DEVELOPMENT AND APPLICATIONS OF MILLIMETER WAVELENGTH, HIGH POWER OPTICALLY PUMPED LASERS*

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Abstract

The performance and applications of high power pulsed lasers in the 0.75 - 2 mm wavelength region is discussed. A narrow-linewidth, oscillator-amplifier configuration, pumped by a grating tuned CO_2 laser, has produced pulsed power levels (~100 nsec duration) of approximately 50 kW at 0.862 mm, 1.006 mm and 1.222 mm.

Introduction

There is presently a need for intense coherent sources in the 0.75 - 2 mm wavelength region. For example, proposed uses of such sources in the controlled fusion program include determination of ion temperature by means of collective Thomson scattering[1] and remote feedback stabilitization by localized plasma interactions with a modulated source[2]. However, conventional microwave sources such as magnetrons which produce power levels in excess of a MW in the centimeter region, produce only a few KW at wavelengths as long as 3 mm[3]. In contrast, optically pumped molecular lasers appear to offer the promise of MW level operation in the region of interest in addition to vastly simplified construction. Several groups have reported narrowline output at the 0.2 - 1 MW level in $C^{12}H_3F$ at 0.496 mm[4 5 6 7]. More recently, 5 kW pulsed operation of a mirrorless superradiance $C^{13}H_3F$ laser has been reported at several wavelengths in the vicinity of 1.2 mm[8]. We describe here a dielectric waveguide oscillator which has produced 20 kW pulsed power near 1.2 mm using $C^{13}H_3F$. The oscillator output has recently been amplified to the 50 kW level. In addition, other optically pumped gases with strong lasing transitions in the 0.75 - 2.0 mm region have been studied using the oscillator as only mW level output has been reported to date[9 10 11].

Experimental Apparatus

The pulsed far-infrared (FIR) oscillator-amplifier system used in these studies is depicted schematically in Fig. 1. The output of a grating tuned TEA CO_2 laser produces the population inversion in the FIR oscillator and amplifier. The 1 m-long FIR oscillator cavity consists of a circular hollow dielectric waveguide (34 mm i.d. glass tubing) and Nickel mesh mirrors. The input mirror admits the CO_2 pump while reflecting the FIR inside the cavity. The output mirror is partially transmitting to the FIR, which exits through a TPX plastic window.

FIR energy measurements are performed with a thermopile. The power is then computed from the beam temporal profile (~100 nsec FWHM) which is obtained with either a calibrated Li Ta O_3 pyroelectric detector (~5 nsec response) or a Schottky barrier diode detector (<1 nsec response). The near field mode pattern is determined by scanning a pyroelectric detector across the FIR beam. The intensity distribution appears to be strongly influenced by the CO_2 pump and typically resembles either an EH_{11} or LP_{11} mode. Spectral linewidth measurements are made with a scanning Fabry-Perot interferometer and also with both a Schottky diode video detector and heterodyne receiver system which uses a cw FIR laser[12] local oscillator. The diodes consist of plated Pt contacts 1 - 5 µm in diameter on uniformly doped, non-epitaxial 5×10^{18} cm ^{3} n-type Ga As and are mounted in an overmoded waveguide mixer package (100 GHz fundamental mode).

Results

Table 1 lists the more promising gases which we have investigated in the oscillator section of our system together with the CO_2 pump line, expected FIR wavelength, pressure at maximum FIR output, maximum pyroelectric detector signal, FIR cavity mirrors employed and CO_2 pump energy. The second number in the column on mirror mesh constants refers to the oscillator output mirror. The CO_2 pump energy referred to above is that within the gain switched spike (~100 nsec FWHM) and is measured inside the FIR cavity. For reference purposes, the 0.75 J pump laser had a long tail (~1 µs) which contained approximately half the total energy. On the other hand, in the 2 J case, the laser was run without N_2 so that the energy was contained primarily in the gain switched spike. The **power outputs listed in Table 1 were obtained by a linear interpolation from the detector calibrations at 447 µm and 1222 µm. For purposes** of comparison, a 600 mV pyroelectric detector signal at 496 µm corresponds to a 10 kW pulse of ~100 nsec duration. As you can see from the table, the maximum output is obtained from is $C^{13}H_3F$ although both the 1253 µm CH_3I and 1965 µm CH_3Br lines have yielded outputs in the neighborhood of 1 kW.

