RADIAL DISTRIBUTION OF THE ATOM AND ION DENSITIES IN THE COPPER VAPOUR LASER DISCHARGE

A. P. Pachkawade
Rajarshee Shahu Science College, Chandur Rly., Amravati, Maharashtra

Abstract:

There is a large radial variation in the discharge parameters which dictate the laser output power and therefore the investigation of the radial distribution of the densities and the spectral emission in the discharge gives large amount of information [1-3] than any other type of experimental technique of procuring data related to the operation of the laser. In the present work we have divided the study of the radial profiles into two categories. The first category consists of evaluating radial profiles of the discharge parameters like electron density, electron temperature, copper atom densities, copper ion densities, etc. and the second category consists of evaluating radial profiles of spectral emission of the discharge from the knowledge of electron temperature and the electron or ion densities. In fact, the electron temperature is the fundamental parameter, which is determined by the cooling of the plasma electrons by the walls and the heating of the electrons due to the discharge current. The radial profile of the electron temperature in the discharge is assumed to be given by the equation.

$$T(R) = T_0 [1-(R/R_0)^2] \qquad (1)$$

Where, T_0 - Axial temperature in eV, R – Radial distance at the point in the tube and R_0 – Radius of the discharge tube. The radial profile of the electron density in the gaseous laser discharge tube is also assumed to have similar shape. Initially, from the profiles of the electron temperature, the radial profile of the densities are obtained. In the second category of the radial profiles, we obtain the radial profiles of the spectral emission of the discharge from the knowledge of the electron temperature, electron and ion densities. Furthermore, we have also computed the radial distribution of the fractional density of the copper atoms at different electron temperatures on the axis of discharge tube

Keywords: Copper Vapour Laser, laser radiation, inversion density, dimensions of the laser plasma.

INTRODUCTION

The gas laser medium is a mixture of electrons, atoms, ions of rare gas and active material in the discharge tube. The densities of these particles is found to be not uniform in different parts of the discharge tube. As a result of this the different parts of plasma get heated to different extent. This non uniform heating of the plasma column gives rise to the variation of plasma parameters across the discharge tube. These plasma parameters show their effect on the contribution of the excitation processes to the laser power output. Hence in order to calculate the power output delivered by a laser discharge column, it is essential to study the distribution of the densities and other parameters along the radius of the tube which are known as radial profiles. A.L. Mckenzie [1] in the year 1977, has measured the radial profiles of densities of CdI, CdII, HeI and triplet metastable state of helium in the He-CdII laser discharge. The measurement were carried out at the discharge current of 300mA and helium pressure of 5 torr and the temperature of the system was 235^{0}C.

Watanabe et al [2] have measured the radial profiles of the densities of the cadmium atoms for different values of the helium pressure. The radial profiles obtained in the experiments were explained by considering the diffusion of the cadmium neutral atom.

In 1983 Goto et al [3] studied several experimental and theoretical aspects of the radial profiles in He-CdII ion laser discharge tube near the optimum value of the discharge parameters. He measured the radial profiles of the emissions at the wavelengths 4416, 3250, 6360, 6355, 2144, 2265, 2749, 2313 and 2195^0A. The radial profiles of the densities of CdI, CdII and the helium atoms in the metastable state are also measured. The laser profiles were measured for single set of parameters. If it would have been measured for different sets of discharge parameters it would have been possible to give proper interpretation.

Izawa et al [4] in 1989 carried out some measurements of radial as well as temporal profiles of the densities of the laser states. The measurements were carried out in the CVL discharge tube of diameter 4.2 cm. They show that the radial profiles show dip on the axis before 50 μsec after on set of the discharge and then profiles do not show any dip at later time. They do not explain the reasons behind this type of behavior of the profiles. Moreover, they also observed that density of the upper laser state show slight radial dependence. They attribute part of the results to the skin effect and part to the radial dependant temperature.

Variation of densities in the discharge tube

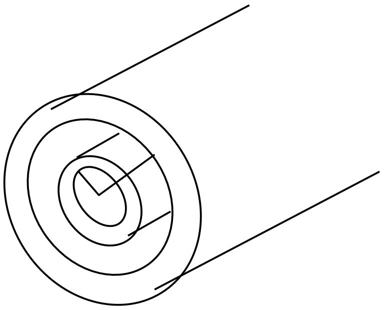

Fig 1: Cross Section showing geometry of the discharge tube

The laser plasma column which is to be investigated is shown in figure 1. A gas column of length l and radius R_0 is excited by electric discharge. The discharge may be divided in to thin co-axial cylindrical shells of radius R and thickness dR. The thickness dR is taken very small so that the parameters which influence the excitation and de-excitation of the laser states may be assumed to be constant over entire hollow cylindrical shell. The measurements of a parameters along a diameter of discharge tube is called as radial profile of that particular parameter.

We obtained the radial profiles of the densities of the ions CuI, CuII, and CuIII for different electron temperature on the axis of the discharge tube. The results are displayed in figures 2, 3, and 4 respectively.

