The NIKE 60 cm ELECTRON BEAM-PUMPED KrF AMPLIFIER

John D. Sethian, Stephen P. Obenschain, and Carl J. Pawley
Naval Research Laboratory
Code 6730
Washington D.C. 20375

Ian D. Smith, Patrick A. Corcoran, and Robert Altes
Pulse Sciences, Inc
600 McCormick St
San Leandro, CA 94577

Malcolm McGeoch
PLEX Corporation
21 Addington Road
Brookline, MA 02146

INTRODUCTION:

NIKE is a large angularly multiplexed KrF laser system under development at the Naval Research Laboratory. NIKE is designed to deliver 2-3 kJ in a 3-4 nsec pulse onto a planar target and is designed to explore the technical and physics issues of direct drive laser fusion[1]. One of the primary goals of the NIKE laser is to achieve ablation pressure nonuniformities of less than 2% in the target focal plane using ISI beam smoothing. These uniformities should be comparable to those required for direct drive of high gain targets.

The 60 cm amplifier, shown in Figure 1, is the largest amplifier in the NIKE laser and is designed to produce 5000 Joules of KrF laser light in a 240 nsec pulse with an input drive of 150 Joules. The amplifier cell has a 60 cm x 60 cm aperture (hence the name) and is 200 cm long. The cell is pumped by two opposing electron beams produced by two independent pulsed power systems. In order to achieve the required gain, the electron beams must deposit 80 kJ (40 kJ per beam) into the gas, which corresponds to a power density of approximately .43 MW/cc. Because KrF is effectively not a laser storage medium (the excited state lifetime is only a few nsec) it is necessary to

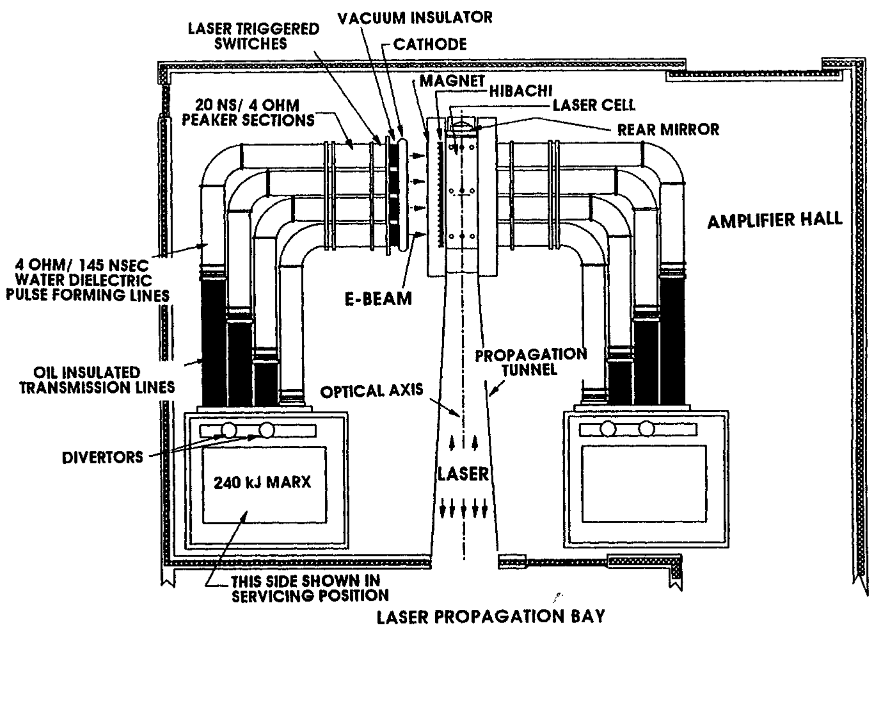

Figure 1: The 60 cm amplifier

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continually pump and extract energy from the cell. (In NIKE, 56 beams, each of 4 nsec duration, are sequentially passed through the cell at slightly different angles. The beams are then recombined, after propagating through different path lengths, so they all focus on target at the same time, giving one, high-power, 4 nsec wide pulse.) In order to assure the gain profile is reasonably constant during laser extraction, the electron beam voltage should vary by less than ± 5% for the duration of the laser amplification; for NIKE this means the flat portion of the voltage should be at least 240 nsec long. The predicted diode power and voltage waveforms for the 60 cm amplifier are shown in Figure 2. The diode voltage (670 kV) and power (387 GW) power are flat to within ±5% for over 253 nsec, which exceeds the laser requirements.

