NASA Technical Memorandum 84541

A BLACKBODY RADIATION-PUMPED CO_2 LASER EXPERIMENT

Walter H. Christiansen, R. J. Insuik, and Russell J. De Young

SEPTEMBER 1982

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

Table of Contents

A BLACKBODY RADIATION-PUMPED CO_2 LASER EXPERIMENT

Walter H. Christiansen and R. J. Insuik
University of Washington

Russell J. De Young
NASA Langley Research Center

SUMMARY

Thermal radiation from a high-temperature oven was used as an optical pump to achieve lasing from CO_2 mixtures. Laser output as a function of blackbody temperature and gas conditions is described. This achievement represents the first blackbody cavity-pumped laser and has potential for solar pumping.

INTRODUCTION

Direct conversion of sunlight into laser light without the need for a complicated intermediate step of energy conversion is a significant advantage for high-power CW space-based lasers. The principle of broadband optical pumping using flashlamps to achieve a working laser is well known and has been put into practice with the ruby laser, the Nd:YAG laser, and dye lasers (ref. 1). Broadband pumping of gas lasers has not been so extensively studied. Recently, however, an optically pumped iodine laser has been demonstrated using a solar simulator (ref. 2).

Solar pumping of bound-bound absorption transitions, typical of infrared lasers, is also a possibility. This approach normally would be very inefficient, and therefore of little interest, due to the fact that the absorption bandwidths of many potential gas laser media are small in relation to the effective bandwidth of the solar spectrum. Consequently, only a very small fraction of the solar energy can be absorbed and converted into laser light. A concept for efficient optical pumping of an infrared laser medium has evolved which has the potential of making these solar-pumped lasers very efficient (ref. 3). In this method, a blackbody heated by focused sunlight is used as the optical pumping source. The basic idea is shown in fig. 1 wherein an insulated body provides the intermediate radiation field. If an optically active medium contained in a transparent vessel is inserted into the insulated cavity, the overall thermodynamic efficiency can be markedly improved. In fact, the potential efficiency of this approach is orders of magnitude greater than utilizing sunlight directly in narrow band absorption media (ref. 3). This improvement allows the entire solar flux to contribute to the lasing because of the thermodynamics of the cavity. If the cavity radiation is withdrawn via the pumping bands of the laser medium, the nonequilibrium part of the radiation field in the cavity is returned to a distribution by thermal re-emission of the hot walls. In this way the pumping radiation of these type lasers are continuously replenished and all of the energy source is utilized (ref. 3). This scenario is schematically shown in fig. 2, where collected sunlight heats a blackbody cavity to 1500°C. Radiation emitted from the wall has the spectral distribution as shown in ①. This emission impinges on a transparent tube containing CO_2 gas which absorbs some of the blackbody emission over a narrow bandwidth at 4.2 μm (shown in ②). This distribution is reasorbed and thermalized by the cavity wall and re-emitted as ③ which repeats the process again.

This laser system seems well suited for space applications, particularly in view of new concepts (ref. 4) of waste heat rejection. Utilizing this pumping concept, laser system studies have been made to megawatt levels (ref. 5), where the overall efficiency of conversion of solar radiation to laser radiation was shown to be 10-20 percent.

This report summarizes recent experimental results on blackbody cavity-pumped CO_2 lasing. This is the first blackbody cavity-pumped laser, and establishes the plausibility of this unique laser pumping concept.

EXPERIMENTAL BACKGROUND AND SETUP

Because of the importance of this idea, an experiment to demonstrate the physics of this laser pumping concept is being carried out at the University of Washington. This experiment utilizes an electrically heated oven which simulates the equivalent solar-heated cavity. Carbon dioxide was selected initially as the lasing medium since its properties are well understood and it is a good candidate for testing the pumping concept. Prior calculations having shown the level of gain and its relationship to the blackbody temperature (ref. 6). These results showed that one should be able to achieve threshold conditions fairly easily with translational temperatures of the gas on the order of 300 K.

