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DEVELOPMENT OF KrF LASERS FOR INERTIAL CONFINEMENT FUSION

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Development of KrF Lasers for Inertial Confinement Fusion

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ABSTRACT

High peak power rare gas halide lasers for applications in Inertial Confinement Fusion are being developed at laboratories across the world. The United States Department of Energy sponsors a program conducted at the Los Alamos National Laboratory and the Naval Research Laboratory. The Los Alamos laser development program is composed of three major elements; the **Aurora Laser Facility** is a 1 terawatt KrF laser designed as an integrated performance demonstration of a target qualified excimer laser system; an **advanced design** effort evaluates concepts that offer the improved performance and lower cost that will be essential for the construction of future lasers in the 0.5 to 10 MJ class; and a **laser technology** program that addresses both performance and cost issues that will be important in advanced laser system designs.

I. INTRODUCTION

The development of high peak power KrF laser technology for Inertial Confinement Fusion (ICF) applications is actively in progress throughout the world with major facilities underway in Japan, Canada, England and the US. The Los Alamos National Laboratory KrF laser development program addresses both near term integrated laser demonstrations and longer term advanced design concepts and the required technology advancements for larger fusion laser systems. In this paper we will review the current progress on the near term technical activities and will describe the future directions of the Los Alamos KrF laser development program.

II. AURORA

The near term goal for Los Alamos is the successful integration and operation of the of the Aurora Laser Facility at the multi-kilojoule level with powers approaching one terawatt. Aurora is a short-pulse, high-power, krypton-fluoride laser system. It serves as an end-to-end technology demonstration prototype for large-scale excimer laser systems of interest to short wavelength ICF investigations. The system to employs optical angular multiplexing and serial amplification by electron-beam-driven KrF laser amplifiers to deliver 248 nm, 5 ns duration multi-kilojoule laser pulses to ICF-relevant targets. Figure 1 shows a schematic diagram of the laser system.

