METAL VAPOR EXCIMER LASER
QUARTERLY PROGRESS REPORT
FOR PERIOD MAY 1, 1977 – JULY 31, 1977

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MASTER

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October 1977

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ABSTRACT

The CdHg excimer program will attempt to determine the existence of optical gain in a discharge pumped high temperature medium. This first quarterly contract period primarily involves detailed design of the experimental apparatus capable of producing high temperature metal vapor. The report begins with the general considerations which went into designing the experiment and follows with descriptions and schematics of the experiment as presently conceived.

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I. INTRODUCTION

The purpose of this program is to investigate the feasibility of metal excimer systems as general energy storage media for the fusion laser program with specific focus on CdHg^* . More precisely, we are investigating discharge pumping as an efficient means of producing CdHg^* , measuring the gain in this system, and, in the event of net positive gain, attempting to produce laser action in the $4700 \text{ \AA}$ region.

This program spans three principal technical areas: high temperature metal vapor production and handling, e-beam ionized and preionized discharge physics, and determination of optical gain and spectral properties of CdHg^* . During this first quarter, the first area has received most attention as design and initial construction of the experiment has taken place. Before discussing progress in this area, we present a brief description of the technical issues which motivated the particular design.

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II. INITIAL ESTIMATES FOR EXPERIMENTAL DESIGN

In the calculations we have assumed that we have a mixture of Cd/Hg/He. The helium is just a buffer and it serves two purposes: (1) it stops part of the high energy electrons that create the secondary electrons, and (2) it is the third body in the excimer formation. The dominant reactions in the formation of CdHg^* are listed in Table I. The laser mixture will be ionized, as given by reaction (1) (Table I), by the high energy electron $\vec{e}$ to form a helium ion He^+ and a secondary electron e_s . These secondary electrons are heated by the applied electric field. Looking at the energy level diagram in Fig. 1 it is clear that the lowest excited manifold of states are the ^3P of Cd that have a threshold at 3.7 eV. It is possible by adjusting the mixture ratio and electric field to tailor the secondary electron distribution such that Cd^* is created preferentially by reaction (2). The excited cadmium atom rapidly recombines with mercury to form the excimer CdHg via reaction (3). The three body rate constant k_3 is estimated to be $^{(1)} 6 \times 10^{-31} \text{ cm}^6/\text{sec}$. Since the radiative lifetime of CdHg^* is $2.8 \mu\text{s}$, $^{(1)}$ energy may be stored in this state for 1 - 2 μs of time before it is extracted by stimulated emission

From reactions (3) and (4) in Table I it is clear that the ratio of the mercury number density to the cadmium number density should be

$$[\text{Hg}]/[\text{Cd}] > k_4/k_3 \approx 2 \quad (2)$$

However, if Cd^* is to be pumped efficiently via reaction (2) then we have to minimize $[\text{Hg}]/[\text{Cd}]$. This will ensure that only a small fraction of discharge energy goes into Hg^* by electron impact of mercury. The mercury number density should be large enough such that the formation time τ_F of CdHg^* be much less than the lifetime of 2.8 μs

$$\tau_F = \frac{1}{K_3 \text{Hg} M} \leq 0.1 \mu\text{s} \quad (3)$$

TABLE I
KINETIC REACTIONS INVOLVED IN CdHg* SYSTEM

Formation Kinetics

- (1) $\vec{e} + \text{He} \rightarrow \text{He}^+ + \vec{e} + e_s$
- (2) $e_s + \text{Cd} \rightarrow \text{Cd}^* + e_s$
- (3) $\text{Cd}^* + \text{Hg} + \text{M} \rightarrow \text{CdHg}^* + \text{M} \quad (k_3 \approx 6 \times 10^{-31} \text{ cm}^6/\text{sec})$

Quenching Kinetics

- (4) $\text{Cd}^* + \text{Cd} + \text{M} \rightarrow \text{Cd}_2^* + \text{M} \quad (k_4 \sim 10^{-30} \text{ cm}^6/\text{sec})$
- (5) $\text{CdHg}^* + \text{CdHg}^* \rightarrow \text{Nonradiating states} \quad (k_5 \approx 2.8 \times 10^{-12} \text{ cm}^3/\text{sec})$
- (6) $\text{Cd} + \text{CdHg}^* \rightarrow \text{Cd}_2^* + \text{Hg}$
- (7) $\left\{ \begin{smallmatrix} \text{Cd} \\ \text{Hg} \end{smallmatrix} \right\} + \text{CdHg}^* + \text{M} \rightarrow \left\{ \begin{smallmatrix} \text{Cd}_2\text{Hg}^* \\ \text{Cd Hg}_2 \end{smallmatrix} \right\} + \text{M}$
- (8) $e + \text{CdHg}^* \rightarrow \text{products}$

Fig. 1 Energy Levels of Cadmium and Mercury

Where M the third body is mainly a rare gas (probably He). Assuming $[M] = 1 \times 10^{19} \text{ cm}^{-3}$ then

$$[\text{Hg}] = 1.7 \times 10^{18} \text{ cm}^{-3} \quad (4)$$

If we require that $[\text{Hg}]/[\text{Cd}] \sim 10$ to fulfill conditions (2), then

$$[\text{Cd}] \approx 1.7 \times 10^{17} \text{ cm}^{-3} \quad (5)$$

From Fig. 2, a cell temperature of $\sim 500^\circ\text{C}$ will be necessary.

