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AUTHOR(S) Reed J. Jensen
David C. Cartwright

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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THE LOS ALAMOS KrF LASER PROGRAM*

Reed J. Jensen and David C. Cartwright

University of California
Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, NM 87545

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INTRODUCTION

Los Alamos is currently developing the krypton fluoride (KrF) laser --a highly efficient laser able to emit very intense bursts of short-wavelength photons--as a research tool for the general study of high-density matter as well as for use in laser fusion. The KrF laser operates at 1/4 μm, close to the short-wavelength limit for conventional optical material, but still in the region where standard optical techniques can be used. The excited-state lifetime of the KrF lasing medium is short--as a result of both spontaneous emission and deactivation from collisions--making it impossible to store energy within the lasing medium for times significant to electrical pumping. However, an optical multiplexing scheme is being developed that will generate short, intense pulses of 1/4-μm light by overcoming the short storage time of the laser and taking advantage of the high gain of the KrF medium.

History

We have been aware of the great advantages of short wavelength lasers for fusion since the early seventies. We are also aware of a firm requirement for high laser efficiency. The invention and development of KrF lasers has allowed us to match pulsed CO_2 laser efficiency but gain a factor of 43 in wavelength.

In early 1975, J. E. Velazco and D. W. Stezer at Kansas State University suggested using krypton and fluorine gas as a lasing medium,[1] and in June 1975, J. J. Ewing and C. A. Brau at AVCO Everett Research Laboratory reported the first laser oscillation for the highly efficient KrF system.[2]

Los Alamos has been involved in the development and use of KrF and other rare-gas-halide lasers since 1976. The work was done originally for the laser isotope separation program, and, in the first year, KrF lasers were used to generate macroscopic samples of photolytic UF_5 from UF_6. At that point the emphasis was on developing high-beam quality, multijoule gas-discharge (rather than electron-beam) lasers. In the late 1970s, Los Alamos pioneered gas cleanup techniques that paved the way to the long-lived rare-gas-halide lasers. These efforts culminated in a KrF laser that ran at 1 J per pulse and 500 pulses per second.

At present Los Alamos is constructing a prototype electron-beam-pumped KrF laser system to scale to very high energy at short-pulse duration. Electron beam pumping provides uniform energy deposition over large volumes. Optical angular multiplexing provides a short optical pulse from a long electrical pulse. The prototype system is named Aurora, and its various components--from the KrF oscillator through four stages of amplification--are shown schematically in Figs. 1 and 2. The gas-discharge oscillator will emit a single beam consisting of a 5-ns, 1/2-J pulse. To achieve optical multiplexing, the original beam will be split into 96 beams before being sent through the various stages of amplification. The final amplifier, called the Large Aperture Module (LAM), will have a lasing volume that is 1 m by 1 m by 2 m long and an output energy in excess of 10 kJ in the 96 beams.

Multiplexing

A prime incentive for optical multiplexing is cost reduction. It has been estimated that a cost minimum can be achieved for KrF laser fusion if there are from 20 to 40 beams of various durations (50 to 5 ns), derived from a single electrical pulse. Rather than build many small systems, the Los Alamos design will use a single optically multiplexed system involving large amplifier stages--a key concept to be demonstrated by the Aurora laser.

Multiplexing starts with the time and angle encoders (Fig. 2), which will take the original 5-ns pulse and split it into 96 angularly separated beams. Each beam travels a different distance so that each is delayed differently; the resulting output consists of a train of 5-ns pulses. Because the pulses are angularly separated, each passes through the amplifier from a slightly different direction. The amplifiers are pumped for a relatively long time--about 500 ns--while the train of short pulses traverses their volume.

The same time-delay concept will be applied in reverse after the final amplification to cause all the beams to arrive at the target at once. A simplified version of this part of the system is shown in Fig. 3, illustrating how the time-of-flight for each beam would differ so that all beams meet simultaneously at the target. As noted earlier, this optical multiplexing technique allows us to take advantage of the high gain and high efficiency of the KrF gas laser to generate a short, high-energy pulse on target. The energy of the electron beam discharge is stored in the variously delayed flights of the 96 individual beams. Moreover, low-cost laser energy is provided by using one large system in which the amplifiers run for a relatively long time, rather than by using many short-pulse systems.

