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An investigation of feasibility of cw or quasi-cw operation of waveguide XeCl excimer lasers is described. Work was conducted under a Phase I SBIR contract.

Double pulse fluorescence recovery measurements were carried out on XeCl laser gas mixtures contained by glass or quartz tubes of submillimeter bore and excited by a pulsed microwave source. Optical gain and loss during and after excitation also was measured using pump-and-probe techniques, and double pulse laser data were collected.

Results of the study indicate that laser kinetic processes will support XeCl waveguide laser operation at duty factors of several percent provided that discharge tubes of sufficiently small bore are utilized.

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FINAL REPORT

AIR FORCE CONTRACT F49620-87-C-0066

"CW EXCIMER LASER"

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Submitted: February 7, 1988

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I. BACKGROUND

The number of potential applications for ultraviolet lasers is arguably larger than for other laser systems operating in the visible or infrared. However, with the exception of frequency multiplied sources, only two types of ultraviolet lasers are available to the scientific community through commercial suppliers. Ion lasers produce continuous emission at wavelengths in the 275 - 350 nm range, and excimer lasers are available to generate high-power short-duration pulses at wavelengths between 351 nm and 193 nm. Although the excimer systems operate with much higher efficiency and span a more interesting range of wavelengths than ion laser sources, current technology is incapable of generating the continuous or quasi-continuous output desirable for many applications. New approaches are needed for efficient generation of cw or quasi-cw coherent radiation at ultraviolet wavelengths.

II. OBJECTIVE

The experiments described below explore the feasibility of constructing cw or quasi-cw excimer systems using an optical waveguide configuration with microwave discharge excitation. Although similar approaches have been used with visible and infrared laser systems little data existed on several issues relevant to excimer laser kinetics, ultraviolet waveguideing and coupling of microwaves to the discharge plasma. The essential uncertainties were:

1. Can halogen donor recombination occur on time scales short enough to allow high duty factor operation?
2. How important are thermal effects?
3. Are there fundamental problems associated with microwave excitation of a very small bore discharge tube?
4. How difficult will it be to fabricate low-loss ultraviolet waveguides?

III. APPROACH

Three types of experiments were carried out:

1. Double pulse fluorescence recovery measurements on XeCl mixtures contained by round quartz tubes of 0.1mm, 0.2 mm and 0.5 mm diameter.

2. Optical gain and loss studies with 0.1 mm and 0.2 mm quartz tubes using pump-and-probe techniques.

3. Double pulse laser emission measurements using a 0.2mm x 2 mm rectangular glass tube.

In the process of conducting these experiments information was also gathered on coupling of microwave power into discharge tubes of small dimension and ultraviolet waveguiding loss in small bore tubes.

IV. APPARATUS

Discharge Tubes

The majority of the kinetics data was gathered using precision bore thin-wall quartz capillary tubing supplied by Polymicro Technologies, Inc. (Phoenix, AZ). As shown in Fig. 1 this tubing is characterized by a tolerance on the internal diameter of ± 6%, a wall thickness of approximately 50 microns and a Kapton overcoat 25 microns thick. The thin wall simplified coupling of the microwave field into the plasma and the Kapton overcoat ruggedized the structure and simplified handling without introducing additional microwave loss. Although these tubes may not have tight enough I.D. tolerances to minimize waveguiding loss they are well-suited to the kinetics measurements undertaken in Phase I.

A rectangular 0.2 mm x 2 mm borosilicate glass tube (Vitro Dynamics, Rockaway, NJ) with internal tolerance of ±10 microns and a 200 micron wall was used in the double pulse laser experiments. Borosilicate glass exhibits modest microwave loss, but is useful for preliminary experiments.

