An EMQ-switched CO2 laser as a pump source for a far-infrared laser with a high peak power and a high repetition rate

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An EMQ-Switched CO_2 Laser as a Pump Source for a Far-Infrared Laser with a High Peak Power and a High Repetition Rate

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***Abstract*—An EMQ-switched CO_2 laser which is Q-switched by a mechanical beam chopper in combination with a pulsed discharge current has been developed for pumping far-infrared lasers. This CO_2 laser produces a very stable output with a peak power greater than 1 kW at a repetition rate of 1000 pps for all transitions in the P and R branches of the CO_2 spectrum. Using it as a pump source for a CH_3F laser, we have obtained 496 μm radiation in 6.5 W peak, 100 ns pulses at 500 pps in the lowest loss EH_{11} mode.**

I. Introduction

CO_2 pumped lasers are important sources at far-infrared (FIR) wavelengths because the output powers are large and many wavelengths are available [1]. Both CW and pulsed lasers have been developed. CW lasers are pumped with CW CO_2 lasers, and the FIR power is usually less than a watt. The pulsed lasers are usually pumped with TEA-CO_2 lasers. The peak pump power can be larger than a kilowatt, but the repetition rate is usually quite low, typically 10 pulses per s.

Higher repetition rates would be extremely useful in many applications, particularly in spectroscopy. Bluyssen *et al.* [2] developed a current pulsed Q switched (EQ switched) low pressure (2.6 kPa) CO_2 pump laser. This produced FIR pulses with output powers greater than a watt at repetition rates up to 350 pps. However, the rotating-mirror technique that they used gave high repetition rates only for the high-gain lines near the center of the P and R branches of the CO_2 spectrum. This limits the number of far-infrared wavelengths severely.

Recently, we developed a modified EQ-switched CO_2 pump laser [3] with a mechanical beam chopper inside the cavity. We call this an EMQ-switched CO_2 laser. The advantage of EMQ-switched lasers is that the maximum repetition rate does not depend on the laser gain [4], and EMQ-switched lasers produce pump powers greater than 1 kW with repetition rates above 1000 pps over the entire R and P branches. A CH_3F dielectric waveguide laser with an EMQ-switched pump produced 496 μm pulses in the lowest loss mode with a peak power of 6.5 W and a repetition rate of 500 pps.

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II. Experimental

Fig. 1 is a schematic of the experimental setup. The CO_2 laser consists of a conventional low-pressure (~3 kPa) gas-flow discharge tube, a ZnSe reflector with 50 percent transmission, and a grating (150 lines/mm). It operates in three modes: CW, Q switched, and EMQ switched, and the mode may be changed conveniently by changing the electrical connections. The laser tube is 1.4 m long with a diameter of 8 mm. The gas ratio for the $He:N_2:CO_2$ mixture is 3 : 1 : 1. Two lenses with a focal length of 1.5 in concentrate the beam. The chopper wheel is placed at the focus of the beam to make the switching time as small as possible. These lenses increase the losses of the laser cavity, reducing the CW power by 7 percent. The chopper wheel is an Al-alloy, and is 160 mm in diameter with 3 mm slits. The slit edges are plated with tungsten 100 μm thick to protect the wheel. The number of slits varies from one to eight. The chopper has an air motor, and the maximum rotation rate is 10 000 rpm. The discharge is synchronized to the chopper with a current modulator. The maximum current is 400 mA, and the length of the current pulses may be varied from 10 to 100 μs.

The FIR laser is a dielectric-waveguide laser. The tube is pyrex, 1.3 m long. The input mirror has a 2 mm diameter hole. The output mirror is silicon, with a transmission of 33 percent at 496 μm. The output window is polyethylene, and there is a grating to protect it from the pump beam.