The lasing experiment is conducted in a non-steady manner; that is, an uncooled sapphire laser tube is exposed only briefly to the blackbody radiation. Lasing should occur until the laser tube and the gas within become hot. In this experiment, a CO_2-He-Ar mixture is illuminated by the radiation field from an electrically heated oven capable of achieving 1500 K. After achieving the proper oven temperature (in the neighborhood of 1200 K - 1500 K), the oven is opened and moved around the laser tube to start pumping action. Data are taken for a few seconds and the heater is then removed from around the laser tube, thus completing the cycle.

The laser tube is 60 cm long, but is only illuminated over the center 50 cm. It has an 8 mm diameter, chosen to match the optical depth of the gas mixture. The optics have been mounted on a breadboard vibrationally isolated from the oven and its support. The laser cavity is nearly confocal with a 1-meter optical path and laser output is taken from a Brewster window reflection. The cavity mirrors are maximum reflectors at 10.6 μm. An electric (glow) discharge apparatus is also built into the system and shown in fig. 3. Running the discharge device with a laser mixture confirms operational alignment of the optics for the blackbody experiment. The discharge apparatus is removed from the optical system when blackbody pumping is used.

PRELIMINARY RESULTS

Preliminary tests have been carried out to measure the heating rate of the laser tube. By sealing off the laser tube and monitoring the gas pressure within the tube, a type of gas thermometry is achieved. The first set of experiments was conducted using an infrared quartz laser tube which has similar physical properties to sapphire. It was found that the gas within the laser tube reached temperatures of 700-750 K after 45 seconds with oven temperatures ranging from 1000-1275 K. Thus, there is sufficient time (≈ 10 sec) for a lasing experiment before the laser mixture becomes too hot.

Figure 4 shows an oscilloscope trace of a typical laser signal from this apparatus at a gas pressure of 10 Torr. At an estimated calibration of 0.16 mw/mv, the laser signal is about 0.4 mw and lasts 3.7 sec. The signal is obtained with a Hg-Cd-Te detector measuring the weakly coupled laser output from a Brewster window. Lasing has not yet been observed with a 5-percent output coupler. The laser signal is chopped at 30 cps, thus giving a hashy look to the trace. However, the upper envelope is clearly defined. Two seconds after the oven is opened and placed around the tube, lasing begins. The heating of the tube and laser mixture terminates the signal.

A series of experiments was conducted over a range of pressures for a fixed laser mixture and the overall results of relative laser output and duration of lasing are plotted in fig. 5. These results show a maximum laser signal and signal duration at 8 Torr. No laser signal was obtained at pressures less than 4 Torr or more than 16 Torr. The results have been very repeatable. The time duration of the signal is consistent with gas heating times.

Prior calculations have shown the level of gain and its relationship to the blackbody temperature (ref. 6) using a simple model for the case of an optically thick gas. Gains exceeding 1 m^{-1} were predicted for moderate oven temperature and under some conditions there is gain predicted for oven temperatures as low as 1100 K. With this model, the gains were calculated to be considerably larger under low-pressure conditions (0.8 Torr CO_2 - 0.2 Torr He) than under high-pressure conditions such as 10 Torr (0.8 Torr CO_2 - 0.2 Torr He - 9 Torr Ar). These early predictions indicated that lasing should occur easily at 1 Torr and progressively become more difficult at higher pressures as inert diluent is added. This trend is not indicated by the preliminary experiments as fig. 5 shows. Figure 5 indicates that the small signal gain must be considerably smaller than originally estimated, at least at low pressures. A numerical code is now being developed to better predict the small signal gain for this laser. This model, which includes diffusion of excited states to the wall and catalytic wall deactivation, is being used to predict the small signal gain g_0 for this laser medium. Early results indicate that this mechanism can account for the trends shown in fig. 5, but further modeling and experimental proof is required.

CONCLUSIONS

The results of this experiment demonstrate the ability to convert broadband blackbody radiation into laser light. Preliminary details of the threshold conditions, the duration of lasing, and the power obtained in lasing under various thermal conditions have been presented. The experimental results fully illustrate the physical principle of the radiation conversion process.

REFERENCES

1. Yariv, A.: Introduction to Optical Electrtonics, 2nd edition, Holt, Rinehart, and Winston, Inc., New York, 1976, pp. 157-197.

