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RARE GAS MONOHALIDE DISCHARGE STUDIES

P.O. 2810103

Submitted To

Lawrence Livermore Laboratory
University of California
P.O. Box 808
Livermore, California 94550

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December 1976

By

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ABSTRACT

This report presents the results of the first phase of an experimental investigation of the minimum e-beam current density requirements for repetitively pulsed XeF lasers with 10 to 100-mJ pulse energy. Measurements were made in the self-sustained and e-beam preionized mode of operation. The e-beam preionized experimental results were similar to those obtained with UV preionization at other laboratories, indicating that ionization phenomena (rather than photodissociation) are dominant in both experiments. Multi-pulse e-beam experiments in a single gas fill resulted in rapid gas degradation, possibly due to electron bombardment of insulated surfaces with subsequent evolution of gaseous impurities.

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I. INTRODUCTION

This report describes the results of an experimental program on the self-sustained and externally preionized XeF laser in support of laser development for the laser isotope separation (LIS) program at Lawrence Livermore Laboratory (LLL). The wavelength of the XeF laser, 353 nm, makes it suitable for use as a visible dye laser pump, and the wavelength is long enough to minimize photochemical decomposition of the dye in comparison with the shorter UV wavelengths of the KrF and ArF lasers.

One of the basic requirements for a commercially viable LIS scheme is that the lasers be repetitively pulsed with the repetition frequency in excess of 1 kHZ. This imposes a severe constraint on the excitation technique used for the laser. Although electron beam excited and e-beam sustained discharges have been used successfully for scalable, high-power rare gas monohalide laser excitation,[1-4] this has usually involved e-beams with very high current density of the order of 10 to 100 amps/cm^2. Such high current densities limit the possible repetition frequencies to less than 100 Hz due to foil heating problems. It is, therefore, desirable to minimize the electron beam current density requirement or to look for alternate excitation techniques to meet the Livermore requirements. The present program was therefore initiated to investigate the minimum e-beam current density requirements and to explore self-sustained discharge operation in a short-pulse laser system, recognizing the modest energy requirements for LIS aoplication.[5]

The experimental results described in this report were obtained with a short-pulse discharge having a pulse width of the order of 20 to 50 nsec. This falls within the pulse length limits expected for the LIS application and helps to limit discharge instabilities arising from two-step ionization processes as discussed by Daugherty, et al.[6]

Section II of this report describes the experimental apparatus, including the various discharge configurations tried in the experiments as well as the discharge diagnostics. The experimental results are presented in Section III together with a discussion of the results, including a comparison of the physical phenomena in the e-beam preionized and UV preionized discharges.

II. EXPERIMENTAL APPARATUS

2.1 Short-Pulse Discharge Circuit

A flat plate Blumlein circuit was chosen to provide a fast low-inductance discharge pulse. This line, which is shown schematically in Figure 1, was folded for economy of space and consists of three parallel plates equally spaced, with the center plate shorter than the outer plates. The line makes use of 0.08-mm copper sheet bonded to a similar thickness of Kapton. The Kapton did not appear to have suffered deterioration during passivation with F_2 although it was usually protected by a glass cover plate in the discharge chamber. The circuit parameters and discharge chamber characteristic dimensions are listed in Table I.

Optimum utilization of the Blumlein pulse characteristics requires that the electrical switch (see Fig. 1) be designed for very low inductance. For this reason, a rail gap switch was built using the triggered spark gap concepts developed at Culham Laboratories[7] and elsewhere.[8] The switch is shown schematically in Figure 2 and the rise time is calculated to be a few nanoseconds. One important factor in minimizing the switch rise time is the development of a large number of spark channels. We found that seven to eight spark channels could be obtained using air in the switch at several atmospheres.

The discharge chamber was constructed from teflon and aluminum for compatability with F_2. It was designed for flexibility so that the discharge electrode geometry could be readily changed. The characteristic dimensions are listed in Table I.

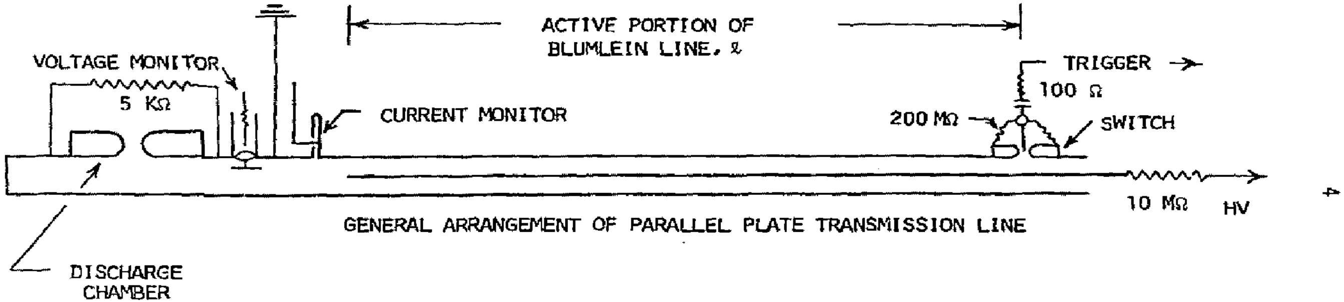

Figure 1. Schematic of Blumlein Line. Conducting Surfaces are 0.075 mm Copper Bonded to 0.075 mm Kapton. 0.25-mm mylar sheets were stacked for the bulk of the dielectric.

