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TITLE MERCURY: A SECOND-GENERATION KrF LASER FOR INERTIAL FUSION RESEARCH

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MERCURY: a second-generation KrF laser for inertial fusion research

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ABSTRACT

The "Mercury" KrF laser facility at Los Alamos is being built with the benefit of lessons learned from the Aurora KrF laser. An increased understanding of KrF laser engineering, and the designed implementation of system flexibility, will permit Mercury to serve as a testbed for a variety of advanced KrF technology concepts.

BACKGROUND

During the last couple of years, theoretical and experimental work has generated renewed interest in direct-drive targets for inertial confinement fusion (ICF) studies. Direct drive is now a technical possibility with the demonstration of beam-smoothing techniques; and although technically more difficult, it holds the potential for substantial reductions in the required laser drive energy when compared with the indirect-drive approach. Wide-bandwidth drivers, with flexible shaped pulses and very smooth beams, allow for reduced plasma instability losses with improved target compression efficiency. Such laser parameters are more easily met with KrF lasers than with solid-state lasers.[1]

The Nike KrF laser[2] under construction at the Naval Research Laboratory (Washington, DC) is being built with a specialized emphasis on beam-smoothness, and it will be committed to a specific class of direct-drive target experiments. In parallel, a newly reconfigured KrF facility, called Mercury, is being built at Los Alamos. Mercury has designed-in flexibility that will allow testing of other KrF advantages and system technology issues such as very broad bandwidth capability, flexible pulse shaping, enhanced efficiency and high shot rate. In the past, technology issues have mainly been addressed using off-line dedicated (and specialized) research systems. This approach ignores effects on system engineering, and as KrF lasers become better understood, a fully integrated system is deemed necessary for testing KrF technology issues because so many of the system parameters are interdependent.

For a period of about four years, up to early 1991, Los Alamos assembled and tested a prototype KrF laser system, called Aurora[3], which was designed to test key concepts of KrF technology and to provide laser energy for ICF experiments. The results of these tests were generally successful, and key elements essential to the use of KrF lasers for fusion research were demonstrated. These included angular multiplexing, rapid multibeam alignment to target and large-volume electron-beam amplifier technology. Some features of the implementation were, however, of limited success, including the use of amplifiers in single-pass geometry, a partially refractive optical train and a complex control system. Basically, these limitations were a result of the ambitious attempt to build a fourth-generation laser system with first-generation experience. Thus, it was deemed prudent to assemble a second-generation system of more modest size, but benefiting from more advanced design. Building upon the lessons learned from Aurora, and working within the confines of a modest budget, Mercury is a smaller system that makes use of as many Aurora components as possible, improving and modifying them as needed. Mercury is being built in two phases: the first phase serves essentially as a whole-system design verification test, and the second phase as a straightforward engineering completion.

MERCURY DESIGN

The Mercury design invokes a reduction in the number of amplifiers, and the remaining amplifiers are used in double-pass configuration resulting in considerably higher stage gains. The predicted energy output (≥1 kJ) is not much lower than that reached with Aurora. Improved reliability for the pulse-power systems is being achieved by a reduction in the charge voltages, currents and pulse lengths (i.e., reduced electrical stress), providing increased time-between-failures for the output switches and bushings. Mass-flow gas mixing and improved gas flow distribution in the amplifier laser heads will allow future investigation of system issues associated with higher shot rates (and important issue for inertial fusion energy applications).

The partially-refractive optical system from Aurora has been replaced with an all reflective design, which provides a much improved beam quality. This combination of an all-reflective optical system and double-pass amplifiers is similar to the architectures proposed for the Laboratory Microfusion Facility and other ignition-class KrF laser facilities. Only three components in the optical train are powered, and they are long-radius spherical mirrors used at near-normal incidence. All optical components have modest specifications for figure and are readily manufactured by standard optical-fabrication practices.

