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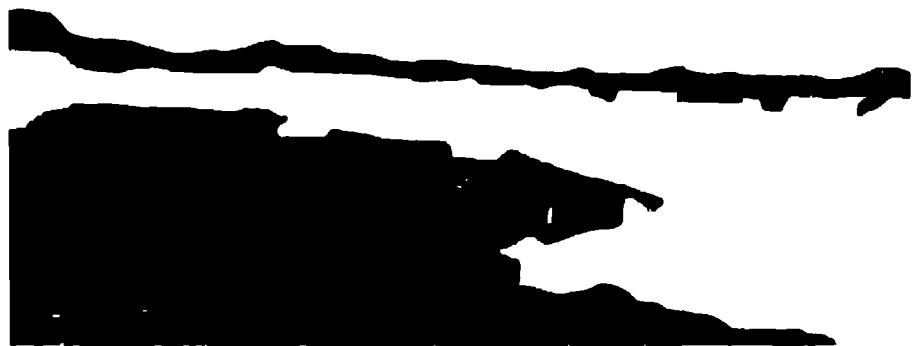
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LASER AMPLIFIER DEVELOPMENTS AT MERCURY

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Abstract

Electron-beam pumped laser amplifiers have been modified to address the mission of krypton-fluoride excimer laser technology development. Methods are described for improving the performance and reliability of two pre-existing amplifiers at minimal cost and time. Preliminary performance data are presented to support the credibility of the approach.

Introduction

The Mercury KrF excimer laser system [1] replaces the Aurora KrF system [2] at Los Alamos. The goal of the Aurora system was to deliver kilojoules of 248 nm light to a target [3]. The Mercury system explores KrF laser technology for inertial confinement fusion applications. Mercury will explore bandwidth, pulse shaping, and short-pulse amplification using an operational KrF laser system, from front end to target.

Mercury incorporates exploration of laser subsystems, including optical, diagnostic, and pulsed power. The pulsed power subsystems have been modified from Aurora hardware. Changes, improvements, and innovations are being incorporated into Mercury. By making incremental changes to working subsystems, this development path saves time and money and improves reliability. New technical ideas are explored on a working system, rather than in isolation.

Mercury Objectives

Table 1 summarizes some of the principal parameters of the Mercury system in Phase I (current) and Phase II (planned). Extensive documentation of Phase I is available in reference [4].

Table 1

Mercury Parameter	Phase I	Phase II
pulse width	200 ps - 5 ns	200 ps - 5 ns
energy on target	120 joules	800 joules
laser spot size	200 microns	200 microns
laser beam count	24	48

Areas of technical development are summarized in Table 2. The KrF laser is a promising inertial fusion energy (IFE) driver, since it incorporates short wavelength (248 nm), broad bandwidth (100 wave numbers), high dynamic range pulse-shaping, high energy efficiency, and the capability for high-repetition-rate operation. Mercury will address many of these parameters.

Table 2

Development Area	Detail
laser beams	broad bandwidth
	pulse shaping
	beam smoothing
laser kinetics	gas excitation
	laser extraction
	amplified spontaneous emission
laser systems	optical fabrication
	integrated diagnostics
	efficiency & reliability

Los Alamos has developed a suite of codes to model the gas excitation, laser extraction, and amplified spontaneous emission processes. The codes are essential for accurate scaling predictions. We have developed on-site optical fabrication methods, which promise to reduce optics costs. An integrated diagnostics system is being installed to monitor and track laser beam properties throughout the system. We are exploring amplifier efficiency and reliability, particularly with regard to the pulsed power systems and electron beam transport from diode to laser medium.

The Mercury facility explores KrF technology issues on a working system, indicating a path for scaling to higher energy systems to meet IFE objectives [5,6,7].

