CHAPTER 1

INTRODUCTION

1.1 Lasers:

The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. In fact laser is a source of light or radiation having a typical set of characteristics. It can be defined as a device that amplifies light by means of stimulated emission of radiation. The idea of stimulated emission was first proposed by Einstein in 1917 (1) while studying emission and absorption properties of quantum system in radiative equilibrium with black body radiation. The first experimental confirmation of stimulated emission was given by Gordon, Zaiger and Towens (2) in 1954 when they built first Ammonia maser. The newly introduced term MASER is an acronym for the Microwave Amplification by Stimulated Emission of Radiation. The first optical laser was realized in 1960 at Hughes research laboratory Maliebu (South California) by Maiman (3) in the form of Ruby (i.e. Aluminium oxide + Chromium) laser. The Ruby laser generates laser output at line of wavelength 6943 Å of pink color. Basically all radiations are electromagnetic in nature but the radiations from the laser are becoming widely applied tool besides science and technology in almost all walks of life due to the following striking special features; 1) high directionality, 2) high intensity, 3) extraordinary monochromaticity, 4) high degree of coherence and 5) wide range of wavelength. Because of wide range of applications number of
different lasers have been discovered till date. A Laser can be realized with solid, liquid or gas as an active medium.

1.2 Copper vapor laser:

Number of solid lasers (4), gas lasers (5,6), liquid lasers (7) and solid state lasers (8) have been investigated experimentally as well as theoretically. All types of lasers are important because each category of lasers has certain advantage over other category of lasers. The gaseous lasers have certain advantages over other types of lasers especially because of the fact that the damages caused to the laser medium can be very easily repaired, whereas, in other types of lasers the damages are irreparable. Solid state lasers are portable and handy, therefore, they can be taken at several places and can be utilized for applications. Liquid lasers deliver tunable beam of light and therefore, have a different set of applications. Solid state lasers can be operated at very low voltages. The metal ions also show the lasing action under typical set of experimental conditions. The ions in the discharge tube being also in gaseous (plasma) state, the metal ion lasers can also be considered as gas lasers.

The CVL which comes under cyclic laser category is a metal vapor laser. It is nothing but the mixture of copper vapors and inert gas excited by electric discharge pulse produces laser action at the wavelengths 5106 and 5782 Å on the $^2P_{3/2} \rightarrow ^2D_{5/2}$ and $^2P_{1/2} \rightarrow ^2D_{3/2}$ transitions of the copper atom (9-16). The mixture is to be excited by high current fast rise time discharge pulse. The intensity of laser radiation at 5106 Å is stronger

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than that at 5782 Å. The CVL can be operated with helium as well as neon as buffer gas. The output of CVL is in the form of pulses of few nsec as the upper laser state has shorter fluorescence life time than the lower laser state (population inversion cannot be sustained for not more than few tens of nsec). The operating temperature of CVL is near 1400 °C so that the material of discharge tube must be such that it should withstand such a high temperature. A special arrangement is to be done for maintaining such a high temperature. There are two categories of laser systems which generate laser beam at 5106 and 5782 Å. In one category beam is produced by 1) passing high current pulses through copper inert gas mixture (17-19) and in another category it is produced by 2) passing two high voltage pulses through a compound of copper consecutively; one pulse for dissociation of the compound and another pulse for excitation of copper atoms produced after dissociation (20-24). The temperature required in the second case is much less than that in the first case. When the laser action is to be obtained from the compound of copper first pulse is used to dissociate the molecules of copper to produce copper atoms in free state. The second discharge pulse excites those copper atoms in to laser states. High efficiency is obtained only when these two pulses are very well synchronized. When the copper inert gas mixture is employed for generating laser action the temperature around 1400 °C must be maintained in the discharge tube in order to produce copper atoms in gaseous form. This method is widely used for producing laser beam as efficiency in this case is high.
The investigation of the CVL properties has received wide attention owing to the fact that it has got wide applications in the field of modern science and technology and high electric efficiency. The CVL may find its applications in newer fields also as the average power of the laser may be scaled to higher values.