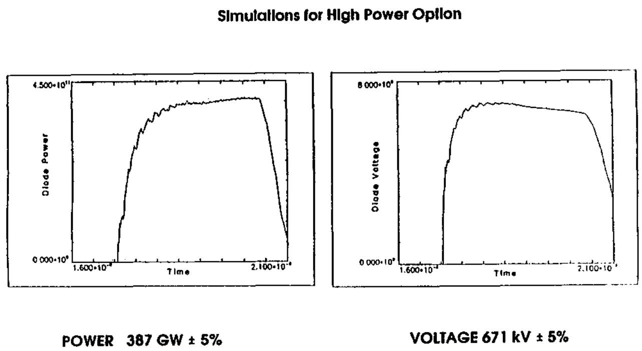

Figure 2: Predicted power (left) and voltage (right) for the 60 cm amplifier. The waveforms are flat to within ±5% for 253 nsec.

COMPONENTS

The 60 cm amplifier is based on a Marx- pulseline- output switch- z stack insulator- field emission cathode architecture. Although it is based on well established technologies, the amplifier does have several novel features, including: radial diaphragm laser triggered switches, a relatively low inductance (and hence fast risetime) for such a large field-emission cathode, and a relatively high transparency hibachi (or foil support) structure. The design of the 60 cm amplifier has been been described in detail elsewhere[2], and is based in large part on the experience gained with the 20 cm amplifier[3], a smaller e-beam pumped system that is now operated routinely as the intermediate amplifier in the NIKE system.

Marx: The Marx generators follow the well-proven ANTARES[4] low inductance arrangement. The Marxes have 24 half stages (i.e. 12 switches) with each half stage composed of two 2.8 μF @60 kV capacitors. Maximum charge voltage is 60 kV/half stage, with an erected voltage of 1330 kV. As oil vapor is highly absorbent at the KrF laser wavelength of 248 nm, the Marx oil tanks have to be completely sealed.

Oil Transmission Lines: Each Marx is connected to four separate oil transmission lines that contain electrically identical 2 Ω resistor/1.2 μH inductor networks. The oil transmission lines vary in length to compensate for the 90° bends in the water dielectric pulselines. These networks electrically isolate the pulselines from each other, and prevent all the lines from discharging into one if a fault develops.

Water Dielectric Pulse Forming lines: Each of the four coaxial pulse forming lines consists of two sections; a 145 nsec long, 5 Ω impedance main section followed by a 20 nsec long, 4 Ω peaker section. The peaker gives an initial higher voltage increase to the leading edge of the pulse in order to reduce the voltage risetime. In order to fit the amplifier into the available space, the pulseforming lines are bent through 90°. While creating a few mechanical complications, the electrical effects of these bends are negligible. Both numerical simulations with a 3-d transmission line code and simple experiments with a scale model show that the bends neither degrade the output pulse risetime, nor compromise the electrical strength of the system[5].

Main Output Switches: Each pulseline is terminated with its own output switch as shown in Figure 3. The switches are SF_6- insulated and consist of two radial nylon diaphragms that each have a single quasi-spherical electrode in the center. The output side of the switch is held at ground by a 100 Ω radial water resistor. The radial diaphragm arrangement follows that used on the NRL POSEIDON generator[6] and on the Rutherford Laboratories Super Sprite e-beam pumped amplifier[7]. This arrangement was chosen over the more conventional tubular housing geometry because of the comparative ease in aligning the laser triggered switches. Each switch is triggered with a laser pulse of about 11 mJ @ 266 nm that is generated by a frequency quadrupled Nd:YAG laser and focussed to a power density of about 5 GW/cm^2. The total inductance of each switch is about 100 nH.