2. Weaver, W. R.; and Lee, J. H.: A Solar Simulator-Pumped Gas Laser. Laser Focus, March 1981, p. 16.

3. Christiansen, W. H.: A New Concept for Solar-Pumped Lasers. Progress in Aeronautics and Astronautics, vol. 16, K. Billman, editor, AIAA, New York, 1978, pp. 346-356.

4. Mattick, A. T.; and Hertzberg, A.: Liquid Droplet Radiators for Heat Rejection in Space. Journal of Energy, vol. 5, 1981, p. 387.

5. Taussig, R.; Bruzzone, C.; Nelson, L.; Quimby, D.; and Christiansen, W.: Solar-Pumped Lasers for Space Power Transmission. Proceedings of the AIAA Terrestrial Energy Systems Conference, Orlando, FL, 1979. AIAA Paper No. 79-1015.

6. Yesil, O.; and Christiansen, W. H.: Optically Pumped CO_2 Laser Mixtures. Journal of Energy, vol. 3, 1979, p. 315.

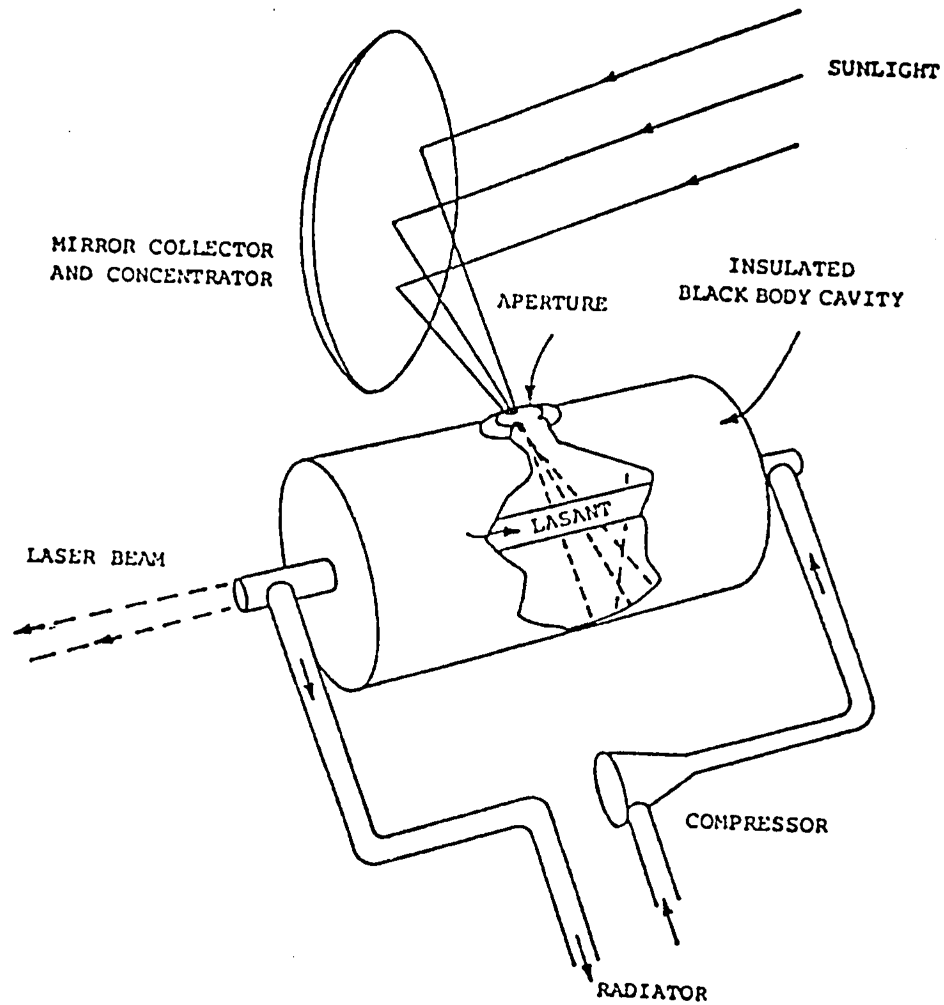

Figure 1. Schematic diagram of a solar blackbody cavity-pumped laser system.

