RF LINAC-PUMPED LASERS*

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Summary

Excitation of gas lasers by a small emittance beam of electrons from an rf linear accelerator has been proposed.[1] Potential advantages of pumping with a linac rather than a fast transverse discharge include higher average power, higher repetition rate and significantly improved reliability. In addition, electron beam pumping should provide improved efficiency and a lower capital cost when compared with discharge pumped lasers.

An experiment to test this concept is in progress at the Los Alamos Scientific Laboratory (LASL). A 4-MeV side-coupled, standing-wave linear accelerator is being used to provide a pulsed electron current of 2 A with a 1-μs duration. The electron beam, focused to a 5-mm dia spot, is confined in the high-pressure gas (⩽10 atm) by a superconducting solenoid with a central magnetic field of 3 T (30 kG).

Experimental studies include: fluorescence of various rare-gas halide mixtures as a function of pressure; transport of the electron beam through the gas; and the optimum configuration of the electron beam, magnetic field and the laser cavity.

Introduction

Electron beams have been used in recent years to pump high-pressure rare-gas halide lasers. Although axial pumping has been used,[2] in most cases these lasers are pumped by an electron beam directed transversely to the laser axis.[3] In the latter arrangement, electrons are produced in vacuum from a cold cathode and accelerated by a pulsed potential of the order of 0.2 to 2 MV, which is formed by a Marx or L-C generator. The electrons enter the high-pressure gas through a thin metallic foil that is usually supported by a mesh or a plate containing closely spaced holes. Usual electron beam characteristics are: current density of 5 to 500 A/cm^2 over the cathode area, total current of 5 to 50 kA and a pulse duration of about 50 ns to 1 μs. Typically only a small fraction (a few percent) of the electron beam energy is deposited in the gas; the remainder of the energy is absorbed either in the walls of the laser or more importantly in the foil and support. The difficulty in cooling the large area foil and support is the principal limitation of this arrangement in attaining high average power. Reliability at high repetition rates is also seriously hampered by the capability of available spark-gap switches.

Axially pumping by a smaller diameter electron beam confined to the laser axis by a solenoidal magnetic field alleviates the limitation caused by foil and structure heating. However, axial beams produced by Marx or L-C generators generally have a kinetic energy that is too low to effectively pump the high-pressure gas, and they are still limited in reliability and repetition rate by spark gap capability.

Linac-Pumped Laser

To avoid the above limitations, we proposed to pump these excimer lasers axially with an electron-beam from a microwave linear electron accelerator. Pumping with a linac electron beam has these potential advantages over conventional methods: higher average power, higher repetition rate and improved reliability. In addition, this arrangement should provide a laser with improved efficiency and lower capital cost when compared with conventional electron beam or discharge lasers. A schematic indicating the expected efficiencies and repetition rate of such a laser is shown in Fig. 1.

Table I gives the projected ultimate performance for transverse discharge lasers compared with the desired performance of the linac pumped lasers.

Table II shows the near-term expected performance for laboratory models. In each case the linac-pumped lasers are expected to be considerably more reliable.

TABLE I
PROJECTED KrF LASER PERFORMANCE

	Transverse Discharge	Linac Electron Beam	
Average Power (kW)	16	10	100
Pulse Repetition Frequency (Hz)	4	10	100
Energy/Pulse (J)	4	1	1
Efficiency (%)	1.5	2	2
Capital Cost ($/watt)	150	250	100

TABLE II
NEAR-TERM KrF LABORATORY PERFORMANCE

	Transverse Discharge	Linac Electron Beam
Average Power (W)	40	60
Pulse Repetition Frequency (Hz)	200	300
Energy/Pulse (J)	0.2	0.2

*Work performed under the auspices of the U. S. Department of Energy.

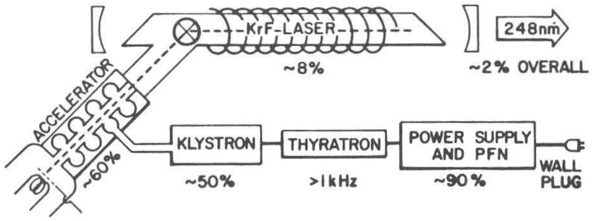

Fig. 1. Schematic of microwave-pumped laser.

