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LASER FUSION EXPERIMENTS AT LOS ALAMOS

Part II: The LASL CO_2 Short Pulse Oscillator-Amplifier System

by

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ABSTRACT

The short pulse CO_2 laser in operation at Los Alamos was developed to produce a short pulse laser beam for experiments on laser-plasma interactions at 10 μm wavelength and to provide an engineering basis on which larger, more efficient CO_2 lasers can be designed. The laser now generates pulses at 10.6 μm wavelength containing 300 joules in 1.5 ns and is presently being upgraded to produce ~ 400-500 joules. The beam is of good optical quality and can be focused into a diameter of approximately 140 μm. The peak power at the focus reaches 7×10^{14} watts/cm^2.

INTRODUCTION

Experimental investigations of the interaction of very intense light beams with plasma at high density are necessary to confirm theoretical concepts for laser-induced fusion. The fundamental requirements for such fusion are set forth in papers by Kidder[1] and Boyer.[2] Theoretical analyses of the process indicate requirements for laser pulse energy greater than 10 kJ delivered in pulses shorter than 1 ns. The overall laser efficiency should be as great as possible and for commercial applications should be greater than 10%. Three laser systems are known which can reach these energies and power levels: Nd:glass,[3] atomic iodine,[4] and CO_2.[5] Only the electrically-excited CO_2 laser, however, shows reasonable promise of achieving an overall efficiency approaching 10% for short pulses.

The successful production of extremely intense pulses of CO_2 laser energy depends on the development of an oscillator-amplifier system that operates at gas pressures sufficiently great to provide adequate bandwidth and economical energy storage, that is, at supra-atmospheric pressures. The LASL laser system consists of an oscillator and 4 amplifier stages, all operating at atmospheric pressure or above. A schematic drawing of the laser system and typical operating parameters are shown in Figure 1. The oscillator is a conventional TEA laser,[6] actively modelocked, which generates single frequency (P-20) TM_{00} pulses of 1.2 ns width. The amplifiers are all externally ionized (e-beam) lasers of Los Alamos design.[7] The modelocked pulse is first amplified by 2 m of preamplifier stages at 1 atmosphere pressure operating essentially in the small signal region and then by 3 m of heavily saturated power amplifiers at > 2 atmospheres pressure. The single-pass small-signal gain through the system is in excess of 10^9. Operating in saturation with interstage isolators, the pulse power gain is about 10^6.

LASER SYSTEM DESIGN AND PERFORMANCE

Oscillator

The oscillator laser and pulse selection system produce single line Gaussian pulses in space and time which are 1.2 ns FWHM and contain about 1 mJ energy per pulse.[8] The pulse selection system, an electro-optics shutter consisting of a gallium arsenide crystal and a ten plate germanium polarizer-analyzer stack results in a pulse contrast ratio greater than 10^4:1. Work is now in progress to enlarge the options available for oscillator pulses. These options include shorter pulses, which are generated by passive and active mode-locking techniques in high pressure CO_2,[9] and oscillator pulses which contain aprroximately equal quantities of energy in transitions from both the 10 μm and the 9 μm vibrational bands.[10] The need and performance of such multi-frequency operation has been described and analyzed.

Amplifiers

CO_2 amplifiers at Los Alamos are based on the generation of controlled discharges in suitable gas mixtures through the application of external electron beams as the ionizing agent with electrical excitation of the lasing molecules provided by a second, nonsustaining discharge.[11] The parameters and scaling laws of these discharges and the associated molecular function has been extensively studied at LASL and are presently well understood. Problems of gas electrical breakdown and arc formation are thereby avoided and the molecular pumping efficiency can be optimized. Relatively large volumes can be uniformly ionized by the electron beam (25 x 25 x 200 cm presently) and the process can be scaled to different geometries and pressures. The amplifier chain was designed as a prototype system in which engineering and physics problems relating to the characterization and operation of larger systems could be evaluated and from which good quality laser pulses of varying energy are available for interaction experiments.