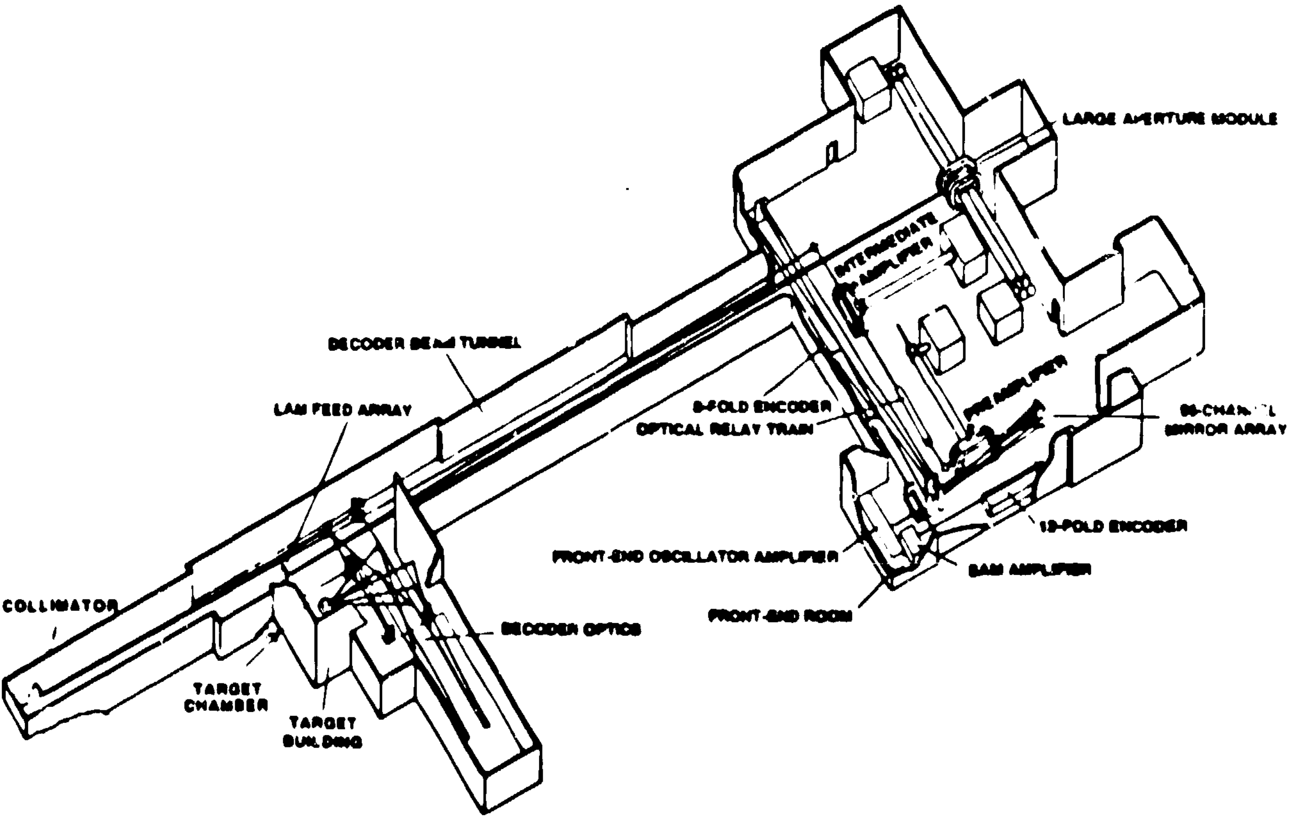

Figure 1. Aurora Laser Facility

The KrF front end, based on commercial discharge laser oscillators and amplifiers, employs a stimulated brillouin scattering phase conjugate mirror to generate a high contrast 5 ns pulse of 248 nm radiation. The single pulse is split by a series of beam scrapers and beam splitters to form a 480 ns train of 96 pulses which are directed to the Pre-Amplifier (PA) and Intermediate Amplifier (IA) by a centered transmitting optical system. After the PA the beams are spatially separated by the reflecting Large Aperture Module (LAM) feed array and brought through the 100 x 100 x 200 cm^3 LAM for final two pass amplification. From the LAM, 48 of the beams are demultiplexed and restacked into a single 5 ns pulse and brought to focus in the target chamber.

Figure 2 shows the target chamber with the 48 beam entrance cone to the right.

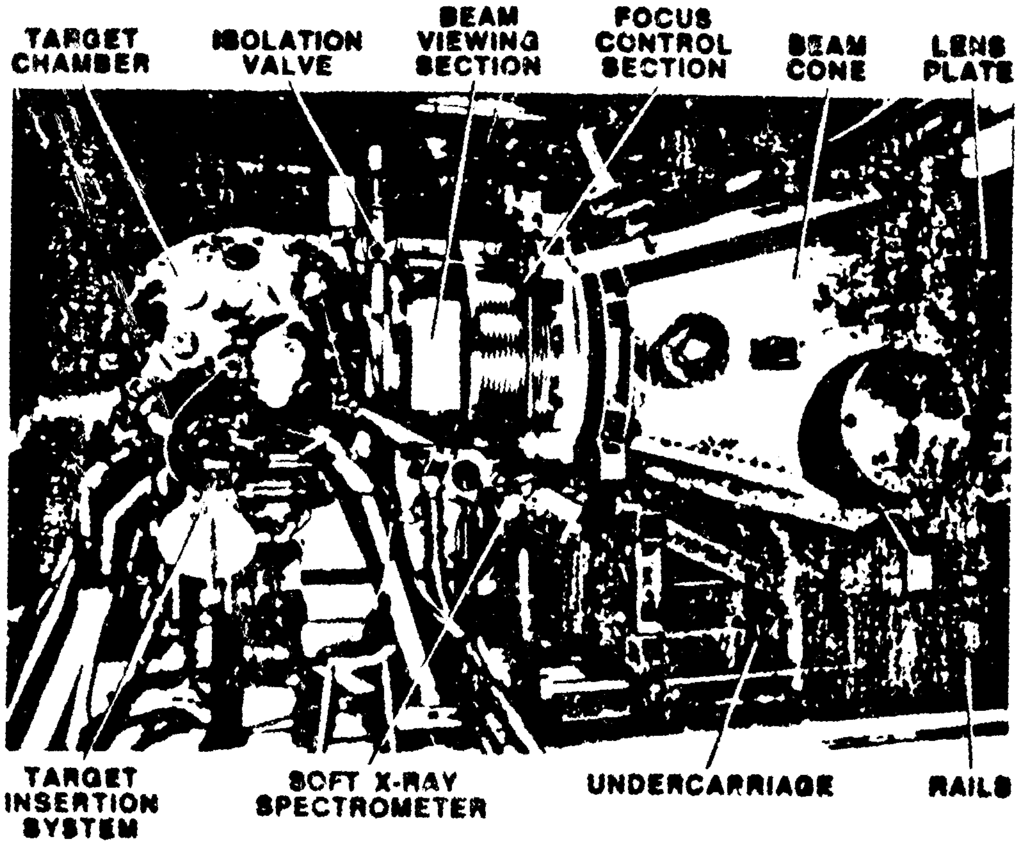

Figure 2. Aurora Target Chamber

The Aurora laser is entering the final stages of system integration. During the past two years, several major construction and integration tasks have been accomplished:

1. Demonstration of 96-beam multiplexing and amplified energy extraction, as evidenced by the integrated operation of the front end, the multiplexer (12-fold and 8-fold encoders), the optical relay train, and three electron-beam-driven amplifiers;

2. Assembly and installation of the demultiplexer optical hardware, which consists of over 300 optical components ranging in size from several centimeters square to over a meter square;

3. Integration of the entire laser system (with the exception of the LAM and the automated final aiming system) and the delivery of low-power 5 ns pulses to the target chamber;

4. Completion of an upgrade to increase the front end output by almost a factor of two;

5. Completion of pulsed power and electron-beam pumping upgrades on the LAM, PA, and Small Aperture Module (SAM). The SAM shows a 40% increase in deposited electron beam energy and the PA deposited energy has been increased by a factor of two; and

6. Beam alignment and propagation from the LAM to the target. LAM optics have been installed, the beams sized to the target chamber, and the SAM, IA, PA, and LAM have been fired in a step-by-step process of integration from the front end to the target.

III. ADVANCED LASER SYSTEM DESIGN

In the longer term the National ICF program will continue to plan for the construction and operation of the next generation driver for ICF physics experiments. In order to determine the applicability of KrF laser technology to future generations of fusion drivers, Los Alamos has begun a design effort to explore systems in the 200 kJ to 10 MJ range. This Advanced KrF Laser Design effort provides information to the KrF program on the design and cost of future KrF laser-fusion systems, and provides directions and goals to the KrF technology development effort. Because no current ICF driver has demonstrated both the required cost and the performance scaling, and because uncertainties exist in laser-matter interactions and target physics, Los Alamos is currently pursuing a range of advanced KrF laser design activities and work is currently in progress to scope a 10 MJ Laboratory Microfusion Facility (LMF), a 400 kJ Intermediate Driver (ID), and an Amplifier Module (AM). In this paper we will discuss the current status of only the LMF design effort.

The Inertial Fusion Division of the Office of Weapons Research, Development, and Testing in the Department of Energy and the ICF Laboratories are conducting a scoping study of an LMF. The purpose of the study is to examine a facility with a capability of producing a target yield of 1000 MJ in a single-pulse mode. The study has two phases. The first phase, completed in October 1988, examined the driver independent aspects of the LMF. This includes the applications of the LMF, the desired shot rate, target fabrication, a work breakdown structure, and a common costing methodology. Phase II has recently begun and is driver dependent. There are three drivers being considered for the facility; KrF and Nd:glass lasers and light-ion accelerators.

The advanced KrF laser design strategy we are following for determining the optimum design for the LMF is to iterate a number of possible architectures to determine the best approach. To date, we have examined three architectures. An attractive feature of KrF laser-fusion systems is their flexibility and wide range of design parameters. We have examined designs where final amplifier energy output has varied by three orders of magnitude. The first iteration uses what we consider to be today's technology, stacking upgraded Aurora large amplifier modules (LAMs). We have found that this approach is probably too expensive and complex, leading to a system that does not appear attractive for the LMF. The second iteration examined an architecture that uses what we consider to be the largest possible amplifier module based on laser physics limitations. Using these modules, a 10 MJ LMF would require only four main amplifiers. This architecture appears to be attractive and affordable for the LMF, but would require substantial extrapolations in technology. In particular, the use of thin-film windows and extremely high-voltage electron beams would be required. We are currently finishing the third iteration, which uses intermediate-sized amplifiers and requires only minor extrapolations in pulsed-power technology. This final iteration uses angular multiplexed amplifier modules 1.3 x 3.9 x 3.8 m^3 in size producing energies in the range of 250 kJ each. Figure 3 shows a schematic layout of these units in a tri-fold cluster which produces 750 kJ in 60 multiplexed beams of 10 ns each.