Peak power is determined from the pulse shape and the average power. The pump pulse shape is measured with a room-temperature HgCdTe detector with a response time of 200 ps, and the FIR pulse shape is measured with a GaAs Schottky barrier diode. The pulse shapes are recorded on a 100 MHz oscilloscope. The pump power is measured with a Coherent power meter, model 210, and the FIR power is measured with Scientech calorimeter, Model 36-0001.

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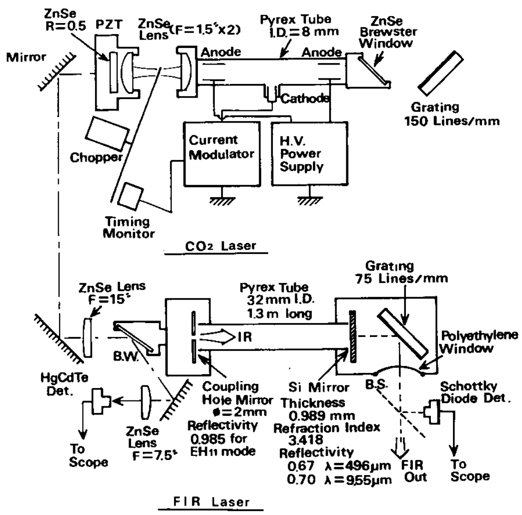


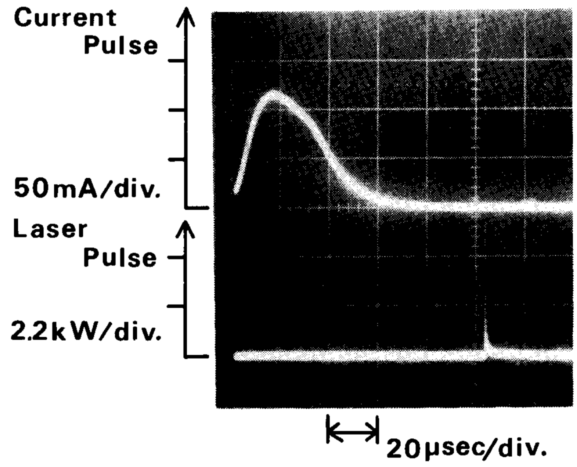
Fig. 1. EMQ-switched pump laser and FIR laser for producing 496 μm radiation.

III. Results

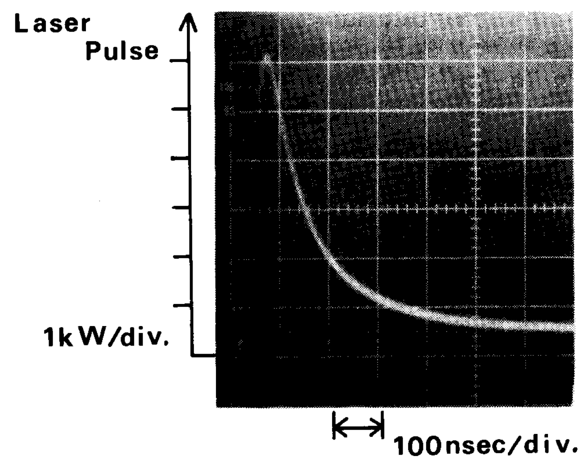
Fig. 2 shows typical current discharge and pump pulse shapes. The laser was operating in the TEM_{00} mode. Fig. 2(a) also shows a 100 μs delay between the start of the current pulse and the pump pulse. This delay is adjusted for maximum output power, and depends on the gas ratio [5]. The optimum delay time for our 3 : 1 : 1 gas ratio is 100 μs.

Fig. 3 compares the output power for the Q-switched and EMQ-switched modes for the 9P20 transition at different repetition rates, and demonstrates that the output power is maintained for repetition rates up to 1300 pps even for the Q-switching mode. For the Q-switching mode, the variation of the power at high repetition rates mainly depends on the relaxation time of the upper laser level including the excited state of nitrogen [4]. On the other hand, for the EMQ-switching mode, the heating of the gas in the laser tube becomes important at high repetition rates. More experiments at different gas pressures will be needed to clarify the details.