Figure 4 is a photograph of the final amplifier under construction. The large oval-shaped features are magnets that provide a 3-kG guide field to direct the electron beam straight into the laser chamber. The two large cylindrical tubes are water dielectric transmission lines that transmit the 1.3 MV electrical pulse to the cathode. Figure 5 shows the amplifier being discharged to produce ultraviolet power.

The LAM met and exceeded its design specifications in April, 1985, when it produced 10.3 kJ in a 400-ns pulse while running as an unstable resonator. The entire Aurora laser system is scheduled to begin operation in December of 1986. The Aurora laser system will provide experience in nearly all of the issues involved in building a very large KrF laser fusion driver. Experience will be gained not only in large KrF amplifier construction and operation, but also in running a whole series of amplifiers with final flux close to the design flux for the system.

In the eventual application of laser fusion, it is expected that several megajoules of ultraviolet laser energy will be required. Economical scaling to those energies requires amplifiers in the 100 to 200 kJ range. Large amplifiers provide more energy per beam and more energy per joule because costs rise only slowly with part count.

The key to large amplifier scaling is diode segmentation. We are testing this scaling by building a 100 kJ power amplifier module (PAM). In Fig. 6 we show a partial assembly of the PAM. It shows the five diode segments on each side of a 3 m high by 3 m long by 1.3 m wide cavity that will produce 100 kJ of KrF laser light. Figure 7 shows dimensions and some detail on this large scale device.

A major issue in this, or any, large KrF laser system is damage to the windows and mirrors. Los Alamos will need to develop coatings with good reflective or transmissive properties that also are resistant to fluorine attack and optical damage. At present, the size of apertures --and, therefore, the overall system cost--depends very sensitively on the threshold for optical damage.

References

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2. J. J. Ewing and C. A. Brau, "Laser Action on the $^2\Sigma^+_{1/2} \rightarrow {}^2\Sigma^+_{1/2}$ Bands of KrF and XeCl," App. Phys. Lett. 27, 350-352 (1975).

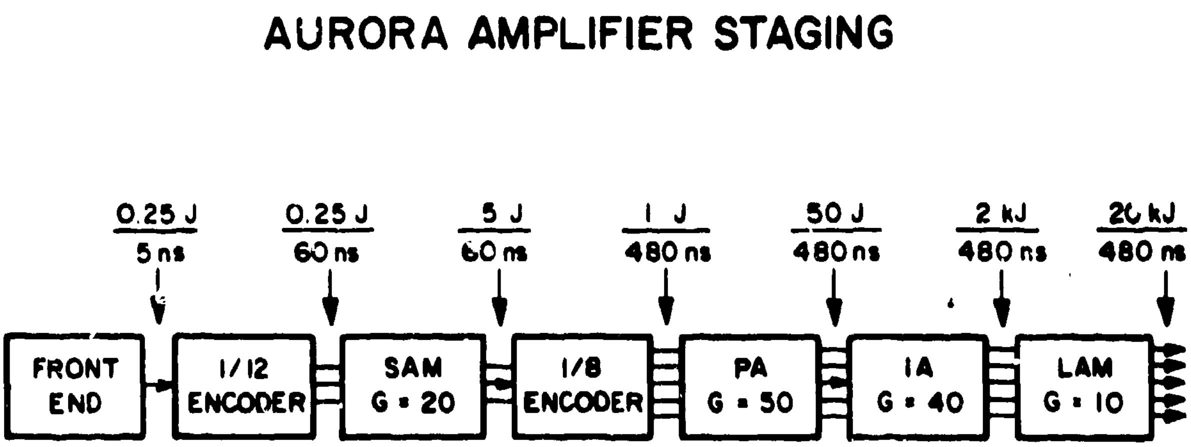

Fig. 1. The power amplifier chain for the Aurora KrF laser system starts with a single 1/2 J beam and ends with about 50 kJ divided among 96 beams.

