CW PERFORMANCE OF OPTICALLY-PUMPED LASERS IN THE MILLIMETER-WAVE SPECTRAL REGION

F. B. Foote and D. T. Hodges
Electronics Research Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
P.O. Box 92957
Los Angeles, California 90009

Abstract

Optically pumped lasers are maturing as powerful coherent sources for the near millimeter spectral region, and especially for wavelengths shorter than 500 μm. Presented here is a summary of performance data and a discussion of the performance expectations for this new type of laser in the .9-2 mm region. The unique characteristics of optically pumped lasers will be described and compared to existing millimeter wave sources.

Introduction

During the past several years, hundreds of new laser transitions in approximately 40 different polar molecules have been reported throughout the 40 μm (7.5 THz) to 2 mm (150 GHz) spectral region[1-3]. These lines are rotational transitions of a low pressure gas (~100 m Torr), inversion being achieved by near-resonant absorption of radiation from a strong IR pump laser[4,5] such as CO_2. In Fig. 1, the basic absorption/inversion mechanism is diagrammed. Ground state molecules in a rotational state (J') are pumped through absorption of a 10 μm photon into an excited rotational state (J). Lasing subsequently occurs producing photons in the near-mm region as denoted by wavelength λ. The molecules then relax back to the ground state at a rate Γ, normally by collisions with other molecules or with the resonator walls. At low pressures Γ is sufficiently rapid relative to the rate of thermalization of the rotational levels to permit a cw operation. Most of the emphasis in developing these lasers has centered on the submillimeter region, where powerful sources are required for the diagnostics of thermonuclear plasmas. CW powers of .4 W at 118 μm (2.5 THz)[6] and pulsed powers of 10^5 W at 496 μm (600 GHz)[7,8] have been reported, but despite the impressive advances at the submillimeter wavelengths, little attention has been given to the potential of optically-pumped lasers in the near-millimeter spectral region (λ = .89-2 mm). This paper summarizes recent experiments designed to characterize the optically-pumped laser as a source of cw coherent near-mm wave radiation. CW powers of 1-10 mW have been achieved at selected discrete wavelengths using a relatively simple and compact structure.

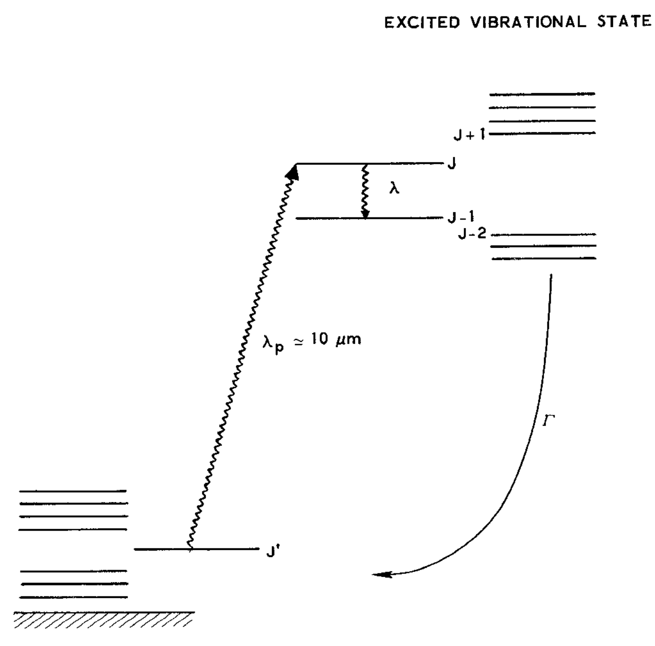

Fig. 1. The basic energy diagram of the absorption/inversion mechanism in near-mm wave lasers.

