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A Novel CO_2/N_2O Waveguide Laser

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Abstract

We present a new design for a waveguide laser which is easily constructed from readily available materials. We have demonstrated its operation for CO_2 (8.5 W output) and N_2O (1.5 W output).

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Introduction

We wish to report the successful operation of a novel and simple CO_2/N_2O waveguide laser. This laser employs commercially available swage-type fittings both as the discharge electrodes and for flowing the lasing medium. Although most of the CO_2 waveguide laser designs[1] have utilized beryllia (BeO) waveguides because of this material's extremely high thermal conductivity and low waveguide losses, it is expensive and its toxicity is a major problem in laser fabrication. As an alternative we have designed and built a laser utilizing an alumina (Al_2O_3) waveguide. We adopted the design guidelines that the laser should be easily and inexpensively constructed from readily available materials. We chose alumina for a waveguide material because it is non-toxic, inexpensive, and adequate in performance. The higher thermal conductivity and lower optical losses of beryllia are not cost-effective here, since for our waveguide dimensions, the wall temperature drop for alumina is only 1.5°C, and the waveguide losses[2] are only on the order of 10^{-3} cm^{-1}.

Laser Design

An exploded view of our laser appears in Figure 1. An alumina tube of inner diameter 2.4 mm, outer diameter 4.8 mm, and length 28 cm served as the waveguide.[3] On either end of the tube we attached an ordinary swage-type stainless steel tee which had been milled off at Brewster's angle for mounting the NaCl Brewster window. These tees were attached to the ceramic tube with teflon ferrules, and served as electrodes for the discharge. The windows were cemented on with silicone rubber sealant (RTV). The laser gas mixture flowed into and out of the laser through the tees. Needle valves on the inlet and outlet lines controlled the pressure and flow rate. A finned heat diffuser (not shown in the figure) was attached to the cathode.

The waveguide rested in a round groove in a water-cooled aluminum block 5 cm x 5 cm x 23 cm. Another grooved aluminum block 1.3 cm x 5 cm x 23 cm was fastened down on top of the tube. Silicone grease was used to improve the thermal contact. Since the waveguide is not directly cooled by the water, there in no need to make water-tight seals around the waveguide tube. The high thermal conductivity of the aluminum insures effective cooling of the waveguide. The temperature drop across the wall of the waveguide itself is

$$\Delta T_W = \frac{P/L}{2\pi\kappa} \ln \frac{b}{a}$$

where P/L is the electrical power dissipation per unit length, κ is the thermal conductivity of the wall, and b and a are the tube outer and inner radii, respectively. For $P/L = 115$ W/28 cm, $\kappa = 0.303$ W/cm°C, and $b/a = 2$, $\Delta T_W = 1.5$°C.

The entire assembly was enclosed in a metal housing so that no high voltages would be exposed. The electrodes were cooled by small electric fans attached to the housing. A spacing of about 2 cm was maintained between the anode and the heat sink block and the end of the block was lined with mylar to prevent electrical breakdown.

We also constructed two similar lasers with different waveguide dimensions. One had a 3.2 mm i.d., 6.4 mm o.d., and 30 cm length, while the other had a 1.6 mm i.d., 3.2 mm o.d., and 12 cm length.

Operating Characteristics

For CO_2 laser operation we used a mixture of 70% He, 20% CO_2, and 10% N_2. We operated the 2.4 mm bore laser at pressures up to 103 Torr (average of inlet and outlet pressures) and estimate that operation to at least 125 Torr should be possible. The optimum power was obtained at 67 Torr at current 10 mA. Under these conditions the voltage drop across the tube alone was 11.5 KV, to which must be added the voltage across the ballast or current regulator--a 15 KV supply should suffice. Although the starting voltage is high, the discharge can be started at lower pressure and the pressure then raised to its optimum value. In multiline operation the power was almost independent of flow rate, but for grating-tuned operation, fast flow was required. With the average pressure held fixed at 46 Torr, the single-line power leveled off at a pressure differential of about 25 Torr between inlet and outlet. Sealed-off operation with our usual gas mixture cannot be maintained for more than a few minutes, but we were able to operate the laser sealed off for 1½ hours with an unoptimized mixture of 14 Torr He, 5 Torr Xe, 5 Torr CO, 4 Torr CO_2, and 2 Torr N_2, at current 3 mA.