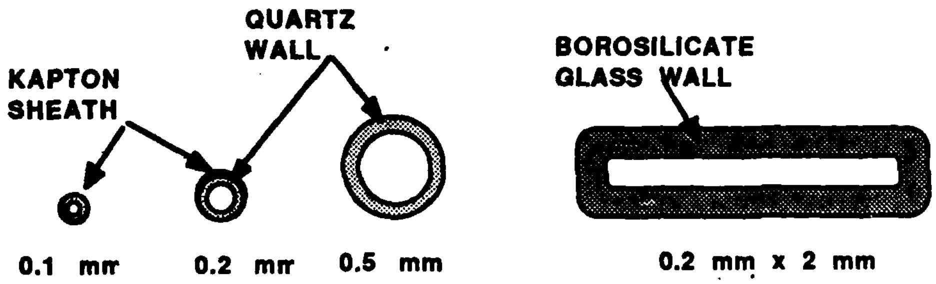


Fig. 1. Cross-sections of discharge tubes used in the waveguide laser experiments. The 0.1 mm and 0.2 mm tubes were encased in a Kapton sheath. All round tubes had a quartz wall, but the rectangular tube had a borosilicate wall.

Tube mounting

All discharge tubes were attached to a rigid aluminum mount using a special mounting fixture. The tubes were placed under tension in an effort to assure straightness, positioned within .001" of the mount and the gap between tube and mount was filled with a small amount of low-viscosity, thermally-setting epoxy. During the mounting process, a HeNe laser beam was guided through the tubes and used to monitor bending of the tube.

The 0.1 mm and 0.2 mm round quartz capillaries were found to be difficult to mount without bending. Surface tension of the epoxy pulled the tube toward the mount in a nonuniform way, and they were observed to be particularly sensitive to thermal distortion of the aluminum mount during the curing process. Larger round tubes and the rectangular tube could be mounted with reasonable straightness using this technique.

Excitation Sources

Excitation of the round discharge tubes was accomplished using a 915 MHz oscillator/amplifier of in-house design. This source could be operated with pulse duration electronically variable between 0.2 and 2 microseconds, peak power in each of its four output channels variable between 0.2 and 5 kW, and at pulse repetition rates limited only by the 200 watt dc power supply. The discharge tube was divided into four 5 cm segments for excitation with each segment driven independently. Fig. 2 shows the microstrip transmission line and slug tuner arrangement used to deliver power to each of the segments. Preionization was achieved by applying a 30 kHz, 1.5 kV sinusoidal voltage to the discharge electrode to produce a pulsed simmer discharge at a 60 kHz pulse repetition rate. To improve pulse-to-pulse uniformity of the microwave discharge the microwave pulse was synchronized to the preionization voltage.

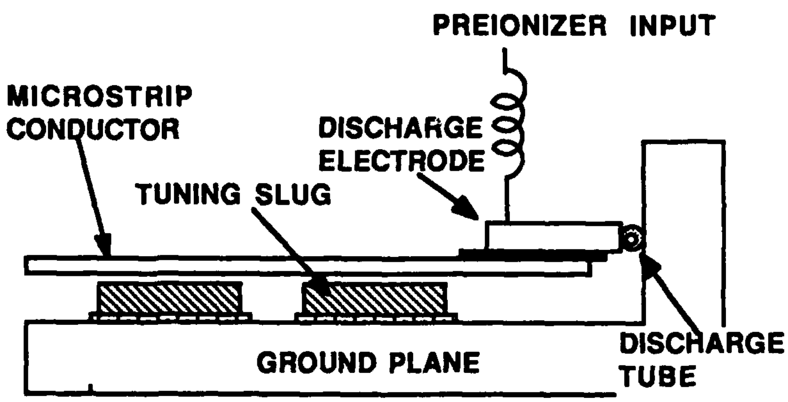


Fig. 2. Discharge configuration used in the segmented 915 MHz amplifier. Microwave power was delivered to the discharge tube by means of a microstrip transmission line. A double slug tuner was used to match the discharge impedance to the 50 ohm generator. The discharge electrode was isolated from the microstrip conductor by a thin Kapton sheet, and a preionization voltage was applied to the electrode through an isolating choke.

Laser data was gathered using a 40 cm rectangular discharge tube segmented into two sections, each driven by a 3.0 GHz magnetron with output power variable between 20 and 50 kW. Pulse duration was electronically variable between 0.2 and 1 microsecond, and pulse repetition rate was limited to 2 kHz.