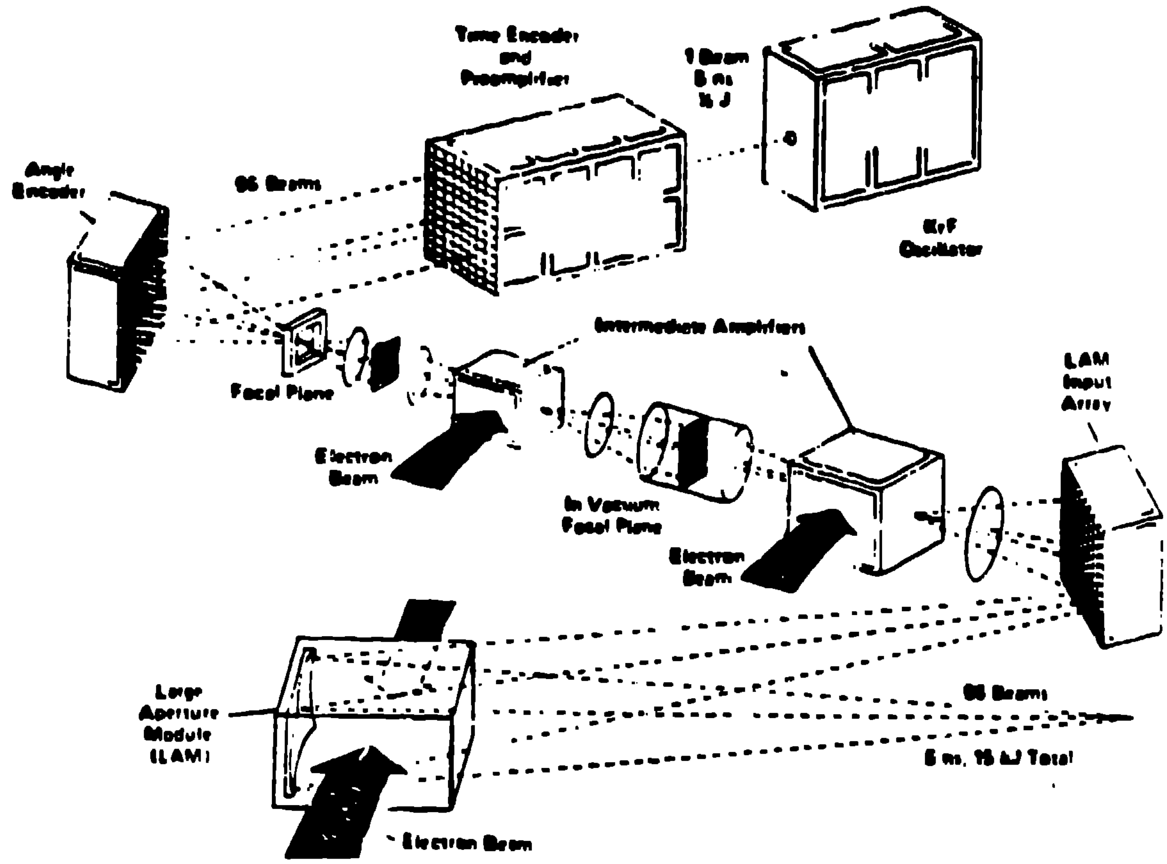

Fig. 2. A conceptual layout for the Aurora laser system. The single beam with 5-ns pulsewidth from the KrF oscillator is divided by the time encoder into a train of 96 temporally separated beams. This splitting is accomplished with aperture dividing the use of partially reflective mirrors called beam splitters, and different path lengths for each beam. Preamplification also takes place in the same apparatus. The angle encoder aims each beam so that it will pass through the central region of both intermediate amplifiers. Final amplification to 15 kJ takes place in the large aperture module. The oscillator is driven by gas-discharge techniques, but the higher intensities in the amplifiers require pumping by electron beam. A demultiplexing arrangement is needed after the LAM if the 96 beams are to be brought to the target simultaneously (see Fig. 6).

