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An Approach to Quantitative Description of Positive-Column He-Cd$^+$ Laser Power Output (λ=441.6 nm) *)

by

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Summary. The results of theoretical determination of characteristics of positive-column He-Cd$^+$ laser power output at 441.6 nm, based on measured data of plasma parameters and known cross-sections and electron energy distribution functions are presented. Comparisons show a good agreement between the characteristics of He-Cd$^+$ laser power output calculated and measured. The importance of processes determining the He-Cd$^+$ laser power output is pointed out.

1. Introduction. Since the proposal and development of He-Cd$^+$ laser (Fowles and Hopkins [1], Silfvast [2]) many papers have been reported (see reviews: Hattori [3], Mizeraczyk [4], Willett [5]), in which the excitation mechanisms and operating characteristics of a positive-column (PC) He-Cd$^+$ laser were made clear to some extent qualitatively.

The purpose of the present work is to make an approach to quantitative description of PC He-Cd$^+$ laser power output (λ=441.6 nm) on the basis of measured plasma parameters, and cross sections and electron energy distribution functions taken from literature. Our effort is to extend the qualitative explanation of saturation effects in PC He-Cd$^+$ lasers presented in [6], by taking into account the electron energy distribution functions given by Vokaty and Mašek [7, 8] which are more proper for He-Cd mixture than the ones (Postma [9]) used in [6]. Also, other atomic processes, neglected in [6], are taken into consideration in the present calculations of behaviour of PC He-Cd$^+$ laser power output.

2. Rate equations. There are some theoretical and experimental evidences that the role of the lower $5p^2P_{3/2}$ Cd$^+$ laser level in the population inversion of 441.6 nm $5pP_{3/2}$ laser levels is negligible (Janossy *et al.* [10], Browne and Dunn [11], Giallorenzi

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and Ahmed [12]). Since population of lower laser level may be neglected, the PC He-Cd$^+$ laser power output at 441.6 nm is simply proportional to the population of the upper $5s^2\ {}^2D_{5/2}$ Cd$^+$ laser level.

The excitation of the upper $5s^2\ {}^2D_{5/2}$ Cd$^+$ laser level is generally held to be mainly due to Penning collisions between He triplet metastable atoms and Cd ground state atoms (Silfvast [13], Browne and Dunn [11], Miyazaki *et al.* [14]). The destruction processes of the upper laser level can take place either through the radiative decay to the lower laser level and ambipolar diffusion of the Cd$^+$ ions or collisions with electrons.

The rate equation for the population of the upper Cd$^+$ laser level in the steady state may be written as

$$M_T N_2 \sigma_P^* v_{T2} - N_2^+ \tau_{\mathrm{eff}}^{-1} - nN_2^{+*}\langle\sigma_2 v\rangle = 0, \tag{1}$$

where N_2, N_2^{+*}, M_T and n are the densities of Cd atoms in ground state, Cd$^+$ ions in the upper laser state, He triplet metastable atoms, and electrons, respectively. The cross sections σ_P^* and σ_2 stand for Penning ionization and electron collisional deexcitation of Cd$^+$ ion upper laser state, respectively. v_{T2} is the relative velocity between colliding He triplet metastable atoms and Cd atoms, v — the velocity of electrons, and τ_{eff} is the effective lifetime of the Cd$^+$ ions in the upper laser level owing to radiative decay and ambipolar diffusion. The bracket denotes averaging over the electron distribution function.

The estimation of the role of electron impacts in excitation of $5s^2\ {}^2D_{5/2}$ Cd$^+$ laser level shows that these processes can be ruled out as an important source of population of this level in the case of "quiet" discharge, i.e. without moving strations. In the case of discharge with moving strations (Willgoss and Thomas [15, 16]) Eq. (1) probably it does not hold.

The He triplet metastable density M_T necessary to solve Eq. (1) can be obtained from the following equation, adopted for the case of He-Cd discharge from the discussions given originally by Miller *et al.* [17], and Browne und Dunn [11] for the discharge in pure He:

$$nN_1\langle\sigma_{1T}v\rangle - M_T\tau_D^{-1} - nM_T\langle\sigma_{Ti}v\rangle - M_T N_2\sigma_P v_{T2} - M_T^2\sigma_{TT}v_{TT} = 0. \tag{2}$$

In Eq. (2) N_1 denotes the ground-state helium-atom density, τ_D is the characteristic diffusion time for the metastables, σ_P — the total cross section for Penning ionization, $\langle\sigma_{1T}v\rangle$ — the rate coefficient for production of triplet metastable atoms by electronic collisions with ground-state helium-atoms, $\langle\sigma_{Ti}v\rangle$ — the rate coefficient for loss of triplet atoms by ionizing collisions with electrons, $\sigma_{TT}v_{TT}$ — the rate coefficient for loss of triplet atoms through mutual triplet-metastable collisions leading to ionization.

Combining Eqs. (1) and (2), the Cd$^+$ ($5s^2\ {}^2D_{5/2}$) ion density in PC He-Cd$^+$ laser discharge can be calculated with the help of the measured values of plasma