

A study and evaluation on a homemade copper hollow cathode discharge laser and designed pulsed power supply parameters

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Abstract

In this work a copper hollow cathode discharge laser was designed and built to utilize copper transitions parameters for laser investigation. A suitable D.C pulse power was constructed particularly to operate this system. The cathode is a free oxygen copper operated in evacuated glass tube and helium in low pressure used as buffer gas. The relation between the pressure and discharge current was investigated and the optimum values obtained at 1.96A for the discharge current and 28 mbar for the pressure of the discharge regime. The spectral lines of the wavelengths 479.72nm, 510.64nm, 558.64nm and 656.61nm were obtained from the spectrum of the emitted intensity have a potential to be laser lines in addition to, possible laser line transitions in the infrared region at wavelengths 782.36 nm. The wavelength of 510.8 nm was selected through a green filter to be oscillated as laser pulses. The maximum output energy of the laser pulse measured by an energy meter is 1.75 m J. The pulse repetition rate measured was 0.670 KHz with pulse duration of 1.4ms.

Keywords: hollow cathode, copper ion, pulse power, electrical discharge

1. Introduction

Hollow cathode metal vapor laser have received great attention and become an important type class of lasers. Laser transitions in the singly ionized species of several metals have been observed in a wide spectral region, expanding from the near infrared to the ultra violet. The main advantages of these laser systems which employing the hollow cathode geometry is the possibility of simple construction, continuous wave (cw) oscillation, low noise, low running voltage, scalability, simultaneous oscillation at many wavelengths, and high efficiency in visible as well as in the ultra violet regions.

The occurrence of simple evaporation of atoms is due to ion bombardment. The cathode structure and the relative masses of the sputtered atoms with the impinging gas ions play a major role in determining the sputtering rate (M.M. Abdelrahman, 2010). Wehner and co-workers, found a periodic dependence of sputtering yield on atomic number (Coltin S. White, 1962). The heavier the carrier gas the higher the sputtering yield. However, the sputtering yield proportional to the discharge current (I) to the power (m)(Howatson A.M,1965):

$$W \propto I^m$$

Where m, is a constant refer to the type of the cathode. Also the dependence of the sputtering yield on the discharge current and the inverse proportionality to the gas pressure to the 5/2 power was reported by Stock's et al and Colin S. White.

$$W \propto \left(\frac{I}{P}\right)^{5/2}$$

In hollow cathode both ions and photons have less chance to get anywhere except to the cathode, and their effectiveness is increased with the depth of the enclosed cavity. In the case of the hollow cathode the fast electrons must follow a path nearly perpendicular to the glow boundary, and that in a strong field of the dark space. A number of electrons can therefore make multiple passages within the cavity, producing a greatly increased number of ions and photons. Hence the current and the emitted intensity are further multiplied.

The hollow cathode discharge HCD has plasma of high electron energy and preferential excitation of highly excited neutral species or ionized species (Annemie Bogaerts et al, 2002). Hollow cathode discharge has been used primarily to achieve laser action in metal ion transition, in which they prove special efficiency. The mechanism of excitation of laser transitions is occurred via charge –transfer reactions between the ground state metal atoms (produce by the sputtering process) and the ions of the carrier gas [eg, He, Ne, Ar]. In many studies copper constituted the material of the hollow cathodes. The excitation mechanisms of atoms and ions in hollow cathode plasma in different electrical regimes such as sputtering or thermal vaporization by D.C regime and the generation of metal ions or atoms by short pulsed regime,(J.R.McNeil,1976). The choice of the copper is refer to the previous observations of many laser oscillations in the copper vapor using the hollow cathode discharge systems which has been shown by spectral reviewing (C. Benvenuti.1995). The atoms were ionized and excited to the upper laser level by charge transfer collisions with ions of the discharge gas (André Anders et al, 2007). .However, in the presence of ions or atoms, radiation can be emitted when the electrons suffer elastic collision and the

kinetic energy transferred to radiant energy.

The occurrence of selective excitations related with emission of spectral lines of copper CuII laser line was investigated. The spectral lines emitted by the transitions from CuII are a sensitive indicator for the presence of the CuII vapor in discharge volume. The possibility of the selective excitation of $3d^9 4s^2-4p$ states by charge exchange, due to the energy resonance (Alfred, 1986).

The discharge dependent metal vapor production by sputtering in the hollow cathode discharge had been described by Warner sputtering theory.

It is capable of the qualitative description of the linear dependence of the charge transfer rate RCT on the current:

$$R_{CT} = \frac{K \cdot N_{cu}}{\tau^{-1} + K \cdot N_{cu}} \frac{J}{C \cdot a}$$

Where k is the charge transfer rate constant, τ is diffusion lifetime of the neon ions, N_{cu} is the mean copper atom density, j is the current density, e is the elementary charge and a is the half width of the slot. Several spectroscopic studies on the spectral lines of singly ionized copper, which have potential to be regarded as lasing lines, had been carried.