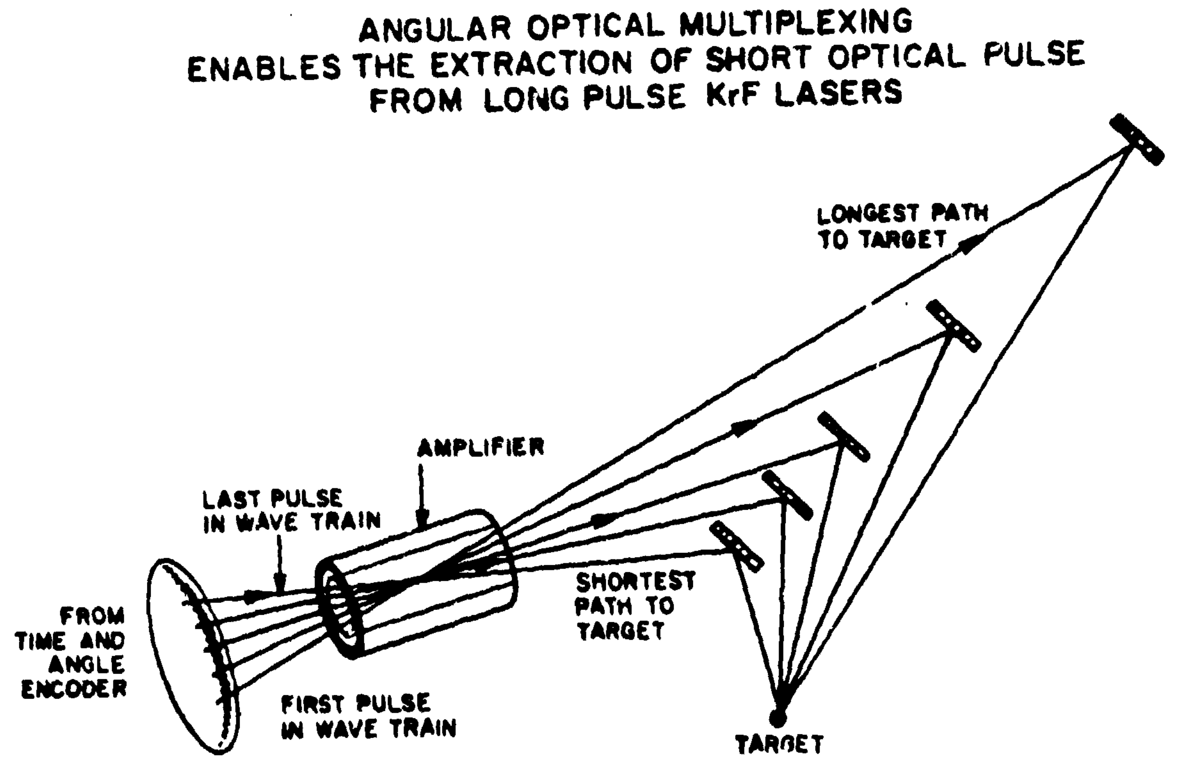

Fig. 3. A simplified optical angular multiplexing device. The five beams from the decoder represent a train of pulses that are separated in time. By adjusting path lengths so that the earliest pulse (crossing from bottom left to upper right) has the longest time-of-flight and the last pulse (crossing horizontally) has the smallest time-of-flight, the pulses can be brought together at the target simultaneously.