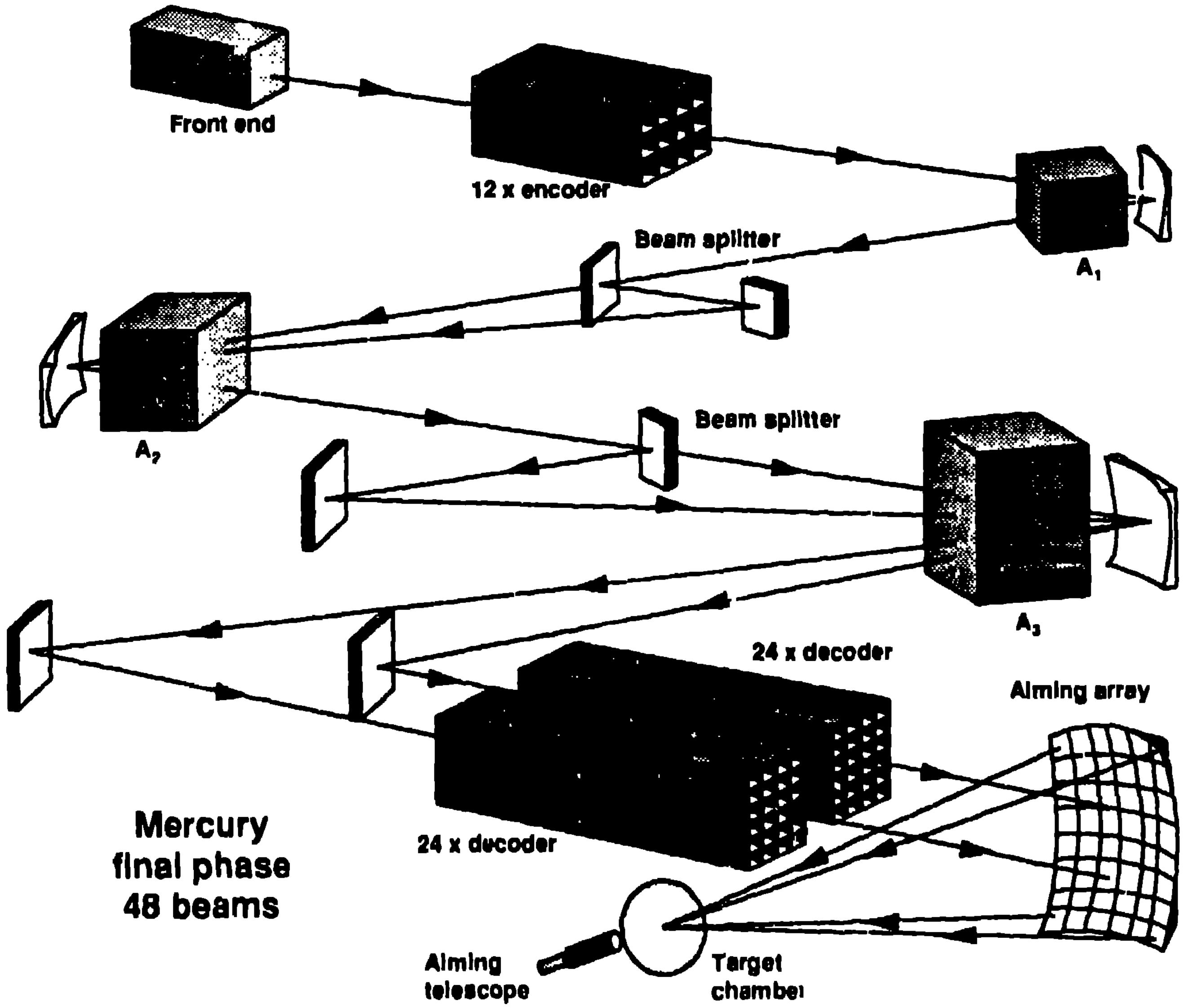

Fig. 1. Schematic diagram of the major elements of the Mercury laser system.