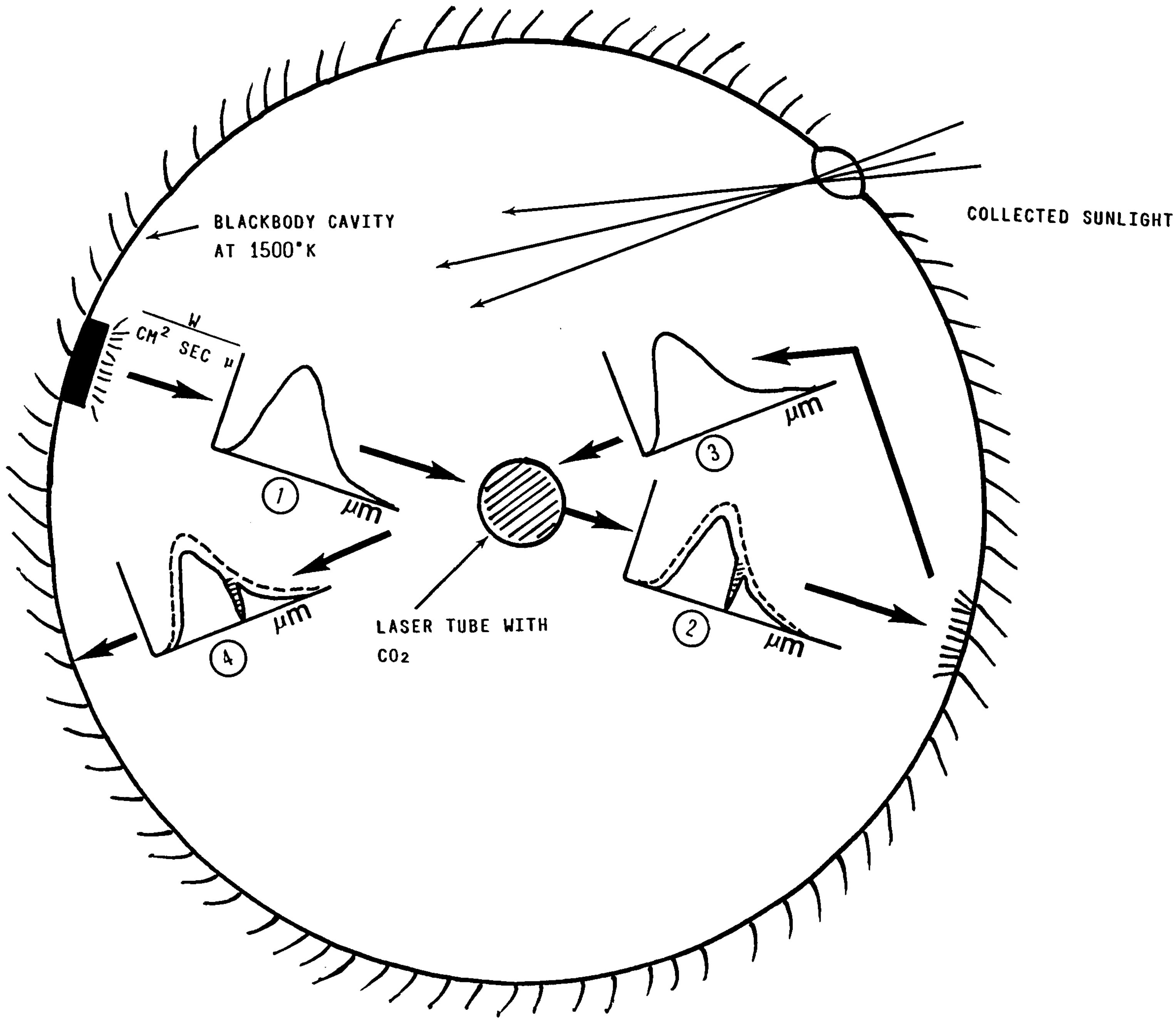

Figure 2. Schematic diagram of the blackbody pumping process.