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Table I

Experimental Parameters

Blumlein Line Characteristics	
Length	350 cm
Width	60 cm
Capacitance	26 nF
Inductance	18 nH
Energy Stored	11.7 J @ 30 kV
Characteristic Impedance	$Z = \sqrt{L/C} = 0.67\ \Omega$
Nominal Pulse Duration	17.5 nsec
Discharge Chamber	
Electrode Length	52 cm
Active Volume	73 cc (52 x 1.4 x 1)
Total Gas Volume	667 cc
Electrode Separation	Variable from 0 - 20 mm
Discharge Chamber Construction	Teflon

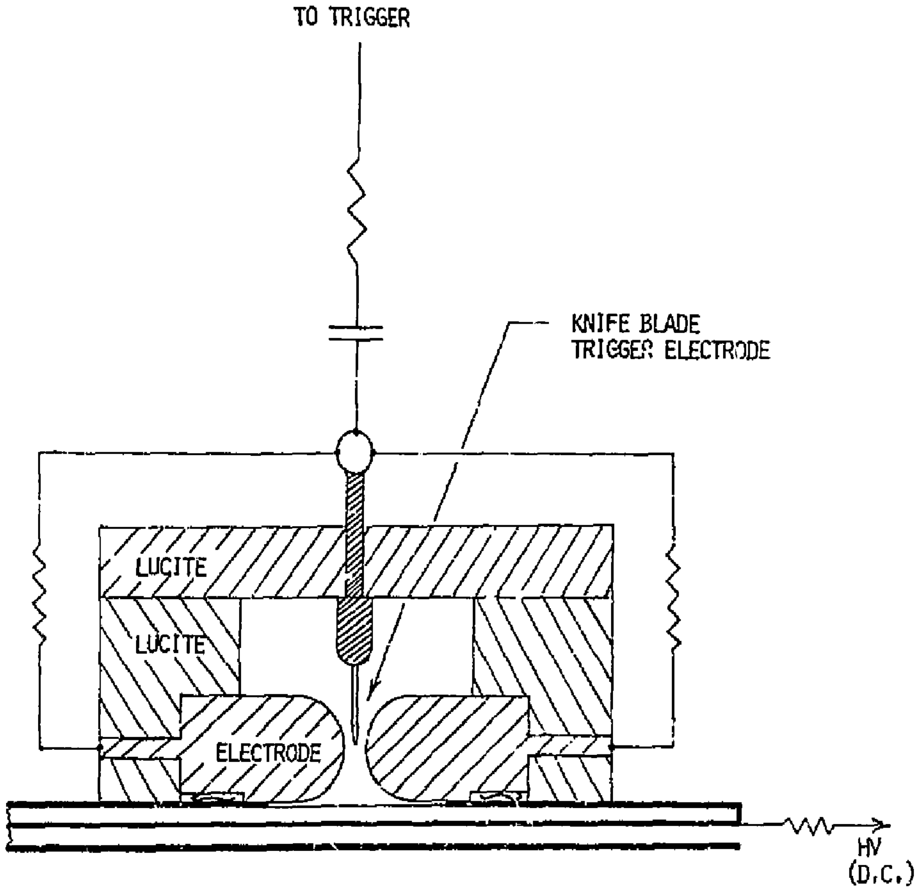
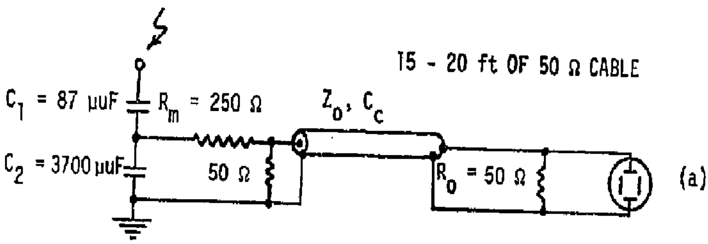


Figure 2. Schematic of Rail Switch for Blumlein Line

Both a current and a voltage probe were used for the discharge diagnostics. The current monitor is a folded stainless steel foil, 5 cm long x 0.0025 cm thick, which is mounted across the 60-cm wide transmission line as shown in Figure 1. The voltage drop across this stainless steel section is measured and is related to the transmission line current by the resistivity of the stainless steel giving a sensitivity of 2.9 x 10^{-3} V/amp.

A capacitive divider, shown in Figure 3a, was used to measure the voltage at the discharge chamber. A capacitance divider is inherently a pure reactance, and, as a result, inductances which are always present lead to high frequency oscillations which may be introduced on the leading edge of the voltage pulse (see Ref. 9). In this reference, it is noted that simply using cable termination ($R_0=Z_0$) with a capacitance divider can result in a differentiation of a rectangular pulse. However, fairly good results are obtained with capacitive dividers by inserting a resistance R_m in series with the cable input as shown in Figure 3. R_m should have a value nearly equal to Z_0 but care must be taken that R_m x C_2 is much larger than the duration of the event to be measured.[9,10] A typical voltage probe oscillogram is shown in Figure 3b. The oscillogram appears to show an accurate shape of the voltage appearing at the discharge chamber, but more experience with the capacitive divider design is required for complete confidence in these measurements.

The performance of the Blumlein/rail gap switch combination was measured using a dead short for the discharge load. This produced a ringing frequency of 8 MHz, which is consistent with the calculated Blumlein circuit parameters and implies a switch inductance of several nanohenries or less.



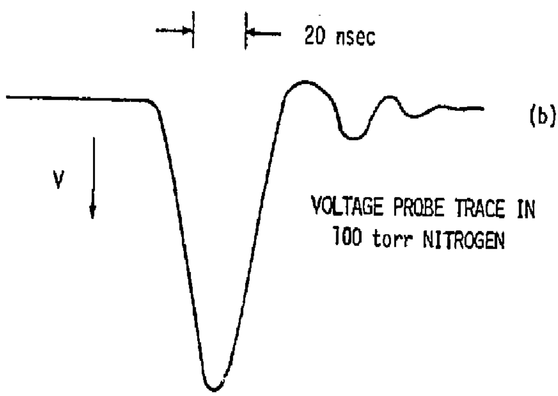


Figure 3. Voltage Probe

2.2 Discharge Configurations

Several different electrode geometries were built for use in these experiments, both in the self-sustained discharge mode of operation and in the e-beam ionized mode. The different geometries include (a) one flat electrode opposed by a wedge-shaped electrode, (b) one flat electrode opposed by a resistor array using copper leads as electrodes with or without cover buttons. In addition, the solid electrode configuration was used together with razor blades mounted between the electrode and the Blumlein conductor. These various configurations are sketched in Figures 4a, b, c, d.

