Study of fractional abundance of different ionic species in the He-Cd^+ laser discharge

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Abstract : Ionization rate coefficient, recombination rate coefficient and fractional abundance of different species of helium and cadmium has been computed as a function of electron temperature. The fractional abundance of an ion of charge z can be determined by taking the ratio of density of the ion of charge z to the summation of density of all possible ionizes states. The knowledge of fractional abundance helps in giving the exact interpretations of the experimental results.

Key Word **- fractional abundance, electron temperature, ionization ,excitation, rate coefficients**

I. INTRODUCTION

The gas laser discharge has not been studied from the point of view of to observe the fractional abundance of different ionic species in the laser discharge at various operating conditions. The relative densities of cadmium ions and atoms have been measured [1,2,3].In the argon ion laser [4] and in He-Se discharge [5] the radial profiles of the spectral emission of the discharge have been observed and interpreted in various ways but the results were not explained by considering the idea of fractional abundance. Whenever the experimental results are to be explained quantitatively, the densities in the laser plasma discharge along and across the discharge must be known accurately. In each laser plasma discharge, it is difficult to measure densities of the ionic species and the radial profiles of the densities. Once a theoretical model which can explain results to the desired level is developed, it goes easier to apply this theory to the various laser plasma discharges.

Whenever an electric discharge is passed through the gaseous medium, it produces ions of different degrees of ionization. The gaseous discharge in the equilibrium state contains typical densities of the neutral atoms and ionized species and the electrons. The collision of atoms and ions of different charges and electrons takes place in the discharge which results in the ionization or excitation. When an ion captures an electron, it results in the formation of an ion of lower charge. In this way ionization and recombination rate reach a certain value so as to set equilibrium. The equilibrium remains in a particular state as long as electron temperature in the discharge tube remains the same. And hence changes the densities of the ions and electrons. A change in the electron temperature results in the change of the values of the ionization and recombination rate. Thus the densities of the atoms ions and electrons are completely dictated by the electron temperature. The discharge emission depends upon the fraction of the total density of the species remaining in a particular ionized state, the electron density and electron temperature. The amount of the fraction of the total density of the species remaining in a particular ionized state is called fractional abundance of that ion [6,7]. Mathematically it is expressed as

$$F_z' = \frac{N_{z'}}{\sum_z N_z} \qquad 1$$

where F_z' is the fractional abundance of the ion with charge z' and N_z' is the density of the ions with charge z'.
When discharge is in the steady state the rate of ions with charge z is equal to the rate of recombination of the ion with charge z+1. Therefore we can write

$$N_e N_z S_z = N_e\, N_{z+1}\, \alpha_{z+1} \quad \text{Or}$$

$$N_z S_z = N_{z+1}\, \alpha_{z+1} \qquad 2$$

where S_z is the ionization rate coefficient of the ion having charge z, α_{z+1} is the recombination rate coefficient of the ion of charge z+1 and N_z, N_{z+1} are the densities of ions with charge z and z+1 respectively. The equation 2 can be written as

$$N_{z+1} / N_z = S_z / \alpha_{z+1}$$

The fractional abundance of a particular species can be determined by substituting z=0,1,2,3,---in equation 3 as

$$N_1/N_0 = S_0/ \alpha_1 , \quad N_2/N_1 = S1/ \alpha_2, \quad N_3/N_2 = S_2/ \alpha_2 \qquad 4$$

Combining all such equations and rearranging the terms , we obtain

$$\frac{N_1+N_2+N_3}{N_0} = \frac{S_0}{\alpha_1} + \frac{S_0 S_1}{\alpha_0 \alpha_1} + \frac{S_0 S_1 S_2}{\alpha_0 \alpha_1 \alpha_2} \qquad 5$$

Taking reciprocal

$$\frac{N_0}{\sum N_z} = \frac{1}{\left[\frac{S_0}{\alpha_1} + \frac{S_1 S_2}{\alpha_1 \alpha_2} + \frac{S_1 S_2 S_3}{\alpha_1 \alpha_2 \alpha_3} \pm ----\right]} \qquad 6$$

where $f_1= N_0 /\Sigma N_z$ is the fractional abundance of neutral cadmium atom.

Density of neutral cadmium atoms may be obtained by using equation 6 for a given electron temperature and from which densities of highly ionized of cadmium species may be obtained. The ratios of densities may be obtained by using ionization and recombination rate coefficient. The Seaton's theory[8] can be used to obtain the ratios of the rate coefficient and the ratios of densities But it is believed that Seaton's theory gives spurious results. The ratios of ion densities of HeI, HeII and HeIII have been obtained by using ionization rate coefficients given by Lotz formula[9,10,11] and the recombination rate coefficients have been computed by using Burgess formula[12,13]. From the different ratios so obtained the fractional abundances of HeI, HeII and

HeIII are calculated as a function of electron temperature as a function of electron temperature from 0 to 10 eV and the results are displayed in figure 1.

II. RESULTS AND DISCUSSION

At the low helium is in the atomic form. The ionization of helium starts from electron temperature 1.6 eV. When the electron temperature is increased above 2 eV, the helium atoms starts getting converted into HeII. The rate of increase of the ionization is very high. For the electron temperature between 2 to 5 eV most of the helium remains in the singly ionized form. As the temperature is increased above 4 eV, conversion of HeII into HeIII takes place. At the temperature above 9 eV entire helium is converted into doubly ionized species. The peak of fractional abundance of HeII appears in the range of 3 to 4.5 eV. And it is a broad peak. The fractional abundance of HeI and HeII is 0.5 at the electron temperature of about 2.1 eV.