Efficient energy conversion in $C^{13}H_3F$ is also observed in the cw mode[13] where power outputs at 1222 µm comparable to those at 496 µm are obtained despite the decreased quantum efficiency. Although $C^{13}H_3F$ appears to offer great promise for both cw and pulsed high power systems, the expense of the gas (~$1k/liter at STP) has perhaps served as a deterent to many investigators. It should be noted, however, that with gas reclamation the costs are greatly reduced over a free flowing system. For example, the experiments described herein were conducted in a system where the gas was cryogenically pumped into a valved stainless steel cylinder after each run. In this fashion, one lecture bottle of $C^{13}H_3F$ will last for many FIR laser fillings.

The pressure dependence of the output of the $C^{13}H_3F$ oscillator is displayed in Fig. 2 for a CO_2 pump level of ~0.50 J. The operating point corresponding to maximum FIR output increases with CO_2 pump power as there is then sufficient power available to pump the increased number of molecules. The energy conversion efficiency (CO_2 to FIR) was ~0.2% or about 46% of the theoretical maximum. This is to be compared with $C^{12}H_3F$ at 496 µm where typical efficiency of ~10-20% of the theoretical maximum are obtained.

The time resolved $C^{13}H_3F$ oscillator output is shown in Fig. 3 using a fast (~5 nsec response) pyroelectric detector. In addition the superradiant output (oscillator mirrors removed) and CO_2 pump pulse are shown using the same pyroelectric detector. The pyroelectric detector does not have sufficient time response to resolve the beating between adjacent cavity longitudinal modes as the cavity free spectral range is ~150 MHz. However, with the Schottky diode detector (~1 nsec response) beating is sometimes observed between a dominant longitudinal cavity mode and an adjacent weaker mode. This can be seen in Fig. 4, which displays the temporal evolution of the amplified FIR output. The spectral power distribution is obtained by digitizing similar traces and performing a fast Fourier transform.

Preliminary amplification measurements have also been made using $C^{13}H_3F$. For these studies a 1.2 m-long, 38 mm-i.d. glass dielectric waveguide was used for the amplifier tube. The available supply of $C^{13}H_3F$ limited the pressure in both the oscillator and amplifier sections to 1.0 Torr which is well below optimum. The FIR oscillator output was also reduced to 7% of the above value since the major portion (~ 2 J) of the available CO_2 was used to pump the amplifier section. The peak output was ~50 kW without correction for the decreased detection efficiency for $\lambda > 1$ mm. For purposes of comparison, the superradiant output from the amplifier (FIR oscillator blocked) was approximately 30% of the amplified output.

Conclusions and Summary

Although many molecular gases have been studied, only a few offer promise of outputs in excess of 1 kW in the 0.75 - 2 mm region. However, as indicated in Table 1, we have found enough strong lines that one does have a measure of step FIR tunability by simply adjusting the CO_2 oscillator grating. The most efficient lasing medium was found to be $C^{13}H_3F$ which yielded pulsed outputs which approached the theoretical maximum efficiency. Using $C^{13}H_3F$, amplified outputs in excess of 50 kW were obtained at wavelengths near 1 mm.

The results discussed above were obtained with a 2 J (10 MW) CO_2 laser. We have recently completed a 50 J CO_2 laser system and are beginning experiments aimed at increasing the output of our $C^{13}H_3F$ laser. If the system efficiency remains near 50% of theoretical maximum, an output in excess of 1 MW is expected.

