Densities of different ionic species in the Copper Vapor Laser as a function of electron temperature

[1]Dr Keshatti S N,[2]Dr Chawhan A G ,
[1,2]Associate Professor,

[1] Department of Physics, Shri Shivaji College, Parbhani
[2] Department of Physics, LBS College,Dharmabad Dist.Nanded

Abstract : The discharge pumped gas lasers have not been explored from the point of fractional abundance of the ions in the discharge. The radial and temporal profiles give some hint about the fractional abundance. The knowledge of fractional abundance of different species in a discharge tube helps in obtaining the rate coefficient of a particular excitation reaction, the radial distribution of density and spectral emission etc.

***Key Words* - fractional abundance, electron temperature, collision, recombination**

I. INTRODUCTION

Several workers [1-3] in the field have studied radial profiles of spectral emission but the experimental results have not been explained taking into consideration the idea of fractional abundance. The concept of fractional abundance have been widely used to explain experimental results in the Tokomak plasma discharge [4,5,6]. 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 because the process of measurement is very tedious and costly. 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. The knowledge of fractional abundance can help in giving exact and detailed interpretation of the experimental results.

Plasma consists of the electrons and the ions with different charges. The collision between the atoms, ions of different charges and electrons results in ionization. At the same time the ions may capture the electrons and results in formation of ions of lower charge. The ionization and recombination processes compete each other so that the ionization rate and recombination rate reach, each to a certain value and equilibrium is attained. As long as the electron temperature is not changed the equilibrium remains in a particular state. A change in electron temperature results in changing the densities of ions and electrons. Thus densities of ions and electrons are completely dictated by the electron temperature. The plasma emission depends upon the fraction of total density of species remaining in a particular ionized state, the electron density and the electron temperature.
"The amount of the fraction of the total density of species remaining in a particular ionized state is called as fractional abundance of that ion". Mathematically it may be expressed as,

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

where $F_{z'}$ fractional abundance of the ion with charge z', N_z, density of ion with charge z'.
The sum runs over all possible ionized states. The fractional abundance of a particular species can be evaluated by using steady state condition

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

Where S_z is the ionization rate coefficient of the ion of charge z, α_{z+1} is the recombination rate coefficient of the ion of charge z, N_z and N_{z+1} are the densities of the ions with charge z and z+1
Equation 2 can be written as

$$\frac{N_{z+1}}{N_z} = \frac{S_z}{\alpha_{z+1}} \qquad 3$$

i.e. N_{z+1}/N_z can be evaluated in terms of S_z and α_{z+1}
As the values of S_z and α_{z+1} are fully determined by the electron temperature. Therefore the fractional abundance and population density of any ion in the plasma depends only on the electron temperature. The fractional abundance of a particular species can be evaluated by using equation (3) by putting z = 0, 1, 2 ... we get,

$$A= N_1/N_0= S_0/\alpha_1 \qquad 4$$
$$B= N_2/N_1= S_1/\alpha_2 \qquad 5$$
$$C= N_3/N_2= S_2/\alpha_3 \qquad 6$$
$$D= N_4/N_3= S_3/\alpha_2 \text{ and so on…} \qquad 7$$

Let us multiply equation (4) by equation (5) we get,

$$A*B = (N_2/N_0) = (S_0/\alpha_1) * (S_1/\alpha_2) \qquad 8$$

On multiplying equation (6) by equation (8) we get,

$$A*B*C = (N_3/N_0) = (S_0/\alpha_1) * (S_1/\alpha_2) ** (S_2/\alpha_3) \qquad 9$$

On multiplying equation (6) by equation (9) we get,

$$A*B*C*D = (N_4/N_0) = (S_0/\alpha_1) * (S_1/\alpha_2) * (S_2/\alpha_3) * (S_3/\alpha_4) \text{ and so on….} \qquad 10$$

On adding equations (4), (8), (9), and (10) we get,

$$F = A + (A * B) + (A*B*C) + (A*B*C*D) + \text{------------}$$
$$F = (N_1/N_0) + (N_2/N_0) + (N_3/N_0) + (N_4/N_0) + \text{-----------}$$
$$F = (N_1+N_2+N_3+N_4+\text{--------}/N_0) \qquad 11$$