2. Experimental and Method

Figure (1) illustrates schematic diagram for the hollow cathode discharge tube that comprising the laser system. The hollow cathode employed in this design is manufactured from oxygen free copper rod (OFC) (McNeil, 1975). The geometry of the cathode is selected to have a cylindrical shape, for efficient vapor producing via sputtering action instead of classical heating. The dimension of the cylindrical cathode used in this work is 30cm in length and 1.2cm for the outer diameter, so that it can be easily handled and also to avoid defect that results from bending due to high temperature during the discharge process. The copper rod is hollowed so that the inner diameter is 0.9 cm. The tube is threaded at one end to enable the adjustment of the gap between the cathode and the anode and to facilitate dismantling of the system.

The cathode tube is surrounded by two cylindrical tubes made of Pyrex glass to withstand the high temperature resulted from the discharge process. The tungsten anode is placed at 5mm distance from the cathode inside the cavity. The aluminum holder cut at the ends and closed by a glass window placed at Brewster angle is permitting the exit of the laser output.

A pulsed power supply was designed to provide the hollow cathode tube with the electrical discharge current. The basic elements of the pulsed power supply include D.C power supply charges the capacitor through an inductor device.

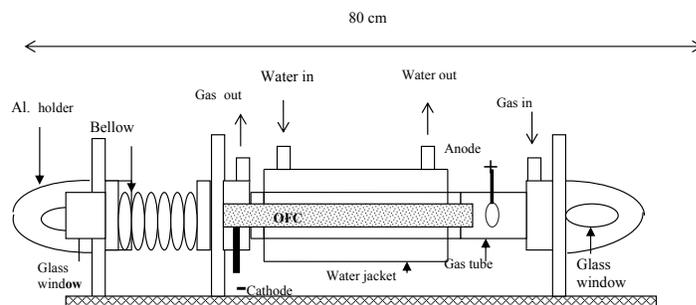
The output current of this device controlled via magnetic relay. Thyatron is known to be the efficient electronic device used in this type of pulsed power supply with a high cost and not easy to be obtained.

The discharge through the tube creates an electrical pulse leads to the establishment of the laser operation. The capacitor used in this circuit is made of two aluminum plates of dimension 37x21 cm in length, width and 5mm thickness. A sheet of plastic of a thickness of 1.2 mm (P.V.C) was used as an insulator of a relative permeability of 3.5. The dielectric strength of the insulated material is in the range of 40-60 KV/mm to prevent the material break down when the potential difference increased beyond a certain value. Two thermal resistances (20 K Ω) each were connected in series with the capacitor to protect the circuit from high currents.

The pressure of the helium buffer gas used in this work is varying from (18-30) mbar to find the optimum condition for the discharge current (D.Zhechev et al, 2001). Water jacket consisting of two coaxial glass cylinders is employed to ensure sufficient cooling. Copper lasers need no resonator because they are self terminating lasers. Copper have low work function and high sputtering threshold which makes it one of the most satisfactory cathodes (Arutiun Ehiasarian, 2007).

The voltage-current was investigated and the discharge current measured at different pressures. The energy per pulse was measured using energy meter (M.C- China). The spectrum of the excited atoms or ions or molecules considered as a finger print of the atoms or molecules themselves.

Fig.1. Schematic Diagram for the Discharge Tube



The spectra of the transitions lines of the obtained output beam from the hollow cathode discharge tube (HCCDT) were collected via a high resolution Miniature Fiber Optic Spectrometer (HR2000). It is a small – footprint modular spectrometer with an optical resolution up to 0.035 nm of the wavelength.. The plane mirror was used at one end to reflect back the beam to increased laser intensity. The transition line 510.8 nm wavelength of He – Cu II is our target in this study and considered one of the promising laser lines in the visible region. A green filter of a maximum transmission of about 35% was used to pass only the desired wavelength. A glass lens of 10 cm radius of curvature was used to focus the beam on the screen that mounted on movable holders.

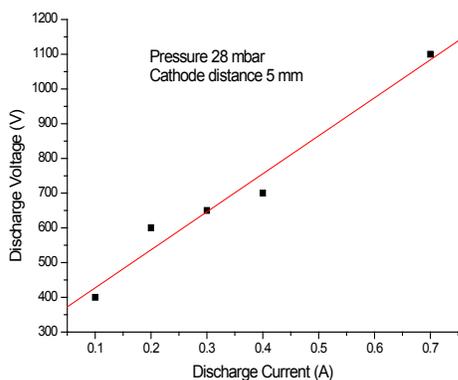
3. Results and discussion

The results of the parameters derived from the homemade hollow copper cathode discharge laser (HCCL) which is operated using pulsed power supply with high efficiency

in the sputtering of atoms from the copper cathode surface . Sparks are emitted by relay switch, which controls the repetition rate of the pulses that fed to the cathode and the anode. The electrical pulses are produced in the spark gap by means of magnetic switch, therefore the frequencies of an on-off electric switch determines the pulse repetition rate of the output beam. These short pulses are dissipated in the discharge volume, so that an important amount of energy equivalent to 36.1 milli-Joules stored in a 957 pF plate capacitor. A high electrical peak voltage of 17kV with the maximum discharge current of 1.9 A is obtained stable electrical discharge of the system. The photo detector circuit also used to show the intensity profile in term of voltage as a function of time using a Cassay lab. Program. The pulse repetition rate was determined via an oscilloscope 100MHz through the designed photo-detector circuit. The average of the recorded values was found to be 0.670 KHz with pulse duration of 1.4ms. The pulse repetition rate is limited due to the mechanical operation of the magnetic relay.

