He-CuII hollow cathode laser in buffer gas pressures in the range of 6 to 100 mBar

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We report measurements of the discharge and laser output from a quadrupolar He-CuII hollow cathode laser excited with a quasi continuous discharge. Operating voltages of about 150 V and threshold currents of 8.5 A in a 20 cm length discharge produced lasing on the 780.8 nm line on a pressure range from 6 mBar to 100 mBar of pure He. The quadrupolar geometry gives the combined effects of a transversal discharge while producing the metal ion vapor through the hollow cathode sputtering, producing laser action on a wider range of pressures than other previous hollow cathode designs. The laser output is found to depend linearly with the cathode current.

Keywords: Quadrupolar He-CuII hollow cathode laser; transversal discharge

Reportamos mediciones de la descarga y salida de un láser de He-CuII de cátodo hueco cuadrupolar, excitado con una descarga cuasicontinua. Voltajes de operación de alrededor de 150 V y corrientes de umbral de 8.5 A en una descarga de 20 cm de largo producen *laseo* en la línea de 780.8 nm en un intervalo de presiones de 6 mBar a 100 mBar de helio puro. La geometría cuadrupolar combina los efectos de una descarga transversal con la producción de iones metálicos por *sputtering* del cátodo hueco, produciendo acción láser en un intervalo de presiones mucho más amplio que en otros diseños previos de cátodo hueco. Se encuentra que la salida láser depende linealmente de la corriente de cátodo.

Descriptores: láser de He-CuII de cátodo hueco cuadrupolar; descarga transversal

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1. Introduction

Hollow cathode lasers have been studied as good alternatives for lasing with metal ions. In these lasers, the vapor metal ions are obtained by sputtering of the cathode material within a buffer gas, normally an inert gas. The hollow cathode discharge has been used since 1974 for excitation of laser lines of vapour metallic ions.

In the He-CuII laser the active media is the copper vapor produced through sputtering of a Cu cathode in a Hollow cathode discharge. Helium buffer gas ions are used to excite laser transitions in double ionized copper by a thermal charge transfer mechanism. The Cu atoms are excited to the upper laser level by a thermal charge transfer reaction between the He ions and the Cu neutral atoms: $He^{+} + Cu = He + Cu^{++} + \Delta E$. There are several laser transitions, the strongest being on the 780 nm. The He-CuII laser was first investigated by Csillag *et al.* [1], and Mc. Neil *et al.* [2] whom reported 23 laser lines within the system, the strongest emission being at the $3d^9 6s(^3D_3)$-$3d^9 5p(^3F_4^0)$ transition on a centre wavelength at 780.8 nm.

Besides the He-CuII laser, there are many other metal ions and combinations with different buffer gases like He-Au [3], He-Al [4, 5], Ne-Cu [1, 6], He-Cd [7, 8] that all together span a range of laser wavelengths from 220 to 800 nm. The main advantage of this kind of lasers is that there is no need to heat up the metal to get vapor of metal ions, this being important for those metals with a high temperature fusion point. While the basic theory governing the production of ions has been well described [9], the design of the discharge chamber and the geometrical shape of the cathodes is yet an important problem, since these parts are important in the discharge stability and in some extent they determine the useful life of the laser. The problems of the lasers with these kind of metallic vapor production are related to the great amount of metal removed from the cathode surface by the sputtering. The metal deposits itself all around the cathodes, making difficult the electric isolation. Other effect of the sputtering is a change in the shape of the cathode in such away that the spatial distribution of ions changes as the laser accumulates hours of use.

There are several versions of hollow cathode arrangements, the most used have been the slotted cathode structure [3] and the hollow cylindrical series of anodes and cathodes [10]. Some other designs have been studied, like the helical cathode [11], the anode-cathode arrangements [12], the Hollow anode-cathode [13] and the series of hollow spherical cathodes [14]. Those designs have drawbacks, for example, transverse discharges give more uniformity in the current density, while segmented designs show less instability with proper ballast at each segment. Helical cathodes and the anode-cathode designs give better stability but they work with high voltages which add some complications to design and to the power supply.