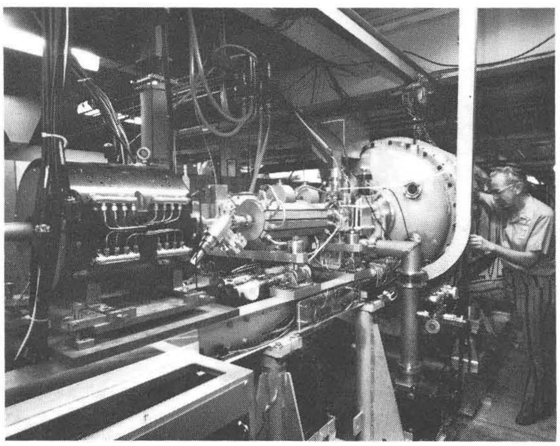

Fig. 2. The LASL 4-MeV electron linac.

Experiment

An experiment to test this excimer laser concept is in progress at LASL. An electron beam from a small microwave linear accelerator is being used to axially excite a high-pressure (≤10 atm) rare-gas halide mixture in a high-pressure cell. The accelerator, which is a side-coupled, standing-wave type, can deliver a pulsed 4-MeV electron beam with 2-A peak current for 1-μs duration at a 50-Hz repetition rate. Modifications are in progress to increase the pulse repetition rate to 300 Hz. The injector tank, prebuncher, accelerator and quadrupole steering and focusing magnet (from right to left) are shown in Fig. 2.

The electron beam, which is focused to a 5-mm dia. spot, emerges from the end of the beam pipe into the air through a 0.1-mm thick stainless steel foil. The beam then traverses about 3 mm of air and enters the high-pressure gas cell through a similar foil.

A superconducting solenoid with a central magnetic field of 3 T (30 kG) confines the beam to a region close to the axis of the gas cell. Otherwise, nuclear scattering of the electrons in the foils and gas would cause the beam to diverge and spread rapidly.

For laser application, the electron beam must be injected off axis and at a small angle with respect to the solenoid and laser axis. This is necessary to avoid the upstream optical mirror that forms part of the laser oscillator. Particle trajectory calculations, ignoring foil and gas scattering, have been performed to find a geometry in which the beam is injected into the laser cavity around the edge of a 25-mm dia. mirror that is coaxial with the magnet axis and forms one end of the optical cavity. The calculated trajectory for a promising case is shown in Figs. 3-7. In this case, the electron beam was injected 8 mm above the magnet centerline and at an angle of 12 mrad (0.7 deg). The foils and mirror are at -0.34 m with respect to the magnet center. This case has been tested experimentally. The results for an electron beam with finite size, divergence and scattering are in reasonable qualitative agreement with the calculated trajectories.

The fluorescent output of a number of xenon fluoride and krypton fluoride gas mixtures was studied prior to attempting laser action. A schematic of the apparatus is shown in Fig. 8. The electron beam entered from the left, passing through a pair of foils in the gas cell. The electrons were confined to a 1-cm dia. cylinder on the cell axis by the magnetic field of 3.0 T. The current out of the accelerator was 2 A, giving current densities in the gas of the same order. The light out of the cell was turned by a mirror to allow adequate radiation shielding of the fast photodiode, and was optically filtered to allow only the lasing wavelength (248 nm for KrF, 350 nm for XeF) to be detected. Checks for background contributions gave null results in all sensible permutations of conditions.

The resulting data are shown in Fig. 9. The fluorescence output (on an arbitrary scale) is derived from the peak voltage of the photodiode signal divided by the measured beam current for each pulse, with appropriate corrections for filter transmissions and wavelength response of the photodiode. The curves represent the best output obtained for each family of gas mixtures. As the light output was not strongly affected by small variations in the mix, the specific proportions (see caption) are not believed to be critical.