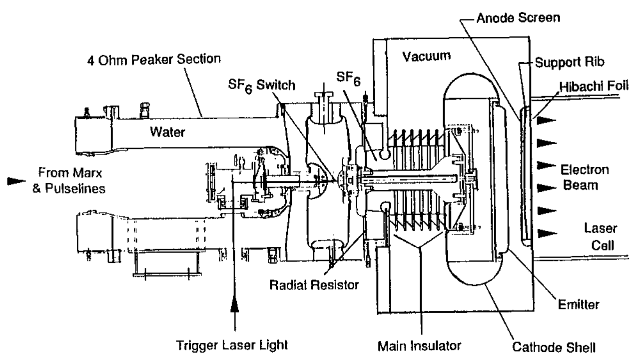

Figure 3: The peaker section, output switch, vacuum insulator, and diode.

Vacuum Insulator: The power is fed from each switch through a conventional z-stack insulator to a common cathode. See Figure 3. The inside-out geometry used here (so named because the vacuum region is outside the insulator, rather than the other way around) was successfully deployed on the LAM of the Aurora laser at LANL[7] and was chosen for its compactness and low inductance. Calculations show that the insulator is operating at about 69% of breakdown of one segment. The entire insulator stack is designed to be assembled on the bench where it can be tested for vacuum integrity and electrical stress before installation.

Diode: The diode is also shown in Figure 3. The cathode shell is electropolished and the average field kept below 70 kV/cm, both of which should prevent emission of parasitic currents to the wall. The emission surface itself is made from blue velveteen following experience learned from the 20 cm amplifier. Note that the design uses a projecting anode, which enables the field to be enhanced in the one region where it is desired, i.e. the anode-cathode gap, and reduced everywhere else. The edge of the emitter is fully radiused and extends 2 cm beyond the edge of the anode aperture. This design has three advantages: it prevents an intense beam halo that would otherwise be emitted from the edge of the cathode; it prevents extensive emission from the radiused region (those electrons would have high angle trajectories and hence be poorly transmitted through the hibachi); and it forms a low stress transition between emitter and the cathode holder.

We have designed the amplifier so the diode impedance and power can be varied according to the requirements of the electron beam or laser kinetics. In the baseline mode, the diode impedance is 1.25 Ω and the total electron beam power from each of the two sides is 330 GW at 650 kV. If we need to pump the amplifier harder to increase the laser output, we have the option of operating at higher charge voltages to increase the diode power to 390 GW (670 KV). If, on the other hand, the laser kinetics call for increased beam current into the gas (for example to increase the deposited power), we can lower the diode impedance to 1.0 Ω to maintain 330 GW at 650 kV, but at a higher current. Finally, we can raise the diode impedance if it is required to stabilize the electron beam. This last option was incorporated in response to a simulation by Jones at LANL[10], who suggested there may be a tilting instability that affects low impedance diodes with applied magnetic fields. Simulations of the NRL 60 cm amplifier suggest the instability will be suppressed by the 4.0 kG guide field, but the results are too close to call. Therefore we have decided to take this possibility seriously and provide for the contingency to raise the diode impedance to 1.5 Ω, which should quench the instability.

Transmission into the laser cell: The electron beam is passed through an anode screen, past the hibachi ribs, and through a Kapton foil into the laser cell. The beam is guided by a 4.0 kG magnetic field. The hibachi ribs are of a new design and composed of a high strength nickel-based alloy which allows them to be relatively thin for a hibachi of this size. They are also mounted vertically. These two features should not only increase the hibachi transmission efficiency, but they should also make the hibachi more resistant to energy losses due to the aforementioned tilting instability. This design has been tested under static pressure loads and has shown the rib can support more than 2 times the operating pressure without bursting the Kapton foil. Our calculations show that approximately 75% of the beam should be transmitted through the Hibachi ribs[2], which themselves are 90% transparent. Assuming the anode screen transmits 75% of the beam, the .0076 cm thick Kapton transmits 97%, then approximately 65% of the beam will be transmitted into the gas. The actual efficiency will probably be about 5-10% less due to gas backscatter.

