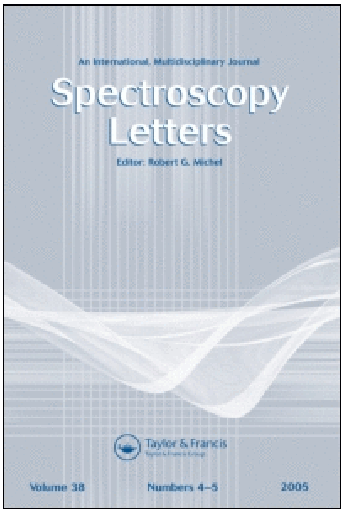

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OPTOGALVANIC EFFECT ENHANCEMENT IN N_2 HOLLOW CATHODE DISCHARGE

KEY WORDS: Optogalvanic effect; Hollow cathode glow discharge; N_2

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ABSTRACT

A considerable increase of optogalvanic signal amplitude for N_2 and hollow cathode plasma stabilization were obtained by using appropriate (N_2+He) mixtures. A qualitative interpretation of this positive effect of He addition was made.

INTRODUCTION

N_2 glow discharge is widely investigated due to its importance for obtaining of nitrogen oxides and compounds. The great interest to this discharge continues by now [1] Recently, the N_2 discharge has also been studied by optogalvanic spectroscopy[2-7]. Some optogalvanic signals (OGS) corresponding to N_2 optical transitions in the visible region are shown in these works. In [8] we have applied the OGS of N_2 for layer and surface profile analysis in a hollow cathode discharge. By using the photoeffect emission from cathode walls we have succeeded both in stabilizing the discharge and considerably enhancing the OGS amplitude.

In this work we have proposed and investigated another approach for N_2 discharge stabilization and N_2 OGS amplitude increase. In order to reach such a positive effect we have used appropriate (N_2+He) mixtures instead pure N_2 discharge.

EXPERIMENTAL

The experiments were performed at a set-up consisting of the following main components: a hollow cathode tube, high voltage supply, nitrogen laser, measuring RC-group, preamplifier, lock-in-nanovoltmeter, and spectrograph. The hollow cathode design is shown in [8] . The cathode is an open-ended cylinder with 6mm diameter and 40mm length. It was axially illuminated by λ=337.1nm spectral line of N_2 laser through special channels. This design turned out to be very useful because not only the pure N_2 OGS was prevented from the harmful influence of the photoeffect but also the rectangular cross-section light emitted by N_2 laser was used in the most effective way. The cathode material (Al) was chosen to be nonresonant to λ=337.1nm generated by N_2 laser. It does not give any OGS under our discharge conditions. The laser flux intensity was $<10^3$kw/cm^2.

The OGS was proportional to the voltage drop change on R=1MΩ resistance. The C=6,7μF condenser separated the discharge high voltage from the measured one. After amplification the OGS was registered by lock-in-nanovoltmeter. The accuracy of spectral line intensity (I) measurement was 5%.

EXPERIMENTAL RESULTS

The OGS=f(i) dependencies (i-discharge current) at pure N_2 discharge and at various (N_2+He) mixtures are shown in fig.1 and fig.2, respectively. The following results arising due to He addition can be obtained by these dependencies:

- The OGS amplitude increases by one order of magnitude;
- The i-region where OGS can be registered becomes more enlarged;

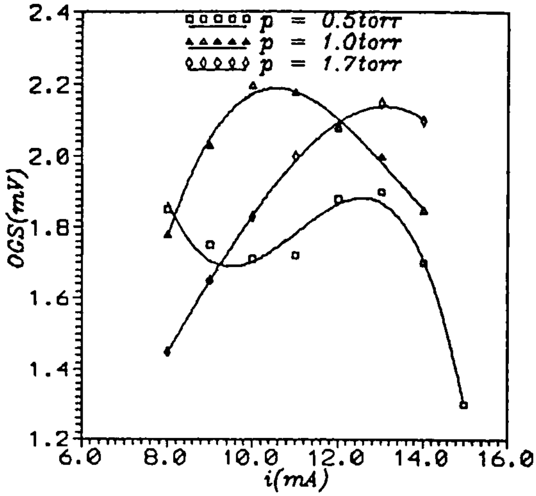

Fig.1. Dependence of the OGS v/s discharge current for pure N_2 discharge.

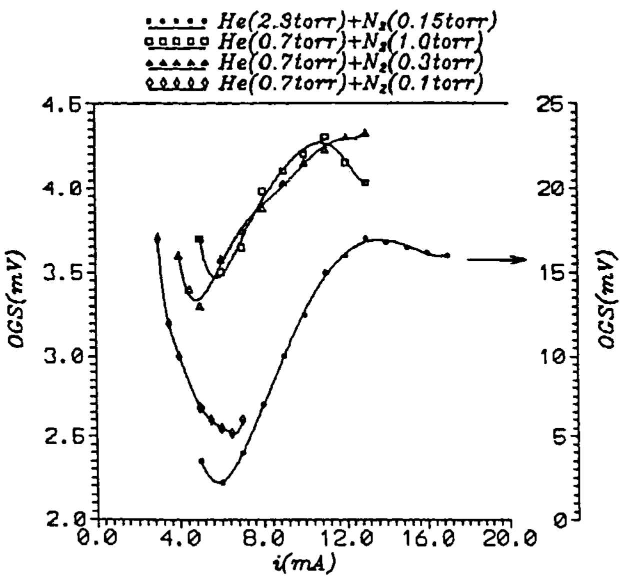

Fig.2. Dependence of the OGS v/s discharge current for various (He + N_2) mixtures.