Fig. 4 shows the peak power and pulse duration of the output pulse as a function of the shutter velocity for the Q-switching mode (0.8 kPa, 10 mA dc). The pulse repetition rate also increases with the shutter speed, but the pulse repetition rate was limited to less than 600 pps so that it should not affect the results, so that the changes result from differences in shutter velocity alone. The peak power is proportional to the shutter velocity and does not saturate even at the maximum velocity of 120 m/s. Multiple pulses were not observed even at the lower shutter velocities for either the Q-switched or the EMQ-switched mode, even though these multiple pulses have often been reported [4], [6]. Multiple pulses cause problems because the peak powers are reduced when they occur. In our laser, the high-transmittance (50 percent) output mirror suppresses the multiple pulses by raising the oscillation threshold.



(a)



(b)

Fig. 2. Oscilloscope traces of the current discharge pulse (a) and CO_2 pulse, with the time scale magnified 200 times (b). The CO_2 pulse is also shown in (a) to indicate the delay. This is the 9P20 transition. The pressure is 1.6 kPa and the repetition rate is 165 pps.

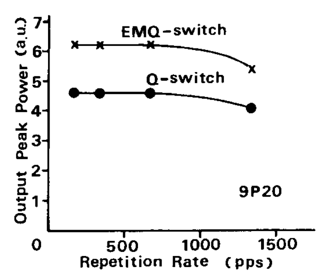


Fig. 3. Peak power versus repetition rate in the Q-switched and EMQ-switched modes for the 9P20 transition. The peak output power at 1300 pps in the EMQ-switched mode is 5 kW. The wheel velocity was 100 m/s and the pressure was 746 Pa. The current in the Q-switched mode was 10 mA dc, and the current pulses in the EMQ-switched mode had a peak of 240 mA and a duration of 65 μs.

The peak powers observed for the transitions of the 9P branch of the CO_2 spectrum are shown in Fig. 5 for the Q-switched and the EMQ-switched modes. Similar results were obtained for the other branches of the CO_2

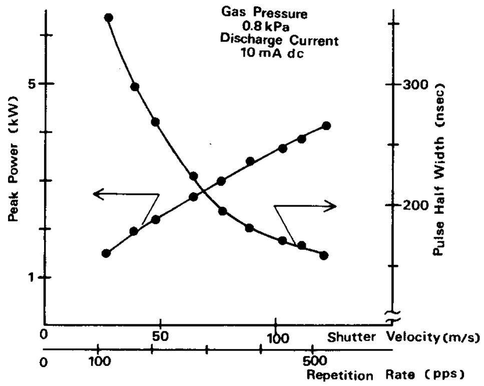


Fig. 4. Peak power and pulse duration of the Q-switched CO_2 laser pulses as a function of the shutter velocity of the chopping wheel. The discharge current was 10 mA dc and the gas pressure was 800 Pa. The pulse repetition rate is also shown on the bottom axis.

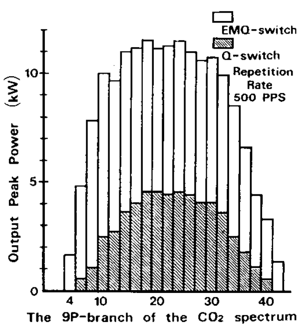


Fig. 5. Peak power for the transitions of the 9P branch of the CO_2 spectrum for the Q-switched pulses (cross-hatched bars, 10 mA dc, 1.3 kPa), and EMQ-switched pulses (open bars, 320 mA, 30 μs duration, 3.2 kPa).