The wedge-shaped electrode was chosen based on some earlier experiments with self-sustained discharges at NRL.[11] The 100-resistor array electrode (each resistor being 22 ohms) was used as a resistively-ballasted electrode to minimize the effects of local discharge instabilities. The addition of the razor blades was an attempt to obtain UV preionization by initiating a corona discharge between the knife blades as had been previously demonstrated in high-pressure nitrogen lasers.[12]

Both the smooth electrode and the resistively-ballasted electrode were used in the purely self-sustained mode of operation as well as with e-beam ionization. In the e-beam experiments, the Blumlein discharge chamber configuration was coupled to the e-beam with the foil window holder acting as the cover plate to the discharge chamber as shown in Figures 5 and 6. The e-beam was generated by a cold cathode electron gun with variable electrode spacing to permit changing the e-beam current density. The e-beam was operated with an applied voltage of 160 kV and the current density was varied over the range from 0.3 to 4 amps/cm^2 through the foil.

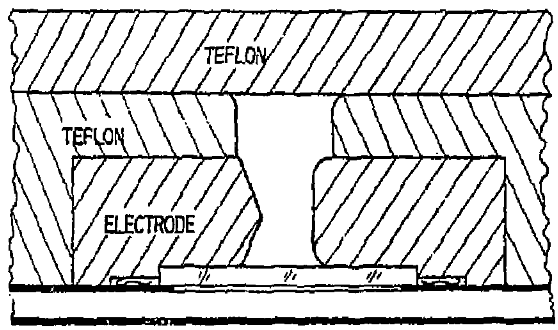


Figure 4(a). Schematic of Discharge Chamber with Simple Electrode Geometry

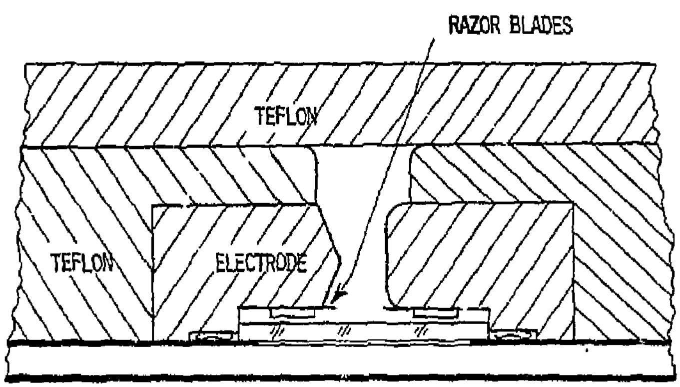


Figure 4(b). Simple Electrode Geometry with Razor Blade Preionization

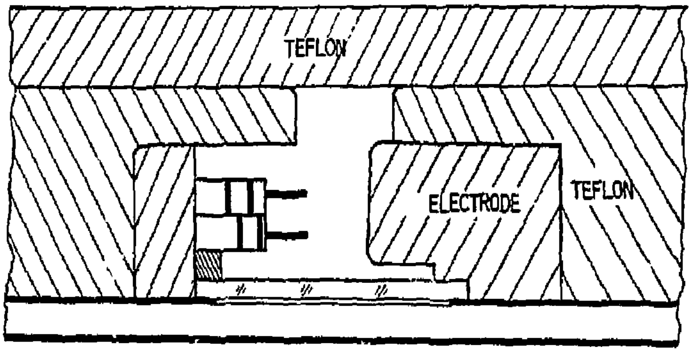


Figure 4(c). One Hundred Resistor Electrode Geometry. Staggered Two-Row Geometry with 1-cm Spacing was Used.

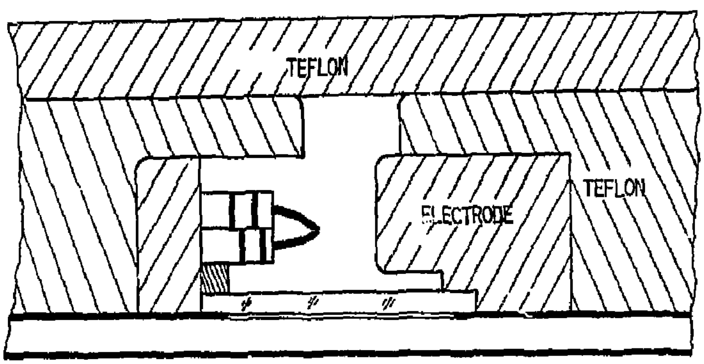


Figure 4(d). One Hundred Resistor Geometry with Electrodes Moved Together.