The helium atoms in the metastable state is one of the colliding partner in the Penning process and singly ionized helium is one of the colliding partner in the Duffenduck process. Thus it is clear that when helium is used as a buffer gas, the electron temperature below 2 eV favors the Penning process and the temperature between 2 to 4.5 eV favors the Duffenduck process. At the electron temperature of 4 eV, the doubly ionized helium (HeIII) starts showing its appearance and its fractional abundance starts increasing where as fractional abundance of HeII starts decreasing and at electron temperature 6.5 eV, the fractional abundance of these two species becomes equal.

The fractional abundances of CdI, CdII, CdIII and CdIV are calculated as a function of electron temperature as a function of electron temperature from 0 to 10 eV and the results are displayed in figure 2. For the electron temperature 0 eV, the only species observed is the atomic cadmium. As the electron temperature is increased about 0.8 eV, the fractional abundance of CdI slightly decreases and it becomes 0.8. More than 80% cadmium is in the neutral form. This region of electron temperature is favorable region for the Penning transfer and Duffenduck process and direct excitation of the laser states.

The singly ionized cadmium starts showing its appearance when the electron temperature is increased above 0.6 eV. Further increase in the electron temperature causes to increase the fractional abundance of CdII and decrease in the fractional abundance of CdI. At the electron temperature of about 1.1 eV, the densities of CdI and CdII becomes equal. Density of CdII reaches its peak value at 1.3 eV. For the electron temperature above 1.3 eV, CdII starts converting into CdIII which is associated with decrease in density of CdII. At about electron temperature of 1.8 eV, densities of CdII and CdIII becomes equal. Further increase in the electron temperature increases the density of CdIII and it reaches its peak value at about 3.6 eV. CdIV starts showing its appearance at abut 2.8 eV and as the temperature increases the density of CdIV start increasing and that of CdIII goes on decreasing.

The study of fractional abundances of cadmium species show that different ranges of the electron temperature are favorable for different excitation processes. It is clear that when electron temperature is below 0.8 eV, it is favorable for the direct electron impact excitation, Penning transfer and Duffenduck reaction. The electron temperature range of 0.8 to 2.5 eV is favorable for Stepwise excitation process.

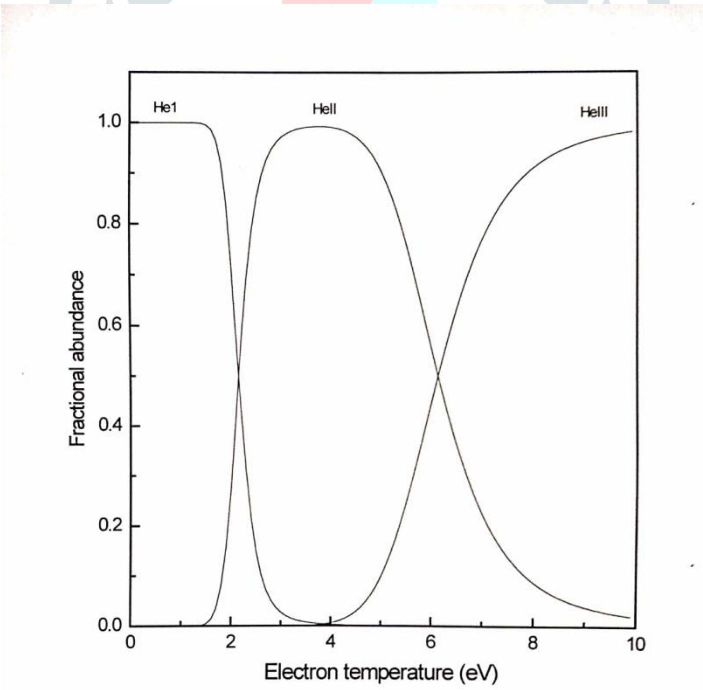

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Fig1: Fractional Abundance of Helium as a function of electron temperature

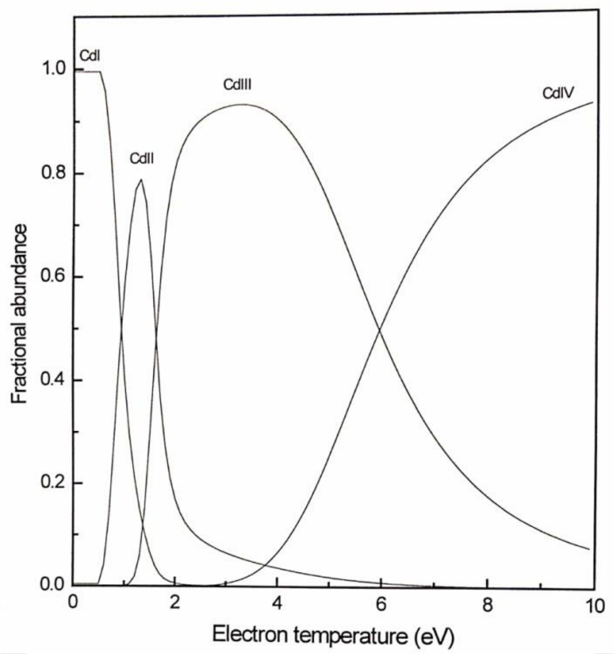

Fig2: Fractional Abundance of Cadmium as a function of electron temperature

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