The discharge electric field should be as large as possible consistent with depositing most of the energy into Cd^* via reaction (2) in Table I. We would like the secondary electron distribution to be sharply depleted for energies above 3.7 eV so as to minimize the amount of energy into Hg^* . Using the AERL Boltzmann code for a $[\text{Hg}]/[\text{Cd}]$ ratio of ten we have determined that an electric field $E \leq 10^3 \text{ V/cm-atm}$ would ensure that only 10% of the discharge energy was deposited into Hg^* .

To obtain lasing action a gain of $> 10\%$ per pass is necessary. As the proposed experiment is 40 cm long, the minimum CdHg^* density can be estimated from the following:

$$[\text{CdHg}^*] \sigma_s > 2.5 \times 10^{-3} \text{ cm}^{-1} \quad (5)$$

where the stimulated gain $\sigma_s \approx 2 \times 10^{-19} \text{ cm}^2$.

Hence

$$[\text{CdHg}^*] \geq 1.2 \times 10^{16} \text{ cm}^{-3} \quad (6)$$

Assuming CdHg^* can be created with an efficiency of 50% and $E = 500 \text{ V/cm atm}$, the discharge current $J_D \geq 20 \text{ A/cm}^2$.

Past research at AERL has shown that e-beam controlled discharges are inherently more stable than discharges without preionization. In fact, for the rare gas halide discharges we have shown that an external source of ionization is essential for stability.⁽²⁾ While it is possible to UV ionize the laser mix the level of ionization is too low if stable pulse lengths of 1 μs are required. The UV ionized-avalanche discharge are typically 100 nsec and less. Because of the lack of control, i. e., rapidly varying electric field and current density, Hg^* will be created, leading to Hg_2^* which photo

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Fig. 2 Vapor Pressure of Mercury and Cadmium as a Function of Temperature

absorbs at 460 nm.⁽³⁾ This discharge is also more inefficient than the e-beam controlled discharges.⁽⁴⁾ Finally, the rapidly varying impedance makes electrical matching difficult and the scale size is limited by inductance.

Because of the limitations of the avalanche discharges we propose to investigate an e-beam preionized discharge. Figure 3 shows the schematic of the proposed experiment. The required secondary electron density will be created by a fast electron generated in a 30 nsec pulse by a Febetron 736. These electrons will be guided by a magnetic field B_0 . If the electron Larmor radius r_L is to be less than 1 cm, then $B_0 \geq 333$ gauss. The anode and cathode will be hollow to enable laser extraction. The quartz cell will be enclosed in an oven capable of going to 600°C. The active media will be about 40 cm long. The fast electrons have 600 keV of energy, enabling the creation of secondary electrons over the entire length of the laser cavity. (See Fig. 4).

Table II gives the e-beam and discharge conditions we expect to achieve in the proposed experiment. The electric field will be 500 V/cm and the discharge current 50 A/cm². For these pump conditions we expect Cd^*/Cd to be less than 1%. Assuming that the electron impact excitation cross section of Cd^* is ten times larger than Cd , the Boltzmann code predicts that less than 10% of discharge energy will be lost to excitation of Cd^* . The efficiency of exciting Cd^* is predicted to be greater than 50%.

Fig. 3 Schematic of E-Beam Preionized Metal Vapor Discharge Laser

Fig. 4 Relative E-Beam Energy Deposition vs Distance Along Discharge Column

TABLE II
ESTIMATED EXPERIMENTAL OPERATING CONDITIONS

E-Beam (Febetron 736)

Beam Energy = 600 KeV

Current Density $\sim 500 \text{ A/cm}^2$

Pulse Length = 30 nsec

Initial Electron Density $n_{e0} = 1.3 \times 10^{15} \text{ cm}^{-3}$

Applied Magnetic Field $B_0 = 500 - 1000 \text{ gauss}$

Discharge Electric Field $E = 500 \text{ V/cm}$

Discharge Current Density $J_D = 54 \text{ A/cm}^2$

$[\text{Cd}^*]/[\text{Cd}] = 7.5 \times 10^{-3}$

$[\text{Hg}]/[\text{Cd}] = 10; [\text{Hg}] > 1.7 \times 10^{18} \text{ cm}^{-3}$

$[\text{CdHg}^*] = 3 \times 10^{16} \text{ cm}^{-3}$

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III. FIRST QUARTER EFFORTS

This initial period of the program has been devoted to detailed design and initial fabrication of the test apparatus for 600°C operation as called for in Task I. A completely new experimental area at AERL has been allocated to this project. While equipment design was underway, the preparation of the laboratory facility was begun; this facility will have an experimental area and control room and provide the extensive power handling capacity for the heater and magnet system.