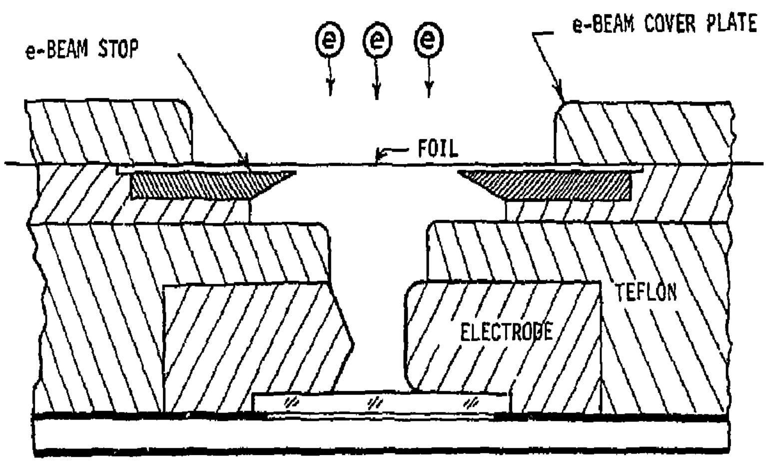


Figure 5. Simple Electrode Geometry with e-Beam Preionization

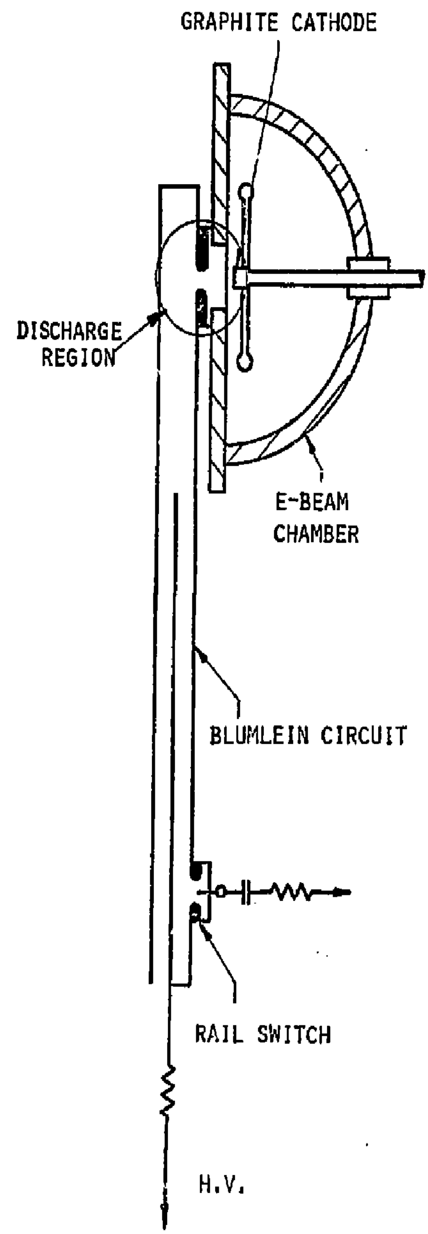


Figure 6. Schematic of MSNW Short Pulse XeF Experiment

2.3 Gas Handling

A stainless steel gas mixing manifold was used to prepare the gas mixtures for these experiments. NF_3 rather than F_2 was chosen as the F-atom donor based on previous experiments at MSNW and elsewhere,[11,13] which suggested that NF_3 was the preferable F-donor molecule. The entire gas handling system was passivated with F_2 prior to preparing the gas mixtures. These were typically 1 to 2% Xe, with 0.3 to 1% NF_3 dilute in helium. The discharge chamber was passivated with F_2 every time it was opened to alter the discharge configuration.

2.4 Cavity Optics

All the lasing experiments were performed with a stable resonator, using a 2-m radius-of-curvature max reflector mirror, opposing a flat output coupler with 10 to 60 percent transmission. The cavity optics were directly mounted on the discharge chamber using flexible stainless steel bellows to obtain mechanical freedom for mirror alignment.

Despite the use of NF_3, some unexpected difficulty was experienced with window deterioration, presumably due to the generation of F_2 or F-radicals following discharge of the gas mixture. Following the initial experiments, all the mirrors were sent back to the manufacturer for overcoating with MgF_2 which considerably improved the resistance of the windows to attack but did not completely overcome the problem.

A photodiode (ITT F4000 S-5) was used to monitor the temporal variation of the laser pulse. A calorimeter (Gentec ED-200) was used to measure the pulse energy.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Experiments were performed using the various discharge configurations described in Section 2.2 with and without e-beam ionization. The results with e-beam ionization were significantly different from those obtained in the self-sustained mode of operation in absolute energy, pressure scaling, and shot-to-shot repeatability with a single gas fill. This section is therefore divided into three parts to describe separately the pulse energy measurements in the self-sustained discharge and the e-beam ionized discharge experiments as well as the measurements of the effects of multiple discharges in the same gas fill.

3.1 Self-Sustained Discharge Experiment

Some initial experiments were made using the wedge and plain electrode geometries to monitor the discharge performance both in N_2 and Xe-NF_3-He mixtures. A temporal variation of the discharge current for both N_2 and XeF lasing are shown in Figures 7a and 7b. The pulse rise time was limited to 10 nsec or more by the rise time of the available oscilloscopes (Tektronix 556). The pulse width is in reasonable agreement with expectation based on the design of the Blumlein but the ringing indicates some mismatch between the load and the line impedance. Some measurements were also made using the fast response photodiode and a typical trace is shown in Figure 8. The pulse half-widths were typically in the range of 20 nsec which is consistent with the discharge current pulse widths.

