O

Novel Methods of Copper

Vapor Laser Excitation

by

**William Bruce McColl, Hong Ching,
Robert Bosch, Mary Brake, and Ronald Gilgenbach**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

✓ A poster session presented at
the Thirty-Second Annual Meeting of the
American Physical Society,
Division of Plasma Physics
Cincinnati, Ohio
November 13, 1990

Supported by Department of Energy Agreement No.
DE-~~SG~~07-89ER12891 and Lawrence Livermore National Laboratory
Subcontract No. B076262

MASTER

ABSTRACT

Microwave and intense electron beam excitation of copper vapor are being investigated to be used in copper vapor lasers for isotope separation. Both methods use copper chloride vapor by heating copper chloride. Helium was used as the buffer gas at 2 to 100 torr. In the microwave system, intense copper lines at 510 nm and 578 nm were observed. Initial electron beam results indicate that light emission follows the beam current.

Microwave Experiment

Equipment Setup

Microwave Circuit Diagram

Asmussen Microwave Cavity

Cavity Length is adjustable from 6 to 16 cm
Coupling Probe depth is adjustable from 0 to 3 cm

**Copper Chloride was vaporized
either with a resistive tape or by
the buffer gas plasma itself**

Fiber Optic Probe

**Photodiode 'sees' Cone of Light
of Diameter 10 mm at
position of Plasma**

Electric Field Probe

**Inner Conductor extends
slightly into Cavity, Outer
Conductor Grounded by Cavity Walls**

Microwave Experiment

Theory

Assume TM_{012} mode, and

$$E, B \propto \exp(j\omega t - jkz)$$

Define plasma permittivity as

$$\epsilon_1 = \left(\frac{j\omega\epsilon_0 - \sigma}{j\omega} \right)$$

Maxwell's equations and separation of variables gives

$$\frac{d^2}{dr^2} E_{zi}(r) + \frac{1}{r} \frac{d}{dr} E_{zi}(r) + \left(k_i^2 - \frac{m^2}{r^2} \right) E_{zi}(r) = 0$$

$$-m^2 E_{zi}(\theta) = \frac{d^2}{d\theta^2} E_{zi}(\theta)$$

$m \equiv \text{separation constant} = 0$ for TM_{012}

$$k_i^2 = \omega^2 \mu_0 \epsilon_i - k^2$$

Use Bessel's functions and Boun. Conditions:

- a) Fields are finite
- b) Electric fields parallel to cavity walls are zero
- c) Tangential fields are continuous across any boundary

These give the fundamental equation

$$\Re[k] = p \frac{\pi}{L} \quad L = \text{cavity length, } p = 2 \text{ for TM}_{012}$$

$$\frac{Y_1(k_2 b) + J_1(k_2 b) \frac{c_1}{c_2}}{Y_0(k_2 b) + J_0(k_2 b) \frac{c_1}{c_2}} = \frac{k_2 \epsilon_3 c_3}{k_3 \epsilon_2 c_4}$$

$$c_1 = Y_1(k_2 a) \frac{\epsilon_2}{k_2} - Y_0(k_2 a) \frac{J_1(k_1 a) \epsilon_1}{J_0(k_1 a) k_1}$$

$$c_2 = J_1(k_1 a) \frac{J_0(k_2 a) \epsilon_1}{J_0(k_1 a) k_1} - J_1(k_2 a) \frac{\epsilon_2}{k_2}$$

$$c_3 = J_1(k_3 b) - J_0(k_3 c) \frac{Y_1(k_3 b)}{Y_0(k_3 c)}$$

$$c_4 = J_0(k_3 b) - J_0(k_3 c) \frac{Y_0(k_3 b)}{Y_0(k_3 c)}$$

Solve the fundamental equation for find k_1

and ϵ_1 , then calculate the absorbed power

$$P_D = \frac{1}{2} \Re \left[\iiint_{\text{plasma}} E(\sigma E)^* dV \right]$$

Then, from the permittivity, σ becomes

$$\sigma = j\omega(\epsilon_1 - \epsilon_0)$$

Assuming elastic collisions and uniform distribution function, σ becomes

$$\sigma = -\frac{4\pi e^2}{3m} \int_0^\infty \frac{\partial f_0}{\partial v} \frac{v^3}{v(v) + j\omega} dv$$

If $v(v)$ is velocity independent, as for helium, σ becomes

$$\sigma = n_e \frac{e^2}{m} \frac{1}{v + j\omega}$$

Calculate n_e and v from real and imaginary parts of σ

**Fit of Data to Function
showing Microwave Attenuation**

Microwave Experiment

Results

Axial Spectra:
Copper laser states are
5105.5 Å and 5782.1 Å

Axial Spectra:
Copper laser states are
5105.5 Å and 5782.1 Å

Solid line shows predicted values

TM₀₁₂ Fields and Plasma Configuration

Calculated Electric Fields
at 76 Torr and 90.4 Watts

Joule Heating Profile showing variations in Pressure

Joule Heating Profile showing variations in Power

Power per Particle (eV/# sec)

Pressure (Torr)

E eff / Neutral Density (V cm /#)

Pressure (Torr)

Electron Beam

Experiment

Electron-beam pumped copper vapor
experimental setup

Febatron Parameters:

Pulse Length 0.4 μ seconds total

Voltage 300 to 500 kVolts

Current < 1.4 kA

PMT signals vs. shot number

CONCLUSION

- Copper laser states excited in abundant amounts
- Electron densities from 10^{10} to 10^{12} cm^{-3}
- Collision frequencies from 10^9 to 10^{11} sec^{-1}
- Cavity efficiencies 85% or more
- Joule heating profiles describe plasma light emission trends
- E / N values from 10^{-18} to 10^{-15} $(\text{V/cm}) / (\# \text{ cm}^{-3})$
- Electron beam work will focus on pulsed copper vapor sources

**DATE
FILMED**

2 / 3 / 94

END