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AUTHOR(S): Thomas E. McDonald
David C. Cartwright
Charles A. Fenstermacher
Joseph F. Figueira
Philip D. Goldstone
William C. Mead
Louis A. Rosocha
David B. Harris

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Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

HIGH POWER KrF LASER DEVELOPMENT AT LOS ALAMOS

T. McDonald, D. Cartwright, C. Fenstermacher, J. Figueira, P. Goldstone, D. Harris, W. Mead, and L. Rosocha

Los Alamos National Laboratory
P. O. Box 1663, Los Alamos, NM 87545

ABSTRACT

The objective of the high power laser development program at Los Alamos is to appraise the potential of the KrF laser as a driver for inertial confinement fusion (ICF), ultimately at energy levels that will produce high target gain (gain of order 100). A KrF laser system prototype, the 10-kJ Aurora laser, which is nearing initial system operation, will serve as a feasibility demonstration of KrF technology and system design concepts appropriate to large scale ICF driver systems. The issues of affordable cost, which is a major concern for all ICF drivers now under development, and technology scaling are also being examined. It is found that, through technology advances and component cost reductions, the potential exists for a KrF driver to achieve a cost goal in the neighborhood of $100 per joule. The authors suggest that the next step toward a multimegajoule laboratory microfusion facility (LMF) is an "Intermediate Driver" facility in the few hundred kilojoule to one megajoule range, which will help verify the scaling of driver technology and cost to an LMF size. An Intermediate Driver facility would also increase the confidence in the estimates of energy needed for an LMF and would reduce the risk in target performance.

INTRODUCTION

The ICF activities at Los Alamos consist of three areas: high power laser driver technology development, target design and fabrication, and target experimentation. As a result of the US Department of Energy (USDOE) initiative to begin planning for a laboratory microfusion facility (LMF) in the 1990s, the Los Alamos program is currently emphasizing driver technology development.

The KrF laser has several attributes that make it an attractive candidate as a laboratory driver at high energy levels.[1,2] The KrF wavelength of 248 nm appears to be near optimum for efficient laser energy to target coupling. Simulations indicate that the front-end pulse shape is retained through the amplifier chain to the target; thus, the required drive pulse shape may readily be obtained. Current estimates of laser energy requirements to achieve high target gain (of order 100) lie in the 5- to 20-MJ range, and, based on a modular amplifier approach, the KrF laser is scalable to the required multimegajoule energy outputs.[3,4] KrF lasers exhibit a high intrinsic efficiency that has been measured to be approximately 14% and computer results indicate tha efficiencies could be as high as 15% - 17%.[5] In addition, the overall system efficiency of a KrF laser is projected to be as high as 10% (wall plug to laser light on target). Because it is a gas laser, KrF can readily be adapted to rep-rated operation. Thus, KrF shows promise for the long-range application of power generation.

AURORA LASER SYSTEM

The Aurora laser system is a prototypical driver on which KrF technology issues are being addressed in a system environment.[2] The laser is designed to produce a nominal 10 kJ in 96 beams having a pulse length of 5 ns. The system employs a multiplexing approach whereby a single 5-ns pulse from the front-end oscillator is split into 96 beams through a series of beam splitters and mirrors. The beam paths are staggered so that the 96 pulses are routed through the amplifier chain sequentially to form a 480-ns pulse train. Each beam path is at a slightly different angle to maintain spatial separation. The approach allows the use of only a single amplifier