The early XeF laser experiments were performed with varying gas mixtures, however the dependence on the gas mixtures did not appear to be very

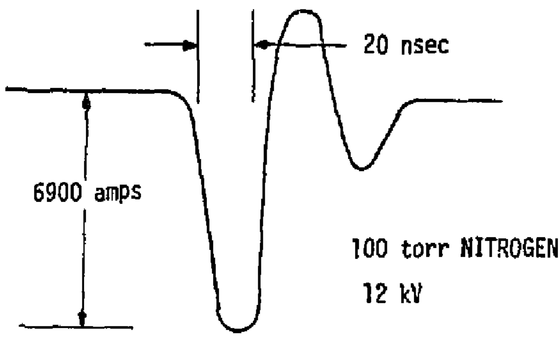


Figure 7(a). Discharge Current-Time Curve

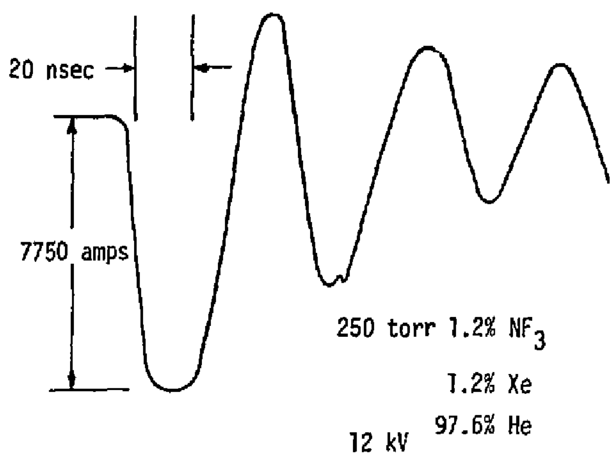


Figure 7(b). Discharge Current-Time Curve

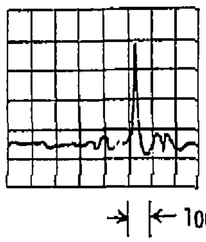


Figure 8. Temporal Variation of Laser Output Pulse

strong and most of the experiments were done with 1% NF_3 and 2% Xe dilute in helium. This is typical of gas mixtures used in other self-sustained discharge experiments.[11,13]

Although the razor blade preionized configuration seemed to work quite well in pure nitrogen, giving better performance than without the razor blades with an output of several millijoules, no success was achieved in XeF laser experiments. Visual observation of the discharge in the XeF experiment indicated arcing across the razor blades. The arcs occurred at discontinuities, i.e., at the edges of the blades, and were not eliminated by increased spacing of the blades. Therefore, experiments with this configuration were dropped very early in the program because of the limited time available. However, this configuration merits further investigation. Recent expermental data by Hasson, et al.[14] suggest that careful design and construction of a segmented transmission line/discharge configuration can be used to obtain UV preionization with the razor blade approach.

The typical laser performance with varying mixture pressure is shown in Figure 9 for both the solid electrode configuration and the resistor array-electrode configuration. These data were obtained with a 60 percent output coupler which gave a maximum optical output at the peak of the pressure curve. The major difference between these two electrode geometries was in the pressure scaling as shown in Figure 9. It is evident that the resistance array cathode led to useful operation at significantly higher pressures, presumably due to the ballasting effect on the discharge. The pulse energy was significantly smaller when the resistor array was capped with aluminum buttons. It should be pointed out that all the data in Figure 9 were obtained

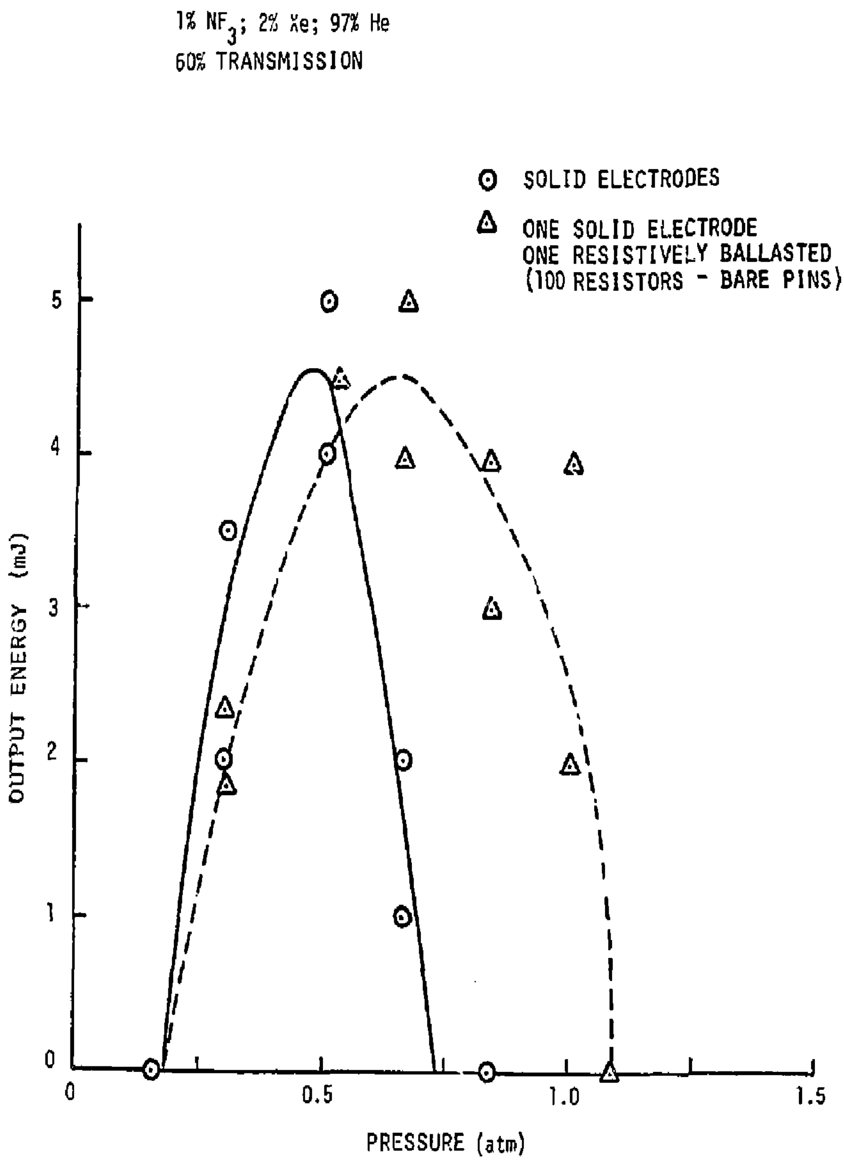


Figure 9. XeF Laser Energy vs. Pressure in Self-Sustained Blumlein Discharge

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with a fresh gas charge for each experimental data point to eliminate interference caused by gas degradation.