Design Concepts

A typical laboratory laser set-up is depicted in Fig. 2. A conventional grating tuned CO_2 laser (λ = 10 μm) is used as the pump source. The piezoelectric (PZT) device fine-tunes the laser approximately ± 30 MHz from a line-center frequency to optimize the match between absorption and pump frequency. CO_2 laser line identification is accomplished by the use of a monochromator. The beam is chopped, collimated, and injected into the millimeter laser cavity. A stepping motor driving an optical stage tunes the cavity by translating one of the end reflectors. A power meter or detector is used in conjunction with a lock-in amplifier if a positive feedback loop is desired. The basic near mm wave laser designs fall into two different categories: (1) the conventional, or Fabry-Perot resonator[5,9], and (2) the waveguide resonator[10,11]. The Fabry-Perot resonator is characterized by free-space modes propagating between two reflecting surfaces; if excessive diffraction losses are to be avoided, resonators of large diameters are required, and these are generally bulky and unfavorable to crucial operating parameters for high power laser performance. For example, a 10-15 cm diameter tube is required for a cavity 2-3 m in length. The waveguide resonator, however, requires much smaller diameters to sustain the low loss modes common to hollow metallic and dielectric structures. This category of laser can be made both compact and rugged; linear polarization is obtainable by the use of rectangular metal or dielectric waveguides.[12] At the present time, the waveguide near-mm type lasers have produced the highest