1.3 Applications of CVL:

High frequency and high power copper vapor laser play a vital role in isotope separation. The uranium isotope required in fission reactors is less abundant in the natural uranium. The required uranium must be enriched and then used as the fuel in the reactor. The CVL and dye lasers pumped by CVL help in the process of isotope separation (25-26).

Several dyes have maximum absorption coefficient in the spectral region where the wavelength of CVL lies and therefore the CVL acts as efficient pump for the dye lasers (27). Further, the dye lasers may be tuned at wavelengths longer than CVL wavelength. The tunable dye lasers delivering nsec pulses at high frequency have applications in the study of the transient phenomenon and two step excitation processes as the excitation by tunable dye lasers is selective process. The kinetics of photochemical reactions may be investigated using the dye lasers pumped by CVL.

The output power of CVL is more than the threshold power required for the observation of several nonlinear phenomenon as high energy is condensed in the pulses of short time duration. Thus CVL is a good candidate for the

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study of nonlinear phenomenon like frequency doubling, frequency mixing, four wave mixing etc (28-30).

The pulse repetition rate of CVL may be of the order of 5 kHz or higher. The high intensity of laser radiation is concentrated in a pulse of few nsec. The wavelength of CVL is very near to the sensitivity of human eye. Due to these properties CVL can be employed in high speed photography (31). About 5000 photographs of an object can be taken in one sec. The technique helps in studying the events taking place on nanoseconds scale. Thus to study time resolved behavior of the objects the CVL may be used. An event taking place on a nanoseconds scale may be frozen and later on it may be studied in detail. It has been shown experimentally that the fast moving events may be recorded on a video tape at a rate of 2000 full frames or 12000 shift frames per second.

As the emission is in green region the CVL can be employed for underwater ranging. For example for measuring the depth of the sea as water has very low absorption cross section for radiations having their wavelength in the green region. The green light passes through water without much attenuation.

The output beam of CVL has power of the order of 1000 W and sufficient angle of divergence. Consequently, the laser beam spreads over large area after traveling few meters of distance. The CVL may be used for the illumination of the large area which is to be investigated. The images of the objects may be projected on the large screens.
In the field of fast fingerprint identification CVL has high potential. It can be used in police departments, banks and other departments also.

Now a days CVL is being employed in medical science (32) for treating cancer patients and for identifying blood samples. The CVL also plays vital role in ophthalmology by treating the patients having eye diseases.

Beside the above mentioned applications, CVL also has its applications in the fields like industry and holography.

1.4 Review of CVL:

The laser action from copper vapors was obtained for the first time in 1966 by Water et al (33). They observed laser action in the copper vapor at 5106 and 5782 Å wavelengths on the transitions of copper atom. The temperature of discharge tube was maintained around 1400 °C. A high voltage high current pulse was passed through the mixture of copper and inert gas.

Water et al (34) improved laser beam characteristics of copper vapor laser. The vapors of copper were produced by heating the discharge tube up to 1420 °C. The tube was placed in an oven and heated by resistance coils. A discharge pulse with fast rise time (200 nsec) and pulse width of 200 nsec was employed for pumping the laser medium. Pulsed laser action was observed at 5106 and 5782 Å on transitions of copper atom. Helium gas was used as the buffer gas. The laser action was observed at 5106 Å even in absence of reflecting mirrors. The laser pulses were having peak power 1.2 kW and pulse width 200 nsec.
For the first time Leonard (35) gave theoretical description of cyclic lasers. He computes ionization and excitation rate coefficient by assuming the electron velocity distribution to be Maxwellian. He determined the inversion density of laser transition as a function of time. The model helps in obtaining the evolution of the optical pulses from the copper discharge. Subsequently, several designs have been proposed by several workers in the field to improve beam quality, efficiency and output power.

Among all the experimental designs, transversely pumped CVL picosecond pulse amplifiers are important. The output power of laser system has been increased by employing oscillator amplifier configuration (36). The low power oscillator with good quality beam is employed to generate stimulating radiation. The amplifier having capacity to store high energy, amplifies the beam coming from the oscillator. The system can generate high power and good quality beam if oscillator and amplifier are accurately synchronized. The system generates 6 W power at 5 kHz pulse repetition rate.