Probe Laser

A XeCl waveguide probe laser was constructed that was excited by a single 3 GHz magnetron and emitted 200 ns pulses at repetition rates extending to 100 Hz. Three to five microjoules were available from this device in a 0.2 mm x 1 mm beam. Transverse mode shape was best described as a near-diffraction-limited central spot with several weaker side lobes in the plane of the small dimension. Simple spatial filtering produced a beam of reasonably good quality that could be used to excite predominantly low order modes in all of the waveguides used. Electronic timing circuits were constructed to allow synchronization of the probe laser with the 915 MHz generator.

Gases

All experiments were conducted using He/Xe/HCl = 1000/10/1 gas mixtures prepared using a passivated manifold, stored in a stainless steel tank, and delivered to the discharge heads through stainless steel transport lines.

V. EXPERIMENTAL RESULTS AND DISCUSSION

Coupling Of Microwave Power Into A Small Diameter Discharge

Microwave power delivered to the discharge region was monitored through the use of directional couplers, and double slug tuners were used with each discharge section to reduce the reflected power to a small fraction of the incident level. Typical examples of the incident and reflected 915 MHz waves sampled by the couplers are sketched in Fig. 3. Using the approach of Brown[1] the power actually deposited into the discharge plasma can be compared with dissipated in parasitic losses of the discharge structure by observing the microwave reflection coefficient of the structure with the discharge ignited and with the discharge off. When power is very efficiently delivered to the discharge plasma, the reflection coefficient with the discharge off is large, and the efficiency of delivery can be determined using high-directivity couplers or VSWR measurements. When the efficiency of delivery is low there is little change in the reflection coefficient between discharge-on and the discharge-off conditions and the efficiency of power transfer to the plasma can be estimated by minimizing the reflection coefficient with the discharge ignited and then observing the reflection coefficient with the discharge off.

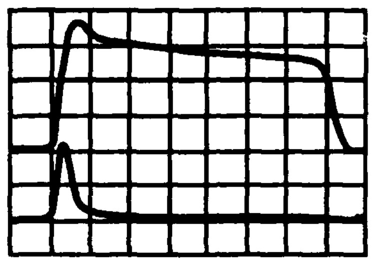


Fig. 3. Typical oscilloscope traces of 915 MHz waves incident upon (upper) and reflected from (lower) one section of the discharge tube. Horizontal scale is 200 nanoseconds/div. Note that some mismatch is observed during the initial breakdown, but very good impedance matching is achieved during the majority of the pulse.

The discharge structure used in these experiments was designed for use with discharge tubes of 0.5 mm bore. With these tubes we have found the efficiency of power delivery to the plasma to typically lie in the range 85 - 95%. At a fixed excitation level the impedance of the plasma presented to the discharge electrode is independent of tube diameter, so that one might expect the efficiency of power delivery to the plasma also to be independent of tube diameter. Our experiments showed, however, that only about 40% of the microwave power was delivered to the plasma contained by a 0.2 mm tube and only about 10% was delivered to the plasma in 0.1 mm bore tube.

Reduction in power transfer efficiency with small bore tubes can be attributed to two factors: (a) the increased role of fringing fields, and (b) higher losses in adhesives used to bond the tube to the ground plane. Fig. 4 is a scale drawing of the discharge electrodes, discharge tube, and bonding epoxy used with a 0.1 mm and 0.5 mm tubes. It can be seen that problems associated with shaping and positioning the electrodes used with small diameter tubes can reduce the fraction of electrode displacement current that actually passes through the plasma. With our current bonding procedures the volumetric ratio of lossy bonding material to discharge plasma increases with small bore tubes due to surface tension of the adhesive. These facts together imply that parasitic losses are higher with small bore tubes in our discharge structure and that higher electrode currents (with higher associated circuit losses) must be used to achieve a given level of excitation. We expect that power transfer efficiencies of 85 - 95% can be achieved with small bore tubes provided that the electrode structure and bonding techniques are suitably modified.