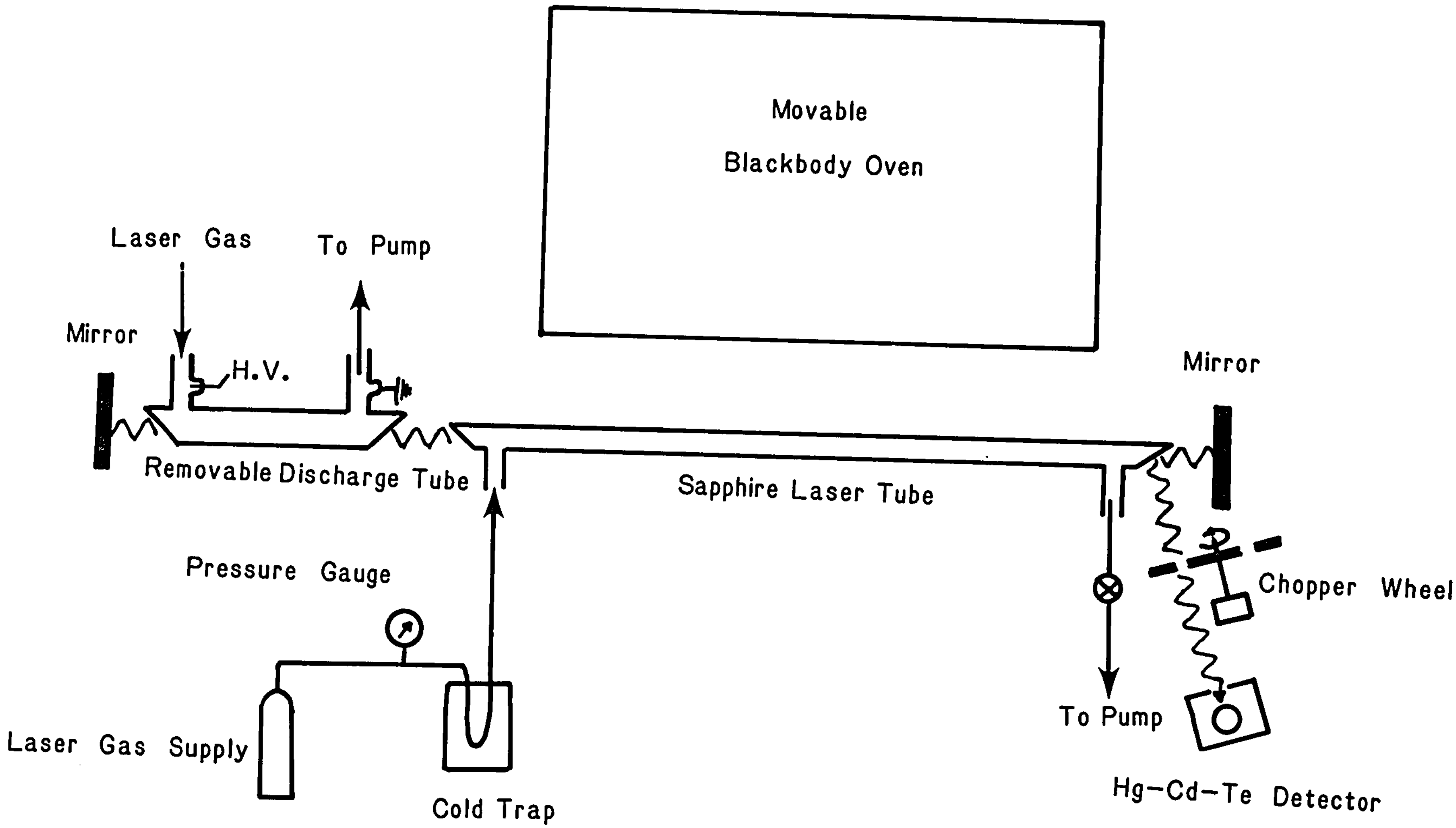

Figure 3. Experimental set-up of the blackbody cavity-pumped CO_2 laser.