The Brewster angle windows are fixed at two ends of laser cavity to improve the quality of the output beam. The Brewster angle windows have 100 % transmission for the radiation's having electric field vector oriented in a specific direction and have less transmission for the radiation's having other orientation of electric field. However, the CVL is a pulsed laser delivering output pulses of about 10 nsec pulse width. The utilization of the Brewster's angle window may not help in the improvement of the CVL operation.
Estep et al (37) replaced Brewster angle window by flat windows and they observed that the laser power increases when flat windows are used.

Kim and Sung studied the output characteristics of the CVL when it is excited by the tunable radiation in order to investigate physical properties of the discharge. It has been observed that the spontaneous radiation at the wavelengths 5106 and 5782 Å are emitted by the gas column. The optical pumping excites only $^2P_{1/2}$ state of the copper atom. The observation of radiation at 5782 Å shows that there is a collisional mixing between the levels $^2P_{1/2}$ and $^2P_{3/2}$.

Coults et al (38) designed green to yellow converter. They observed the green to yellow conversion efficiency to be about 50 % in their experiments.

High power and high repetition rate picosecond pulses have their applications in the field of study of fast phenomenon, excited state lifetime measurement kinetics of the photochemical reactions and nonlinear optics. McDonald and Jonah in the year 1984 developed picosecond pulse amplifier using CVL discharge pulses of 20-30 psec width from tunable argon ion pumped dye laser are amplified by CVL discharge. The output of amplifier has peak power 1MW and pulse repetition rate 5 kHz.

At the university of Albuquerque, New Mexico a group of scientists has carried out several experiments on transversely excited CVL (39-42). The transverse electric field could excite the laser states efficiently and laser beam may be obtained at 5106 and 5782 Å wavelengths. A flat plate
double blumelein pulse forming circuit was employed to generate fast pumping current pulse which excited the laser states. Looking to the lifetimes of upper and lower laser states it seems that transverse electric field pumping is most suitable and efficient. The transversely excited lasers generally operate at relatively higher gas pressure. The main problem with this kind of lasers is introduction of arcing which limits output power. The origin of arcing is non-uniformity of electrode shape used in gas discharge.

Kushner and his colleagues (43-45) carried out several theoretical calculations and studied different processes in CVL discharge. They studied the effect of pulse repetition rate, the electron temperature, the ion temperature, the collision cross sections, the electron density, the buffer gas density, the gas temperature, the discharge tube diameter, etc on the laser output pulse. The equations for the electric discharge pulse, the laser output pulse and interpulse after glow period are simultaneously integrated over many cycles and the consistent solutions have been obtained.

The investigation of radial and temporal profiles give concrete basis for study of excitation process in the laser plasma. Kushner and Warner (45) investigated theoretical aspects of the laser discharge having large cross sectional area. They attributed that the annular shape of the leading part of the laser pulse to skin effect and hence explained few results. They have studied the evolution of the electron temperature, the electron density, the excited
state density in time. They have also obtained the radial distribution of the
electron temperature, electron density, density of upper laser state hence the
power delivered by particular element of the plasma in the discharge tube.
Ultimately the expression for the output power from the discharge tube of
various diameters are obtained.

Later in the year 1984 Izawa et al (46) and in the year 1992
Hayashi et al (47) have studied the radial and temporal behavior of the
densities of the laser states and output power respectively. Izawa et al
measured the densities of the active states of the copper atom using a dye
laser and CVL itself.

K. Hayashi et al studied the effect of addition of hydrogen to the
CVL excited in the large diameter discharge tube. It has been observed
that in the leading part of the laser beam the output is in annular form
and in the lagging part it is less annular when neon is used as buffer
gas. The addition of hydrogen to the discharge reduces the larger radial
variation of the intensity across the laser beam increasing uniformity of the
output power across the laser beam. The experimental results are explained
by considering heat loss due to the addition of hydrogen gas.

In order to obtain large average output power the increase in the volume
of the active medium is advised (44, 45). However the large diameter
discharge tubes pose some different types of problems. The output of the laser becomes annular in shape reducing the average output power.