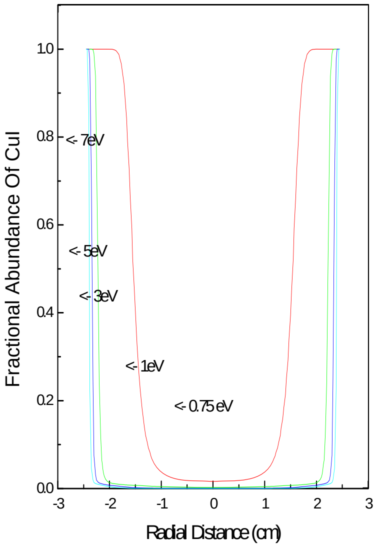

Fig 2: Normalised radial profile of fractional abundance of neutral copper for different electron temperature on the axis of the discharge tube

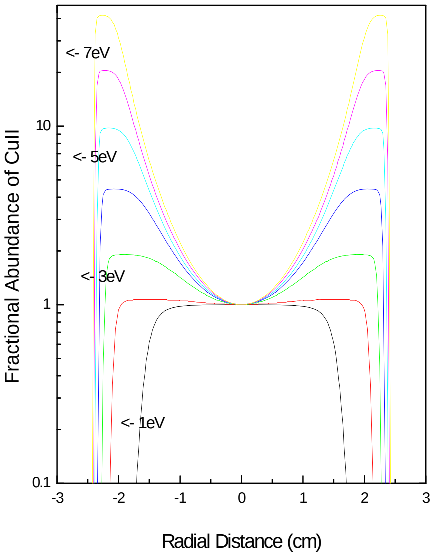

Fig 3 Normalised radial profile of fractional abundance of CuII for different electron temperature on the axis of the discharge tube

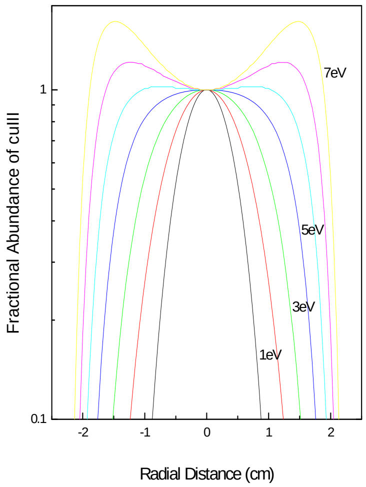

Fig 4 Normalised radial profile of fractional abundance of CuIII for different electron temperature on the axis of the discharge tube.

The electron temperature profile is assumed to be given by the equation 1. When there is no discharge current passing through the laser medium, entire copper is in atomic state, it is represented by the horizontal line parallel to X-axis in figure 2. If the electron temperature increases, the atomic copper on the axis of the discharge tube is converted into singly ionized copper. The ionization is maximum at the axis because the electron temperature is maximum at the axis. The electron temperature is go on decreasing towards wall, the ionization also decreases. Thus the copper atom density go on increasing from axis towards the tube wall. Further, increase in the electron temperature increase the ionization rate and more and more copper gets ionized. As a result of this the density profile of CdI goes on deepening on the axis and the width of the well goes on increasing as the temperature is increased. At low temperatures very few atoms on the axis of the discharge tube gets ionized and CuII show its appearance. The radial profile of the CuII at low temperature is bell shaped as shown in figure 3. The width of bell go on increasing as the temperature at the axis increases. When the temperature is further increased a step comes and the top of the bell gets broadened and curve starts showing dip on the axis. The dip goes on deepening as the electron temperature is increased to higher values and the two side peaks shift towards the walls. The radial profiles of CuIII in figure 4 shows the same behavior as those of CuII except the electron temperature at which the profile start showing dip on the axis.

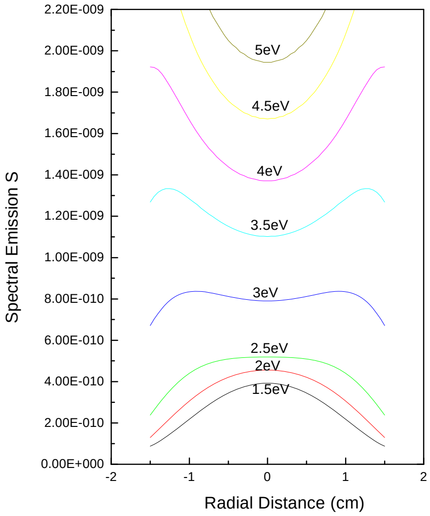

Fig 5 Radial profile of spectral emission of $^2P_{3/2}$---- $^2D_{5/2}$ transition of the discharge at various electron temperature on the axis

The radial profile have different shapes for different electron temperature at the axis and the electron temperature does not remain uniform during the evolution of discharge pulse. By adjusting the proper scaling factor, we obtain the radial profiles of spectral emission of $^2P_{3/2}$---- $^2D_{5/2}$ and the results are displayed in figure 5. The computations show very good agreement with the experimental observations of Izawa et al [4]. The discharge pulse has fast rise time so the electron temperature also increases rapidly and then decreases relatively slowly. Izawa et al have obtained the radial profiles at different temperatures. We assume these profiles may be same because the temporal behavior of the electron temperature is same as that observed by the experiment.