The experimental results shown in Figure 9 were obtained with an electrode spacing of approximately 1.5 cm. Experiments were also performed with electrode spacing ranging from 0.8 cm to 2 cm. In general, the pressure scaling effects were similar with these different electrode spacings but the lasing performance, i.e., pulse energy, was quite sensitive to the spacing and the performance became more erratic at the smaller gap spacings. This change in performance may be due to modification of the cathode fall region resulting from the changing electric field distribution. Visual observation of the lasing pulse shape indicated a rectangular pulse shape with narrower dimension across the electrodes. This was consistent with observation of pitting on the electrodes which indicated that the discharge was running predominantly near the center of the electrodes.

3.2 E-Beam Preionized Discharges

In these experiments, the 1-μsec e-beam pulse was fired at a predetermined time before the Blumlein discharge pulse; the time delay varying from 0 to 50 μsec. For this reason, the experiments are termed e-beam preionized rather than e-beam sustained since dissociative electron attachment processes such as $e + NF_3 \rightarrow NF_2 + F^-$ would result in the disappearance of the electrons on a sub-microsecond time scale.

Typical experimental data for these e-beam experiments are shown in Figure 10. Some initial experiments indicated improved performance with lower NF_3 concentration for these e-beam preionized experiments than for the self-sustained experiments described in Section 3.1. The NF_3 concentration was reduced from 1 to 0.3 percent, this mixture being typical of those used in pure e-beam and e-beam sustained discharge experiments.[4,15]

It is interesting to note from these e-beam experiments that the lasing pulse energy is almost independent of the e-beam current density over a wide range of current densities if the discharge and the e-beam pulse are coincident. Furthermore, the output pulse energy does not depend upon coincidence between the e-beam and the main discharge pulse at the higher current densities. However, the output energy decreases with decreasing preionization at a fixed delay time.

One can compare these e-beam preionization data with results obtained by UV preionization from experiments performed at NRL[16] and LASL[17] during the course of the MSNW experimental program. In principle, the basic discharge and kinetic behavior should be the same with either a UV or an electron source if the assumption is made that the only function of the source is to ionize a small fraction of the gas. (The discharge and kinetic behavior would be completely different if photodissociation were the prime effect of the UV source leading to some F-radical which was important in the kinetic scheme.) The fact that lasing, with large pulse energy, does not depend upon coincidence

Electrode Spacing 1.4 cm

0.3% NF_3:1% Xe:98.7% He

1 atm pressure

60% Transmission

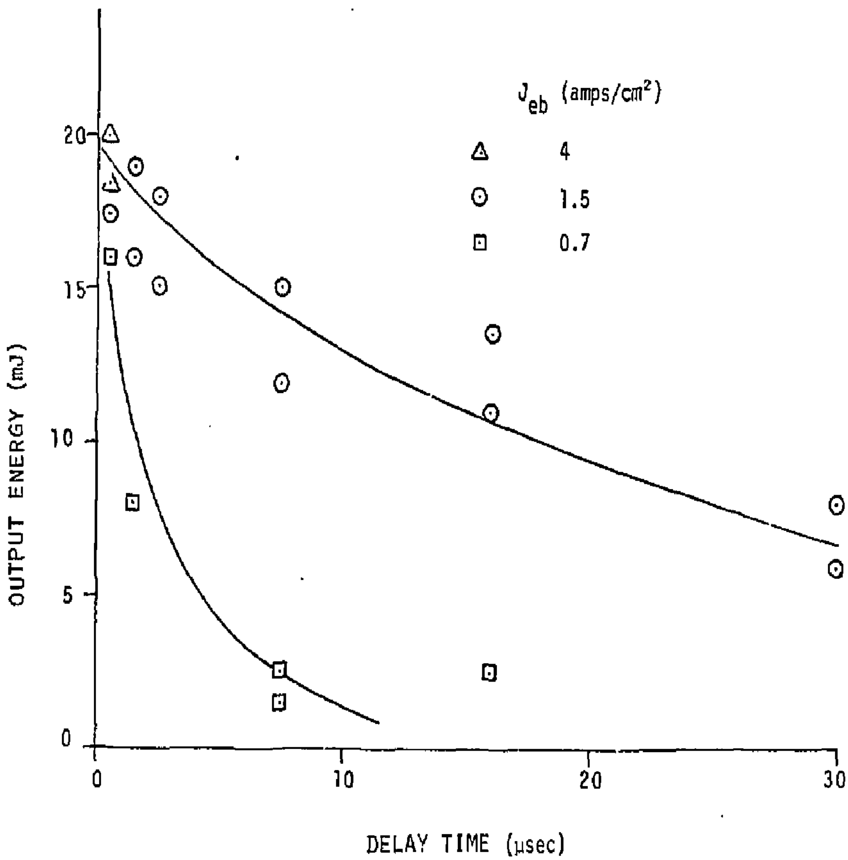

Figure 10. XeF Laser Energy vs. Time Delay Between Preionizing and Main Discharge Pulses

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between the ionization and the main discharge pulse indicates that ionization phenomena are dominant in both the UV and the e-beam experiments.