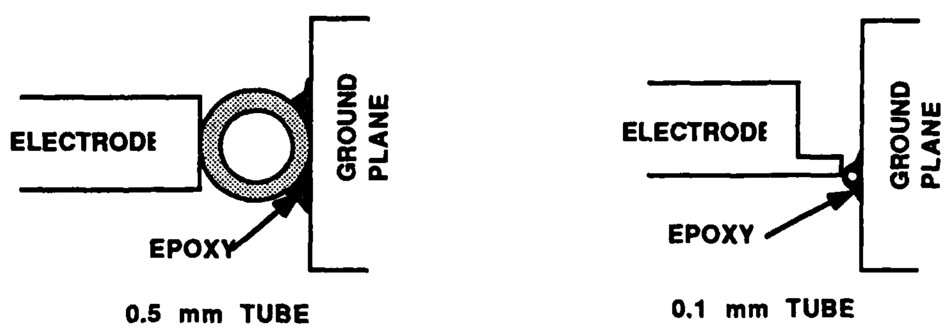


Fig. 4. Small bore tubes place severe constraints on positioning of the discharge electrodes and tube bonding techniques. Bonding epoxy exhibits microwave loss and very small amounts must be used to achieve efficient power transfer to the plasma. Misalignment of electrodes can remove the tube from the high field region, and allow dissipation of available power in other parts of the discharge structure.

Double Pulse Fluorescence

Kin..ics studies of excimer laser systems benefit from the fact that the lower laser state is very weakly bound so that fluorescence of the laser transition is proportional to optical gain. Microwave discharge excitation of the laser gas results in UV gain that typically decreases after a few hundred nanoseconds as can be seen by observing the discharge sidelight during long excitation pulses. Fig. 5 demonstrates the temporal dependence of UV gain under various excitation conditions. The peak gain increases with excitation level, but the duration of high gain simultaneously decreases. The decrease in gain during long-duration excitation places a fundamental limit on laser pulse duration. It is thought to be primarily a result of halogen donor dissociation although other processes may contribute[2].

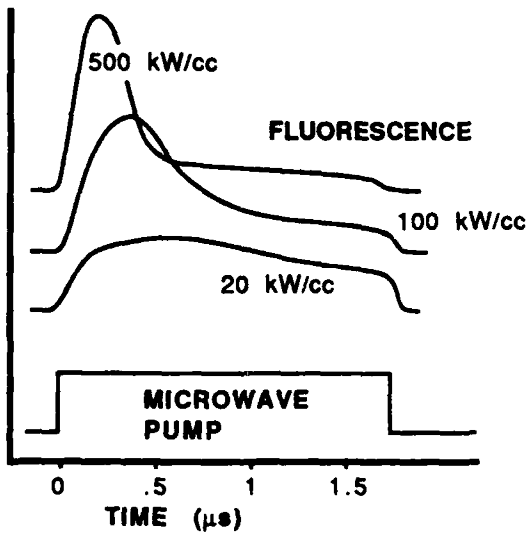


Fig. 5. Qualitative temporal shape of fluorescence and 308 nm gain at selected excitation levels. Peak gain at 20 kW/cc is typically one order of magnitude smaller that peak gain at 500 kW/cc.

The pulse repetition rate of a waveguide excimer laser is also fundamentally limited by halogen donor dissociation and the amount of time required for halogen recombination and other recovery process to occur between excitation pulses. It is therefore important to investigate halogen recombination and other recovery processes as a first step toward evaluating the potential of a waveguide excimer laser for quasi-cw operation. By exciting the medium with two excitation pulses, varying the delay between them, and observing the resulting fluorescence emission the rate at which the medium returns to its unperturbed state after excitation can be determined.

