## TRANSVERSELY EXCITED HIGH PRESSURE CARBON-DIOXIDE LASER

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# (Received 15 February 1973)

With the development of transversely excited atmospheric (TEA) carbon-dioxide lasers in 1970, it is possible to obtain short laser pulses in the mega-watt peak power range from a modest length of the laser. At high pressures, the linewidth of the laser transition is dominantly collision-broadened and hence a large linewidth is available at atmospheric pressure. Increased gain-band-width product in the TEA lasers provide large inversion density and hence large optical energy.

A high pressure carbon-dioxide laser has been constructed. It employs a continuously running gas mixture of  $CO_2$ ,  $N_2$  and He upto a total pressure of about 100 torr. The laser is excited by 18 kv electrical pulses of about 1.0  $\mu$ sec duration and about 1000 amperes peak current. Laser pulses are produced in the gain-switched regime whereby about 100 kw peak power pulses of about 0.5  $\mu$ sec duration are produced. The laser output has been detected by a fast photon drag detector whose rise-time is in the subnanosecond range. The detector is also fabricated in the laboratory.

## Introduction

Pulse excitation of the gases transverse to the laser oscillations and the uniform distribution of electrical discharge over the entire length of the laser facilitate the operation of the  $\rm CO_2$  laser near atmospheric pressure. Small inter-electrode spacing in the transversely excited atmospheric (TEA)  $\rm CO_2$  lasers permits electrical breakdown of the gases by about 25-40 KV pulses. Increase in the population inversion in the TEA lasers yields large peak power gain-switched laser pulses. Beaulieu (1970) employed a meter long TEA laser tube and produced 0.5 mw peak power laser pulses of 0.5  $\mu$ sec duration.

The population inversion density in the TEA lasers is proportional to the gain-bandwidth product (Patel 1971; Gibson et al. 1971). It has been observed that the gain-bandwidth product increases with the increase of the total pressure of the ternary mixture of gases used in the laser (Patel 1971; Gibson et al. 1971), and hence more output is obtained at higher pressures.

#### EXPERIMENTAL DETAILS

The type of laser constructed for the experiment is similar to one used by Beaulieu (1970). Fig. 1 shows a cross-section of the excitation system. The laser is constructed in a vacuum tight bakelite box of size  $100 \times 10 \times 10$  cm. The anode is made of a 1.0 cm diameter polished brass rod. The cathode consists of a string of 100 pins, 0.75 cm apart, each pin being loaded by a 1000 ohm resistor. The anode rod is fixed in the bakelite box in such a manner that the laser oscillations

310 B. S. PATEL

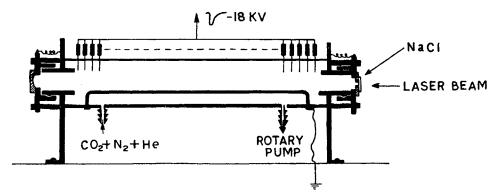


Fig 1. A cross-sectional diagram of the laser box.

utilize the space just above the rod. Such electrode arrangement provides maximum optical gain (Patel 1971; Gibson et al. 1971). The optical cavity comprises of a 600 cm radius of curvature concave mirror and a plane mirror. The power is coupled out of the cavity through a 0.2 cm hole in the plane mirror. A rock-salt plate is suitably held against the coupling hole to make the laser box vacuum tight. The laser output has not been optimized. The mirror holders are held with the help of 0-rings slipped onto small glass tubes which are cemented to the laser box.

The electrical excitation pulses are obtained by discharging a high voltage capacitor of 0.02  $\mu$ F. The capacitor is initially charged to a voltage upto 18 kv and then discharged via a spark-gap. The value of the capacitor is optimized for maximum laser output at 0.02  $\mu$ F. The negative going 15–18 kv electrical pulses have a duration of about 1.0  $\mu$ sec and a repetition rate of about one pulse a second. To obtain such short electrical pulses it is important that the high-voltage capacitor and its associated circuitary have low inductance ( $\sim$ 50 nano-henry). The spark-gap is triggered by suitable electrical pulses obtained through a high-voltage pulse transformer.

The laser output is detected by a fast photon drag detector (Gibson et al. 1970). The detection of the laser radiation is based on the transfer of momentum between the laser photons and the free charge carriers of a semiconductor. For 10.6  $\mu$ m radiation, a useful material for the detector is p-type germanium of suitable conductivity (Patel 1973). This detector is simple to construct and it operates at room temperature. The only drawback of the detector is that it is rather insensitive, which can be overlooked when the laser power to be detected is in the range of tens of kilowatts. The rise-time of the detecting system is less than 10 nanosecond, which is primarily limited by the bandwidth of the displaying oscilloscope and the amplifiers.