Amplifier Modifications

Mercury Phase I uses two electron-beam pumped laser amplifiers to achieve greater than 100 J on target. Aurora's first and fourth amplifiers have been modified to meet Phase I objectives. Aurora's second and third amplifiers were decommissioned. The cost and time for reconfiguration have been reduced compared to building new amplifiers. Reliability has been increased by modification of proven designs to reduce the parts count and to reduce the electrical stresses.

Mercury Amplifier 1 (A1 or Charon) achieves an increase in pump power over its previous incarnation, the Aurora Small Aperture Module (SAM), by incorporating a magnetic guide field and a diode-foil structure that protrudes into the laser cavity. Electron pumping is intensified in the extracted volume. The Marx generator capacitance is reduced, achieving a great enhancement in reliability, particularly foil lifetime, with no degradation in pumping.

Mercury Amplifier 2 (A2 or Pluto) is a downsized version of the Aurora Large Aperture Module (LAM). The laser-cavity aperture is reduced from 100 cm to 40 cm. The laser is pumped from only one side, reducing the pulsed power parts count by two. In addition, the pulse length is reduced by 25%, and the voltage is reduced by 20%. Improved reliability is anticipated through parts-count reduction and electrical-stress reduction. A new foil-support structure is designed to reduce mechanical stress on the foil.

Modifications to Charon (Amplifier 1)

The first amplifier, Charon, was constructed by modifying Aurora's first amplifier, Small Aperture Module (SAM).

Pulsed Power Reduction

The SAM amplifier started life as a Maxwell Excitron, pressed into service on Aurora to boost the laser energy from a Lumonics amplifier. It was nominally a run-down Marx with a peaker. The Marx generator was 229 nF (two 800-nF capacitors in each of seven stages) in series with 600 nH and 2.5 Ω. The peaker is 9.5 nF in series with 50 nH. A self-breaking output switch connects to an 8-Ω diode through 300 nH. A trigatron diverts the tail of the pulse through 120 nH and 3 Ω. The pulsed power's task is to pump the laser amplifier for a 60 ns laser extraction period.

Figure 1 shows the diode voltage from the pulsed power circuit model (70 kV per stage), including operation of the diverter. The darker trace of Figure 1 shows the Marx generator as it is to lay.

reduced to one capacitor per stage. The divertor cuts off the RC decay of the pulse, leaving the peaker signature. The useful pulse is essentially the same for both circuits, but the energy absorbed by the divertor is significantly reduced with the modification.

In actual operation, the new circuit has proven far superior to the original. In the past, when the divertor failed to operate, the pressure foil was destroyed by heating from the long, unclipped tail of the pulse. Now the pressure foil survives. Reliability has been greatly enhanced.
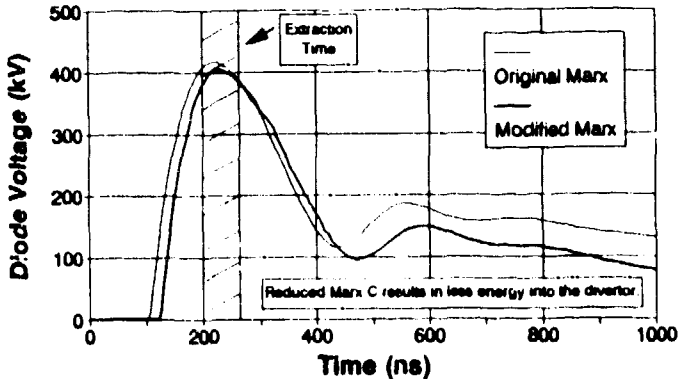

Figure 1. The capacitors are reduced from two per stage on SAM Marx generator to one per stage on Charon. There is little effect on the diode waveform. Reducing the stored energy puts less stress on the divertor and increases foil lifetime.

Pump Power Increase

Figure 2 shows the small-signal gain in SAM and in Charon. Small-signal gain is an indicator of the pump power in the laser gas. The Phase I Mercury design calls for 4.5% cm⁻¹.

