February 1982

Simple powerful tunable single-mode and mode-locked TEA CO_2 laser

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(Received 27 July 1981; accepted for publication 5 October 1981)

A simple method for constructing a single longitudinal-mode CO_2 laser that is tunable within individual rotational transitions is presented. Useful power levels, typically 0.3 J per pulse in a single-mode beam, are obtained from a single-stage device. Mode-locked output can also be obtained from the laser. In addition, design and construction of a local oscillator for making absolute *in situ* frequency measurements is described.

PACS numbers: 42.55.Dk, 42.60.Kg

INTRODUCTION

Many laser applications, including laser photochemistry and optically pumped lasers, require the use of a laser having high peak power, tunability, and in addition a very narrow bandwidth. Transversely excited, atmospheric-pressure (TEA) CO_2 lasers have high peak power, are grating tunable between rotational transitions, but have a broad linewidth. The pressure broadened gain bandwidth of a TEA CO_2 laser is about 3 GHz, and will typically include 40 longitudinal modes of the cavity, although usually fewer than ten of these modes will oscillate, and the laser linewidth will be typically 0.5 GHz. By forcing oscillation on a single mode the linewidth can be reduced to a few megahertz or less. Methods for obtaining single-longitudinal-mode (SLM) output from a TEA CO_2 laser include using a gain cell,[1] an etalon,[2] injection techniques,[3] and selective absorbers.[4-6] This paper describes design and operation of a laser that utilizes selective absorber gases as the mode controlling element.[4,5] The laser produces 300 mJ SLM pulses in a single stage configuration, is piecewise tunable across the gain bandwidth of many CO_2 lines, and is simple in construction.

I. DESIGN

The laser system (Fig. 1) incorporates two laser cavities within the same structure. One, the TEA laser, provides the SLM output. The second, unnecessary for operation of the SLM TEA laser, is a small longitudinal discharge CO_2 laser used as a reference or local oscillator to measure frequency displacement of the high-power laser from the CO_2 line center using heterodyne techniques. This allows absolute *in situ* measurement of the SLM TEA laser frequency to within 10 MHz. Both cavities are grating tunable over the various CO_2 rotational transitions and provision is made for monitoring laser frequency without interfering with the main beam so that the TEA laser offset may be continually monitored during an experiment.

An important advantage in this design is that SLM and mode-locking operation can be obtained by the simple procedure of inserting a gas cell into the optical cavity. For applications not requiring precise frequency measurements the local oscillator is unnecessary. However with the local oscillator it is possible to make absolute spectroscopic measurements comparable to a good diode laser.

Because thermal and mechanical stability of the optical mounts are important factors in determining the ultimate frequency stability of the laser, an Invar frame has been incorporated into the laser system to reduce drift of the laser frequency resulting from expansion of the optical cavity due to temperature variations. Additionally, temperature compensation is provided by counter-expanding aluminum optical mounts. The structure is enclosed in Plexiglas to eliminate air currents and the four Invar rods are covered with urethane foam and wrapped in aluminum foil to further desensitize the system to thermal variations. The 1-in. Invar rods were positioned so as to provide the most rigid optical support structure possible, while not interfering with proper placement of other components. The Invar rods are mounted on three brackets each containing rubber insulators of 3 mm thickness to reduce transmission of vibrations to the structure. The entire laser system is on an aluminum slab 50 mm thick, which is further isolated from the table by 50 mm of foam rubber. Mechanical rigidity and shock isolation are important to eliminate pulse-to-pulse jitter in the laser frequency due to vibrations.

The plates on which the optics are mounted are constructed of 1-in. aluminum. Three plates are used, one for the two output couplers, and one apiece to mount the gratings for the two lasers. The two plates to which the gratings are mounted may be moved longitudinally to select an optimum cavity length under various conditions, such as substitution of a different absorption cell. Generally the shortest cavity length possible is best as it provides maximal longitudinal mode spacing. The reference laser cavity is 80 cm long, and the TEA laser cavity is typically 150 cm long. The gain medium of the TEA laser is produced by a Lumonics 101 kit with a 50-cm-long active region. Brewster windows on both ends seal the gain section.

