The Electra KrF laser system

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Abstract. This paper presents a brief overview of the Electra laser system and reports on the most recent results. The laser system consists of an electron beam pumped main amplifier with an aperture of 30 cm x 30 cm, an e-beam pumped 10 cm x 10 cm pre-amplifier, and a KrF discharge laser serving as the seed oscillator. The electron beam amplifiers are pumped from both sides. Full laser system shots have been completed with a laser energy of 450 J. The main amplifier, operating as an oscillator, has demonstrated 25,000 continuous laser shots at 2.5 Hz single sided pumping as well as 16,600 shots @ 2.5 Hz at ~300 J/shot within 2 hours.

1. Introduction

Electra is a Krypton Fluoride (KrF) laser system at the Naval Research Laboratory used to advance the technology towards a KrF laser driver for inertial fusion energy [1-4]. Electra consists of two electron-beam pumped amplifiers and one commercial discharge laser. The main amplifier includes two identical pulsed power systems; each generates a 500 kV, 110 kA, 140 ns e-beam that pumps the laser gas from opposite sides. Depending on the cathode and hibachi (laser gas/vacuum interface structure) configuration, the laser output energy ranges from ~300 to ~700 J per shot.

The pre-amplifier pulsed power system operates two diodes at 175 kV, 70 kA, and 50 ns. Initial pre-amplifier laser experiments with a first generation cathode and hibachi, and with a 0.5 J discharge laser serving as the seed oscillator, produced a yield of up to 25 J [5].

This paper will discuss the performance of the individual laser amplifiers and the combined Electra laser system. Recent advances of specific components are discussed that improve the durability of the overall laser system.

2. A KrF laser amplifier

Figure 1 shows the main components of a KrF laser amplifier. A pulsed power system supplies a high voltage/high current pulse to a cathode, which generates an electron beam in a vacuum diode. The e-beam, guided by an axial magnetic field, propagates through a hibachi (rib structure supporting a pressure foil), the pressure foil, and pumps the laser gas. The amplifier has two opposing e-beam diodes to provide uniform pumping of the laser gain medium. Two windows enclose the laser cell and a gas recirculator assures fast recovery of the laser gas conditions. An input laser seeds the amplifier and laser light is extracted.
3. The Electra laser system

The main amplifier of Electra is operated in two modes: as an oscillator for durability tests and as an amplifier for entire laser system shots. It has a laser aperture of 30 cm x 30 cm and uses a laser gas composition of 39.7% Kr, 60% Ar and 0.3% F₂ at a total pressure of 1.23 or 1.36 atm. The input and output windows are tilted at 14 degrees and AR coated on one side for 248 nm with their uncoated surfaces exposed to the laser gas. As an oscillator, it includes a rectangular flat mirror with a 98.5% reflectance coating at 248 nm and a parallel, uncoated fused silica output coupler that provides a reflection of 8% (total of both surfaces). In this configuration, it produces average output energies greater than 700 J with strip cathodes and ~300 J with the less efficient monolithic cathodes [5-6]. The main amplifier has run at repetition rates of up to 5 Hz, and it has operated as a laser oscillator at 2.5 Hz for 25,000 continuous shots with e-beam pumping from a single electron beam and 16,600 shots within a 2 hour period with double sided e-beam pumping. The laser output is consistent for long duration rep-rated runs as shown in figure 2. In an amplifier configuration the flat mirror and output coupler are replaced with a plano-concave mirror with a focal length of ~26 m.

![Figure 1. The main components of a KrF amplifier.](image)

**Figure 2.** Main amplifier laser output pulses sampled during a larger than 8,000 continuous shot run at 2.5 Hz, operated in an oscillator mode. The laser energy varied from 302 J for the 1st shot and 1,000th shot to 260 J for the 8,000th shot.

A LPX 305i (Lambda Physik) KrF discharge laser has been used to seed the pre-amplifier with 0.5 J. The subsequent output from the pre-amp is up to 25 J. For these initial experiments, the pre-amplifier with a laser aperture of 10 cm x 10 cm uses monolithic velvet cathodes and a simple hibachi
without an attempt to pattern the electron beam. This results in a relatively low efficiency system. Laser gas mixture in the pre-amplifier was 19.7% Kr, 80% Ar and 0.3% F₂ at a total pressure of 1.09 atm. Output laser energies of more than 30 J are expected with more efficient next generation hibachis and strip cathodes.