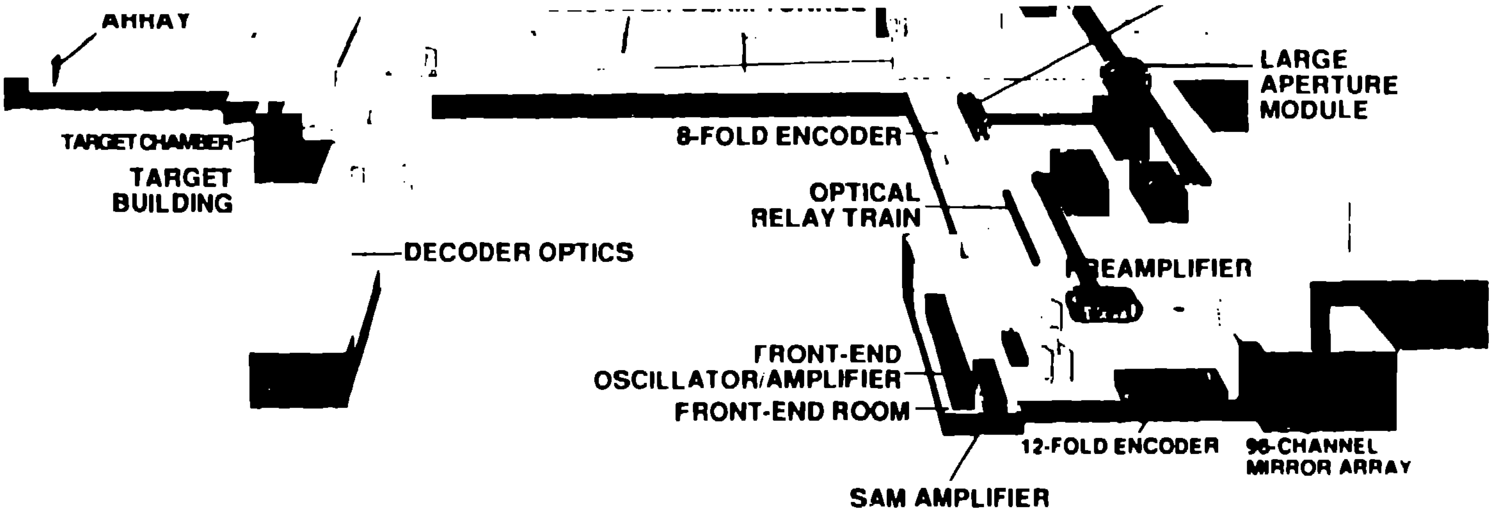

Fig. 1 An artist's view of the Aurora system showing 48 beams delivered to one side of the target. To bring all 96 beams to target for two-sided illumination, a second set of decoder optics and a second target chamber cone would be installed.

chain. Beam alignment is maintained in real time by a self-adaptive, optimal control system. The alignment system achieves beam alignment within 5 minutes and has a pointing accuracy of 5 micro radians.

Initially, 48 of the 96 beams, approximately 5 kJ, will be brought to one side of the target to demonstrate beam control, focusability, and contrast. Initial experiments will concentrate on beam characterization and laser-matter interaction at KrF wavelengths. Later plans include the possibility of bringing the full complement of 96 beams to the target for two-sided illumination at approximately 10 kJ for target implosion experiments in convergent geometry. Specific issues to be addressed in Aurora are: (a) uniform e-beam pumping of large laser volumes and staging of large amplifiers, (b) optical angular multiplexing and demultiplexing of multiple beams with corresponding beam alignment, (c) control of amplified spontaneous emissions (ASE) and parasitics in large amplifiers, and (d) control of prepulse and maintenance of beam contrast.

Figure 1 is an artist's concept of the Aurora system with 48 beams being sent to target. All 96 beams are brought to the recollimator array. From the recollimator array, 48 beams are taken through the optical demultiplexer and to the target chamber. To bring all 96 beams to target, a second demultiplexer would be installed on the opposite side of the target chamber from the first demultiplexer, through which the second 48 beams would pass.

Within the past year, an improved front end system has been installed on Aurora that provides a reproducible pulse and has an energy contrast ratio that has been measured between 10^{-6} and 10^{-7}. The Aurora amplifier system consists of a chain of four amplifiers after the front-end, which are referred to as

TABLE I
INITIAL OPERATING PARAMETERS OF THE AURORA AMPLIFIERS

Unit	PFL Pulse Length (ns)	E-Gun Voltage (kV)	Average Current in Gas (A/cm^2)	E-gun Area (cm x cm)	Input Light Energy (J)	Output Light Energy (J)	Stage Gain	Clear Aperture (cm x cm)
SAM	100	320	19	12 x 100	0.8	15	18	10 x 12
PA	650	520	16	20 x 300	1.1	40	35	20 x 20
IA	650	520	6	40 x 300	30	270	9	40 x 40
LAM	650	650	14 (each side)	100 x 200	200	2,000 to [illegible]	10 to [illegible]	100 x 100

the small aperture module (SAM), the preamplifier (PA), the intermediate amplifier (IA), and the large aperture module (LAM). The amplifiers are all e-beam pumped and are designed to provide a total system gain of 4×10^5. The LAM has been tested as an unstable resonator and, although nonoptimized, produced in excess of 10 kJ of 248-nm laser radiation. The system is currently undergoing integration and checkout in preparation for initial operation by the beginning of 1989. The amplifier parameters during this initial operation phase are given in Table I.

