OUTPUT POWER OF COOPER VAPOR LASER AS A FUNCTION OF ELECTRON TEMPERATURE

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Abstract : In the present work, we have assumed the radial profile of the electron temperature and the electron density have the shape like zero order Bessel function of the first kind with maxima at the axis of the discharge tube. With the above mentioned assumptions of the radial profiles; we obtain the power delivered by the discharge column having length l and radius R_0. The temporal behavior of the annular shape of the output laser beam has been described.

***Key Words* - electron density, electron temperature, ion density, ion temperature, discharge current, electron impact excitation, fractional abundance**

I. INTRODUCTION

The parameters which influence the laser output power do not have uniform value along and across the discharge tube. The factors that influence the laser output power are electron temperature, electron density, copper atom density etc. Thus the total power output would be summation of all such contributions. As the discharge tube employed for operating discharges is cylindrical the plasma column is also supposed to have cylindrical symmetry. We assume that radial profiles of electron temperature and electron density to have shape like zero order Bessel's function of first kind with maxima on the axis of the discharge tube. The simulating radiations travelling parallel to the laser axis and perpendicular to the mirror plane are the most effective because the radiation travelling in the other direction may be treated as oblique radiation and they escape laser cavity after travelling certain distance through the laser plasma column. Thus the volume element parallel to the tube axis and perpendicular to the mirror plane is responsible for the intensity of the out coming laser radiation at a particular position.

The Power Delivered By Volume Element dV Of The Discharge Tube At Laser Wavelength.

The electron temperature is the most important parameter of the radial variation of EIE rate coefficient, fractional abundance, the electron density and hence the laser output power. The electron impact excitation is the most dominant process of excitation compared to the processes of excitation like Penning excitation, Duffenduck excitation and Cascading processes. Thus contribution of other processes on the generation of laser power may be considered as negligible. Thus the power delivered by the laser discharge is obtained by taking into consideration only electron impact excitation. The power delivered by the volume element dV is expressed as

$$\mathbf{dp \;\alpha\; Cu^{*}\, n_e\, R_u\, dV\, h\nu} \qquad 1$$

where Cu^* is the density of copper atoms, n_e is the electron density, R_u is the electron impact excitation rate coefficient and dV is the small volume element under consideration.

When the radiation density is sufficient all the photons emitted by the volume element at the laser wavelength get added to the laser beam. Thus the contribution of the volume element dV to the laser power would be same as RHS of equation 1. The output power of the laser beam can be determined by the density of copper atoms Cu^*, the electron density n_e and the electron impact excitation rate coefficient R_u . In addition to this the density of copper atom depends upon the total density of copper in the discharge which can be determined by the temperature of the discharge. Increase in the temperature of the discharge tube increases the total density of copper species. However this increase in the copper density may decrease the electron temperature as it has been observed in the metal vapor discharge [1-4]. This leads to decrease in the fractional abundance of the copper atoms. Thus increasing the discharge tube temperature continuously will not help in increasing the value of Cu^*. Also the electron density is not a direct function of the electron temperature. The increase in the electron temperature may increase the fractional density of ionized species and the detached electrons may increase the electron density. The factor R_u increases as the square root of the electron temperature. Although the factor R_u may be expressed in terms of electron temperature by some function, the product R_uCu^* cannot be describes a well defined function. Again the optimization of these parameters does not help as these parameters do not have uniform values across the discharge tube. The total power delivered by the discharge column must be optimized and not the individual factors Cu^*, n_e and R_u. Since the factors in equation 1 are the function of the electron temperature and the electron temperature is not same for all the values of R. The power delivered by the volume element having value dV(R) is rewritten as

$$\mathbf{dp(R) = Cu^{*}(R)\, n_e(R)\, dV(R)\, R_u(R)\, h\nu} \qquad 2$$

All the parameters $Cu^*(R)$, $n_e(R)$, dV(R) are functions of distance of the point from the axis. Hence in actual practice the power optimization may be done by obtaining total power as a function of the temperature on the axis of the discharge tube.