The absorption cell used for mode selection is 50 cm

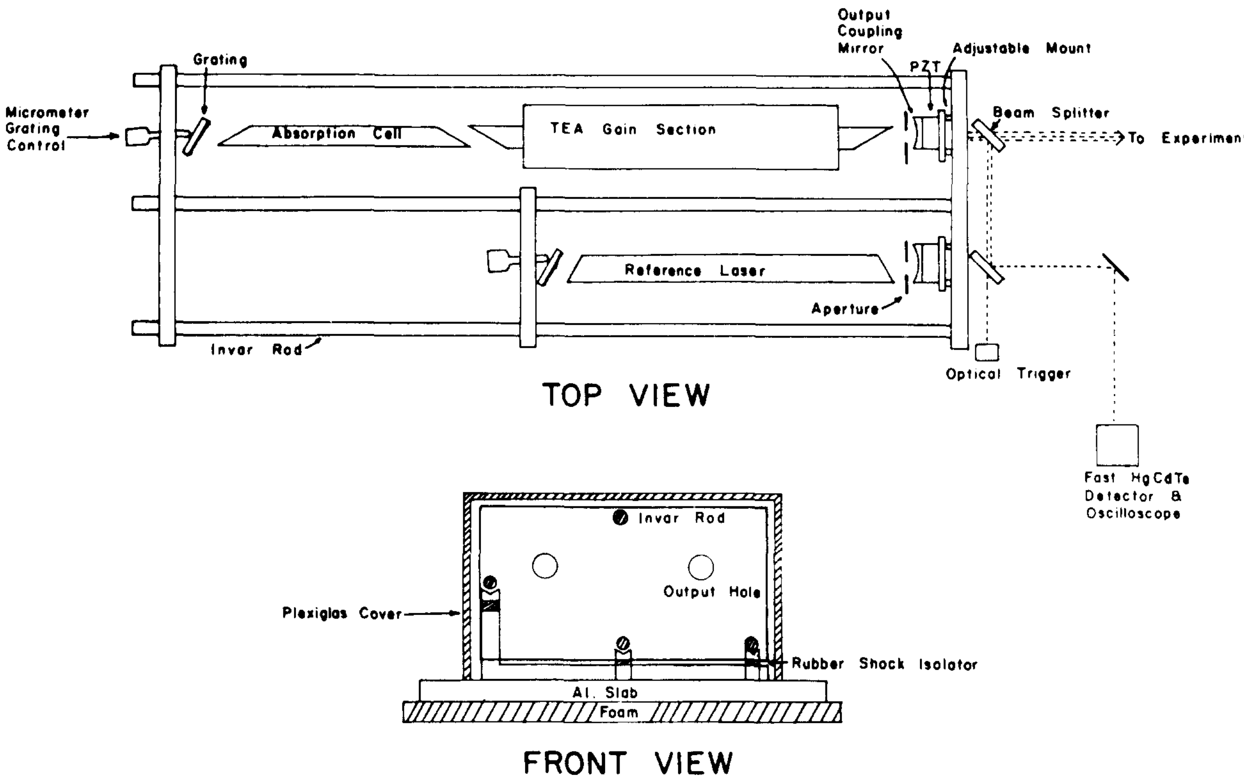

FIG. 1. Schematic of laser including selective absorber cell and local oscillator.

long and is similarly sealed with NaCl Brewster windows. The cell is equipped with one port to which a low-pressure gas handling system is attached. The pressure of the selective absorber gas should be monitored precisely for stable operation; it is advisable to use a capacitance manometer-type monitoring device. For high-repetition rate operation it would be useful to add a feedback circuit to adjust and control cell pressure automatically. Cell pressures typically vary from 0.1 to several Torr, depending on the gas being used.[5] Mode locking is achieved by slightly increasing the pressure of the absorber used for SLM operation. A list of selective absorber gases may be found in Ref. 5. As an example, gases producing SLM operation on all lines from 9R(10) to 9R(30) include CCl_3F, CCl_2F_2, $CBrF_3$, $CHCl_2F$, $CHClF_2$, and mixtures of these.