The final power amplifier of the system has active volume 2 m long, with an optical aperture of 400 cm^2, and operates at 2 atmospheric pressure. The peak inversion energy density in this amplifier is 12 joules per liter. Approximately 30% of this energy (300 joules in the optical aperture) is available on the 1.5 ns time scale of the single frequency oscillator pulse. The electrical energy deposited in the amplifier up until the moment of gain maximum is 20 kJ, for an overall electrical-to-optical efficiency (excluding heater power to the hot cathode electron gun) of 1.5%. On a unit volume basis the electrical-to-optical efficiency is 2.2%. The electrical parameters of the electron guns and the gas discharge characteristics of the four amplifiers in the chain are summarized in Fig. 2.

A particularly important question in any evaluation of CO_2 amplifiers is the efficiency of amplification of short pulses.[12,13] The population inversion energy is distributed over a rotational energy manifold of the excited vibrational level. The time scale for energy extraction from all of these rotational sublevels by a single rotational transition requires cross-relaxation between these levels. This cross-relaxation time for energy extraction is greater than the relaxation time of a single level by the factor $1/\kappa(J, T_r)$, ($\approx$ 15 for the case of interest). This factor arises because one is asking for <u>all</u> the energy of these levels to be extracted through the single lasing level as opposed to asking that a <u>single</u> level be repopulated to its equilibrium value by its fifteen neighboring levels. Hence, the total rotation reservoir is accessible only to single-line oscillator pulses with $\tau_{pulse} > \tau_{rot}/\kappa$. This limitation can be overcome provided the oscillator pulse contains frequencies corresponding to several rotational transitions for a given vibrational transition, i.e., (001→100), or alternatively it contains frequencies for the two vibrational bands (001→020 as well as 001→100) with differing J values.[14]

Interstage and Backscatter Isolation

The suppression of interstage oscillations at high overall gain (~10^8) has been achieved by the insertion of gas cells containing bleachable molecular gases (sulfur hexafluoride, ammonia or butane) and helium between the various amplifiers as well as through separation. The amount of bleachable absorber required to prevent prelasing is determined by measurement. This bleachable cell improves the contrast ratio of the pulse as well.

The plasma generated by the interaction of the focused laser beam with solid matter reflects as much as 5% of the incident energy back into the focusing optics of the laser system.[15] The reflection is amplified as it passes back through the amplifiers and may exceed the damage threshold of some optical components. Amplifier reflections have been eliminated by deliberately providing beam waists in the optical path where plasmas are generated at the appropriate time. When the energy density of the outgoing pulse exceeds about 4×10^8 watts/cm^2 (if it does not, a secondary laser focused on the intersection of the beam and the film is necessary) an ionized seed plasma is created which terminates the return pulse. About 20% of the outgoing pulse energy is sacrificed to generate the film plasma.