The decrease in laser energy with increasing time delay between the e-beam and discharge pulses can be interpreted as simply due to the loss of negative ions by two- and three-body ionization processes where the negative ion is probably formed by dissociative attachment during the ionization pulse itself. This is also consistent with the observations by the two groups using UV preionization.[16,17]

Some results for the pressure dependence of the pulse energy with e-beam ionization are shown in Figure 11 for two different gas mixtures. These experiments were performed with near coincidence of the e-beam and discharge pulse and an e-beam current density of several amps/cm^2. The performance might be expected to improve with increasing gas pressure due to the linear dependence of the ion-pair production on the gas pressure. In this regard, the pressure dependence of the low NF_3 concentration mixture seems entirely reasonable. The unexpected pressure dependence of the high NF_3 concentration gas mixture may be due to collisional deactivation at high pressures by the NF_3, but this is pure conjecture since there is no information available on collisional quenching of XeF*.

The pressure dependence of the e-beam ionized experiments is significantly different from that of the self-sustained experiments and, in particular, the e-beam ionization permits operation at much higher pressures. Although the detailed physical phenomena in e-beam (or UV preionization) experiments are not well understood at present, it is certain that the discharge is far more uniform with the e-beam preionization due to the uniform energy deposition by the primary electrons.

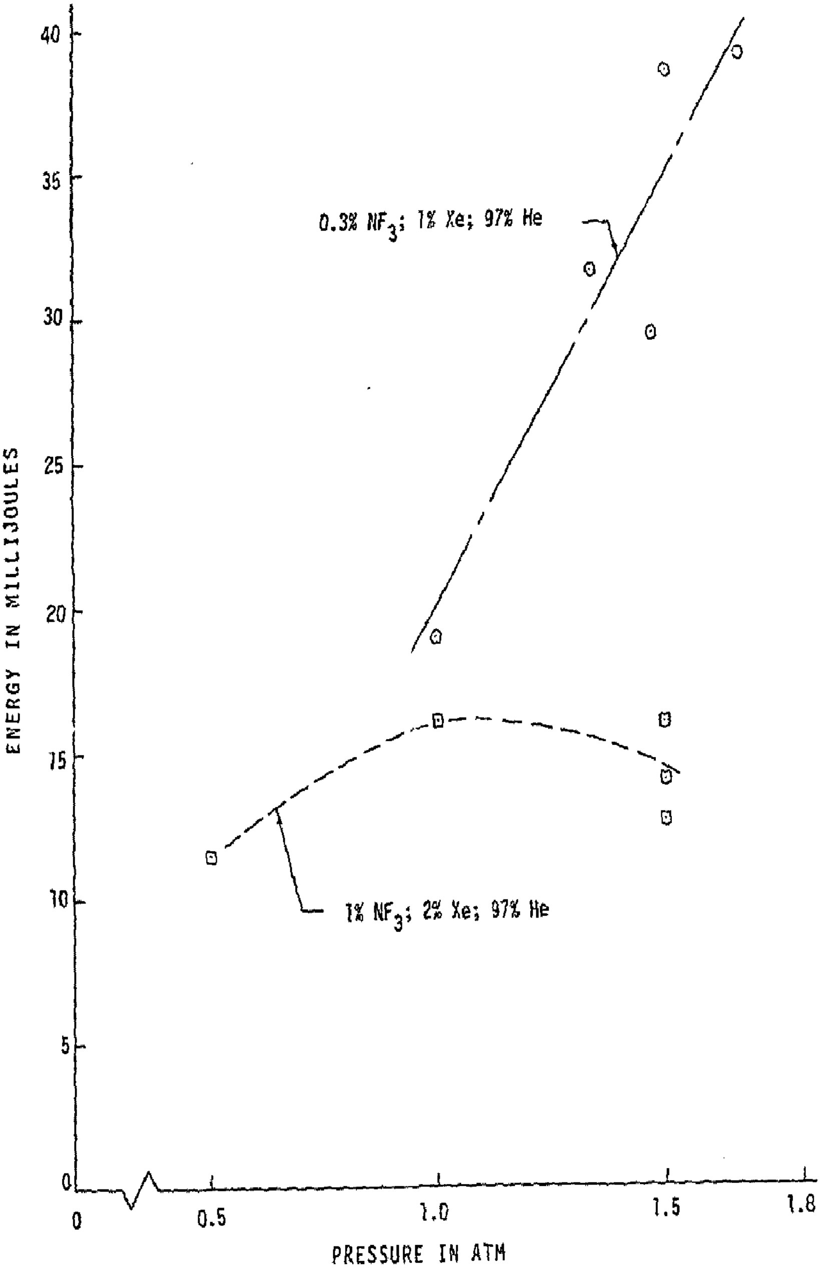

Figure 11. XeF Laser Energy Vs. Pressure in E-Beam Preionized Discharge

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3.3 Gas Degradation Experiments

Because of the importance of gas degradation on the laser performance and its impact on cost for repetitively-pulsed operation, experiments were made to monitor the variation of the laser pulse energy with the number of discharges in a single gas fill. These experiments were performed with the plain electrodes and the resistor array. The repetition frequency in these experiments varied from 0.1 Hz to 2 Hz.

Some results for both the self-sustained and the e-beam ionized discharge are shown in Figure 12 using the solid electrodes. The data in Figure 12 were obtained at 1 atm pressure and 30 kV applied voltage in 0.3% NF_3-1% Xe dilute in He. The entire system was carefully passivated with F_2 prior to these experiments. The results are very encouraging since they indicate over 50 discharge pulses to degrade the performance by a factor of 2 and are comparable with the best data obtained in KrF. There is some indication from the data that wall effects are still present since the laser output seems to decrease with the repetition frequency.

The e-beam data is quite pessimistic in comparison with the self-sustained discharge data and the difference is not understood at present. However, one possible cause for the rapid degradation of the gas with e-beam ionization may be electron bombardment of the insulated surfaces and the possible subsequent evolution of gaseous impurities. It would be useful to repeat these experiments with UV preionization.