The front-end components have been reconfigured into a more flexible system that can now generate adjustable pulse lengths from 200 ps to 5 ns, with arbitrary pulse shape. The combination of available shorter pulse length and improved focusability (<200-μm spot size) will make available power output up to >4 TW with focal intensities up to >10^{16}W/cm^2 for the nominal 1 kJ that Mercury is expected to generate when completed. That intensity level provides useful capability for both direct- and indirect-drive ICF experiments.

A schematic diagram of the conceptual design of the Mercury laser system is shown in Figure 1. The front end, depicted in Figure 2, consists of an oscillator with multiple Pockels-cell switches, generating a single pulse of arbitrary shape and pulselength. The contrast ratio can be enhanced by the addition of more Pockels cells after the first preamplifier. The resulting beam is replicated 12-fold with angle and time encoding (5 ns beamlet spacing) by aperture division, and is then amplified in a double pass through a 12 x 12 x 100 cm^3 electron-beam-pumped amplifier (A1). This 12 beamlet train is then further replicated 2-fold by amplitude division, and is angularly encoded before a double-pass through a 20 x 20 x 100 cm^3 intermediate electron-beam-pumped amplifier (A2). Finally, each of the two 12 beamlet envelopes is again replicated 2-fold by amplitude division, and is angularly encoded for a double pass through the final 55 x 55 x 200 cm^3 electron-beam-pumped amplifier (A3). The resulting 48 beamlets then pass through an optical "decoder" system, which removes their time delays and focuses all of the beams simultaneously onto the target.