Usually the static volt-ampere characteristics or the impedance measured at particular value of the discharge current. Typical discharge current as a function of the discharge voltage in the copper hollow cathode discharge is represented in figure (2). The behavior seemed to be linear after the breakdown voltage. The I-V characteristics at high currents are complicated by the fact that the heat flow in the cathode rise its temperature M. Zlatanović, 2010.

Fig.2. V-I Characteristics of Hollow Copper Cathode Discharge



Measurements were done to achieve the best conditions for optimum hollow cathode laser performance and the helium pressure was kept constant 28 mbar. The pressure of helium is increasing and consequently, the discharge current is rising and thereby the laser output power to a certain limit. This parameter may affect drastically the lasing action. The intensity is increasing with current may be explained in terms of the copper ions

as a result of the high current, accordingly great population in the upper laser level. Figure (3) illustrate the dependency of the discharge current on the helium pressure. The pressure of the helium gas plays a dominant role in determining the output energy of the laser.

The recorded emission spectrum of the resulted radiation from the hollow cathode discharge tube (plasma of copper ions) is shown in figure (4). The spectral lines obtained have the potential to be laser lines recorded from the collected data of the wavelengths: 479.72nm, 510.8 nm, 558.64nm and 656.61(J.F.Asmus et al, 1968, Afred Z.Mesezane et al, 1986), There are some indications for probable laser line transitions in the infrared region specially the wavelengths 782.36 nm and 860 nm (K.A.Peard et al, 1993).

Fig.3. Effect of Helium Pressure on Discharge Current

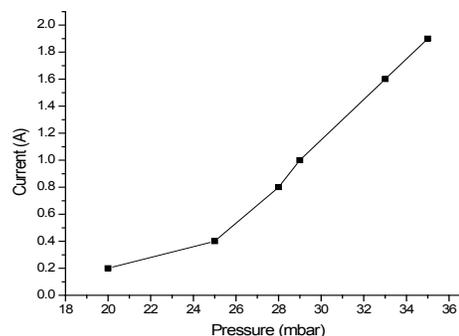


Fig.4. Spectrum of the radiation beam emitted from the hollow copper cathode discharge tube.

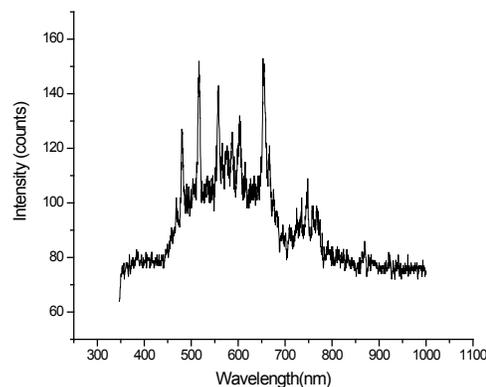
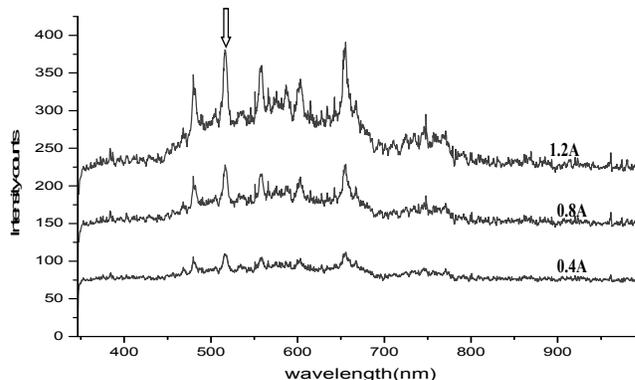


Fig.5. Influence of the discharge current on the intensity of the transition lines



The reflective mirror on the other end is feeding back the radiation beam into the tube to amplify the output power. The output beam is passed through a green filter to have the laser pulses on the cross center of the energy meter for the measurements of the pulse energy. The energy per pulse of 1.76 mJ is obtained at optimum helium pressure 28 mbar and current of 1.96 A.

4. Conclusions

The designed D.C pulse power supply was succeeded in generation of stable electrical pulse for plasma creation and laser production. A home- build hollow copper cathode discharge laser, operated in a pulse mode at wavelength 510.8 nm and energy of 1.76 mJ was performed. The optimum discharge current was found to be 1.9 A at Helium pressure of 28mbar. The investigated I-V characteristics demonstrate typical behavior of linearity of such system. Usually the stability of the system comes from its power supply; however the problem of using the *Thyratron* had been overcome in the new design of the power supply. The trouble shootings during a long operation time were inconsiderable, which in turn minimizes the cost of fabrication of this type lasers. The peaks intensity appeared in the spectrum have a potential to be laser lines at wavelengths 479.72nm, 510.8nm, 558.64nm and 656.61nm, and in infrared region the wavelengths 782.36 nm which are agreed fairly with literature.

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