Initially the laser-extracted volume of SAM started approximately 6 cm from the pressure foil. A 50% improvement in laser pumping was predicted by extending the foil forward by 4.5 cm into the laser chamber. This assumes no extra electron beam losses in the increased drift space from anode to foil. Additionally, the pumping would be more uniform across the extracted volume.

There was no magnetic guide field on SAM. A Monte-Carlo electron beam energy deposition calculation (DEP3D) indicated that the pumping would be doubled by adding a 1-kG magnetic guide field and leaving the extracted volume in the same location. The decrease in electron scattering out of the extracted volume (upward and downward) increases the pumping.
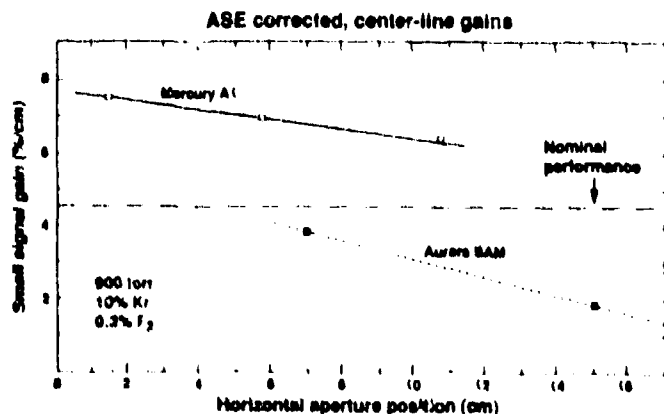

Figure 2. The laser extracted volume is moved closer to the diode foil and a kilogauss guide field is added. This increases the laser pumping significantly and reduces spatial inhomogeneity.

We modified the foil support structure and added a guide magnetic field to SAM. The upper curve of Figure 2 indicates considerably higher small-signal gain, by a factor of two to four times, and only 20% variation across the extracted region. The small-signal gain is everywhere above the 4.5% cm⁻¹ required.

Modifications to Pluto (Amplifier 2)

The second amplifier, Pluto, was constructed by modifying Aurora's fourth amplifier, Large Aperture Module (LAM) [8]. Figure 3 shows the modified LAM diode.

LAM's pulsed power architecture was a set of two Marx generators that each charged two PFLs in parallel. The PFLs were discharged into two opposing diodes by trigatron switches. Divertors were provided to discharge the PFLs into matched resistors when the output switches failed to fire.
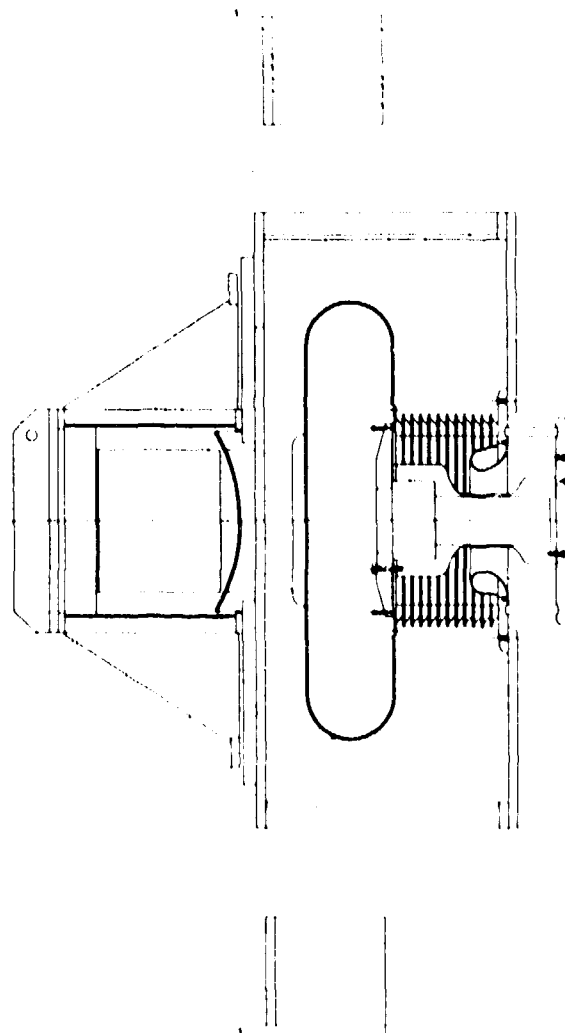