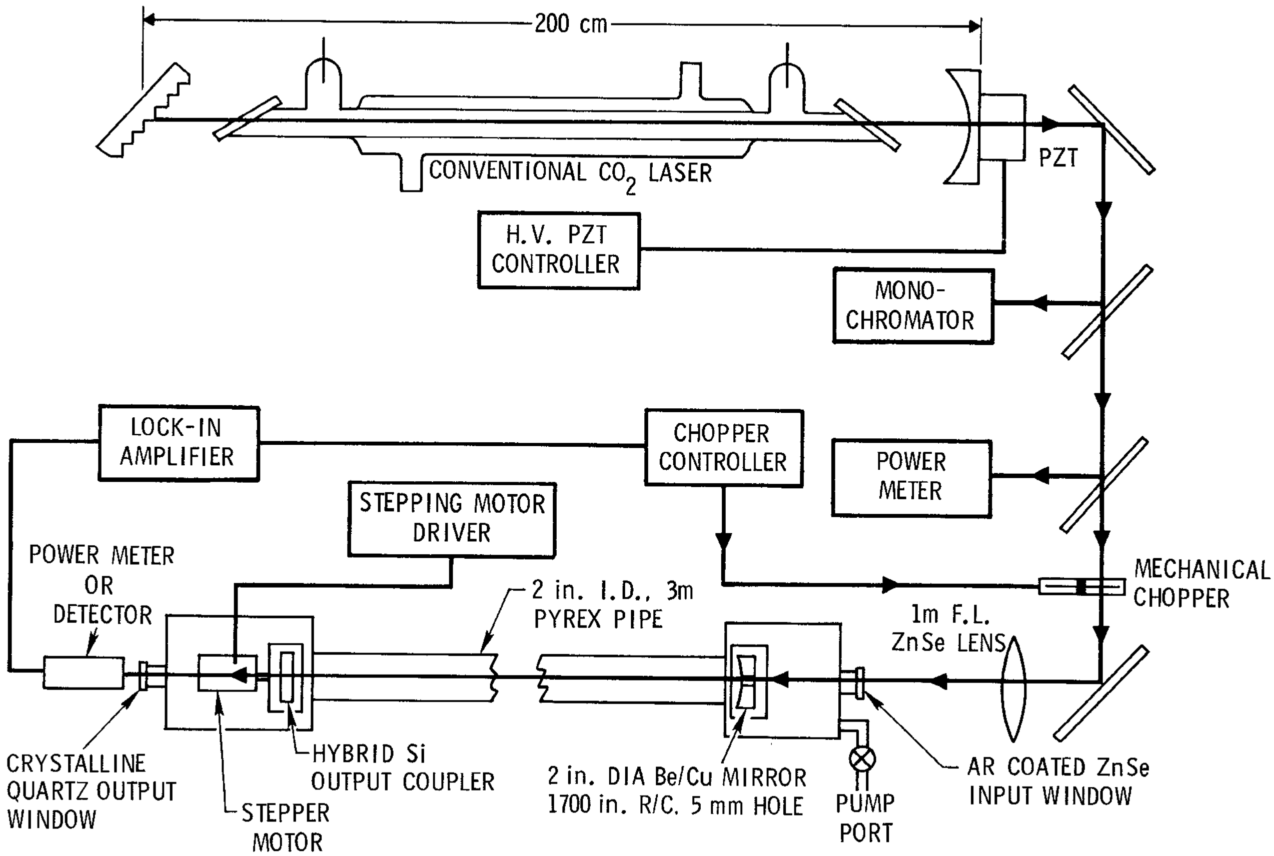

Fig. 2. A typical laboratory millimeter wave, optically-pumped laser arrangement using a CO_2 pump laser and waveguide resonator. Both metal and dielectric waveguides have been used.[2]

output powers, with excellent mode quality,[6, 13, 14] using both metal and dielectric resonators.

It is well known that the power and mode quality of the output are definitely correlated to the mode quality of the injected CO_2 pump beam at the operating frequency offset from line center.[13] A uniform intensity profile across the pump beam, injected into the resonator with relatively large F number optics, is necessary for high power operation since loss mechanisms other than absorption by the lasing medium (mainly resonator wall absorption) lead to low conversion efficiency of pump power into near-mm output power. This is especially critical in gases with absorption coefficients less than $\sim .01\ cm^{-1}Torr^{-1}$. The interaction of injection optics, pump beam mode quality, and properties of the near-mm laser cavity at the pump wavelength, dictates the quality of the near-mm optically pumped laser performance.

Performance Summary

Table I gives an overview of optically pumped laser performance in the near-mm region. The pump laser line is denoted by branch transition and rough wavelength in μm. The power was measured with a commercial bulk absorbing calorimeter which was calibrated at the wavelengths of interest. The diffi-

Table I

wavelength (mm)	(frequency) (GHz)	molecule	cw power (mW)	pump designation	pump power (W)
0.89	(345)	CH_2CF_2	5(3m, D)	P(22)10.6	60
1.063	(282)	CH_3I	0.5(3m, D)	P(38)10.8	45
1.222	(245)	$^{13}CH_3F$	10(2m, D)	P(32)9.7	45
1.253	(239)	CH_3I	1.0(3m, D	P(32)10.7	50
1.572	(191)	CH_3Br	0.5(1m, M)	P(4)10.4	35

culty of the calibration leads to a factor of 2 uncertainty in the power measurement. The length of the laser used and the resonator type (metal, M, or dielectric, D) varied over the measurements, and the length (in meters) and type (M or D) are specified in Table I after the cw power value. The theoretical efficiency limit for the near-mm wavelengths is approximately 100 times greater than the measured values, due mostly to weak absorption of the pump radiation by the gases used ($\approx 5\%\ m^{-1}$).[13,14] This is considered the major obstacle for high power operation (near the theoretical limit).

The spectral quality of this source is excellent with a linewidth $\Delta\nu$ better than $10^{-7}\nu$. However, the tuning range is limited to ~1 MHz.

Conclusions

The advantages of an optically-pumped laser as a source for mm wavelengths include simplicity and spectral purity. Power levels should improve by an order of magnitude with continued effort. As shown in Fig. 3, it compares favorably with Impatt diodes in power over the .89-1.5 mm wavelengths, and while carcinotron sources exhibit superior power capabilities (1 W at 300 GHz), they suffer from poor coherence ($\Delta\nu/\nu \sim 10^{-3}$) and excessive expense. At 2 mm and longer wavelengths, good sources are available. It is unlikely that optically-pumped mm laser output powers will exceed .1W or that significant line tunability will be available. Further investigation into laser performance however will certainly result in a higher density of mm wave lines, and, hopefully, a number of strong transition wavelengths at the 10-100 mW level such as 1.222 mm in $^{13}CH_3F$.