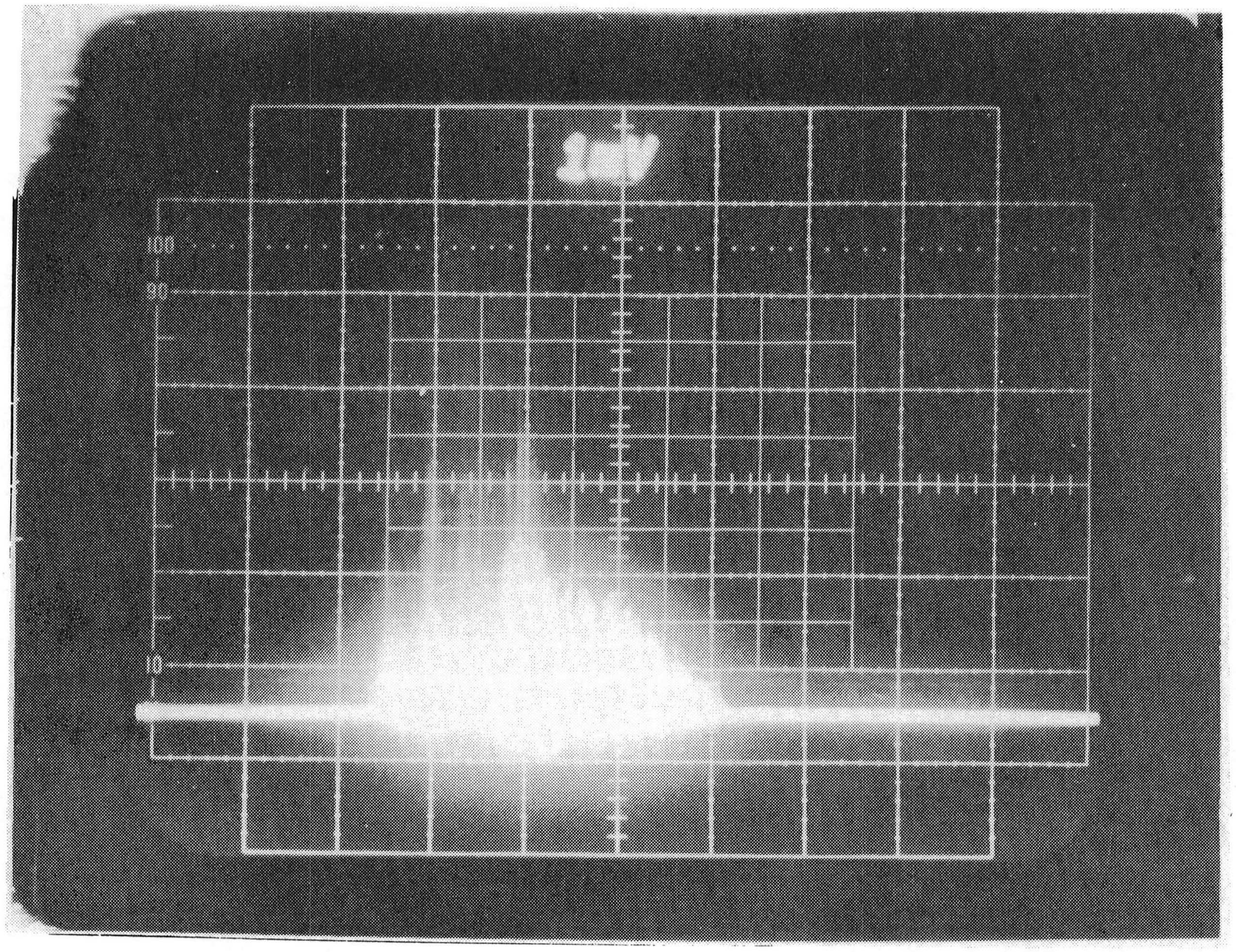

Figure 4. Blackbody-pumped CO_2 laser signal chopped at 30 Hz. The vertical axis is 1 mV/div, the horizontal axis is 1 sec/div, and the total pressure is 8 Torr.