The equation for the fractional abundance can be written as

$$\text{Fractional abundance} = 1/(F+1) \qquad 12$$
$$= 1/\{[(N_1+N_2+N_3+N_4+\text{--------})/N_0]+1\}$$
$$\text{Fractional abundance} = 1/[(N_0+N_1+N_2+N_3+N_4+\text{--------})/N_0]$$
$$\text{Fractional abundance} = N_0/[(N_0+N_1+N_2+N_3+N_4+\text{--------}) \qquad 13$$

The denominator can be written as

$$N_0+N_1+N_2+N_3+N_4+\text{--------} = \Sigma N_z$$

Thus equation (13) can be written as

$$\text{Fractional abundance} = N_0/\Sigma N_z \qquad 14$$

The equation (14) gives fractional abundance of neutral atom.
In general the fractional abundance of an ion with charge z can be written as

$$\text{Fractional abundance} = N_z/\Sigma N_z \qquad 15$$

The knowledge of fractional abundance of different species in a discharge tube helps in obtaining the rate coefficient of a particular excitation reaction, the radial distribution of density and spectral emission etc.

The CVL discharge is in the form of pulses of short time duration. The ionization and recombination rates very as the time goes and the balance point shifts from one position to other position changing the fractional abundance as a function of time. The total density ΣN_z is determined by the helium pressure in the discharge tube. If the pressure is known then total density of helium can be determined by the equation

$$\Sigma N_z = 10^7 * 10^{16} * p \text{ cm}^3$$

where p is the pressure in Torr at room temperature.

The total density of copper in the discharge tube is a function of helium pressure and the gas temperature in the discharge tube. The total density of copper increases with the increase in the temperature of the discharge tube if the helium pressure is kept constant. For the constant gas temperature of the discharge tube the total density of copper in the discharge decreases as the helium pressure is increased.

II. RESULTS AND DISCUSSION

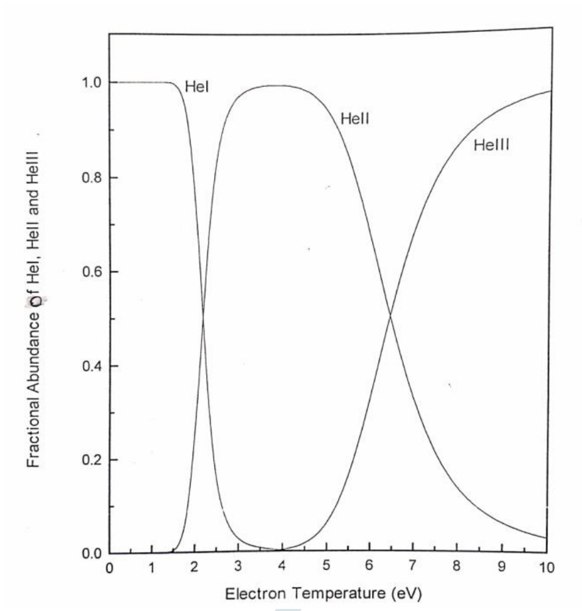
From the knowledge of ionization and recombination rate coefficient we have computed fractional abundance of HeI, HeII and HeIII as a function of electron temperature from 0 through 10 eV. The results are displayed in figure 1. At low electron temperature the helium is in atomic form. The ionization of helium starts from electron temperature 1.6 eV. Above this temperature the helium atoms starts getting converted into HeII ion. 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 5 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. The fractional abundance of HeI and HeII is 0.5 at the electron temperature of about 2.1 eV. Below 2 eV electron temperature most of the helium is in the atomic state and for the electron temperature between 2 to 5 eV most of the helium is in the singly ionized form.

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.

We have computed fractional abundance of NeI, NeII, NeIII and NeIV as a function of electron temperature from 0 through 20 eV. The behavior is similar to the behavior of fractional abundance of helium. The results are displayed into figure 2

The behavior of fractional abundances of CuI, CuII, CuIII and CuIV 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 3. For the electron temperature below 0.8 eV more than 80% of copper is in the neutral state. Since the CVL operates on $^2P_{3/2} \rightarrow {}^2D_{5/2}$ and $^2P_{1/2} \rightarrow {}^2D_{3/2}$ transitions of atomic copper in this region is helpful for the processes like Penning transfer, Duffenduck reaction and electron impact excitation. The colliding partner required in the Penning process is available for the effective collision to take place. However the colliding partner HeII required for the Duffenduck process has very small abundance at such low electron temperature.