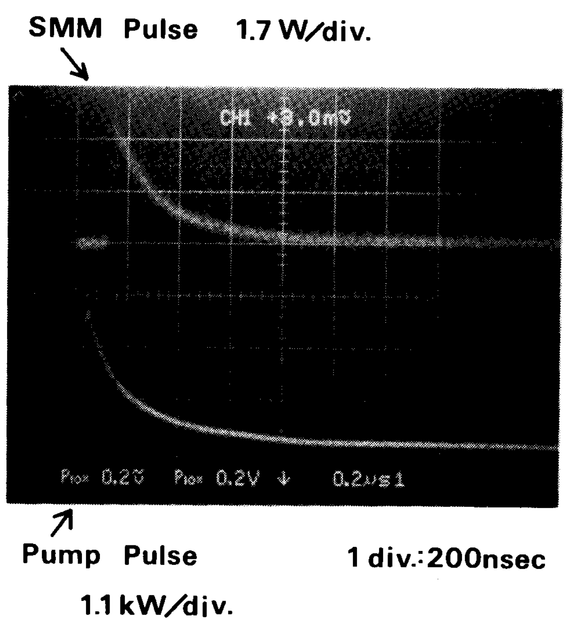


Fig. 6. Oscilloscope traces for a 496 μm pulse and the pump.

spectrum. The EMQ-switched mode gives much more powerful pulses, with peak powers of greater than 10 kW. The power is large even for transitions far from the center of the branch, like 9P6, 9P36, and 9P38, which are especially important for pumping CH_3OH and CH_3OD FIR lasers [2].

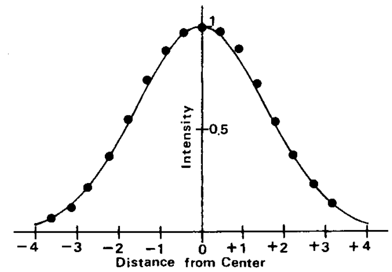


Fig. 7. The transverse intensity profile of a 496 μm radiation pulse from the CH_3F laser. This intensity distribution has been measured 1.5 m away from the silicon output mirror. The solid line gives the theoretical intensity distribution of a Gaussian beam with a 7.5 mm beam waist at the mirror.

In the EMQ-lasers, we found an interesting relationship between the peak pulse power and the peak discharge current. Generally, the peak power increases with the discharge current, but at currents above 320 mA, the pulse distorts and shortens, dropping to zero only 100 ns after the start of the pulse. This limits the peak power we can achieve. A similar effect was observed by Meyerhofer [4], who reported that it was caused by burning of the chopper blade. Our blades are tungsten coated, and this allows us to produce 12 kW pulses without distortion.

Figs. 6 and 7 show typical output from the CH_3F laser when it is pumped by the EMQ-switched CO_2 laser. In Fig. 6, the pulses are of similar length, but there is a delay of 120 ns between them. This delay time depends on the gain of the FIR emission line, which in turn depends on the CH_3F pressure and the pump power and duration [7]. The smallest delay time in our laser is 90 ns. Fig. 7 shows that the mode in the dielectric waveguide is the lowest-loss EH_{11} mode. We have achieved a 6.5 W peak 496 μm pulse at a repetition rate of 500 pps with a 6 kW peak power pump on the 9P20 line. The quantum conversion efficiency is 11 percent, which is 1.5 times better than the best efficiency reported for a CW laser [8].

IV. Conclusion

EMQ-switched CO_2 lasers had not previously been used as pump sources for far-infrared lasers, even though they have a number of advantages: simple construction, high-repetition rate, high-power, and excellent transverse mode stability. The problems were that multiple pulses often appeared with lower peak powers and pulses distorted when the chopper wheel burned. We solved these problems by using a high-transmittance output mirror, and by coating the chopper with tungsten. These improvements make the EMQ-switched laser a practical pump for FIR lasers. Using an EMQ-switched CO_2 laser as a pump source for the CH_3F laser, we obtained peak pulse powers of 6.5 W at 496 μm at 500 pps in the lowest loss EH_{11} mode. This demonstrates that the EMQ-switched is an excellent CO_2 pump source for FIR lasers.

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