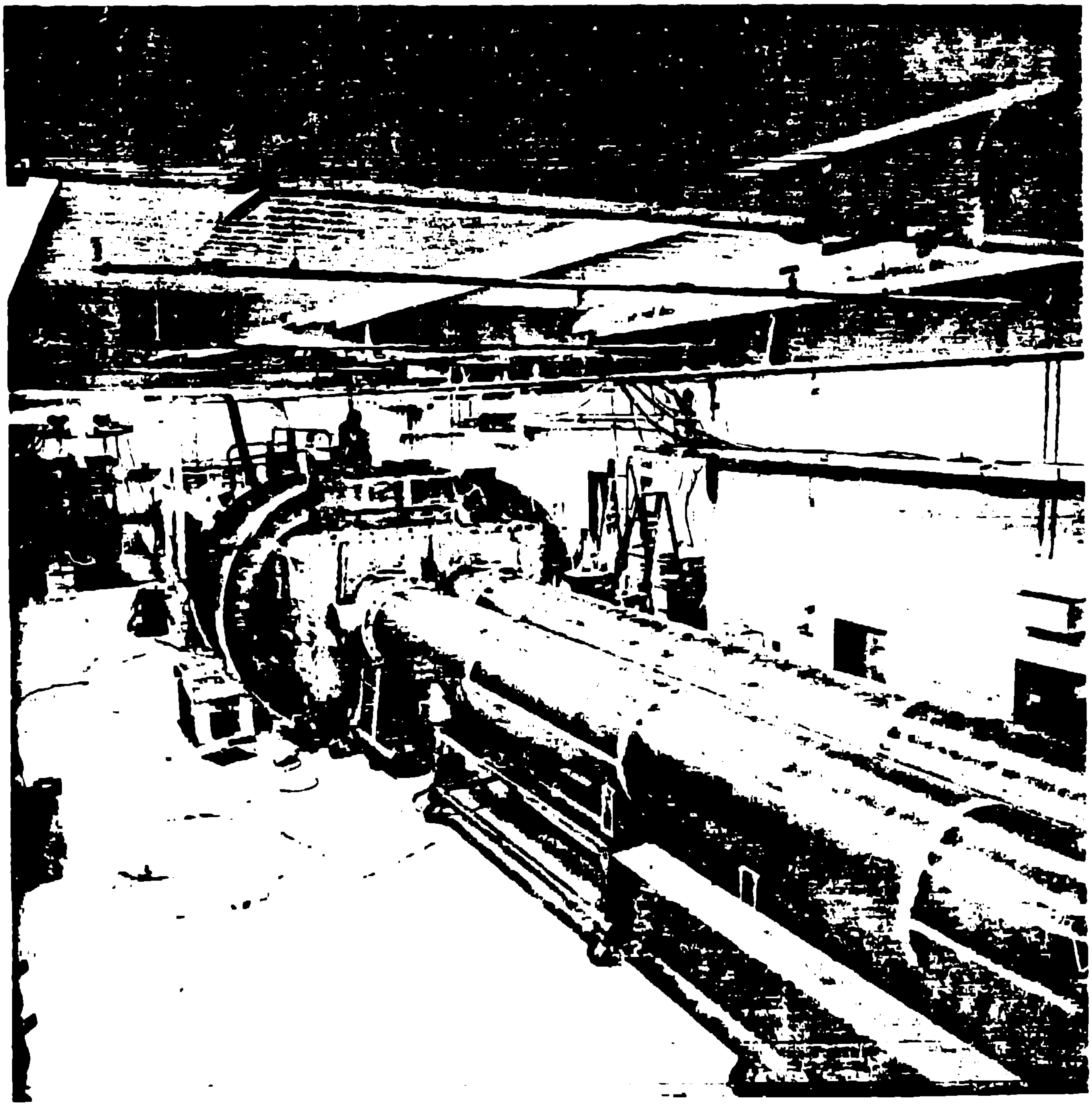

Fig. 8. The KrF laser system's final amplifier, the LAM, under construction.