It is desirable to use a high-pressure gas, because this will increase the beam energy deposited in the laser. This criterion makes the neon diluent superior in every regard (save for the cost) for both xenon fluoride and krypton fluoride. The choice between these excimers for the best lasing candidate is not as clear, because the lasing depends on many factors. The narrower linewidth of xenon fluoride may make it competitive in spite of the greater light output of krypton.

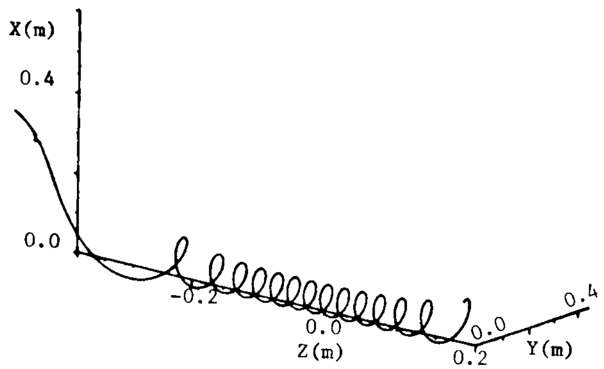

Fig. 3. Isometric view of calculated electron beam injection into superconducting magnet. Distances in meters. The magnet axis is colinear with the z-axis, and the magnet extends from -0.165 to +0.165 m.

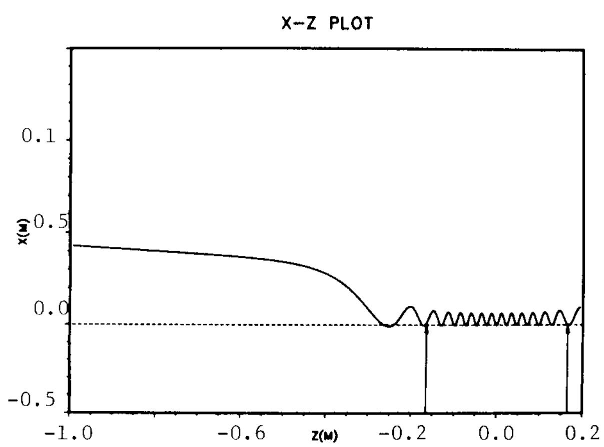

Fig. 4. The X-Z calculated electron trajectory.

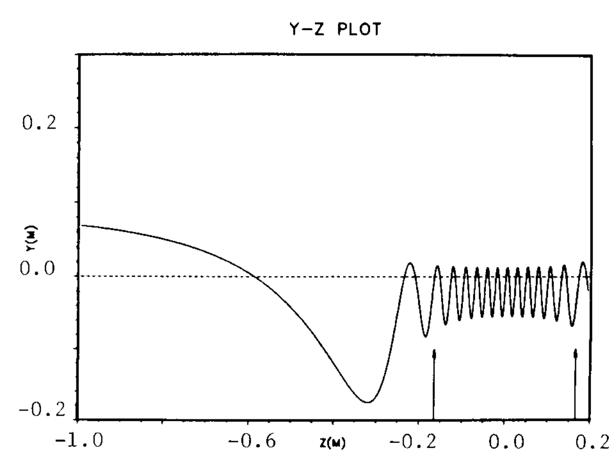

Fig. 5. The Y-Z calculated electron trajectory.

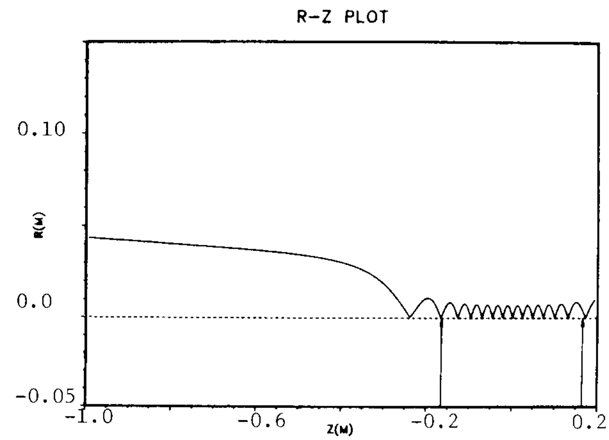

Fig. 6. The R-Z calculated electron trajectory.