We are not aware of other experimental data on recombination of HCl in XeCl lasers. However, a preliminary estimate of the expected post excitation recovery rate can be obtained by considering only the recombination of HCl via three-body collisions in the bulk gas and diffusion to the tube walls. A theoretical estimate of 2×10^{-32} cm^6/sec for the rate constant for HCl recombination in helium buffer has been given by Soviet researchers[3]. Since the 3-body recombination rate for H and Cl depends on the Cl and H density after excitation as well as the He density some uncertainty always exists in estimates of the bulk recombination rate in the active medium. In the double pulse measurements experimental parameters were adjusted to produce conditions conducive to a high degree of HCl dissociation so that the initial H and Cl densities were approximately equal to the unperturbed HCl density. Under these conditions the bulk recombination rate could be expected to show a quadratic pressure dependence.

Wall recombination should reflect the inverse pressure dependence of the diffusion coefficient. Assuming that recombination at the wall is almost instantaneous, the effective rate for wall recombination is approximately equal to the rate at which the relatively massive Cl atoms diffuse to the wall. This rate can be calculated for various geometries from the diffusion coefficient for Cl atoms in He buffer which we estimate to be 0.5 cm^2/sec-atm.

Comparison of the bulk recombination and diffusion rates allows estimation of the importance of wall processes under various conditions. Fig. 6 shows that in a 100 micron tube wall effects should dominate at pressures below 3.5 atm with bulk recombination becoming important at

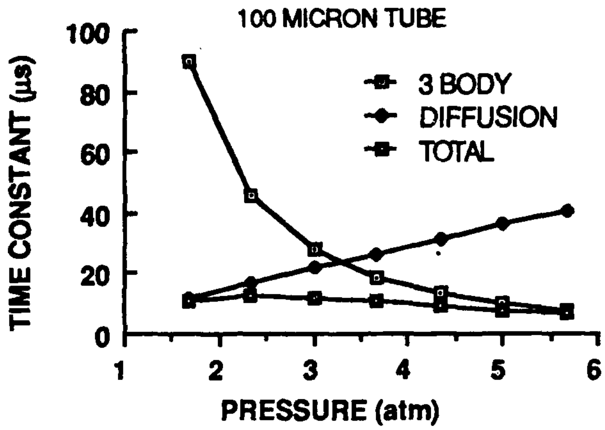


Fig. 6. HCl recombination time constants for He/Xe/HCl = 1000/10/1 mixture in a 100 micron tube. Both 3-body effects and diffusion to the walls are considered. The net time constant shows only a weak pressure dependence.

higher pressures. This figure also indicates that the net time constant for HCl recombination in a 100 micron tube should be approximately 12 microseconds over a fairly broad pressure range. Since the time required for atoms to diffuse to the wall is proportional to the square of the tube diameter, wall effects are expected to be almost negligible in tubes of diameter greater than a few hundred microns.

For the double pulse recovery measurements the discharge plasma was excited with the first pulse at a high level for 1.5 microseconds to produce a fluorescence temporal shape similar to that shown in Fig. 5 for 500 kW/cc excitation, i.e., a sharp peak followed by a low-level "tail". At the end of this initial excitation pulse gain had fallen to a low level, and a high degree of HCl dissociation could be expected. After a variable delay a second, a nearly identical microwave pulse was applied (see Fig. 7), and the amplitude of the second fluorescence peak was measured. The change in fluorescence between the end of the first pulse and the beginning of the second provided an indication of the degree to which the medium had recovered its original capability of producing optical gain.