References

1. Rosenbluh, M., R. J. Tempkin, K. J. Button, "Submillimeter Laser Wavelength Tables," Appl. Optics Vol. 15, pp. 2635-2644, November 1976.

2. Yamanaka, M., "Optically Pumped Gas Lasers - A Wavelength Table of Laser Lines," Rev. Laser Engr. (Japan) Vol. 3, pp. 57-98, March 1976.

3. Gallagher, J. J., M. D. Blue, B. Bean, and S. Perkowitz, "Tabulation of Optically Pumped Far Infrared Laser Lines and Applications to Atmospheric Transmission," Infrared Phys. Vol. 17, pp. 43-55, 1976.

4. Chang, T. Y. and T. J. Bridges, "Laser Action at 452, 496, and 541 μm in Optically Pumped CH_3F," Opt. Commun. 1, pp. 423-426, April 1970.

5. Chang, T. Y., "Optically Pumped Submillimeter-Wave Sources," IEEE Trans. Microwave Theory Tech. Vol. MTT-22, pp. 983-988, December 1974.

6. Hodges, D. T., F. B. Foote, and R. D. Reel, "Efficient High-Power Operation of the CW Far-Infrared Waveguide Laser," Appl. Phys. Letters, Vol. 29, pp. 662-664, November 1976.

7. Semet, A. and N. C. Luhman, Jr., "High Power Narrow Line Pulsed 496 μm Laser," Appl. Phys. Letters 28, p. 659 (1976).

8. Woskoboinikow, P., Z. Drozdowicz, K. Isobe, D. R. Cohn, and R. J. Tempkin, "A High Power, Narrow Linewidth D_2O Laser at 384.6 μm," Physics Letters, Vol. 59A, pp. 264-266, December 1976.

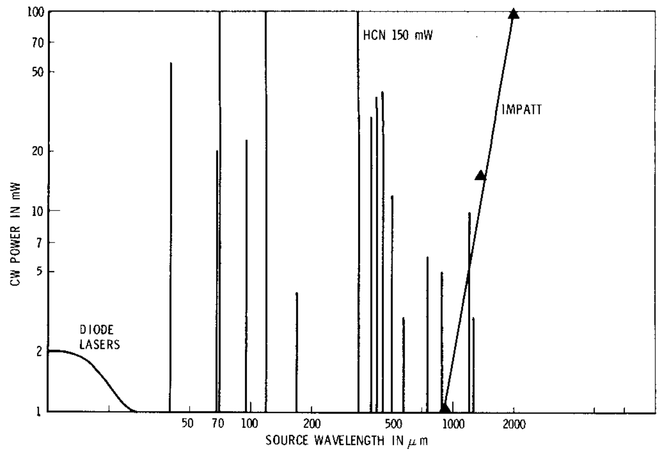

Fig. 3. Optically pumped laser performance summary from ~30 μm to 1.5 mm.

9. See the review by H. Kogelnik and T. Li, "Laser Beams and Resonators," Proc. IEEE, Vol. 54, pp. 1312-1329, October 1966.

10. Degnan, J. J., "The Waveguide Laser: A Review," Appl Phys. Vol. 11, pp. 1-33, 1976.

11. Yamanaka, M., "Optically Pumped Waveguide Lasers," J.O.S.A., July 1977 (to be published).

12. Yamanaka, M., H. Tsuda, and S. Mitani, "Mode Properties in Optically Pumped Far Infrared Rectangular Waveguide Lasers," Opt. Comm. Vol. 15, pp. 426-428, December 1975.

13. Hodges, D. T., F. B. Foote, and R. D. Reel, "High Power Operation and Scaling Behavior of CW Optically Pumped FIR Waveguide Lasers," IEEE Journal Quant. Electron., June 1977 (to be published).

14. Schubert, M. R., M. Durschlag, and T. A. DeTemple, "Diffraction Limited CW Optically Pumped Lasers," IEEE J. Quant. Electron. June 1977 (to be published).