Computation Of Total Power Delivered By The CVL Discharge

In order to calculate the total power delivered by the delivered by the discharge tube it is assumed that all the atoms which are excited to the upper laser state contribute to the emission of the radiation at laser wavelength. If the discharge tube is perfectly aligned the discharge column has cylindrical symmetry so that all the parameters will have same values inside a thin hollow coaxial cylindrical shell of radius R and thickness dR. We can approach more closely to the assumption by making the thickness dR as small as possible. The contribution of this shell having unit length in the emission of the laser power at laser wavelength may be written as

$$\mathbf{dp = 2\pi\, R\, dR\, n_e^*\,(R)\, Cu^*\,(R)\, R_u\,(R)\, h\nu} \qquad 3$$

The value of radius R of the shell ranges from zero on the axis to R_0 at the wall of the discharge tube. Thus the total power delivered by the discharge tube is obtained by integrating equation (3) from 0 to R_0

$$P = L\int_0^{R_0} 2\,\pi\, R\, dR\, n_e(R) Cu^*(R) R_u(R) h\nu \qquad 4$$

where L is the length of the discharge tube.

As the functions Cu^* (R) and R_u (R) are not well defined functions of R it is difficult to integrate equation 4. Thus the numerical computations can be used to evaluate the integral for different values of axial temperature T_0. Two different sets of computations can be carried out as i) for constant electron density across the discharge tube and ii) for the electron density given by

$$\mathbf{n_e = N_e(0)\,[1-(R/R_0)^2]} \qquad 5$$

For the first set of the calculations the equation is modified as

$$P = 2\pi\, L\, h\nu\, n_e \int_0^{R_0} R\, dR\, Cu^*(R) R_u(R) \qquad 6$$

and for the second set of computations the equation is modified as

$$P = 2\pi L R\int_0^{R_0} h\nu\, Cu^*(R) R_u(R) N_e(0)\left[1-\left({R^2}/{R_0^2}\right)\right] dR \qquad 7$$

II. RESULT AND CONCLUSION

We have computed the fractional abundance of neutral copper atoms Cu*, the EIE rate coefficient Ru and the product of the fractional abundance of copper atoms and EIE rate coefficient Cu^*R_u. The results are displayed in figure 1. The value of Cu^*R_u is maximum at the electron temperature of about 3 eV. The parameter Cu^*R_u go on decreasing if the electron temperature is increased. The value of Cu^*R_u reduces by a factor of 5 at electron temperature of about 1.2 eV and 5.5 eV. It is very difficult to maintain constant electron temperature across the discharge tube. In general the electron temperature is maximum on the axis of the discharge tube and minimum near the walls of the discharge tube. The discharge must be operated at such conditions that the maximum value of the discharge has favorable electron temperature.

For the calculations of total output power we have assumed that the electron temperature and electron density have radial profiles like zero order Bessel's function. We have taken discharge tube of diameter 2.5 cm. The interval dR is taken to be 0.2 cm. The laser output power is a function of axial temperature T0 has been obtained for the laser transition at wavelengths 5106 A^0 and 5782 A^0 and the results are displayed in the figures 2 and 3. From the figure 2 it is observed that initially the laser output power increases as the electron temperature is increased. When the electron temperature on the axis reaches the value of 2.5 eV, the output plasma starts getting saturated. The output power becomes maximum at the electron temperature of about 3 eV. Further increase in the electron temperature results in the decrease in the output power. Thus it may be stated that the electron temperature on the axis must be in the neighborhood of 3 eV. The value of electron temperature cannot be maintained constant throughout the discharge tube but a pulse forming network can be designed so that we can get the electron temperature in the neighborhood of the favorable region for the maximum time interval. The behavior of output power with the electron temperature on the axis at 5782 A^0 wavelength similar to the behavior at 5106 A^0. The initial increase in the power as the electron temperature increases is because of the increase in the electron impact excitation. After reaching the maximum value the power decreases as the electron temperature increases. This is due to decrease in the fractional density of CuI. If we imagine that the temperature axis is treated as time axis, the curves displayed in the figures 2 and 3 show very close agreement with the experimental results [5-6]. When the discharge pulse is fired the electron temperature starts increasing and reaches a peak value. After some time the electron temperature go on decreasing and reaches to zero.