The gas pressure used in the experiment is  $CO_2$  at 45 torr, air at 30 torr and He at 40 torr. A continuous gas flow at a slow rate is maintained in the laser box to reduce any vacuum leak in the laser system. An oscilloscope trace of the laser pulse is shown in Fig. 2. The laser pulse is actually found to occur with a delay of a few micro-seconds after excitation. This observation is consistent with the earlier observation that the optical gain in the laser cavity builds to its peak value after a few micro-second of excitation (Patel 1971). The initial spike of the laser

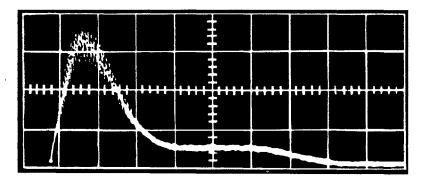


Fig. 2. An oscilloscope trace of the laser pulse Peak-power is about 100 KW and the time base is 200 nanosecond/div.

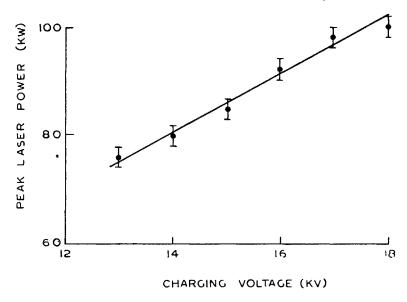


Fig. 3. Variation of peak laser power output with the charging voltage.

pulse has a width of about 200 nanosec, and is followed by a tail of about a microsecond (and sometimes even longer). This tail is believed to be produced by slow transfer of energy from excited nitrogen molecules to the upper laser level (Patel 1971). The super-structure on the gain-switched laser pulse is due to self-mode locking (Lyon et al. 1970) of the laser resulting from the non-linear property of the gas plasma. Fig. 3 shows the variation of peak pulse power with the charging voltage. Clearly, the laser output increases with the increasing voltage. Maximum peak power is around 0.1 mw. More power could be produced by higher charging voltages, for example, a system of this type working at pressure of CO<sub>2</sub> at 35 torr, N<sub>2</sub> at 15 torr and He at 700 torr and using a voltage of about 30 kv could produce a peak power of about 0.8 mw (Patel 1971). After filling the gases, the laser could be sealed-off, and the output of the sealed laser remains practically the same upto

312 B. S. PATEL

one hour of continuous operation. When helium is not used in the gas mixture, the laser pulses are still produced but the laser peak power reduces to about 60 kw. This result is quite expected and can be explained as follows. The laser output is proportional to the gain-bandwidth product. In the absence of helium, the optical gain of the gas mixture is not very much affected. The collision-broadened linewidth of the laser is proportional to the total pressure of the gas mixture, and hence the gain-bandwidth product in the absence of helium is reduced to about two-thirds of that in the presence of helium.

### DISCUSSION

The inversion density in the laser is proportional to the gain-bandwidth product, The optical gains observed in the TEA laser are appreciably less than the pulseexcited conventional low pressure laser where gains of the order of 8.0 dB/m are obtained. At higher pressures the bandwidth is increased, and even when allowance is made for this increase, the fraction of inverted CO2 molecules at higher pressure is about an order less than in the low pressure lasers. Consequently, working efficiency of the high pressure laser is about one per cent. This decrease in the efficiency (compared to the low pressure CO<sub>2</sub> lasers) cannot be due to a muchreduced life time of the upper laser level at high pressure, because even at an atmospheric pressure it is long enough to prevent any appreciable decay to have occurred before the laser intensity reaches its peak value after the excitation. The low efficiency is thus due to the filamentary nature of the discharge, which occupies only a small fraction of the oscillation mode volume. An important feature of the TEA laser is that a large laser linewidth is available for producing short laser pulses by modelocking. The linewidth of the TEA laser is expected to be around 3.5 GHz (Patal and Swarup 1973) and hence mode-locked laser pulse of sub-nanosecond duration are possible. Cavity-dumping can then be used to single out a mode-locked pulse of large peak power. The cavity-dumping of the transversely excited lasers has recently been reported (Patel 1972).

There are several other advantages of the TEA  $\rm CO_2$  laser over their low pressure counterparts. The foremost is that it gives out more optical energy. The gain-switching eliminates any external Q-switching device. Dissociation of  $\rm CO_2$  molecules is insignificant and hence sealing-off is comparatively easier. The linewidth of the TEA laser is homogeneously broadened and hence it is possible to extract more efficiently the stored optical energy in the laser as against the low pressure laser where linewidth is mostly Doppler broadened. At the atmospheric pressure, the rotational relaxation is expected to be a few nanosecond, and hence the gain-switched laser pulses of 0.5  $\mu$ sec-duration are likely to avail of all the vibrational energy at a single vibrational-rotational transition.

The low working efficiency of the TEA laser is rather a drawback. Efficiency can be greatly improved by using uniform excitation techniques (Lamberton and Pearson 1971), and still more laser peak power can be obtained.

#### ACKNOWLEDGEMENTS

Thanks are due to Dr. Prem Swarup for his encouragement during the work and also to Mr. R. S. Sinha for his technical assistance.

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