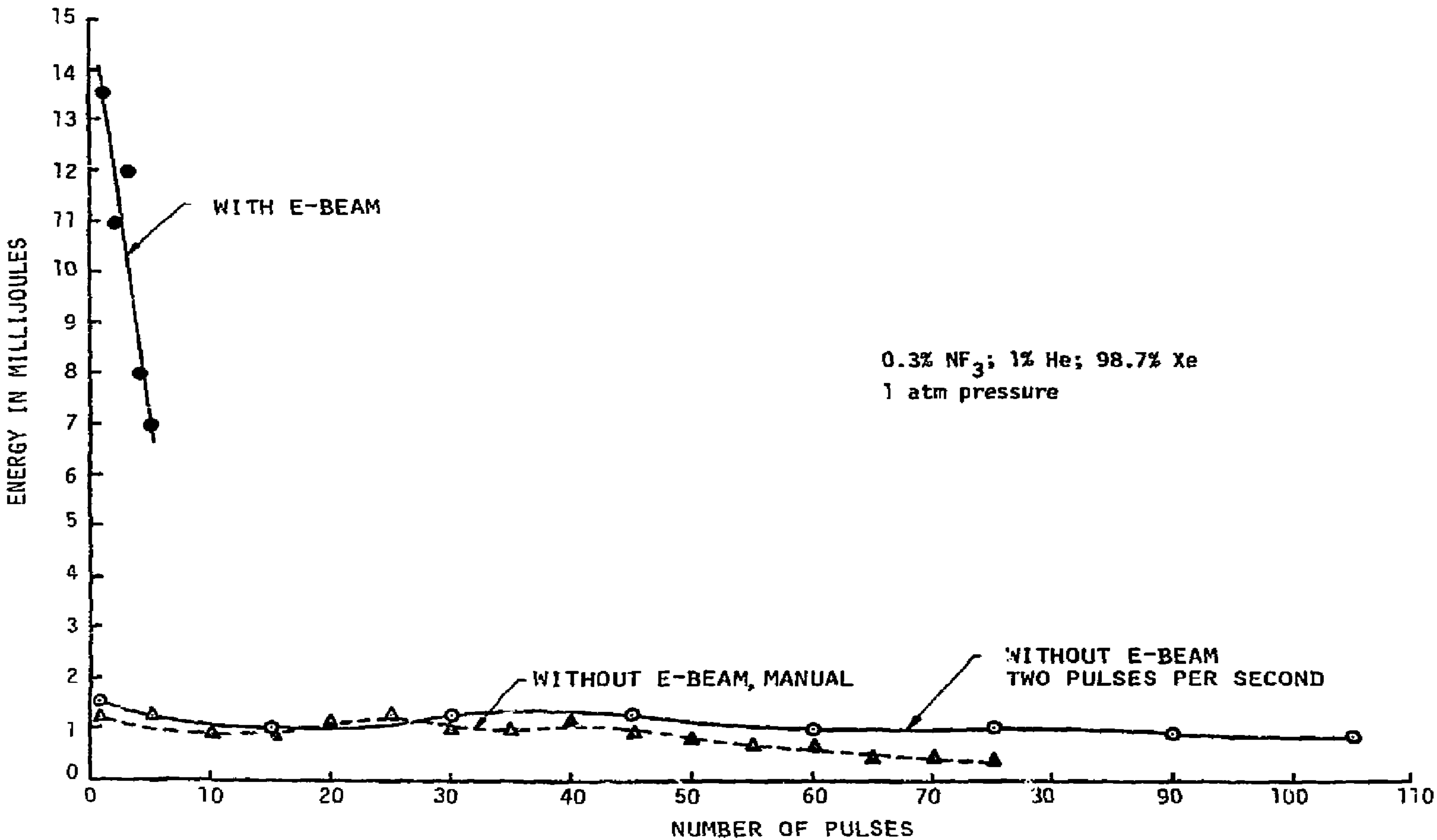

Figure 12. XeF Laser Energy Variation with Number of Discharge Pulses

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REFERENCES

1. J. J. Ewing and C. A. Brau, Appl. Phys. Lett. 27, 350 (1975).

2. J. A. Mangano and J. H. Jacob, Appl. Phys. Lett. 27, 495 (1975).

3. M. L. Bhaumik, R. S. Bradford and E. R. Ault, Appl. Phys. Lett. 28, 23 (1976).

4. J. A. Mangano, J. H. Jacob and J. B. Dodge, Appl. Phys. Lett. 29, 426 (1976).

5. Technical Information Statement, Lawrence Livermore Laboratory, August 5, 1976.

6. J. D. Daugherty, J. A. Mangano and J. H. Jacob, Appl. Phys. Lett. 28, 581 (1976).

7. J. Gruber and T. James, Culham Laboratory Report CLM-P 176, March 1968.

8. P. Champney, Physics International Report PIIR-23-76, October 1976.

9. G. N. Glasoe and J. V. Lebacqz, Pulse Generators, Dover Publications.

10. A. J. Schwab, High Voltage Measurement Technique, MIT Press.

11. R. Burnham, F. X. Powell and N. Djeu, Appl. Phys. Lett. 29, 30 (1976).

12. V. Hasson and H. M. von Bergmann, J. Phys. E. 9, 73 (1976).

13. C. P. Wang, H. Mirels, D.G. Sutton and S. N. Suchard, Appl. Phys. Lett. 28, 326 (1976).

14. V. Hasson, J. Brink, H. M. von Bergmann and K. Billman, Paper presented at the 29th Gaseous Electronics Conference, Cleveland, October 1976.

15. E. R. Ault, R. J. Bradford, Jr. and M. L. Bhaumik, Appl. Phys. Lett. 27, 413 (1975).

16. R. Burnham and N. Djeu, in press, Appl. Phys. Lett.

17. R. C. Sze, Private Communication.

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