Initial tests have been performed with the entire laser system as shown in the schematic of figure 3. The 0.5 J seed laser beam is angular multiplexed [7] into two beams and then amplified by the pre-amp. The output of the pre-amp is further multiplexed into a total of 6 beams, each with an average pulse duration of ~20 ns, which are sequentially amplified by the main amp. A total single shot laser output energy of 450 J has been achieved, and the laser system has been successfully rep-rated in a burst of 5 shots @ 5 Hz averaging ~320 J per pulse.

4. Development of KrF laser components

The key components under development are an efficient pulsed power system; a durable electron emitter; a long-lived pressure foil structure (hibachi); a laser gas recirculator; and optical windows (see figure 1). All of these components affect the efficiency and durability of the overall laser. In addition, the durability of some laser components are interlinked, e.g., the durability of the pressure foil is in part dependent on the performance of the pulsed power system and the cathode. The following subsections will discuss some of the KrF laser components in more detail.

4.1. Pulsed Power Systems

The main amplifier uses a first generation pulsed power system that serves as a test bed to develop KrF laser components. It includes output switches that require refurbishment after 50,000 to 100,000 shots due to electrode erosion. Elimination of these spark gap switches will improve the durability and efficiency of the pulsed power system. Two solid-state switches are presently under evaluation for spark gap replacements: (a) laser gated and pumped thyristors that are under development by L3 Communications [8], and (b) the Applied Pulsed Power thyristor switches, Model S33 [9].

4.2. Cathode and Electron Beams

Cordierite ceramic honeycomb cathodes with a carbon fiber primary emitter have been tested for 5 x 10,000 shots over 5 consecutive days without breaking the diode vacuum, as well as 25,000 continuous shots at 2.5 Hz from a single sided diode into laser gas. This type of cathode has very high performance including fast rise and fall time, low gas evolution, and highly uniform electron beam emission. Cathode improvements are currently underway, which include cooling of the cathode back plate, modifications of the ceramic honeycomb construction, and the coating of the cordierite to further enhance its mechanical durability.

![Figure 3](image.png)

**Figure 3.** The Electra KrF laser system with the LPX KrF discharge laser, the pre- and the main amplifiers. Angular multiplexing is used to match the input laser pulse duration to the electron pump pulse duration of each amplifier. Details of the multiplexing with time delay are not shown for clarity.
4.3. Pressure Foil Cooling

Without active cooling, the foil temperature reaches ~300°C at 1 Hz, > 500°C at 2.5 Hz, and ~600°C at 5 Hz operations (limited by radiation cooling). Three successful techniques have been tested to cool the pressure foil during long duration rep-rated runs. (a) Forced convective cooling by the recirculating laser gas. In this application the laser gas velocity along the foils was increased with a fixed "v-plate" that forces most of the laser gas flow through narrow slots before traversing the foil. The addition of up to 10% of helium enhances the cooling with no observable penalty in laser performance. (b) Forced convective cooling by gas jets below the e-beam pumped region. (c) Cooling by a water mist trapped between two foils. Techniques (b) and (c) have been developed by Georgia Institute of Technology and all approaches have been tested on Electra's main amplifier. Infrared pyrometer measurements indicate temperatures of the 25 µm thick stainless steel foil below 280°C with a monolithic cathode. It is projected that the foil temperature will be below 450°C with the high efficiency cathodes operating at 5 Hz. This is below the long-term thermo-mechanical fatigue limit of the stainless steel foil. To this date, all laser shots have used technique (a) to cool the foil.

5. Summary.

The Electra laser program has been successful in advancing the technologies required for a durable and efficient KrF laser. Current achievements include high electron beam deposition efficiency into the laser gas, successful hibachi thermal management using forced convective cooling that will maintain the foil below stress limits at 5 Hz, and an advancement in durability of the overall laser system by attaining 25,000 continuous shots at 2.5 Hz on the main amplifier. Initial full laser system shots have achieved a laser energy of 450 J. Future work will include the continuing development of the durable, high performance ceramic cathode, and an advanced scalloped hibachi, which should allow us to extend the foil lifetime well beyond 10^6 continuous shots.

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