In this work we report a study of a quadrupolar cathode-anode structure, where the laser region consists of a cylindrical hollow cathode but with two open slots at the opposite ends of its diameter, the anodes are placed near those open

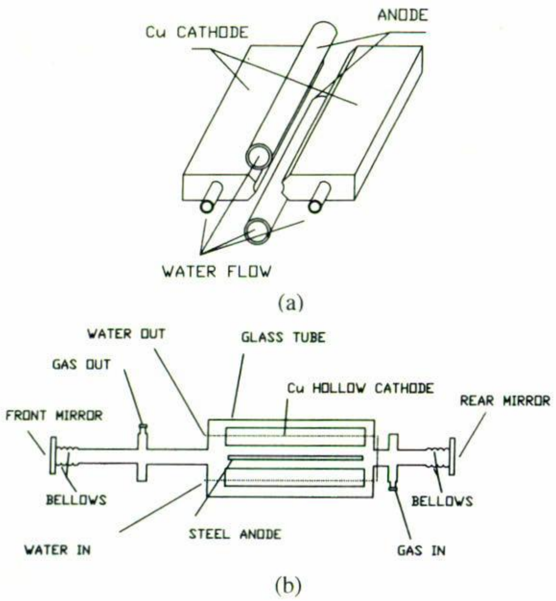

FIGURE 1. a) Cross section of the quadrupolar hollow cathode laser and b) the laser setup.

slots and outside the hollow cathode region. This geometry produces a very symmetrical region of discharge, producing a more stable spatial accumulation of copper ions along the optical axis. The ion production of this quadrupolar hollow cathode had been compared against rectangular slot and a helical kind of hollow cathodes by Acosta *et al.* [15], although the quadrupolar geometry does not provide significantly higher copper ion densities than the others, there are practical advantages of the design, for example, it is easier to produce than the helical one, and also, the alignment of the optical axis is easier than the rectangular slot type because of its more symmetrical cathode discharge region. Also, there is no reason why this design could not be used in a larger array of quadrupolar segments. The system works also with a voltage between the anodes and cathodes of around 150 V which is lower than the voltage needed in some other designs, this reduces the difficulties of working with high voltage and high current power sources.

2. Description of the laser

The general shape of the electrodes is shown in Fig. 1a the hollow cathode had an internal diameter of 7.5 mm. The discharge takes place in a length of 20 cm this length was determined by the availability of the material and there is no reason why a larger discharge length could no be fabricated. Both the copper cathodes and the stainless steel anodes are cooled with a continuous flow of circulating water. The discharge chamber was made of a Pyrex tube of 3.5 inch internal diameter with Teflon walls supporting the cathodes and the anodes.

The whole laser is shown in Fig. 1b, The laser resonator consisted in two high reflectivity mirrors ($\lambda = 780$ nm), with a total transmission coefficient of 0.3% at the output coupler. The total length of the resonator is 1.5 m, although the discharge chamber is only 30 cm long, the internal cavity was enlarged to 1.5 m with glass tubes and stainless steel bellows to allow the alignment of the mirrors. A 60 cm distance form the discharge chamber to the mirrors was used to reduce the contamination of the mirrors by sputtered metal from the discharge. The pressure in the discharge chamber was monitored and controlled in the range of 1 to 100 mBar.

The laser was pumped by an electrical discharge driven by a specially built power supply, in which the power delivered was controlled by an industrial type SCR in a phase-controlled system. This system produced a train of current pulses at a repetition frequency of 120 Hz, and the pulse shape and pulse width of these current pulses were determined by the parameters of a pulse forming network which finally delivered the train of current pulses to the laser head, to give quasi-continuos pumping. This source produced trains of current pulses of about 500 μs FWHM, with peak currents up to 20 A, and voltages ranging from 0 to 500 V.

3. Experimental results and discussion

We were able to make simultaneous measurements of current pulses and optical laser output. Measurements of the output laser pulse energy were made with a Molectron P3 pyroelectric head and a J1000 measuring and averaging unit. A 780 nm interference filter with a passband of about 10 nm was used in front of the detector head to provide wavelength selectivity, although it cannot discriminate between the 780.8 and the 782.6 nm CuII laser transitions. The CW output power was also measured with a Newport power meter model 815. The temporal shape of the laser pulses was monitored with a Tektronix oscilloscope TDS-520 and the current pulses where measured with a dynamic current probe Tektronix A503, the voltage was also measured with a Tektronix A6902B high voltage probe.

The transversal mode structure was monitored with a charge coupled device (CCD) camera and a TV monitor with a 780 nm filter used to isolate the laser output from the light of the discharge. Multimode structure was observed.

Filling the laser head with pure Helium, we found laser oscillation over a much wider pressure range than any other designs of hollow cathode laser to our knowledge [12, 14]. In Fig. 2 we show the output laser pulse energy for a centre wavelength of $\lambda = 780$ nm using pure Helium as buffer gas. The excitation from the train of 500 μs (FWHM) current pulses produced a train of laser pulses with a typical pulselength of about 200 μ s FWHM and a gaussian pulseshape. The average of laser pulse energy is reported against the average peak of the current pulses. The graphs show a tendency to saturation for higher gas pressures, and the highest output is not centered on a range of 6–12 mBar typical in earlier designs of hollow cathode lasers, instead the curves are more like the typical output from laser excited with a transversal discharge. These results show then a combination of hollow cathode