Beam-train alignment is largely static except for active feedback control of two mirror stations: the individual beam mirrors at the input to the PA where all beams pass through a common input pupil and the large back mirror inside the LAM. Aiming of the beams is accomplished at the final mirror station, which is shown in the photograph of Figure 2. Beam spot quality specifications call for 95% of the energy to fall within a 200-micron circle and that the intensity be uniform to ± 30% over the central 120 microns. The control system for beam aiming consists of a microscope that relays to a video camera an enlarged image of the actual spot produced by the overlap of all 48 beams. The video image is analyzed and corrections made to improve spot quality.

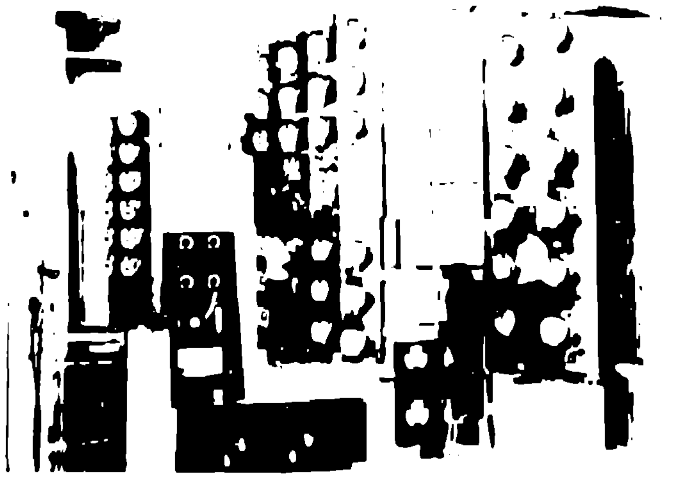

Fig. 2 Photograph of the final aiming system mirror array.

The Aurora target system consists of the target chamber, beam cone, and lens plate assembly. The target chamber is a 1.57-m diameter, 7.6-cm-thick stainless steel sphere that is attached to the beam cone-lens plate assembly by a valved cylindrical transition section and a bellows. The target chamber has a total of 75 ports including 16 pairs of opposing ports and two opposing 53-cm beam ports for the f/1.8 beamlet bundles. This configuration allows easy diagnostic access to almost the entire 4 π solid angle around the target. Figure 3 is a

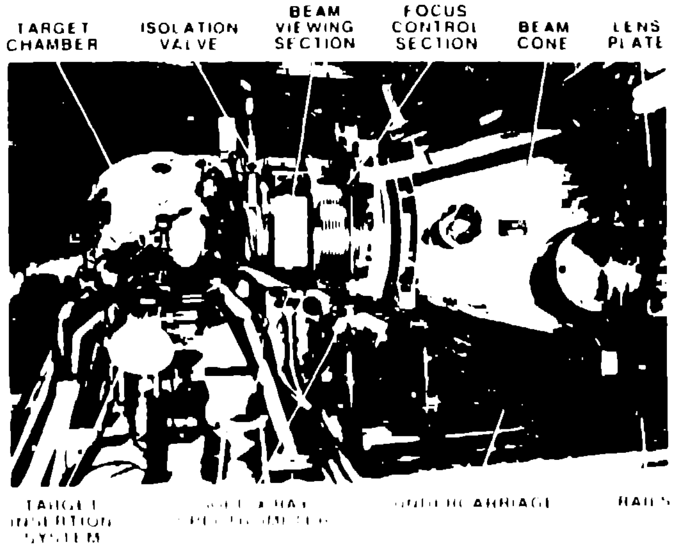

Fig. 3 Photograph of the assembled Aurora target system showing major subsystems and components.

system showing major subsystems and components. The target insertion system is an air-lock single-target insertion mechanism. The target is held on the end of a slender stalk, which is mounted on a cart with a three-axis micropositioner. A dual chain drive transfers the cart across the air-lock gate valve and cams it into position on a kinematic base with a positioning reproducibility of 5 microns.