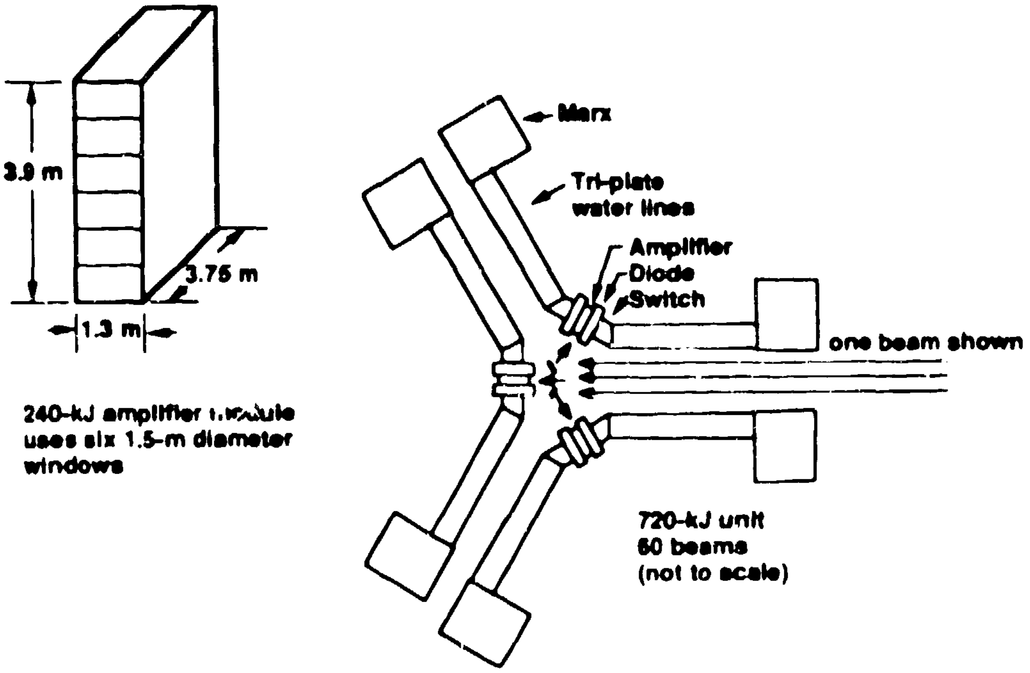

Figure 3. 750 kJ KrF Laser Unit

Although the final LMF design has not yet been chosen from this array of iterations, we currently expect it will be close to the third design iteration described above. From these design activities we can determine the major cost drivers for such a facility and from them determine cost reduction goals and the required technology programs.

IV. KrF TECHNOLOGY

The current costs of all laser drivers are unacceptable for an LMF scale system. In order to reduce these costs to an acceptable level we are currently structuring our advanced technology programs to address the major cost drivers identified by the design studies. Figure 4 shows the laser driver cost broken down by system for a design based on current Aurora technology compared to the design using the 250 kJ laser module described above. The optics and pulse power account for 60% of the total cost for the Aurora based designs producing an unacceptably high laser system cost. Advanced design concepts have identified technology areas that can be improved to reduce the over all system costs. The results of these technology improvements are shown in figure 4 for the LMF technology designs where the optics and pulse power costs have been reduced to 19% of the total system cost, and the total system cost is reduced by a factor of five.