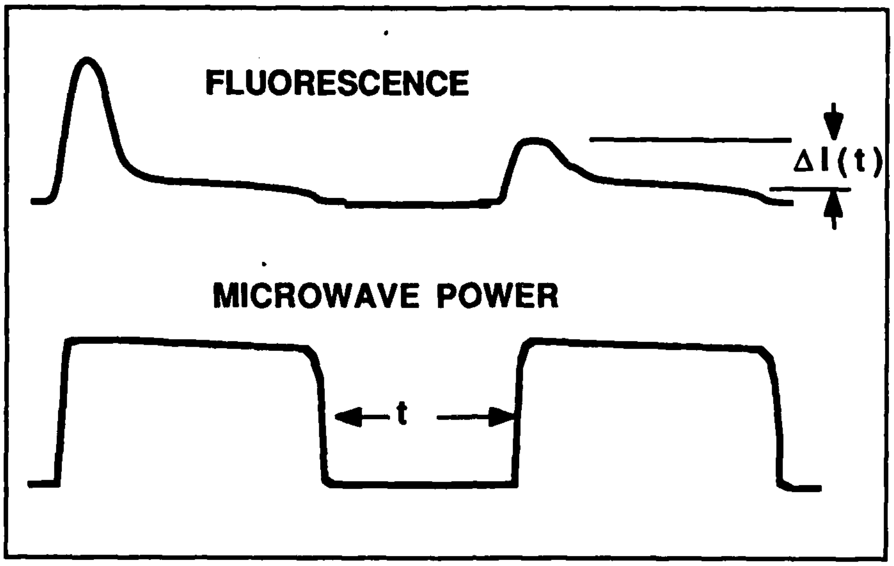


Fig. 7. Typical excitation and fluorescence pulses in the double pulse fluorescence experiments. The change in the peak fluorescence of the second pulse, ΔI, was used as a diagnostic of gain recovery.

Figures 8(a) - (c) compare measured fluorescence recovery data with theoretical estimates for tubes 100, 200, and 500 microns in diameter at a pressure of 20 psig. The theoretical estimates in these figures assume that fluorescence is proportional to halogen donor density and include only bulk and wall recombination processes. As can be seen there is very good agreement between the simple theory and experimental data for all three tubes. For the 100 micron tube recovery is characterized by a time constant of 12 microseconds. The data show that even if the halogen donor population is fully depleted during excitation there is sufficient recovery after only 10 microseconds to provide 50% of the initial gain in a subsequent pulse.

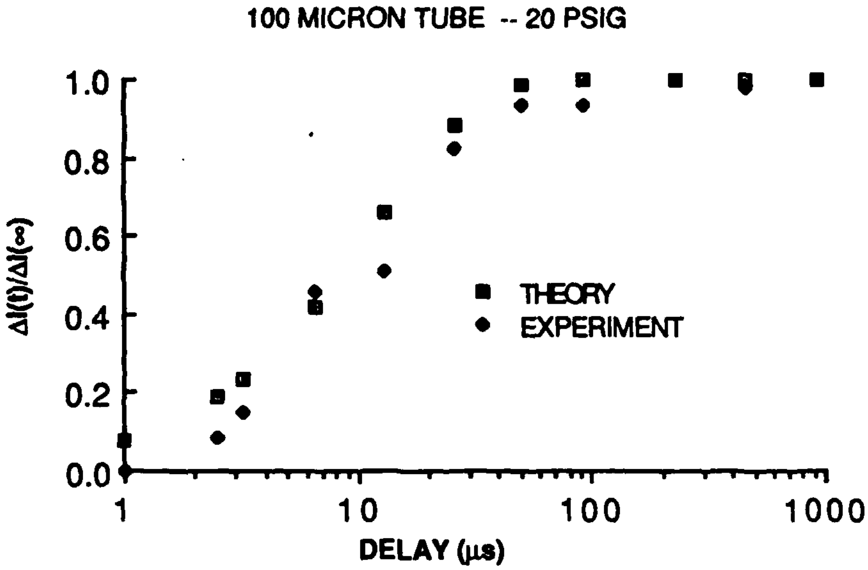


Fig. 8(a). XeCl fluorescence recovery for a discharge tube of 100 micron bore at 20 psig.

