Thus, we obtained the experimental evidence of a nonrealisation effect and optical gap existence in the nonideal plasma radiation (absorption) spectrum. The optical gap can achieve 5.5 eV or higher values. Therefore, all the levels of optical transitions of atoms can disappear in a strongly nonideal plasma, except the ground state. As the consequence, when calculating statistical sums, one has to use the statistical sums of a nonexcited atom with outer shell electron in a ground state. Since some levels disappear, the recombination rate and radiation intensity of the continuous spectrum are decreasing.

It is obvious from the foregoing: the Boltzman distribution of the upper level population is disturbed. In such a case the nonideal plasma can be considered as a nonequilibrium one. Therefore, to use the "growth curves" for finding the metal atom density on the plasma channel surface, as it was done in [11], is impossible due to disappearance of the upper levels and disturbance of the Boltzman distribution. The values of N_e, obtained using the plasma frequency, are in accord with the values of N_e obtained by the formula of [6] given for an optical gap ΔE in the absorption spectrum.

3. CONCLUSIONS

At the initial stage of the discharge all the absorption line levels disappear and the optical gap width in the spectrum achieves the value $\Delta E \geq 5.5$eV.

With γ decreasing, the gap width decreases too and the levels with increasingly higher excitation potentials are observed. The Boltzman population of the upper absorption line levels is disturbed and, consequently, it becomes impossible to apply the "growth curves" for determining the metal atom density on the plasma channel surface.

The H_α line in the discharge spectrum with high concentration of metal atom impurities was not observed.

The intensity of recombination spectrum radiation increases with increasing number of lines that appear in the radiation and absorption spectra. This is an evidence of the fact that the recombination coefficient increases with decreasing the degree of plasma nonideality and increasing the number of levels, at which the recombination can occur.

REFERENCES

1. V.M. Batenin, P.V. Minaev. On features of the behavior of electro-conductivity and dense low-temperature plasma radiation // *TVT*, 1971, N 9, p. 676-682 (in Russian).
2. L.L. Pasechnik, P.D. Starchik, O.A. Fedorovich, V.V. Yagola. Investigation of the vizible radiation accompanying the underwater explosion of conductors // *Proceedings of the 3-rd Republican Conference" Scientific Fundamentals of Electrohydraulic Effect and Their Use in the Mechanical Engineering and Metalworking,* Nikolaev, 1973, p.41 - 42 (in Russian).
3. A.S. Kakljugin, G.E. Norman. Thermodynamic, optical and transport properties of low-temperature plasma. *Encyclopedia of low-temperature plasma. Introductory Volume/* Ed. by Acad. V.E. Fortov. M.: "Science". MAIK, "Science / Interperiodika", 2000, Sec. 3, p.402-408 (in Russian).
4. G.A. Kobzev, J.K. Kurilenkov, G.E. Norman. To the theory of optical properties of nonideal plasma // *TVT(15)* . 1977, N 1, p. 453-460 (in Russian).
5. G.E. Norman. Continuous spectra of nonideal plasma radiation (absorption). // *TVT(17).* 1979, N 3. p.453-460. (in Russian)
6. V.S. Vorobyov, A.L. Homkin. Influence of potential fluctuations in plasma on the population of high-excited conditions of atoms // *Plasma Physics.* 1982, v.8, N 6, p. 1274-1284 (in Russian).
7. C. Korliss, U. Bozman. *Probabilities of transitions and forces of oscillators of 70 elements*. M.: "Mir", 1968 (in Russian).
8. O.A. Fedorowich // *Problems of Atomic Science and Technology. Series "Plasma Electronics and New Methods of Acceleration" (6).* 2008, N 4, p. 283-287 (in Russian).
9. *Methods of plasma research/* Ed. by V. Lohte-Holtgreven. M.: "Mir", 1971 (in Russian).
10. P.P. Kulik, G.E. Norman, L.S. Polak. Chemical reactions in the nonideal plasma // *Chemistry of High Energies*. 1977, v. 11, N 3, p.195-213 (in Russian).
11. R.V. Mitin. *Investigation of arc high-frequency and pulse high-current gas discharges at high (up to 100 atm) and ultrahigh (up to 2000 atm) pressure*: Thesis for a Doctor's degree on phys.-math. sciences. Kharkov, 1973 (in Russian).

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О НЕРЕАЛИЗАЦИИ ЛИНИЙ ВОЛЬФРАМА ДО ОСНОВНОГО СОСТОЯНИЯ В НЕИДЕАЛЬНОЙ ПЛАЗМЕ ИМПУЛЬСНЫХ РАЗРЯДОВ В ВОДЕ

О.А. Федорович

Рассматривается динамика появления линий поглощения вольфрама в неидеальной плазме импульсного разряда в воде (ИРВ) при введении в канал примесей метала по мере релаксации плазмы. На начальной стадии разряда (3 мкс) в спектре не наблюдается ни одной линии поглощения вольфрама и водорода. Величина оптической щели ΔЕ превышает 5.5 эВ. Через 20 мкс, по мере релаксации плазмы, появляются вначале линии поглощения с переходами с основного уровня на уровни с верхними энергиями, не превышающими 3.24 эВ, т.е. с величиной щели 4.74 эВ, и на 53 микросекунде величина щели составляет 2.22 эВ. Оценки концентрации электронов в плазме по величине щели и по плазменной частоте хорошо согласуются.

ПРО НЕРЕАЛІЗАЦІЮ ЛІНІЙ ВОЛЬФРАМУ ДО ОСНОВНОГО СТАНУ В НЕІДЕАЛЬНІЙ ПЛАЗМІ ІМПУЛЬСНИХ РОЗРЯДІВ У ВОДІ

О.А. Федорович

Розглянуто динаміку появи ліній поглинання вольфраму в неідеальній плазмі імпульсного розряду у воді (ІРВ) при введені в канал домішок металу по мірі релаксації плазми. На початковій стадії розряду (3 мкс) в спектрі не спостерігається ні одна лінія поглинання вольфраму і водню. Величина оптичної щілини ΔЕ перевищує 5.5 еВ. Через 20 мкс, по мірі релаксації плазми, з'являються спочатку лінії поглинання з переходами з основного рівня на рівні з верхніми енергіями, які не перевищують 3.24 еВ, тобто з величиною щілини 4.74 еВ, і на 53 мкс величина щілини складає 2.22 еВ. Оцінки концентрації електронів в плазмі, зроблені за величиною щілини і за плазмовою частотою, добре узгоджуються.