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Publication Date

1978-07-01

LBL-7854
UC-37

Energy and Environment Division

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July 1978

Lawrence Berkeley Laboratory University of California/Berkeley
Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

LBL-7854

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ABSTRACT

A stable carbon monoxide laser capable of oscillation on transitions in the fundamental 1 → 0 band is described. This laser is also capable of a quasi-continuous tunability in the range of 4.7 to 8 microns.

The sensitive and unambiguous detection of carbon monoxide (CO) requires a laser which emits at wavelengths where CO absorbs strongly. The strongest infrared absorption occurs in its fundamental $1 \leftarrow 0$ vibrational band, from about 4.5 to 4.8 microns. Hot bands, such as $2 \leftarrow 1$, do not absorb significantly at reasonable temperatures since the $v=1$ level, 2100 cm^{-1} above the vibrational ground state, is not thermally populated except at very high temperatures. The overtone bands, such as $2 \leftarrow 0$, are not as strong as the fundamental because the matrix elements for these transitions are small.

A coventional carbon monoxide laser might be thought of as a likely candidate to provide wavelengths corresponding to strong CO absorption; but in fact, these lasers operate only on hot bands, at wavelengths greater than 4.8 microns. In this paper we describe an electric discharge laser utilizing the scheme developed by Djeu[1] for eliminating self-absorption in the unexcited and regions of the discharge tube. The findings of Brechignac and Martin[2] show that a laser capable of oscillating in the $1 \rightarrow 0$ band may also be tuned to very long wavelength transitions in high vibrational bands. We have found that our laser is tunable to 6.47 microns, and is capable of even longer wavelength operation, given the proper optics. This long wavelength tunability greatly increases the versatilityof the device.

No fundamental design innovations have been introduced, but several changes have been made in Djeu's design, making the laser <u>stable</u> and <u>easier to operate</u>. A drawing of the laser discharge tube appears in Figure 1. The tube was constructed of pyrex. Helium is flowed in through the outermost ports (A) so as to sweep out CO molecules from the unexcited end regions and prevent self-absorption. Nitrogen, CO, some more He, and Xe were flowed in through the ports above the outer electrodes (B). All the gases were exhausted through the center of the tube. A gas mixture of 0.16% CO, 30% N_2, and the balance He at a total pressure of 4.4 torr was used. A small quantity of Xe, comparable to the CO concentration, was usually added.

The discharge tube was enclosed in a liquid nitrogen cooling jacket. Unlike earlier designs, the cooling jacket was completely closed off except for four 1-cm diameter tubulations. Liquid nitrogen was flowed in through one of these, and the boil-off was exhausted through the other three. In earlier designs, where there were no ring-seals around the electrodes, it was more difficult to prevent cold air from coming down onto the table and causing thermal contraction, perturbing the laser alignment. The cooling jacket was enclosed in Armstrong Armalok insulation for 1 1/2 inch nominal diameter pipe, with insulation thickness 1 1/2 inches. The combination of completely enclosed cooling jacket and Armalok insulation resulted in a reliable power stability.

Teflon window holders were used for the Brewster windows. The holders slid over the ends of the tube and sealed with O-rings. The windows were sealed to the holders with O-rings and were held in place by the external pressure of the atmosphere.

The electrodes were large-area nickel cylinders which were mounted as close as possible to the main tube so as to cut down discharge voltage and unneeded power dissipation.

The outer electrodes served as anodes, and the center electrode was the cathode. Currents of typically 5 mA in each discharge section were used. An electronic current regulator similar to that described by Posakony[3] was placed between the cathode and ground so as to regulate the sum of the currents in the two discharge sections. It was necessary to use 300 KΩ ballast resistors between each of the two anode power supplies and the anodes to balance the current in both discharge sections. Typically, it is more desirable to use a single anode and two cathodes, both with current regulators. However, this would require placing the center electrode at a very high voltage, and this was found to produce breakdown problems. Two 20 KV supplies were used. The striking voltage was 18 KV and the total voltage drop across ballast, discharge, and current regulator when the laser was running was about 10 kV. Increases in CO concentration required for long wavelength operation of the laser resulted in larger discharge voltages and higher optimum currents.

For short-wavelength multiline operation we used CaF_2 windows, a 5 meter radius of curvature dielectric coated ZnSe output mirror having 98% reflectivity at 4.7 microns, and a 6 meter radius ZrCu mirror. For single-line operation at short wavelengths, the latter mirror was replaced by a 300 line/mm grating blazed for 4 microns. For long-wavelength, single-line operation, we used NaCl windows, a 10 meter radius gold mirror with a 2 mm coupling hole, and a 300 line/mm grating blazed for 5.4 microns.