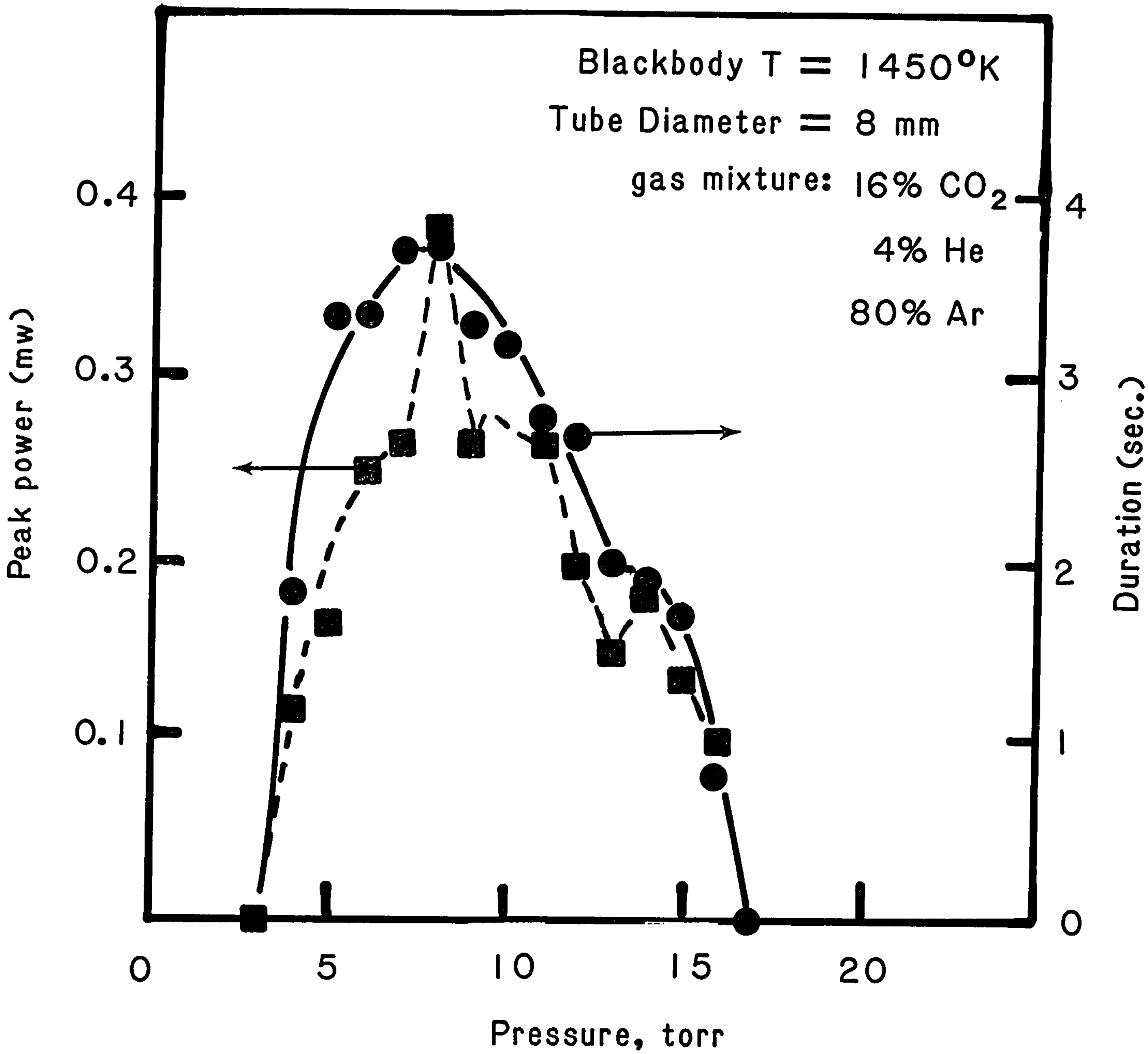

Figure 5. Peak power and lasing duration versus pressure for an estimated output coupling of 0.05 percent.

1. Report No. NASA TM-84541	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: A BLACKBODY RADIATION-PUMPED CO_2 LASER EXPERIMENT		5. Report Date: September 1982
		6. Performing Organization Code: 506-55-13-01
7. Author(s): Walter H. Christiansen[1], R. J. Insuik[2], and Russell J. De Young*		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address: Langley Research Center, Hampton, Virginia 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered: Technical Memorandum
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

[1]University of Washington
[2]University of Washington
*Langley Research Center

16. Abstract

Thermal radiation from a high-temperature oven was used as an optical pump to achieve lasing from CO_2 mixtures. Laser output as a function of blackbody temperature and gas conditions is described. This achievement represents the first blackbody cavity-pumped laser and has potential for solar pumping.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
CO_2 Laser Blackbody Pumping Optically Pumped Lasers	Unclassified -- Unlimited Subject Category - 36

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	13	A02

For sale by the National Technical Information Service, Springfield, Virginia 22161