The laser cell: The laser cell and diode boxes are a single large monolithic unit constructed of stainless steel with 5 cm thick quartz windows at either end. Both windows are mounted in non-parallel planes and neither are perpendicular to the cell axis in order to prevent prevent parasitic buildup of ASE. The cell is designed to operate at pressure of up to two atmospheres, with an overpressure jump of up to 0.7 atmospheres when the amplifier is operated

Divertors: The pulselines operate at about 65% of the maximum allowable electrical stress, and hence should be fairly immune to breakdown. However if the main switches fail to fire and the system is subjected to a full "ringing cycle" (i.e. energy oscillates between Marx and pulselines), the maximum electrical stress on the lines will be exceeded, and the pulselines will be virtually guaranteed to break down. We have installed an electrically weak but mechanically strong "sweet spot" in the system to ensure the resulting 50 kJ (the energy stored in one pulseline) under-water arc does not damage the lines. However the accompanying boom will no doubt shake the floor to the point of disrupting the optics. To prevent such an undesirable event from occurring, we have incorporated two SF_6-insulated divertor switches that discharge the pulselines safely into a 3 Ω resistive load. These switches are copies of the successful Rimfire design developed at Sandia[10] and are triggered 400 nsec after the main switches are supposed to fire by a timing circuit that derives its initiation signal from the erected Marx. Thus the divertors are triggered independent of whether the Marx is triggered or prefires.

STATUS:

As of this writing (June, 1993) one entire side of the amplifier has been constructed and its pulsed power components fully tested. Figure 4 shows the peaker voltage and output current of the system operated at 110% normal operating voltage (corresponding to the "high power mode"). Each line was fired simultaneously, but each was connected to its own independent 5 ohm resistive load. The voltage on all four lines was 1.3 ± .04 MV, and the current through each load 140 ± 4 kA. As can be seen, all four lines are switched out at the same time, and all four have the flat output waveform required for uniform electron beam pumping of the laser cell.

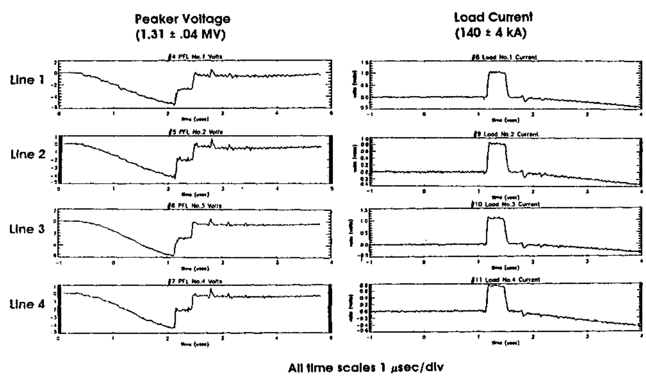

Figure 4: Output waveforms for resistive load tests

The performance is shown in finer detail in Figure 5, which shows the voltage across the resistive load of one line. In this figure three shots are overlaid. Again the line was operated at 110% normal operating voltage. As can be seen from the figure, the jitter, risetime, flat waveform, and reproducibility are more than adequate for the NIKE laser.

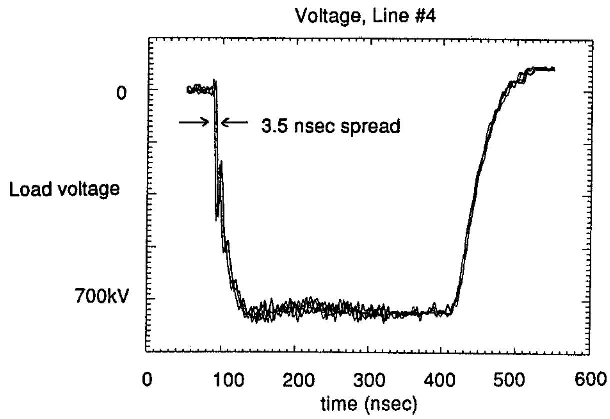

Figure 5: Output of one line, three shots overlaid

Electron beam tests have just begun, and preliminary results show all four lines behave identically. We expect the electron beam tests to be completed late in 1993 and the entire system, including the second side, to be operational and ready for laser tests early in 1994.

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