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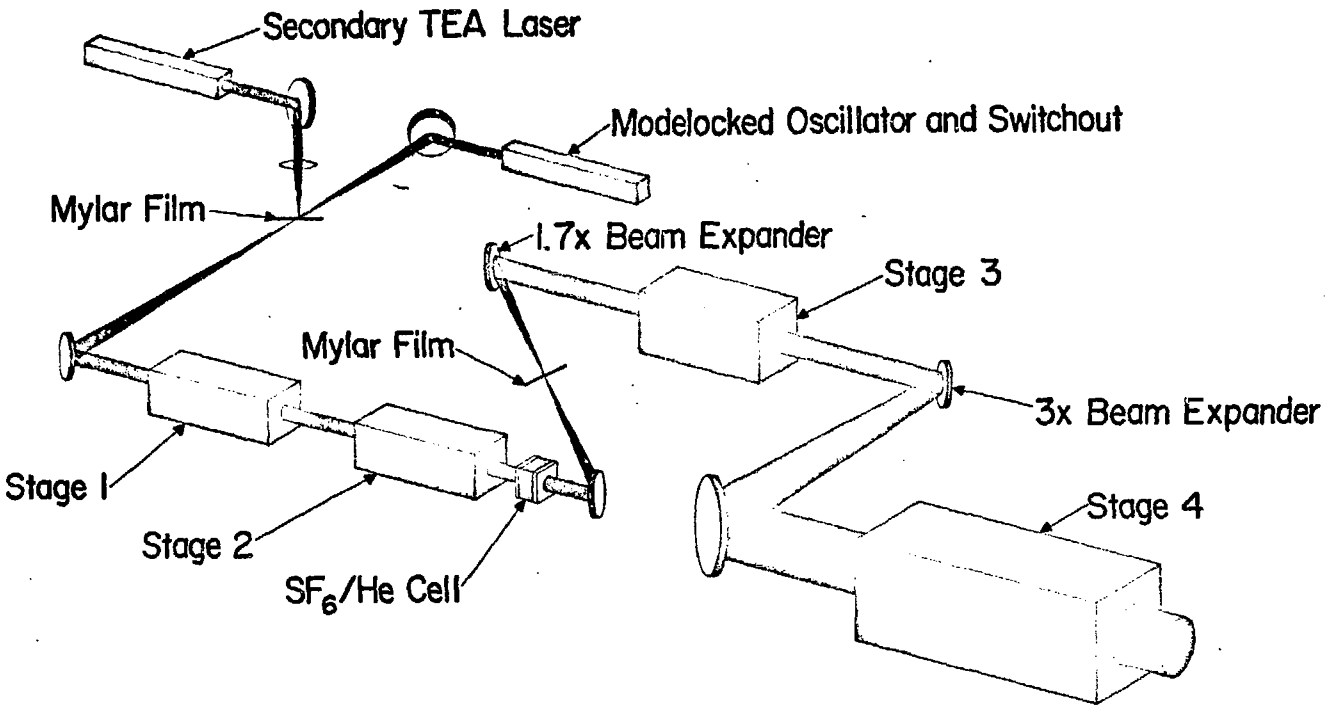
FIGURE CAPTIONS

Fig. 1 - Schematic of CO_2 oscillator-amplifier chain which produces pulses containing 200 j in 1.5 ns

Fig. 2 - Electrical parameters of the electron-beam controlled amplifiers

Fig. 1
Schematic of a CO_2 oscillator-amplifier chain which produces pulses containing 200 j in 1.5 ns



Small Signal Gain – P(20) 10^9

Saturated Gain – P(20) 2×10^5

Component	Volume Litre	Gain $e^{g_0 L}$ – P(20)	Pressure Torr	$\Delta N \hbar \omega$ Joules	Energy Out Joules	Fraction
Oscillator		5	600		<0.001	
Stage 1	1.4	165	600	12	0.1	<0.01
Stage 2	1.4	165	600	12	1.1	0.09
Stage 3	4	125	1800	100	20	0.20
Stage 4	80	320	1400	900	200	0.22

Parameter	Stages 1&2	Stage 3	Stage 4
Electron Beam			
Energy	120 kV	155 kV	250 kV
Current	100 A	500 A	1500 A
Current density	0.12 A/cm^2	0.60 A/cm^2	0.27 A/cm^2
Gas			
Pressure	600 torr	1800 torr	1400 torr
Electric field	4.3 kV/cm-atm	3.9 kV/cm-atm	3.5 kV/cm-atm
Current	5000 A	16000 A	50000 A
Current density	6.3 A/cm^2	20 A/cm^2	9 A/cm^2
Gain (P(20))	0.051 cm^{-1}	0.049 cm^{-1}	0.031 cm^{-1}
J/liter-atm.	150	150	85
Efficiency $\frac{g_0(J)E_s}{J/\text{liter}}$	6.5 %	6.2 %	6.9 %

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Fig. 2
Electrical parameters of the electron-beam controlled amplifiers