The low-pressure reference laser is constructed of a 7-mm ID Pyrex tube 65 cm long. The pulsed electrical discharge is supplied by a 9-nF doorknob capacitor switched with a thyratron. The Brewster windows are mounted to the tube using ground-glass couplings to minimize maintenance problems.

The rear reflector of each of the laser cavities is a grating. The grating for the TEA laser is a 100-groove/mm gold-coated master, blazed at 10 μm. A master grating is necessary for the high-power laser to reduce grating damage from high flux densities. The low-pressure reference laser is tuned with a 150-groove/mm replica grating blazed at 9 μm. The higher groove density provides greater dispersion which is necessary for proper operation in the shorter cavity. Both gratings are mounted in adjustable fixtures directly to the 1-in. aluminum plates.

The front reflectors for the two cavities are mounted to the forward plate on an adjustment mechanism for cavity alignment. In addition, between the mirror and adjusting mechanism is a piezoelectric translator (PZT) for adjustment of the cavity length over a distance of 10 μ. Inside each of the two laser cavities is an adjustable aperture to eliminate multiple transverse mode operation. Two NaCl windows are mounted on the outside of the endplate which holds the output couplers. These windows split off small portions of the laser beams and combine them colinearly so that the beat frequency can be monitored with a fast HgCdTe detector.

An electronic control unit was designed and built to supply the trigger signal to the lasers and to control the PZT voltages. The unit contains a master trigger section with variable rate which supplies a pulse every 0.2 to 20 s to the four-channel delay section. Variable amplitude pulses (0–40 V into 50Ω) of 5 μs duration can be individually delayed from 0 to 100 μs to synchronize the TEA laser output pulse with the reference laser. Two extra channels are provided for synchronization of other equipment such as oscilloscopes or other lasers. Also included in the unit are two variable power supplies of 0 to 1.2 kV range for operation of the PZTs. Digital display of the PZT voltage is provided.

II. OPERATION

The system is set up for operation by tuning the two lasers to the desired rotational transition with the gratings, then introducing into the evacuated absorption cell enough of the selective absorber gas to quench oscillation in the TEA laser. Then the gas is evacuated slowly until the laser is lasing with moderate power. At this point the TEA laser pulse shape should be checked with a fast detector to ensure SLM operation, evidenced by a smooth pulse with no modulation.

The reference laser will generally need to be peaked by adjusting the cavity length with the PZT since the gain bandwidth at low pressure is less than the cavity-mode spacing. By carefully watching for peak amplitude of the lasing it is possible to ascertain the position of line center. Allowing both laser beams to strike the detector simultaneously and colinearly produces a heterodyne signal from the detector giving the frequency offset from the CO_2 line center at which the TEA laser is oscillating. Adjustment of the PZT on the TEA laser output coupler can yield a tuning range nearly equal to the mode spacing of the cavity, although it is dependent on the particular selective absorber gas used. Shifting the frequency beyond the tuning range of the laser with a particular absorber gas in the cell usually requires using another gas with different absorption characteristics.[5]

The laser has been observed to be stable within a range of 15 MHz for periods of 20 min. Pulse-to-pulse frequency jitter and absolute frequency stability is approximately 10 MHz. Single-mode energy per pulse is approximately 70% of the laser operating multiple longitudinal mode and the typical pulse energy is 300 mJ.

ACKNOWLEDGMENT

This work was supported by the Department of Energy. It is a pleasure to acknowledge valuable conversations with C. R. Jones.

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