Figure 3. The diode of Pluto has a 40 cm high by 200 cm long emitter, rotated two degrees to counteract electron beam twisting. The laser chamber has a 40 cm square aperture. The stacked ring high-voltage bushing is oil filled. One of two guide field magnets is shown. The advanced design foil support structure is depicted.

Aperture Reduction

The laser aperture was reduced from 100 cm square to 40 cm square. The emitter height was also reduced from 100 cm to 40 cm. The reduced aperture size requires considerably smaller and cheaper fused silica windows on the laser chamber and allows single sided pumping (see below).

The fabrication of the Pluto laser chamber was facilitated by the existence of a 40-cm aperture laser chamber from the Aurora Intermediate Amplifier (third amplifier). The chamber was designed for a 3-m electron beam. We cut out the center of the stainless steel chamber and rewelded it for use with the 2-m electron beam of Pluto.

A 10-cm thick adapter plate was used on LAM to attach the laser chamber to the diode chamber. A thinner 4-cm adapter plate is used on Pluto, reducing the drift region in the diode by 6 cm.

Pulsed Power Reduction

Calculation of laser pumping and extraction indicate that 35% higher small-signal gain is expected at 600 torr than at 900 torr. [105 kW/cc specific pump power and 10%/90% krypton/argon mixture were used in the calculations.] Operation at 600 torr allows single-sided pumping with good spatial uniformity across the 40-cm laser extraction region.

Single-sided pumping on Pluto, compared with double-sided pumping on LAM, reduces the major pulsed power components by a factor of two and improves diagnostic and maintenance access to the diode and laser chambers. Only one Marx generator, one pair of pulse forming lines (PFLs), and one diode are required for Mercury. The reduction of components increases reliability.

Electrical stress parameters were also reduced, with the exception of diode current density. The water-filled, stainless steel PFLs were reduced in length by 25%, from 10.8 m to 8.0 m. The decision to use a 240-ns laser pulse train on the Mercury system, rather than the 480-ns pulse train of Aurora led to the reduction in PFL length. (One meter of PFL equals 60 ns of diode operation.) The required diode voltage is 550 kV on Pluto, versus 700 kV on LAM, a reduction of 20%. The shorter pulse duration, coupled with lower voltage, promises to increase reliability through stress reduction, particularly on bushings and switches. These were the high failure rate components of the Aurora pulsed power system. Charge transfer through the Pluto switches is only 60% of LAM.

Further improvements in reliability could be achieved by reducing the risetime of the diode, which would allow further PFL reduction, and by diverting energy from the PFLs to a resistive load after the pulse, which would prevent afterpulse ringing.

Diode Modification

Diode current density is increased by a factor of two, from 25 A cm² on LAM's 100-cm by 200-cm emitter to 50 A cm² on Pluto's 40-cm by 200-cm emitter. The anode-cathode gap was reduced from 8 cm on LAM to 5 cm on Pluto to maintain 1.5-Ω impedance. For cold-cathode diodes, impedance varies like A ^{1}V ^{0} ^{5}D ^{2} (Area, Voltage, a-k gap Distance) [9].

A thin foil was installed on the back of the foil support structure. This foil serves as anode and as an absorber for low-energy electrons in the electron beam afterpulse. We have used such a prefoil on SAM and Charon and found that it prolongs the life of the pressure foil. In addition, we have seen evidence that wire anodes are imaged through the pressure foil and into the laser gas [10]. The prefoil avoids this inhomogeneity and may induce less transverse heating of the beam.