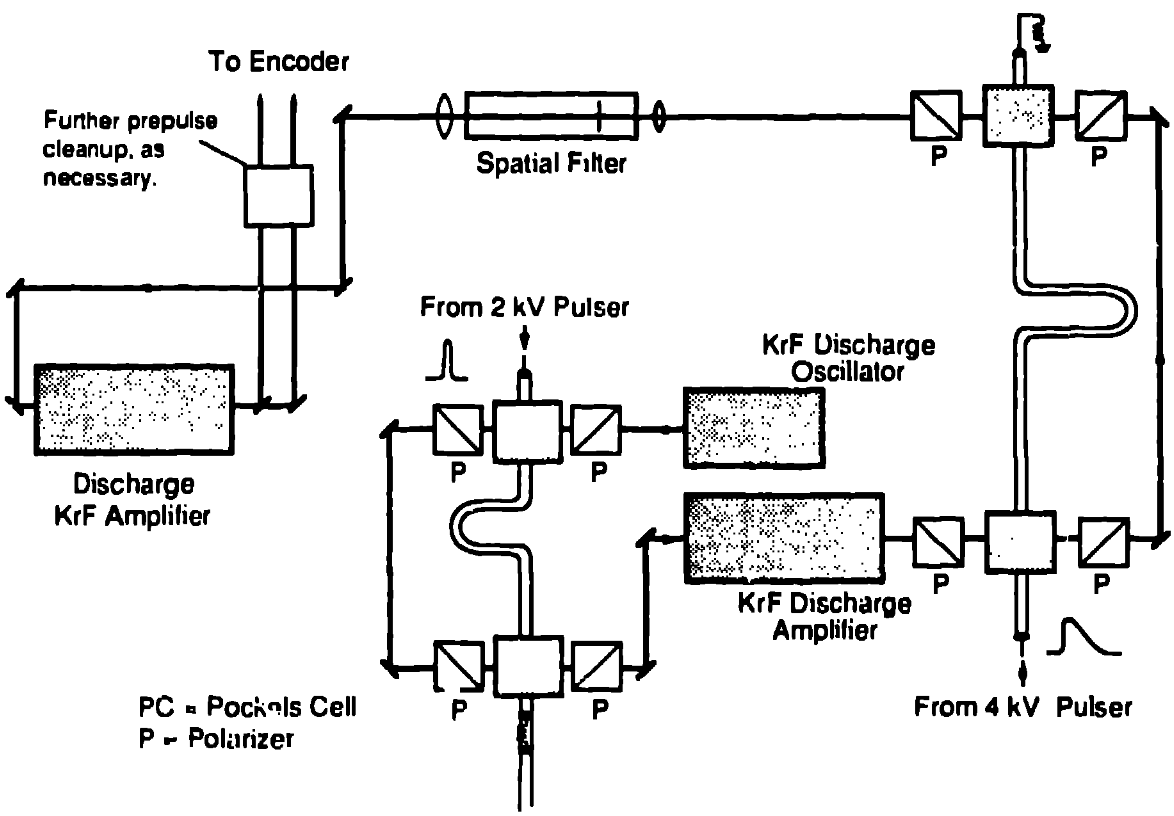

Fig. 2. Design of the Mercury front end.

A number of design verification tests have been performed, demonstrating the feasibility of key aspects of the design, and testing every step of the implementation. For example, while Figure 3a demonstrates the flexibility of the improved front end for generating various pulse shapes, Figure 3b confirms the ability to extract energy in the desired pulse shape by generating the proper input pulse shapes.

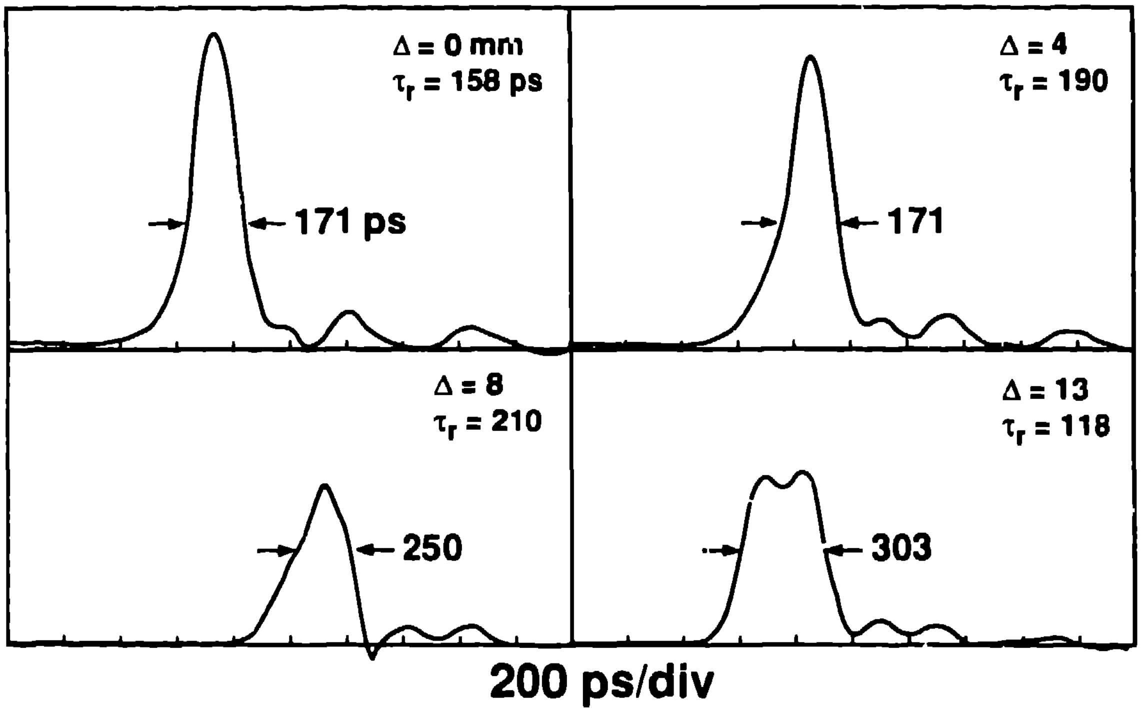

Fig. 3a. Various pulse shapes produced by the new Mercury front end.