The experimental area will be arranged as shown in Fig. 5. The experiment can be run entirely remotely to minimize danger to operating personnel if there is a failure in the vacuum and vapor handling systems. In the event of the gain tube failure, an exhaust pump vents the oven directly outside. All signals run through semi-rigid coaxial cables under the floor and into the screened room located in the control room. This procedure has worked well previously in minimizing the electrical noise produced by the e-beam and sustainer discharge. All temperatures are controlled from and monitored at the main console; the lines into the control console carry low power signals to power controllers located near the experiment which gives us the flexibility to add heating capacity while leaving the control system fixed.

The following sections deal with the design and schematics of these various elements of the system.

1. Discharge Tube and Oven
2. High Temperature Gas Supply
3. Temperature Control Circuitry
4. Vacuum System Layout and Control Circuitry

1. DISCHARGE TUBE

A detailed drawing of the quartz discharge tube is given in Fig. 6. The side arm permits longitudinal pumping of the medium while leaving an unobstructed optical path. The tube is primarily quartz except for the molybdenum seals which allow coupling to the remainder of the vacuum and vapor

H1836

LAYOUT OF N169 & N179

Fig. 5 Room Layout for CdHg* Experiment

Fig. 6 Quartz Discharge Tube Design

handling system. These quartz-molybdenum seals are designed to operate in air at temperatures near 500°C . Above 500°C , deterioration is rapid in air. We plan to enclose each seal in a loose fitting metal jacket through which hot argon will flow, thereby purging O_2 from around the molybdenum.

Brewster windows are used to lower reflective losses; these windows will be enclosed in an evacuated extension to eliminate turbulence produced refractive index gradients as the temperature drops from 600°C to ambient.

The e-beam will enter through the side arm and be guided by the 9 coils (2 not shown); it will pass through 2 foils, the first located at the e-beam output of the Febetron, the second, made of beryllium, within the oven where it separates the vapor from the vacuum. This second foil must operate at 600°C to avoid condensation of the cadmium. Again a vacuum section insulates the high temperature of the oven's interior from the lower temperature exterior.

The discharge tube is placed with an oven whose heater section is insulated with low conductivity ceramic fiber. The oven is fitted with a blower and vent automatically actuated by a rupture of the quartz vessel.

2. HIGH TEMPERATURE GAS SUPPLY

The Hg, Cd and He supply both are located in a second oven with its own temperature controllers. Two compartments independently set the source temperatures for the cadmium and mercury. Figure 7 shows the arrangements of the two different supplies, each of which is mounted in a large copper block having its own heater and thermocouple sensor. All valves are pneumatically actuated for remote operation; these valves are designed for operation at 650°C . Since the two vapor supplies must be connected, heat flow from the higher temperature cadmium supply must be minimized to maintain the mercury supply at its considerably lower temperature. We will lengthen the tubing connecting the two supplies to reduce the thermal gradient while leaving provision for a heat leak out of the mercury area to maintain the lower mercury source temperature.

This gas supply and the discharge tube oven will be coupled via flexible metal tubing insulated and heated to keep its temperature above that which defines the cadmium density.

3. TEMPERATURE AND VACUUM CONTROL CIRCUITRY

The temperature and vacuum control schematic is given in Fig. 8; the vacuum system layout in Fig. 9. All valves are remotely actuated and interlocked to prevent discharge of hot metal vapors into the room without first having passed through a cold trap. In addition, the interlocking prevents valves to the mercury and cadmium supplies opening simultaneously and keeps the metal vapors from entering the evacuated regions at the Brewster windows and between the discharge volume and the Febetron output. There are three main temperature controllers for the discharge tube oven, and the mercury and cadmium supplies. A fourth temperature readout can select any of 10 thermocouples mounted throughout the system to check for temperature variations. Figure 10 is a photograph of the actual control panel.

4. MAGNET CONTROLS AND SUPPLY

The guiding magnets are controlled from an additional panel mounted below the vacuum and temperature control panel. We produce a linearly rising current ramp which provides up to 1200 A at 80 V to the series connected 9 element magnet. Since the power dissipation is so large, the magnet ramp exists for 10 sec only. At some predetermined point on the ramp, the magnet control circuitry produces a trigger pulse which fires the Febetron to initiate the discharge.

Fig. 8 Schematic of Heater and Vacuum Control Circuitry

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Fig. 9 Vacuum System Schematic

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Fig. 10 Vacuum and Temperature Control Panel

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IV. SUMMARY

In the May through July period detailed design of most elements of the high temperature experimental apparatus has been completed; fabrication of a few elements has begun. These efforts relate to Task I which calls for construction of an experimental facility capable of operating at 600°C.

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