The electron beam is distorted when traveling from cathode to laser chamber, because the electrons follow the twisted magnetic field lines created by the combination of guide field and self field. The beam suffers shear and rotation, as indicated by imaging on film [10]. We constructed the cathode to allow counter rotation of the electron emitter and installed it rotated by two degrees. Imaging the beam on PERM film indicated that the technique worked.

Foil Support

Figure 4 shows the predicted performance of Pluto with 40% and 60% electron transmission from the diode through the foil support structure to the pressure foil. Figure 5 shows transmission data for a conventional planar structure [11] that incorporates a 1-mil titanium anode/prefoil. The rib structure blocks 12% of the electron beam in this design. The non-normal passage of the electron beam through the structure produces shadows, causing enhanced losses.

This experiment, without pressure foil, indicates that Pluto pumping will be adequate.
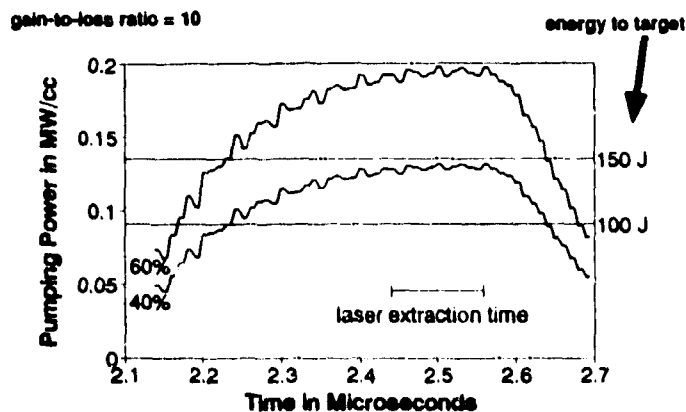

Figure 4. Model predictions indicate that 120 J to target will be achieved. The energy produced is sensitive to the electron transmission of the Pluto foil support structure.
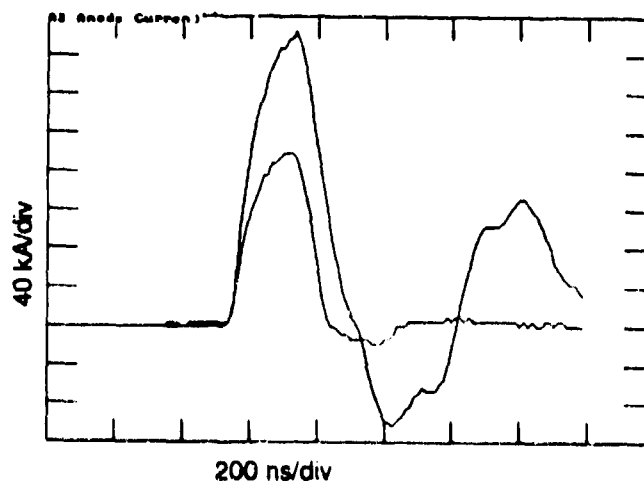

Figure 5. Measurements with the Pluto foil support and a 1-mil titanium anode/prefoil. Comparison of currents entering and leaving the support indicate 60% electron transmission.

High Transport Foil Support

A high-transport foil support structure has been designed for Pluto. This support structure is based on a curved geometry for foil support, which takes advantage of the strength of foils and support cables when used in pure tension. It is a departure from the traditional support structures, designed with thick ribs to maintain a planar profile. A full description of this design was presented at this conference [12].

Our goal is to increase the energy transport from diode to laser gas from present values of 30% to the 50-60% range. The increase in transport efficiency will make future KrF amplifiers cheaper and more efficient. The HF mission, in particular, is very sensitive to the energy efficiency of the KrF laser system.

Conclusion

Modifications to Charon are complete and the amplifier is operational. The pump power exceeds requirements and spatial uniformity has been improved. Foil lifetime has been greatly enhanced. with foils now surviving undiverted shots.

Modifications to Pluto are complete and the amplifier is undergoing qualification. The pulsed power system is operational. Diode tests indicate that it will meet requirements. Laser tests are imminent.

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