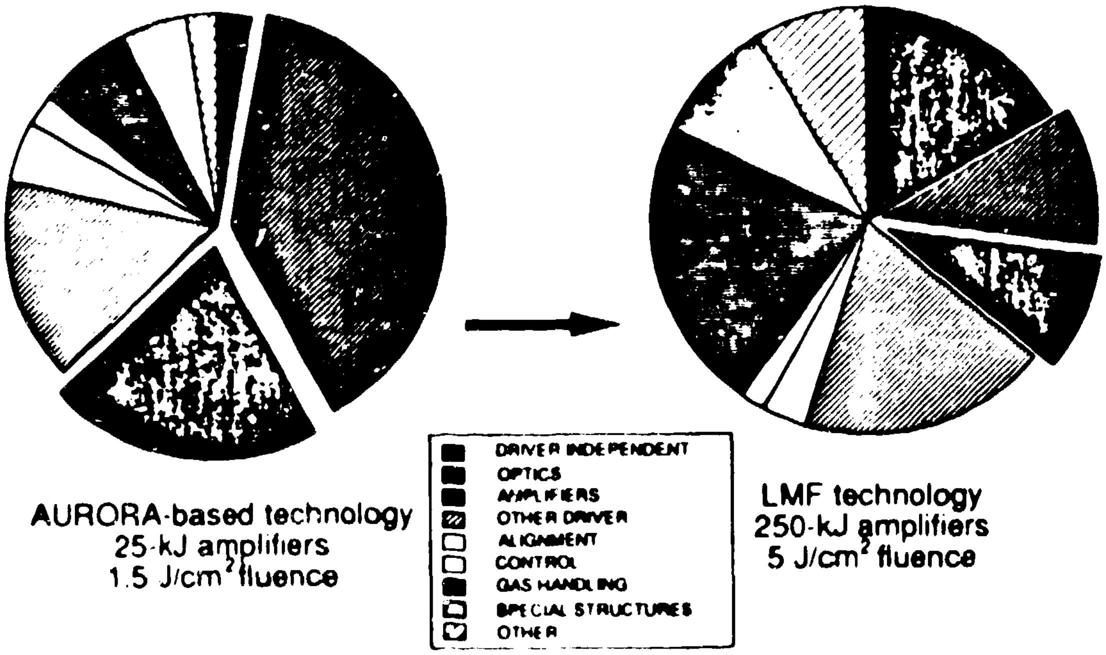

Figure 4. Distribution of Costs for LMF Scale KrF Lasers

The KrF laser technology development program addresses cost reductions for the LMF designs in the areas of optics, pulse power and laser performance as well as those technical issues effecting system reliability and modeling accuracy. Each of the four major thrust areas is outlined below.

KrF Modeling program -- An effort is currently underway to incorporate the recent LAM and SAM measurements into the laser kinetics, extraction, and propagation codes in order to better predict the performance of the entire Aurora system during the current kilojoule performance campaign. A 2-D propagation code will be incorporated in order to accurately account for the presence of saturable (ozone) and nonsaturable absorbers in the Aurora beamlines. A significant number of laser physics issues will also be addressed theoretically. Theoretical work to support past and present experimental investigations of F_2 burn-up, intrinsic efficiency, and pumping kinetics at high energy deposition (~150 J/l typical for an LMF design) is also underway. Work to benchmark both ASE codes and the e-beam propagation/deposition model is also scheduled.

Laser Performance -- An active experimental plan utilizing the existing e-beam pumped devices has been implemented to address the issues of energy deposition, nonsaturable absorption, energy extraction, and fluorine burnup. A new Laser Scaling Test Bed (LSTB) facility is being constructed at Maxwell Research Laboratories which will allow experimental investigation of energy extraction, ASE effects, and energy deposition up to 200 J/l for pump pulses from 0.5 to 2.0 us.

Optical Technology Development -- The primary cost drivers for a KrF LMF facility are energy extraction (laser physics) and optical component cost and performance. Three major activity areas will be addressed here. The optical damage threshold for 248 nm coatings has steadily increased over the last few years (from ~ 1 to ≥ 6 J/cm^2) through an interactive development program between Los Alamos and commercial suppliers. This effort will be continued with an emphasis upon fluorine resistant coatings, low scatter coatings, and high damage threshold. Large reflective and transmissive optic costs will be addressed through a series of contracts to develop advanced substrate and replication technology, as well as a complimentary internal effort to address composite mirror construction and mirror mounting technology.

Pulse Power Technology Development -- The pulse power effort will be directed toward three major issues. Experimental and theoretical work to extend the current e-gun technology (0.7 MeV) to relativistic energies (≥ 1 MeV) will be performed using the existing facilities and the planned Amplifier Test Unit (ATU) The ATU will also be used to develop the technology necessary to increase the large area electron beam transmission from the current ~30% (LAM) to the 60 to 80% level. Electron trajectory modeling, composite foil structures, and low obscuration hibachi structures will be investigated. A long range materials development effort to prove the feasibility of using co-polymer dielectric transmission lines to replace the pulsed charged water lines is also being implemented.

V. CONCLUSION

High energy, high peak power KrF lasers represent a promising new technology for inertial confinement fusion applications. In order to evaluate this technology Los Alamos is conducting a series of integrated system demonstrations with the Aurora Laser Fusion facility. Future applications of this laser are being evaluated by a coordinated program of advanced designs and technology development programs. If these evaluations are successful, KrF lasers will provide the national ICF program with an attractive future driver candidate for the Laboratory Microfusion Facility in the late 1990's time frame.