Aurora has three modes of operation: maintenance, subsystem, and integrated. In maintenance mode, the control system allows an operator to actuate individual devices such as relays, valves, or similar devices; to turn power supplies on and off; and to examine monitors on many individual components of the laser system. In subsystem mode, the control system can be used to charge and fire individual Marx generators and amplifiers. In integrated mode, the system charges and fires the entire Aurora laser from the front end to the LAM.

Initial diagnostics on Aurora will be directed at beam characterization such as spot size, uniformity, intensity, and the major issue of beam contrast. Initial target experiments will concentrate on energy deposition, absorption, and x-ray conversion. Key measurements include: (a) time-resolved measurements of absolute soft x-ray emission (20 eV - 2 keV), (b) soft x-ray pinhole camera imaging of target emission, (c) soft x-ray spectroscopy, and (d) scattered light amplitude and distribution. Later target experiments will address hydrodynamic instabilities and, if the full complement of 96 beams is brought to the target, drive symmetry. Instrumentation for these measurements will include a calibrated hard x-ray detection system, x-ray diode arrays, and UV spectrographs. Plans call for nearing initial system checkout and is expected to become fully operational at the 1- to 3-kJ level during the calendar year 1989.

KrF SCALING

The scaling activity at Los Alamos is currently examining design options and tradeoffs for multimegajoule KrF laser driver facilities and investigating impacts of design parameters on facility cost. A standardized costing method has been developed to determine comparative costs of designs.

A parameter study was done of four designs, one using Aurora technology and the others assuming significant but realistic technology advances. The preliminary results are shown in Figure 4, which is a graph of cost versus optical fluence as a function of amplifier module size for a 10-MJ driver facility. This graph shows that the cost of these particular designs is not strongly dependent upon optical fluence past approximately 4 J/cm^2. However, an increase in amplifier module size together with technology advances can lead to significant cost reductions over designs employing present Aurora technology. From these studies, it appears that KrF designs have the potential of reaching cost goals in the neighborhood of $100 per joule.

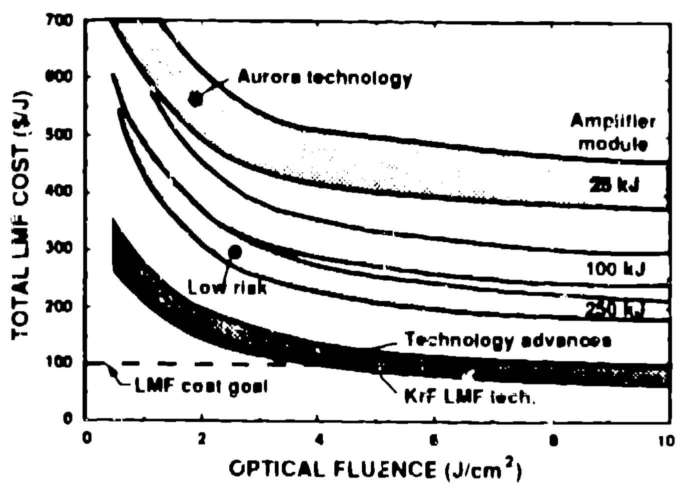

Fig. 4 Graph of parameter study results showing potential for cost reductions of a multimegajoule KrF driver facility.

PROGRAM DIRECTIONS

Based on current estimates and technology scaling, the cost of a multimegajoule LMF is expected to be quite high, of order $1 billion. It should be noted that even this estimate assumes significant advances over existing driver technologies. Much uncertainty exists in the scaling and costing of all driver technologies that could significantly affect the ability of an LMF to reach the stated goal of a 1000 MJ yield.

In view of the technology, cost, and physics uncertainties in scaling to a multimegajoule size facility, and the fact that the apparent energy and power requirements of an LMF exceed by over 2 orders of magnitude the capabilities of the largest drivers that have yet been put on target, the authors believe it would be prudent to develop and use an "Intermediate Driver" as the next step to an LMF. An intermediate driver in the few hundred kilojoule to one megajoule range would 1) demonstrate driver technology and establish the cost basis for multimegajoule drivers, and 2) reduce the uncertainties in reactor-scale laser-plasma coupling, indirect-drive target optimization, and cryogenic target performance in a near-ignition regime. Also, at the intermediate driver level, a KrF laser facility could be designed to have interesting direct-drive capability if the work at University of Rochester, Naval Research Laboratory, and Los Alamos continues to show promise.

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