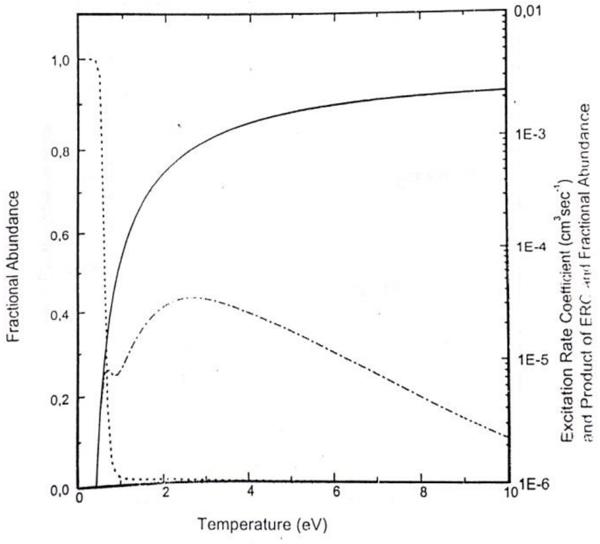

Fig.1 The fractional abundance of CuI(Dotted Curve) electron impact excitation rate coefficient of ($^2P_{3/2}$) state(solid Curve) and the product of these two as a function of electron temperature(Dash Dot Curve)

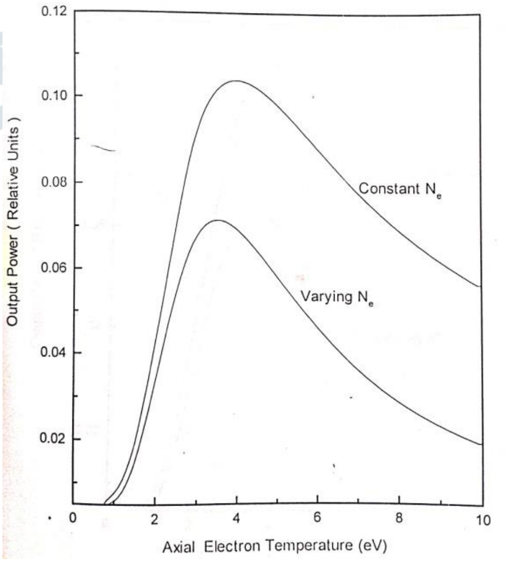

Fig.2 Output power as a function of electron temperature on the axis of discharge Tube with 1)Constant Ne 2) Varying Ne across the discharge tube for 5106A^0 transition of copper atom

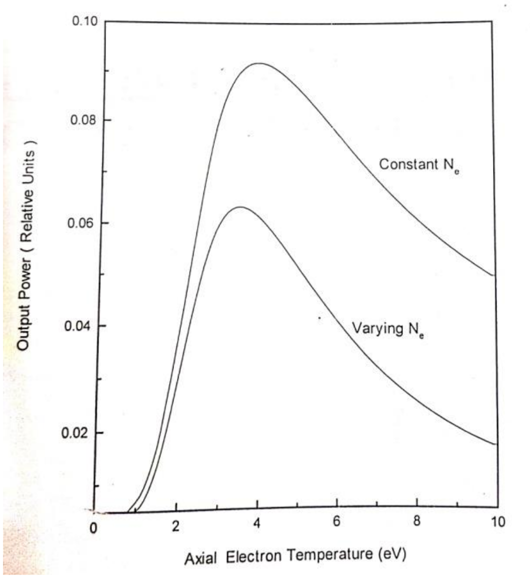

Fig3. Output power as a function of electron temperature on the axis of discharge Tube with 1)Constant Ne 2) Varying Ne across the discharge tube for 5782A^0 transition of copper atom

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