The ionization and recombination processes have not been investigated theoretically and experimentally. The idea of fractional abundances of ions of helium and copper is not yet introduced by any of the workers in the field. The radial and temporal behavior of the output power and densities has not been satisfactorily explained by the theory developed so far. In the case of addition of hydrogen, the reduction in the radial variations is explained by considering high thermal conductivity of hydrogen. However other possibilities are not explored in detail.

In the present work we employ the model developed by Pawar et al (48-49) for the gas lasers to the copper vapor laser.

The model was initially developed to explain experimental results in the He-Cd$^+$ (49) laser discharge. The model could explain almost all experimental behaviors of the discharge. Subsequently the model was employed to explain experimental results in the He-Se$^+$ laser discharge and the results were successfully explained. Thereafter the model was applied to the other gas lasers like He- Zn$^+$, Argon ion etc. It explained the experimental results in all gaseous lasers satisfactorily.
In the present work, I have explained the experimental results in CVL using the model. The ionization rate coefficients of copper, helium and neon ions have been computed as a function of the electron temperature. It is believed that the ionization rate coefficients are solely determined by the electron temperature. The recombination rate coefficient is sum of two rates i.e. radiative recombination rate coefficient and dielectric recombination rate coefficient. The dependence of the rate coefficients on electron density has been neglected as the density in the CVL is of the order of $10^{13}$ cm$^{-3}$. From the knowledge of ionization and recombination rate coefficients, the fractional abundances of helium, neon and copper are obtained.

In CVL, the pumping and excitation pulse is of short time duration as the laser is cyclic. The temperature of electrons in the discharge tube initially increases, reaches to peak value and then declines to zero. The rise time of the pulse is of the order of few nanosec and decay time is of the order of few microsec. When the discharge pulse is fired the electron temperature is maximum on the axis and it goes on decreasing as time advances. Such profile assumed has temperature profile to be triangular in shape. Considering discharge electron temperature to be of this form, the electron impact excitation depending upon fractional abundances of different ions of helium, neon and copper have been obtained. The spatial variations of laser power are obtained by assuming the radial profile of the electron temperature to be like zero order Bessel’s function. For this temperature profile the radial profiles of the
densities of CuI, CuII and CuIII have been obtained. The radial profiles of
spectral emission at laser wavelengths have also been computed. The spectral
emission profiles are compared with experimental values. The radial profiles
of the densities of the laser lower state and laser upper state also have been
obtained. There is a very close agreement between the experimental results
and present computations.

The investigation of radial profiles of spectral emission itself show that
the output laser beam has annular shape. The non annular shape at the
lagging part of the output pulse and the annular shape of the laser beam
in the leading part are also explained with the help of the computations.
The above mentioned shapes of the profiles are explained by temporal profiles. It
has been shown that the effect is independent of diameter of the discharge tube.
In the smaller bore tubes the effect is there but in the larger bore tubes
the effect is more prominent.

I compute the output power delivered by the laser plasma of various
dimensions. The important factor in the determination of output energy of laser
pulse is initial inversion density. It also determines the pulse shape, pulse
height and pulse width of the laser output pulses. The inversion density of
the laser transition are obtained as a function of the electron temperature
and it is studied how the density decays as a function of time. The
output laser beam pulse width limited by the initial inversion density has been studied.

Analytical expression for the angle of divergence of the output beam of the pulsed laser has been obtained. The lasers like Nitrogen, Lead vapor; Magnesium vapor and CVL have large gain. In some cases the laser action may be obtained without mirrors. Consequently the angle of divergence in pulsed laser is larger than that of multiple pass laser. When the discharge pulse is fired through the CVL discharge tube the intensity of the laser pulse starts building up by the amplification of spontaneous emission. When the amplifying radiations pass through medium for the first time they get amplified and the angle of divergence is large in the beginning. As time goes the angle of divergence gets reduced. We have obtained the angle of divergence of a single pass laser as a function of initial inversion density.

I have extended the model computations to study the characteristics of the UV copper ion laser. I have obtained radial profiles of densities and the spectral emission in case of CuII laser in chapter 7.
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