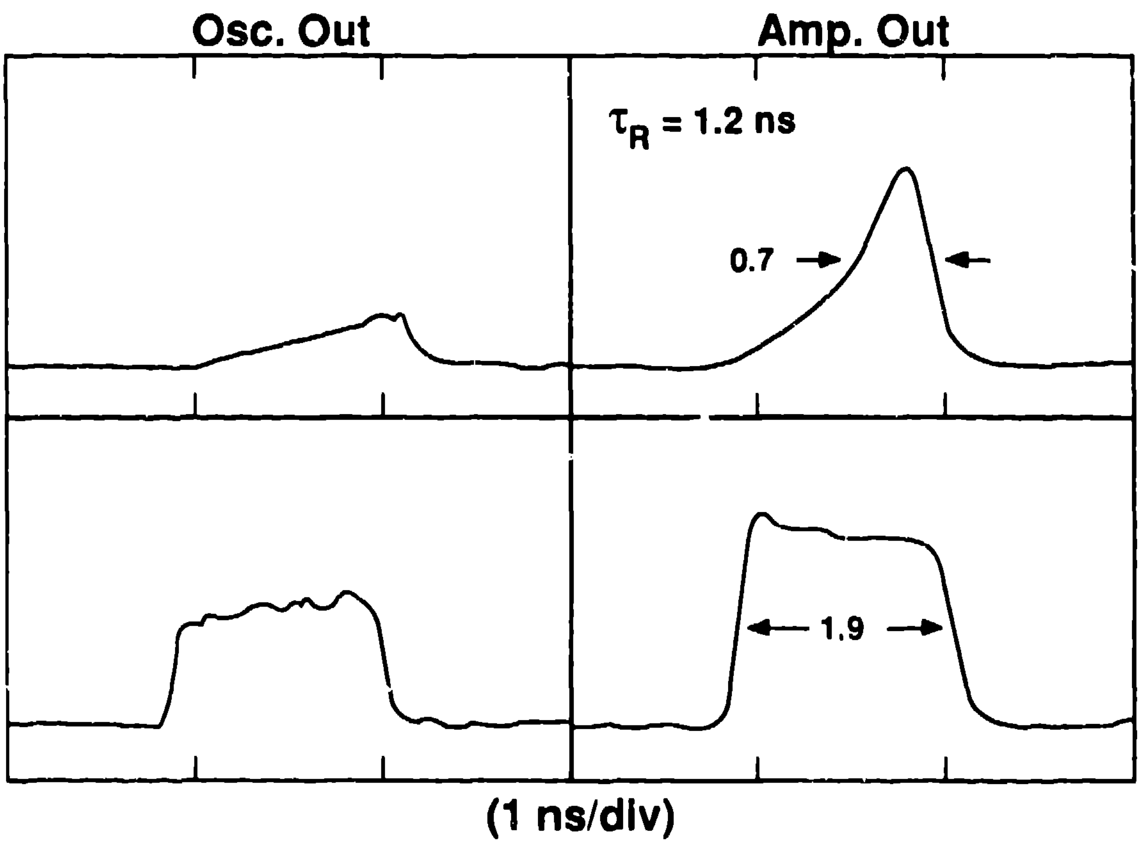

Fig.3b. The effects of system gain on two different pulse shapes.

Tests are being conducted on the new reflective optical system, at various stages of implementation, to verify the ability to achieve focal spot sizes of <200 μm (90% encircled energy). As they are assembled, we are testing for the specified performance from the amplifiers. We have also carried out a series of measurements of full-intensity beam propagation through the entire air pathlength in the beam tunnel, to understand stimulated Raman scattering effects and verify the absence of degrading nonlinear optical effects at design intensities.

At the time of this writing Mercury is approximately half-completed, and several sub-system components have been successfully tested. The expected performance of Mercury has been calculated with an end-to-end computational model that includes essentially all aspects of the system from pulse power to laser kinetics and optical-beam propagation. These calculations have invoked conservative (and, wherever possible, measured) values for all of the operating parameters. The subsystems that have been tested thus far have significantly exceeded the required specifications. Thus, we expect Mercury, when completed (Spring 1994), to readily meet its performance goals, and to provide us with a flexible testbed for KrF technology development and advanced concepts that will impact future ICF systems.

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