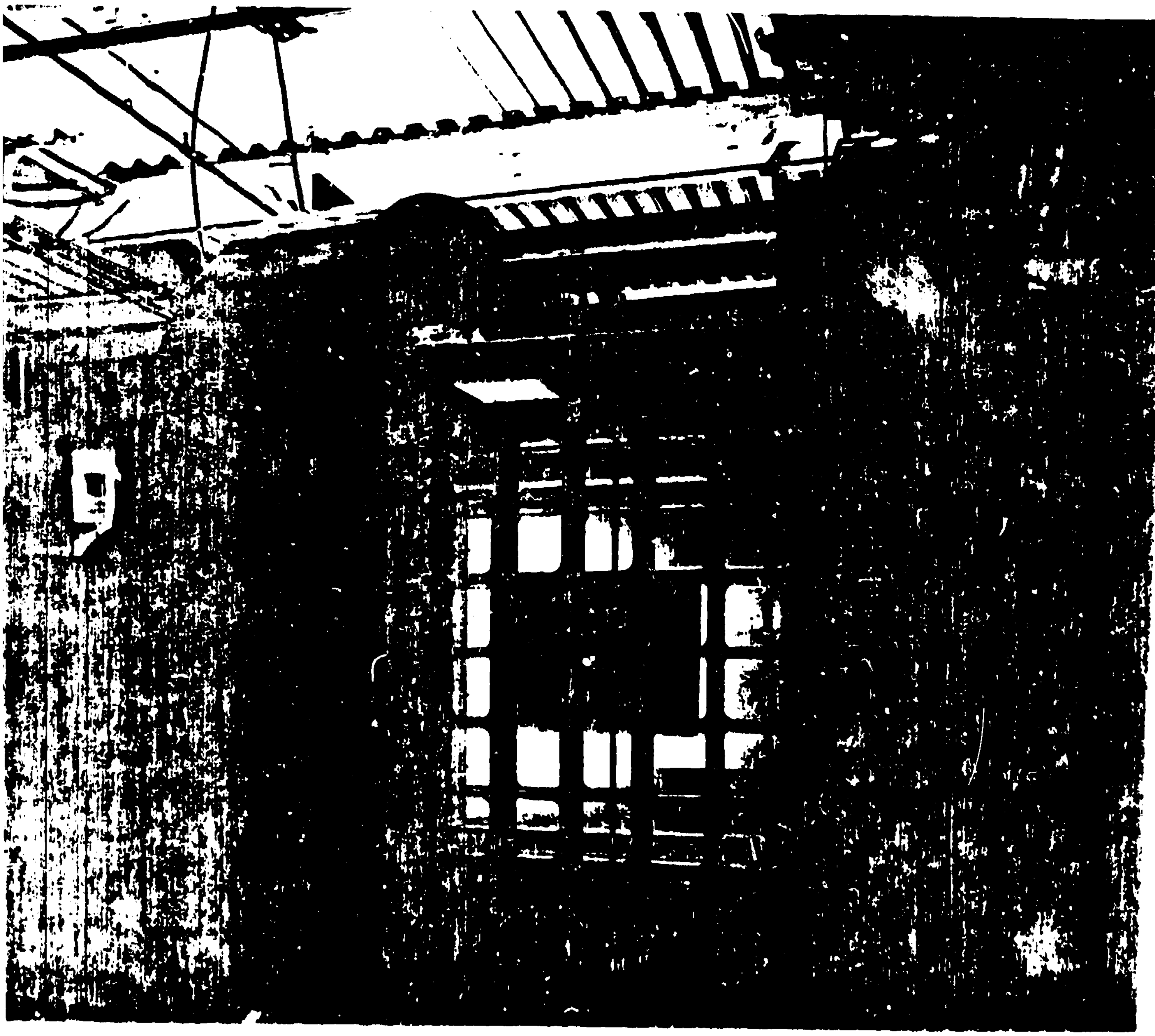

Fig. 5. The LAM being discharged to generate ultraviolet power at a wave-
l gth 1/4 μm.

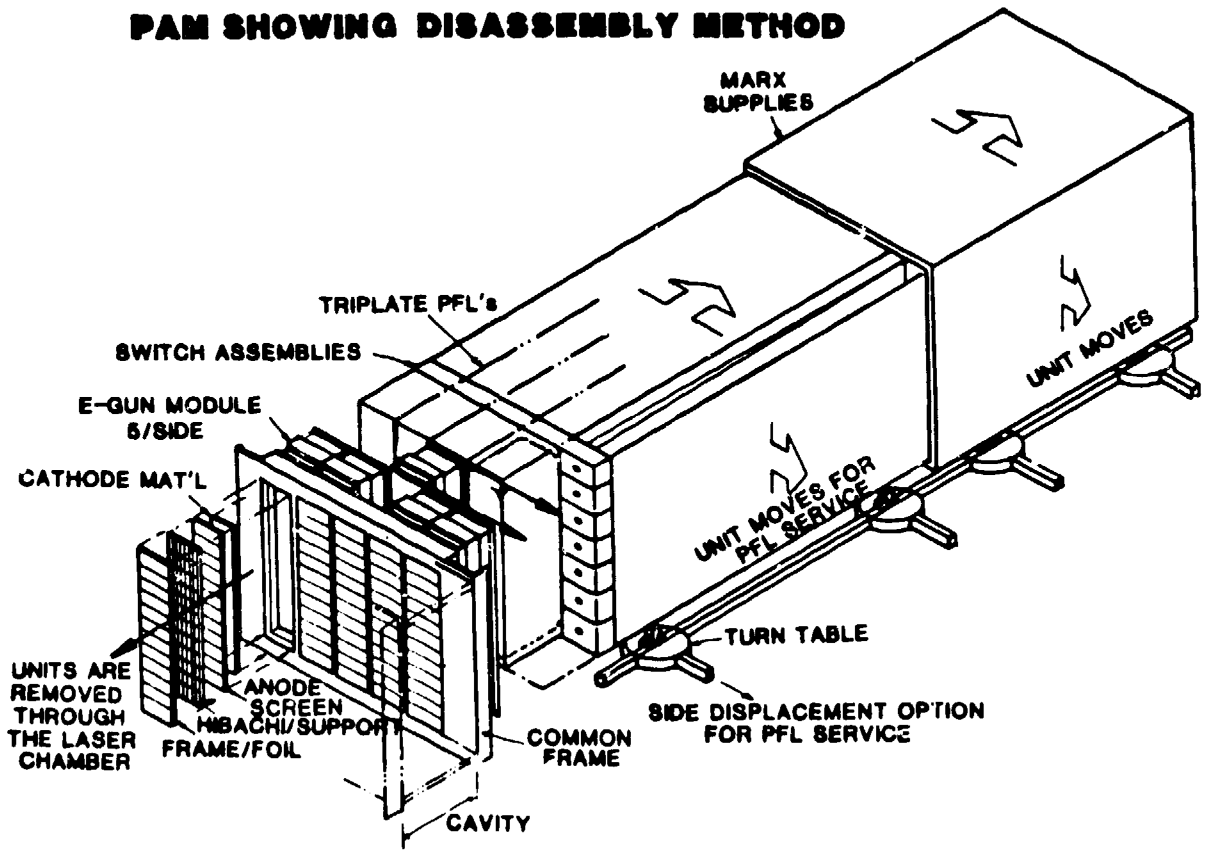

Fig. 6. Power Amplifer Module.