The singly ionized copper starts showing its appearance when the electron temperature is increased above 0.5 eV. The density of reaches its peak value at about 1.5 eV. For the temperature above 1.5 eV, CuII starts getting converted into CuIII. In the electron temperature range 0.8 eV to 3.3 eV, the fractional abundance of CuII is more than 0.5 eV. The electron temperature range 0.8 to 3.3 eV is important from the point of view of designing and building CuII laser. The range of electron temperature where the appearance of the species CuIII is prominent is less important in the present work. The ionization of CuIII starts at about 1.5 eV but the rate of increase of fractional abundance of CuIII is very low. The fractional abundance of CuI and CuII are equal near electron temperature 3 eV. The peak of fractional abundance of Cu III is rather broader. At the electron temperature of about 7 eV, the fractional abundance of CuIII and CuIV becomes equal. The favorable electron temperature region for the investigation of the behavior of CuI is quite narrow and it is between 0 to 2.5 eV.



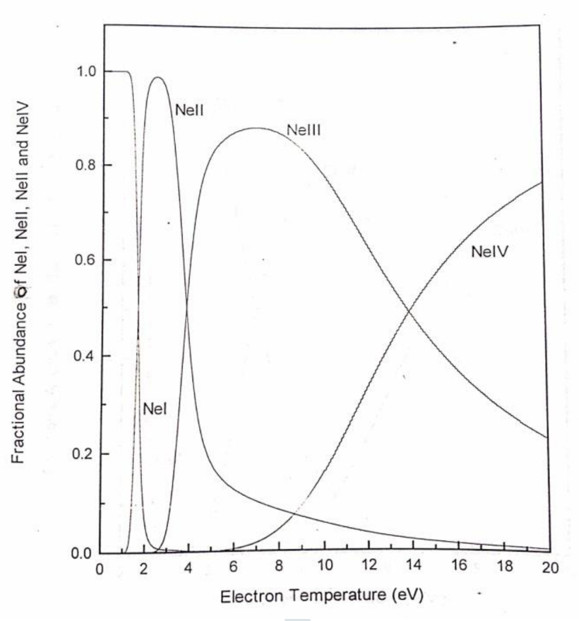


Fig.1 Fractional Abundance of HeI,HeII and HeIII as function of Electron temperature

Fig.2 Fractional Abundance of NeI, NeII ,NeIIIand NeIV as Function of Electron temperature

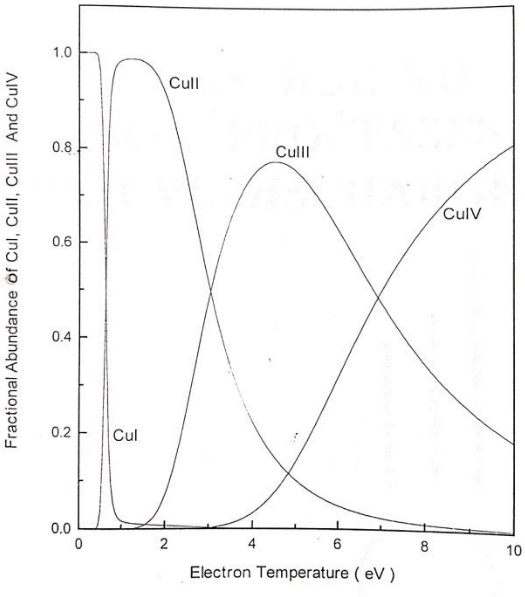


Fig.3 Fractional Abundance of CuI,CuII,CuIII and CuIV as function of Electron temperature

REFERENCES

[1] M J Kushnar abd B E Warner, J Appl Phys, Vol 54, No 6, P 2970-82 (1983)
[2] Y Izawa, T Shimotsu, Proc SPIE Int Soc Eng (USA), Vol 1041, P-19-24 (1989)
[3] Kazuo hayashi, Yasushi Iseki, Jpn J Appl Phys, Vol 31, P L 689,(1992)
[4] C Jordan, Mon Not R Astro Soci, Vol 148, P-17,(1970)
[5] TFR Group, Nucl Fusion, Vol 20, P-207 (1978)
[6] P H Summers,Mon Not R Astro Soci, Vol 169, P-663,(1974)