We investigated the performance of the laser for several optical resonator configurations. When a flat high reflector and a flat 95% output coupler were placed as close as possible to the ends of the waveguide, an output of 4.8 W was obtained. Many prospective users may favor this configuration because, while not optimal, the components are relatively inexpensive and readily available. We also investigated a cavity consisting of concave high reflectivity and output coupling mirrors, both of approximately 34 cm radius of curvature, as suggested by the theory of Abrams.[4] The output coupling used, 7%, was less than the optimum value of 16% found by using a coupling plate, but was chosen to increase the number of lines obtainable in grating-tuned operation. With the two concave mirrors, a local maximum in power was observed, as expected from theory,[4] when the mirrors were separated from the ends of the waveguide by approximately half their radii of curvature (actually slightly less than half.) However, the overall maximum power was obtained when the waveguide-mirror spacings were approximately equal to the radii of curvature. In this configuration we obtained an output of up to 8.5 W. The laser operated exclusively in the EH_{11} mode except for a few far-from-optimal waveguide-mirror spacings, for which a donut mode was obtained.

Line selection was achieved by replacing the high reflector with a 150 line/mm grating blazed for 10.6 μm placed close to the end of the waveguide. On the strongest line (P(20) at 10.6 μm) we observed an output of 1.1W, the low power probably partly due to mode coupling losses. To reduce these losses we employed a cavity configuration with the grating placed behind an anti-reflection coated intracavity lens of focal length 35.6 cm, located approximately 35 cm from the end of the waveguide. The purpose of the lens is to collimate the divergent beam from the waveguide onto the grating, and then to refocus the grating reflection back into the end of the waveguide; such a configuration was first used by Van Lerberghe et al.[5] This increased the power to 1.9 W on P(20). The spectrum of lines we were able to obtain in grating-tuned operation included P(6) through P(44) and R(4) through R(38) in the 10 μm band, and P(10) through P(30) and R(10) through R(28) at 9μm. We have not determined the tuning range on each line, but with our present long cavity it will be limited by the free spectral range of 150 MHz.

We successfully operated our laser as an N_2O waveguide laser. With a mixture of 51% He, 20% N_2, 16% CO, and 13% N_2O, with inlet and outlet pressures of 59 and 25 Torr, respectively, and with the cavity consisting of two concave mirrors (as described above), we obtained 1.5 W output. Pressure and gas mixture appeared to be roughly optimal since any changes resulted in decreases in power. Optimal current for this gas mixture and pressure was 4.5 mA, and the discharge voltage was 14.7 KV. Fast flow was found to be essential; hence the large pressure differential across the tube. Thus far, grating tuned operation has not been achieved.

Returning now to CO_2 laser operation, we investigated the 3.2 mm bore laser using flat mirrors near the waveguide ends and obtained 4.6 W at optimal pressure 56 Torr and current 10 mA. With the 1.6 mm bore laser (having a much shorter waveguide) we obtained 2.5 W at optimum pressure 100 Torr and current 7.3 mA with optimally positioned 15 cm radius concave mirrors. Operation of this laser at pressures up to 146 Torr was achieved. However, we had frequent problems with damage to the windows of this laser, and have therefore concentrated our efforts on the 2.4 mm bore laser.

One final comment: in the case of operation with small bore waveguides and short radius concave mirrors, the already large divergence of the beam emerging from the end of the waveguide is accentuated further by a plano-concave output mirror substrate. Therefore, it is advisable to use a positive meniscus lens with a reflective coating on its concave side as the output coupler to achieve a collimated beam.

Conclusions

We have presented a new waveguide laser design which can be implemented with very modest expenditure and machining effort, and which avoids use of the toxic material BeO. In its present form the design is not applicable where high frequency stability is needed due to the requirements for forced air cooling of the electrodes and for fast flow of the laser gas. However, if the user is willing to abandon the convenience of using commercial swage-type fittings as electrodes, he may design electrodes which can be cooled by an electrically insulating liquid. Slower flow can also be used at a sacrifice in output power.

We would like to point out that, while we have emphasized the use of alumina as a waveguide material, the same design concepts are applicable to materials such as beryllia and boron nitride, and would be especially attractive for the latter material since it cannot be satisfactorily epoxied.[6] Use of these materials becomes essential for very small bore lasers, for which the optical losses of alumina are too high. Furthermore, the use of swage-type fittings both as the discharge electrodes and as a conduit for flowing the lasing gases is also applicable to laser designs other than waveguide ones.