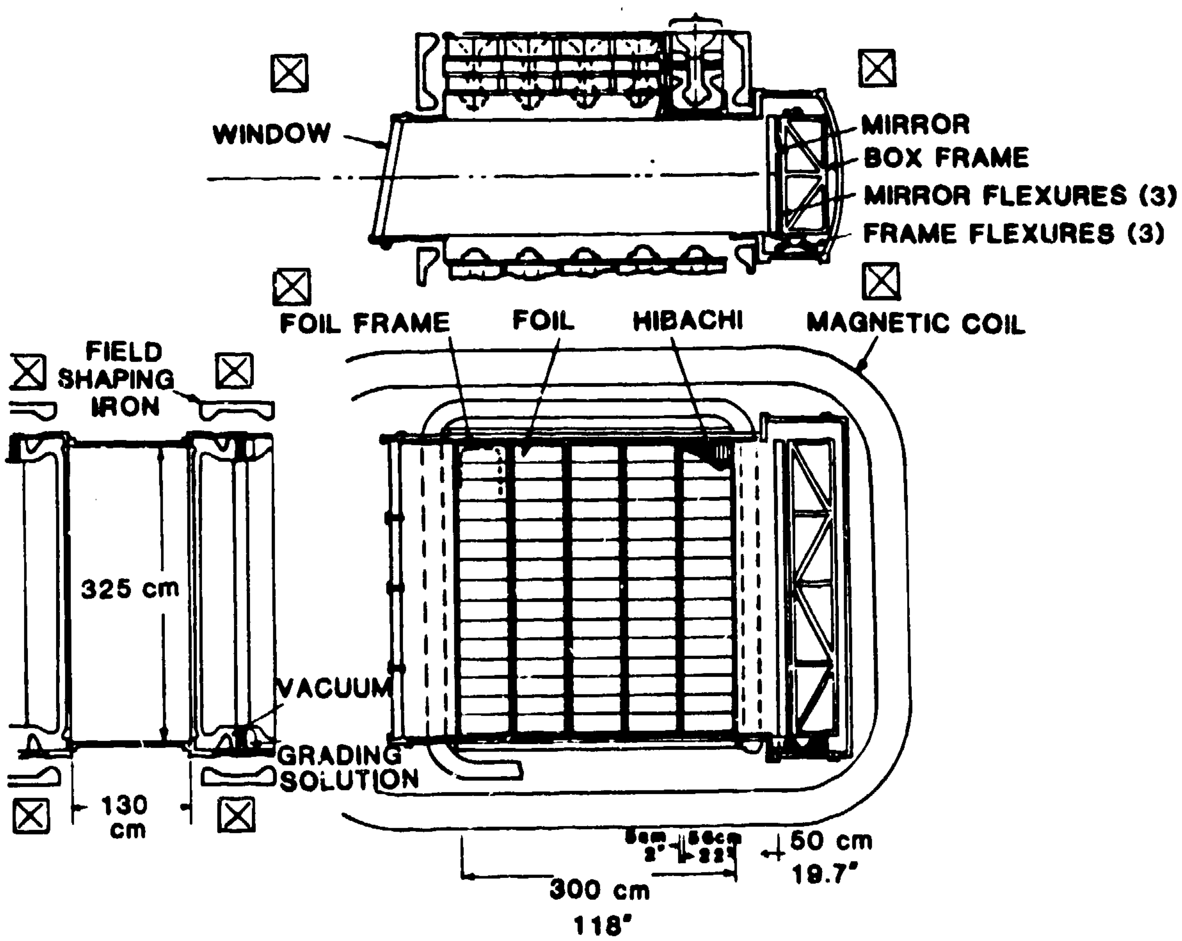

Fig. 7. PAM diode, laser chamber, and magnet assemblies.