Acknowledgments

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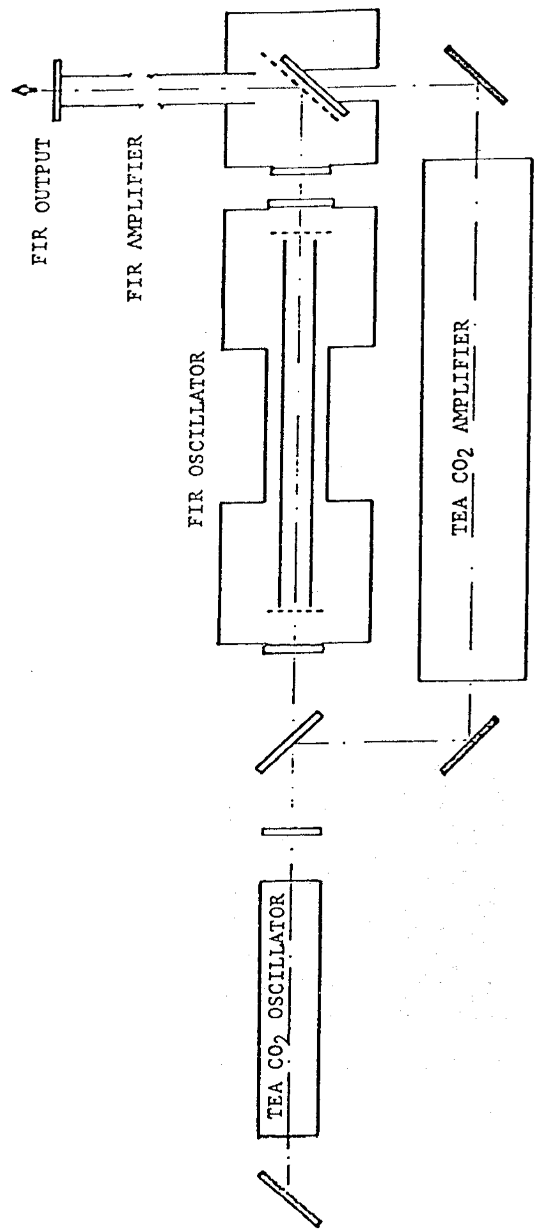

Fig. 1 Schematic of the mm-wavelength optically pumped laser system.

TABLE I

PULSED FIR OSCILLATOR RESULTS

Molecule	CO_2 Pump Wavelength (μm)	Wavelength (mm)	Mirror Mesh Constants (μm)	Power (kW)	Pressure (Torr)	Pump Engergy (J)
$C^{13}H_3F$	P(32), 9.63	0.862	101.6, 423.3	30	1.0	1.00
	P(32), 9.63	1.006	101.6, 423.3	30	1.0	1.00
	P(32), 9.63	1.222	101.6, 423.3	30	1.0	1.00
CH_3Br	P(28), 10.7	1.965	50.8, 423.3	1.3	3.0	2.0
	R(14), 10.4	0.749	50.8, 169	0.01	2.5	2.0
$CH_3C\ell$	R(12), 9.3	0.944	50.8, 169	0.016	2.5	0.50
	P(26), 9.6	1.887	50.8, 423.3	0.19	3.0	2.0
CH_3CN	R(20), 9.3	1.352	50.8, 423.3	0.045	3.0	2.0
CH_3I	P(32), 10.7	1.254	50.8, 423.3	0.84	3.0	2.0
$C_2H_3F_2$	P(22), 10.6	0.890	50.8, 169	0.045	1.5	2.0

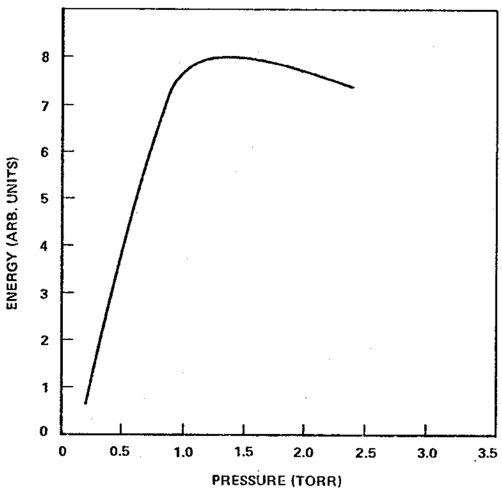

Fig. 2 **Pressure** dependence of the $C^{13}H_3F$ oscillator **energy** output.

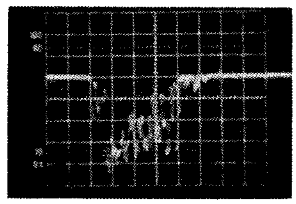

Fig. 4 Time resolved output of the $C^{13}H_3F$ oscillator output using a Schottky barrier diode detector (< 1 nsec response).

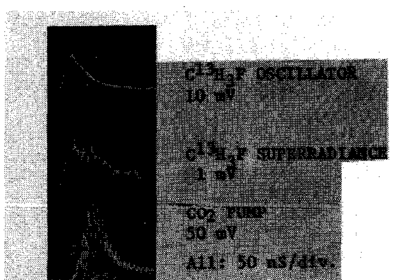

Fig. 3 Time resolved output of the $CH^{13}H_3F$ oscillator output using a pyroelectric detector (~5 nsec response).