Transitions P(8) through P(12) in the $1 \rightarrow 0$ band (wavelengths 4.734 to 4.773 microns) have been observed in single-line operation, with a maximum power of 8.1 mW observed for the $P_{1-0}(11)$ transition. A summary of these observations appears in Table 1. Also listed in Table 1 is one hot band transition, $P_{2-1}(12)$. This transition was found to be of some usefulness in optoacoustic CO detection due to its near coincidence with a CO 1 ← 0 absorption line.[4] In concurrence with Houston and Moore,[5] we have found that lasing on the 1 → 0 transitions is possible without the addition of xenon, and in fact the $P_{1-0}(8)$ transition was observed only in the absence of Xe. However, for the other 1 → 0 transitions, addition of Xe always resulted in a considerable improvement in performance.

Without changing the discharge current, gas mixture, or optics from those used in obtaining the 1 → 0 transitions, we can grating-tune the laser to 70 transitions in the range from 4.7 to 5.4 microns. Increasing the CO concentration and the current, still with no change in optics, gives many new longer-wavelength transitions and makes possible much higher powers for many of the observed transitions (for example, 250 mW at 5.000 microns). With the long-wavelength optics we were able to obtain single-line operation on 95 transitions between 5.170 and 6.466 microns. On the long-wavelength end, we were limited by the fact that the angle of incidence of the beam onto the grating was almost 80° and the alignment was very difficult. Also, horizontal positioning of the grating became very critical in order to prevent the beam from hitting the edge of the grating. With a less dispersive, longer-wavelength blazed grating and optimum output mirror, we expect that cw oscillation on transitions in the 36 → 35 band, beyond 8 microns, can be achieved.

We thank J. Clark, C. Dasch, and M. Kelly for helpful suggestions.

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Table 1. CO laser lines observed having coincidences with CO $1 \leftarrow 0$ absorption lines.

Laser Line	Frequency[a] (cm^{-1})	Power (mW)		Nearest CO Absorption Line	Frequency[a] of Absorption Line (cm^{-1})
		Maximum	Typical		
$P_{1-0}(8)$	2111.5434	1	0	$P_{1-0}(8)$	2111.5434
$P_{1-0}(9)$	2107.4231	3.7	2	$P_{1-0}(9)$	2107.4231
$P_{1-0}(10)$	2103.2688	6.5	5	$P_{1-0}(10)$	2103.2688
$P_{1-0}(11)$	2099.0815	8.1	5	$P_{1-0}(11)$	2099.0815
$P_{1-0}(12)$	2094.8612	2.8	1	$P_{1-0}(12)$	2094.8612
$P_{\cancel{1-0}}(12)$ 2-1	2068.8025	51		$P_{1-0}(18)$	2068.8476

[a] T.R. Todd, C.M. Clayton, W.B. Telfair, T.K. McCubbin, Jr., and J. Pliva, J. Mol. Spectrosc. 62, 201 (1976).

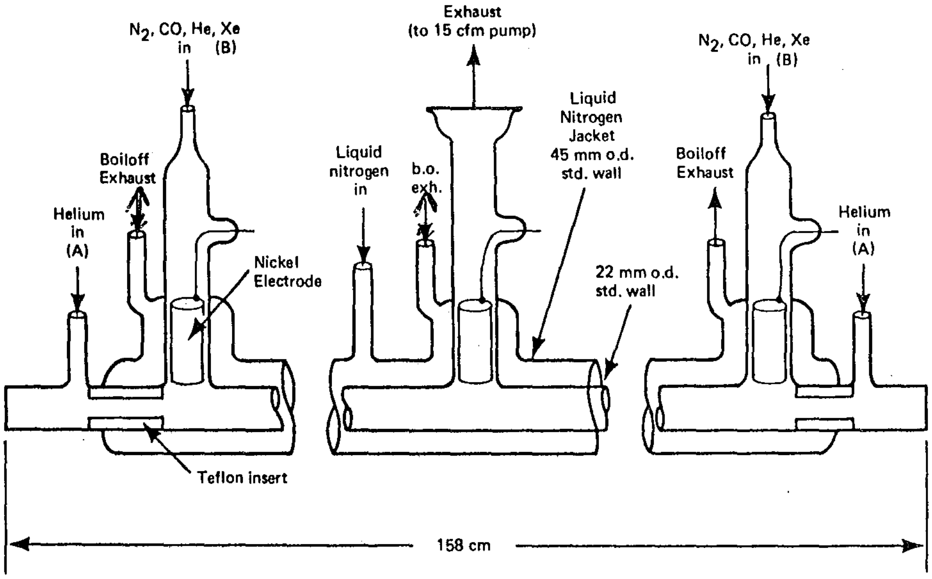

Fig. 1. Schematics of the CO laser plasma

XBL 773-654

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