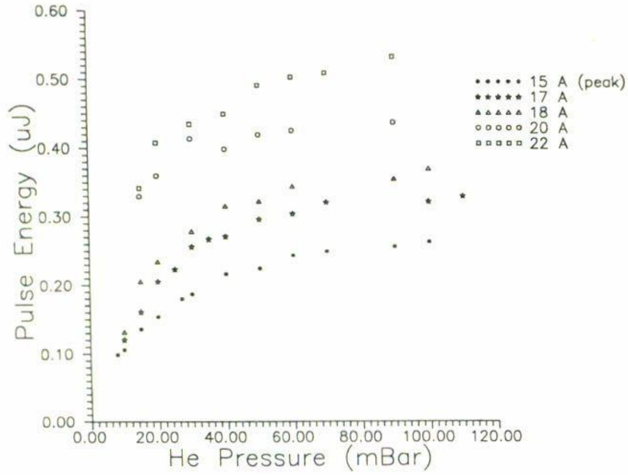

FIGURE 2. Output laser pulse energy *versus* pressure, for different cathode currents (peak).

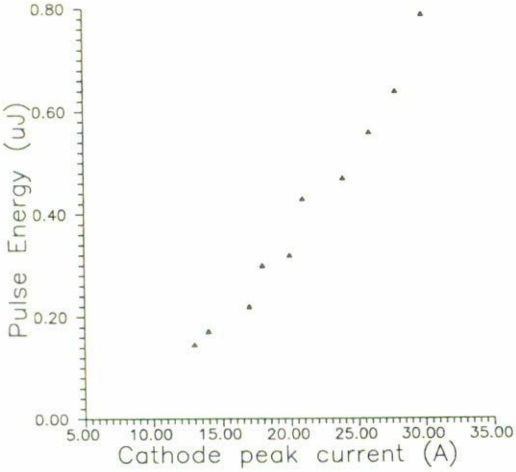

FIGURE 3. Laser pulse energy dependence on the cathode current (peak), He pressure 100 mBar.

metal vapor production and excitation through a transversal discharge. We tried to use the typical combinations of 5% Argon and Helium, or Helium and Neon to increase the pulse energy, but the addition of those gases produced an irregular discharge, with sparks and no increase of the laser yield. The threshold current was about 8.5 A (at the peak of the current pulse) although it was slightly different for different gas pressures. For a constant buffer gas pressure, the pulse energy increases linearly with the peak current, as shown in Fig. 3. The highest pulse energy obtained with the laser was limited by the maximum current of our power supply, and the short pulselength of the current pulses. Figure 4 shows the voltage applied on a pair anode-cathode.

The results show lasing for a range of pressures much broader than the conventional designs of hollow cathodes; The wide range of pressures of operation means that the discharge produced by the quadrupolar geometry not only produces the high vapor ion density necessary to lase, but also

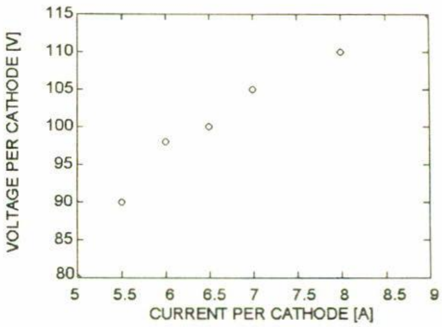

FIGURE 4. Current *versus* Voltage (peak values) on a pair anode-cathode.

gives a combination of transversal discharge and hollow cathode characteristics which could be used in advantage, in order to obtain a higher laser output, in our case the maximum laser pulse energy obtained seems to be limited by the short length of the discharge and by the short pulselength of the current pulses given by our electric power supply. Although we used a discharge length of only 20 cm, there is no obstacle to use a larger discharge or a series of quadrupolar sections in order to increase the output, of higher repetition frequencies in order to get a larger averaged quasi CW output.

The device will also be studied using other metals and buffer gases to get more useful wavelengths, like the UV emission at 270 nm of the combination Ne-CU, where the hollow cathode laser is a good alternative instead of the excimer lasers.

The quadrupolar design shows also a tendency to erode the cathodes in the centre more than in the edges, this being one of the problems of operation of these lasers. Sputtering also took place in all the surface of the cathodes, producing copper deposits on the inner glass wall of the chamber. In our present work, we where more interested in getting more power and more simplicity with the quadrupolar geometry, leaving the solution of the enlargement of the useful life of the device for a future work.

In conclusion, we show a quadrupolar design of hollow cathode laser which combines the metal vapor production with laser output from a transversally excited laser. The device is simpler than other designs and it is easy to fabricate. It works with low voltages and the maximum output seems to be limited by the current in the power supply. This design could be scaled in order to get greater outputs and it could also be used for UV light production through other combinations of buffer gases.

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