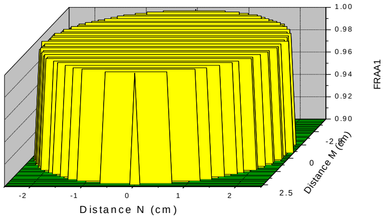

Fig 7: Radial distribution of copper atoms in the discharge tube for temp on the axis = 0.25 eV

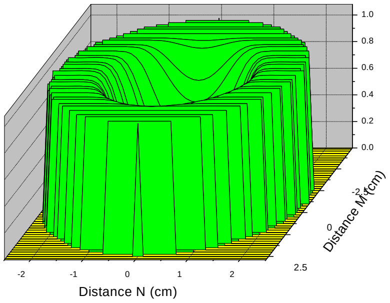

Fig 8: Radial distribution of copper atoms in the discharge tube for temp on the axis = 0.75 eV

The radial distribution of neutral copper atoms in the discharge tube for different electron temperatures on the axis is computed and the results are displayed in figure 7, 8 and 9. The figures show the three dimensional representation of the radial profiles of neutral copper atoms. The electron temperature on the axis of the discharge tube is less i.e.0.25 eV, the fractional density of the copper atom in the discharge tube is maximum through out the tube.

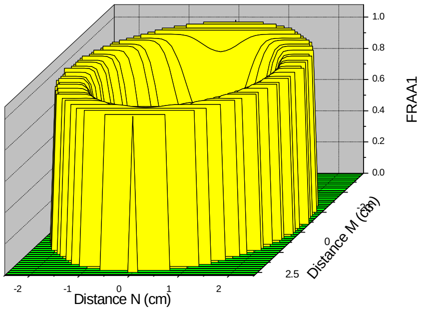

Fig 9: Radial distribution of copper atoms in the discharge tube for temp on the axis = 1 eV

As the electron temperature on the axis of the tube goes on increasing the fractional density of the copper atom goes on decreasing and at the axial temperature of about 1.0 eV, the copper density becomes still less and the fractional density of singly ionized copper atoms show its appearance.

Annular shape of the laser beam

For increasing the laser power the workers in the field increased density of the gas particles and volume of the laser cavities by increasing the diameter and length. The process of increase in the length of the discharge tube has its own limit because if the length is increased beyond certain limit, the discharge cannot be operated of the discharge tube[4,5]. The researchers who increased the diameter found that because of the increase in the diameter the laser beam of the annular shape is obtained instead of increase in output power. The idea of the annular shape laser beam comes from the nature of the radial profiles of spectral emission of the discharge at a laser wavelength.

Kushner and Warner have explained the annular shape of the output by considering skin effect. Recently, Hayashi et al [6] have studied the annular shape of the laser beam in details. They used neon as a buffer gas and studied the effect of hydrogen on the annular shape of the output beam. They observed that the addition of hydrogen in the plasma discharge, the beam becomes less annular in shape. The reason for this was attributed to the high thermal conductivity of the hydrogen. Because of the high thermal conductivity of the hydrogen, the metastable density decreases and the laser power increases.

If the stimulating radiation density is sufficient, entire population inversion is exhausted by the stimulated emission. The laser output at a point in the laser beam would be proportional to the spectral emission intensity at that point. The laser output would have the same profiles as the radial profiles of the spectral emission. If the radiation density is low, a part of the population of upper state is lost in spontaneous emission. The laser beam coming out would have less intensity at these points. If the stimulating radiation is less than its threshold value or the inversion density is less than its threshold value, the laser beam does not come out from that portion of the discharge. Thus, if the radiation density is low, the radial distribution of the laser beam is different than the radial distribution of the spectral emission.[7,8]

References:

1. A. L. McKenzie J. Phys, B: At. and Mol. Phys, 7, L 141 (1974)

2. K. Watanabe, S. Watanabe and T. Sakurai J. Appl. Phys, Vol. 52, P. 3255 (1981)

3. T. Goto, Shimuzu, S. Hattori and T. Sakurai J. Phys. D: Appl. Phys, 16, P. 261, (1983)

4. M. J. Kushner and B. E. Warner J. Appl. Phys., 54 (6), P. 2970-82, (1983)

5. Y. Izawa, T. Shimotsu, Ch. Yamanaka N. Nakashima, E. Fujiwara, T.Yamanaka, S. aki S.Kuruma, T. Takeda and et al Proc. SPIE, Vol 1041, P. 19-24, (1989)

6. K. Hayashi, Y. Iseki, S. Suzuki, I. Watanabe, E. Noda and O. Morimiya Jpn. J. Appl., Vol. 31 D: L1689-91, (1992)

7. Wang Yubo, Mao Bangning, Chen Li, Wang Limin and Pan Bailiang "Optics communications", Vol 278, PP.138-141 (2007)

8. Yangjian Cai and Sailing He JOSA A, Vol.23, PP.2623-2628, (2006)