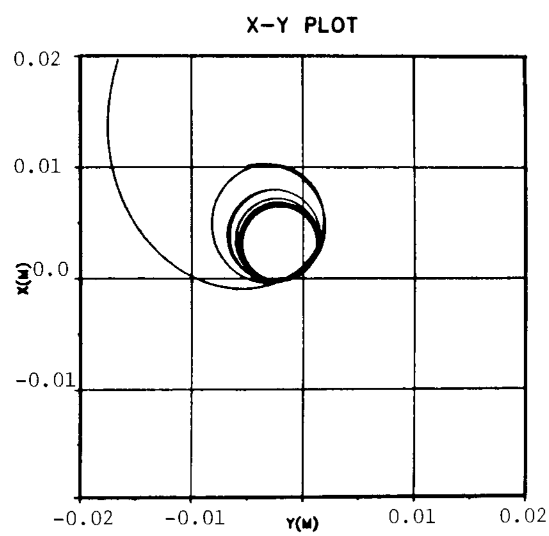

Fig. 7. The X-Y end view of calculated electron trajectory.

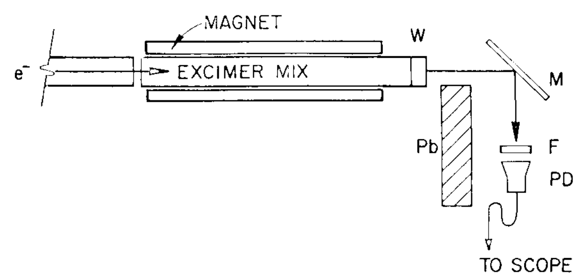

Fig. 8. Schematic of the apparatus used for fluorescence measurements. The electron beam enters the high-pressure excimer mix cell from the left, and photons exit the cell through a quartz window, W. The light is turned by mirror, M, filtered of all but the lasing wavelength by filter F, which falls on the fast photodiode PD. The photodiode is shielded from radiation by lead bricks, Pb.

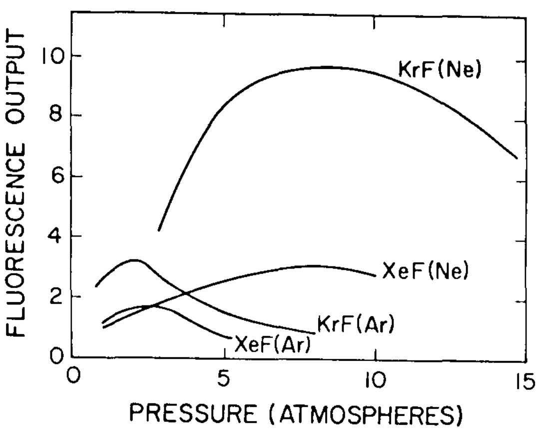

Fig. 9. Summary of fluorescence data. Gas compositions were:
KrF(Ne); 0.01% F_2/0.20% Kr/bal.Ne
XeF(Ne): 0.04% NF_3/0.12% Xe/bal.Ne
KrF(Ar); 0.04% F_2/1.0% Kr/bal.Ar
XeF(Ar); 0.2% NF_3/1.0% Xe/bal.Ar

References

1. C. A. Brau, T. R. Loree, S. D. Rockwood and W. E. Stein, "Linac Lasers," 8th Winter Colloquium on Quantum Electronics, Snowbird, Utah and 1978 IEEE International Conference, Monterey, CA.
2. J. M. Hoffman, A. K. Hays and G. C. Tisone, "High-Power UV Noble-Gas-Halide Lasers," Applied Physics Letters, Vol. 28, No. 9, 1 May 1976.
3. 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," Applied Physics Letters, Vol. 27, No. 6, 15 September 1975.