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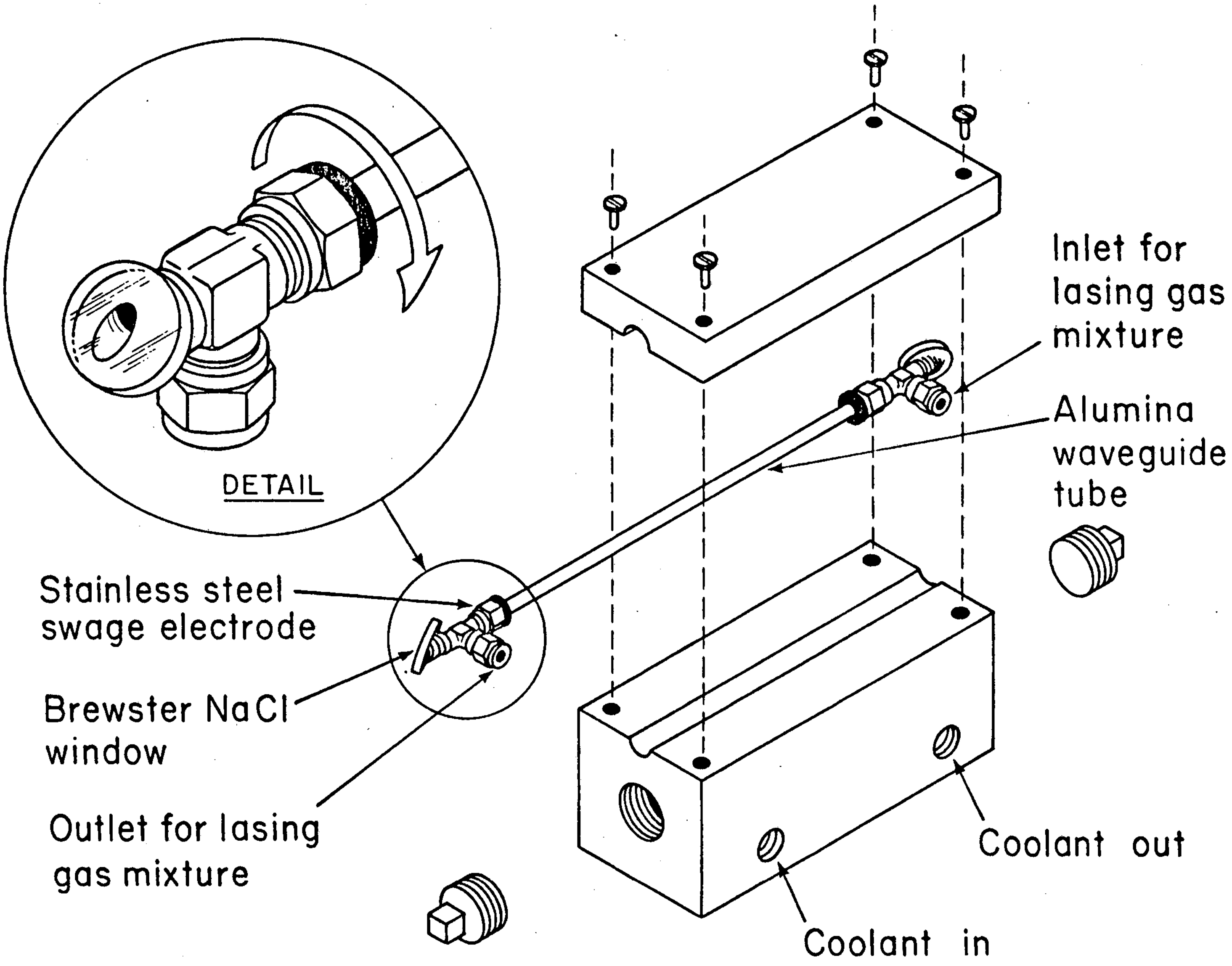
FIGURE CAPTIONS

FIG. (1) Exploded View of the Laser Design.


DETAIL
Inlet for lasing gas mixture
Alumina waveguide tube
Stainless steel swage electrode
Brewster NaCl window
Outlet for lasing gas mixture
Coolant out
Coolant in

XBL 795-1603

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