- The OGS amplitude increase is directly proportional to p_{He}/p_{N2} ratio (p-gas pressure);
- Specific minimums in i=(6-7)mA interval appear in OGS=f(i) function at (N_2+He) mixtures;
- The stabilization of hollow cathode discharge is considerably enhanced.

The I=f(i) dependencies for different spectral lines of N_2, N_2^+,N,N^+ and He were registered in pure N_2, pure He and (N_2+He) mixture at p_{He}/p_{N2}=2.3 torr/0.15 torr (where the OGS amplitude has maximum increase). The comparison of I was made at equal i-values and at pure gas pressure where the spectral lines have maximum intensity.

Table 1 shows that at (He+N_2) mixture the intensity of all measured nitrogen spectral lines increases in comparison with pure N_2 discharge. At the same time all investigated He spectral lines decrease their intensity in comparison with pure He discharge. Especially, in i=(6-7)mA interval, were N_2 OGS shows some peculiarity, this I increase becomes about 20 time for registered spectral lines of N_2^+ while it is about 20% for all N_2 spectral lines. At these discharge conditions the intensity decrease of registered He spectral lines is maximal.

RESULTS AND DISCUSSION

It is well known that main carriers of energy in N_2 molecules are the metastable triplet state $N_2(A^3\Sigma_u^+)$ and the vibrational excited state of basic $N_2(X^1\Sigma_g^+)$ state (fig.3) (referred to as N_2(A) and N_2(X), respectively). The life-time of N_2(A) can reach even seconds. These metastable states are of basic importance in discharge sustainment by three main channels for ionization: ionization by collisions of metastables with electrons or other metastables, super elastic collisions between metastables and electrons (enhancing higher energy part of electron energy distribution function [EEDF] and as a result - the ionization) and secondary ionization, flowing after electron emission from cathode walls caused by metastable bombardment[9] . Usually, obtaining of nitrogen plasma with high concentration is not difficult process especially in a hollow cathode discharge.

TABLE 1. Change of I(in He + N_2)/I(in pure N_2) and I(in He+ N_2)/I(in pure He) ratios for different He and nitrogen spectral lines.

λ [nm]		I(in He+N_2)/I(in pure N_2) at p_{He}/p_{N2}=2,3 torr/0,15 torr; p_{N2}=0,5 torr	
N_2 357,7	N_2 380,5	↑ (25-35)%	
N_2 337,1		↑ ≈ 10 times	
N_2^+ 391,4	N_2^+ 427,8	↑ (10-15)%	i=(3-17)mA
N 415,1	N 410,9	↑ 20%	
N^+ 399,5		↑ 40%	
N_2^+ 391,4	N_2^+ 427,8	↑ ≈ 20 times	i=(6-7)mA
N_2 357,7	N_2 380,5; N_2 337,1	↑ 20%	
$λ_{He}$ [nm]		I(in He+N_2)/I(in pure He) at p_{He}/p_{N2}=2,3 torr/0,15 torr; p_{He}=2,4 torr	
344,7; 361,3; 381,9; 388,8; 392,6; 396,4; 400,9; 402,6; 412,1; 414,3; 438,7; 447,1		↓ 25%- 4 times	i=(3-17)mA

↑- ratio increase; ↓- ratio decrease

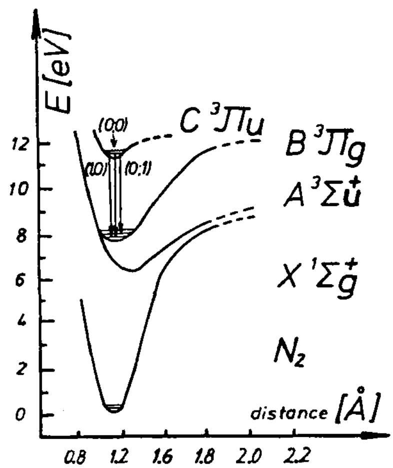

Fig.3. Energetic diagram of the main electronic levels of N_2.

This is a good precondition for a high amplitude OGS registration in this spectral source. On the other side, the EEDF of N_2 in this discharge is known to have a specific minimum in (2-2,5)eV interval corresponding to the maximum of excitation cross-section of the vibrational levels of $N_2(X)$ electronic level by collisions with electrons [10]. This peculiarity very often makes discharge stability worse. Obviously, He addition enriches the EEDF of N_2 discharge both with electrons having energies in the mentioned interval and with more energetic electrons. This results in more effective excitation of N_2 molecules to their metastable levels whose cross-sections of direct ionization by electrons are very high [11]. As a result not only the discharge becomes more stable but also the population of the low level $N_2(B)$ of illuminated transition increases and thus, the OGS amplitude increases.

We also would like to add that much higher thermal conductivity of He than the one of N_2 probably gives a considerable contribution to better discharge stability by using (He + N_2) mixtures.

Concerning the deep minimums of OGS=f(i) functions for (He+N_2) mixtures at very narrow i-interval [i=(6-7)mA] we have assumed that they were caused by Penning reaction between singlet and triplet He metastables and N_2 molecules, namely:

$$He(2^3S_1;2^1S_0)+N_2 \rightarrow He+N_2^{+*} + e^- + \Delta E.$$

The decrease of N_2 molecule concentration as a result of this reaction causes OGS amplitude decrease since its amplitude is directly proportional to $N_2(B)$ population. This reaction is well known to be very likely under discharge conditions similar to ours [12]. Furthermore, the high increase of $I_{N_2^+}/I_{N_2}$ ratio at i=(6-7)mA for (He+N_2) mixture (Table 1) can be taken as a proof of our assumption. We suppose that the dynamic OGS registration should give some useful information for this reaction. Our investigations in this direction are in progress.

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