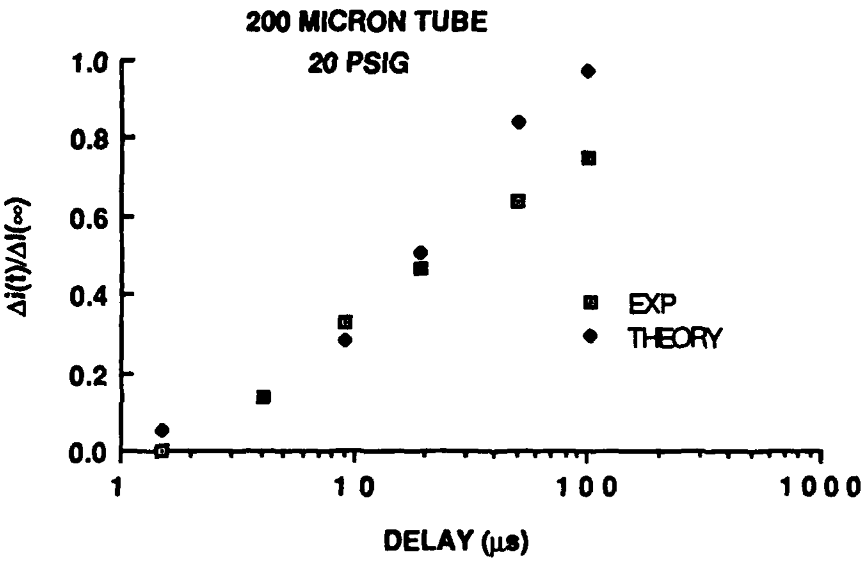


Fig. 8(b). XeCl fluorescence recovery for a 200 micron tube at 20 psig.

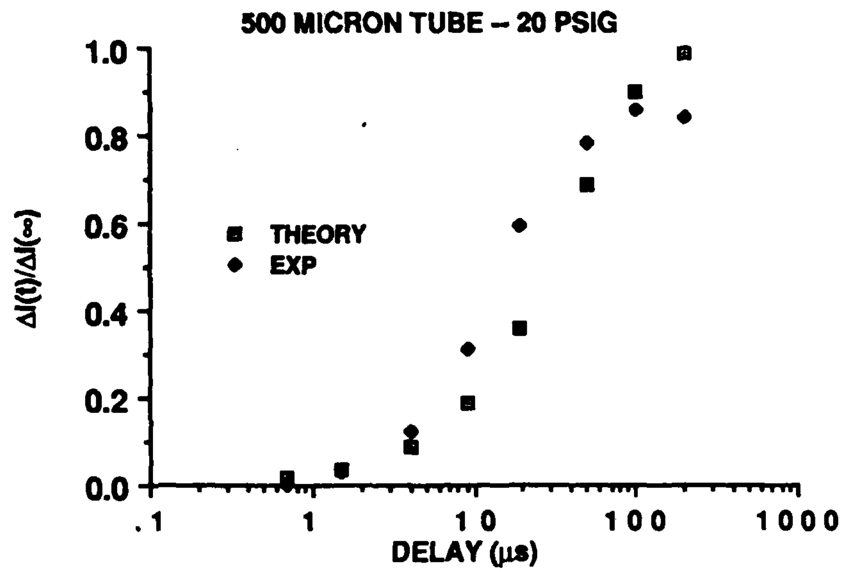


Fig. 8(c). XeCl fluorescence recovery for a 500 micron tube at 20 psig.

Bulk recombination rates were fast enough to make wall effects relatively unimportant in all but the 100 micron tube. Consequently, fluorescence recovery rates do not vary dramatically among the three tubes. Thermal distortion processes show a much stronger dependence on tube diameter as will be seen in the following section.

Pump - Probe Gain Measurements

Taken alone the sidelight fluorescence studies suggest that useful optical gain may exist for several microseconds at reduced pump levels, and that recovery of the medium after excitation is very rapid. However, prior experiments have suggested that distortion of the optical quality of the active medium occurs after excitation and may ultimately impose limits on pulse repetition rate and pulse duration. To explore loss processes associated with discharge excitation the probe oscillator described above was directed through the waveguide during and after the discharge to monitor changes in net optical gain and optical distortion. The oscillator beam was approximately matched to the waveguides using an antireflection-coated quartz lens of 10 cm focal length.

Figure 9 shows single pass gain and loss produced in a 200 micron tube at pump power levels both above and below those normally used for laser excitation. The 1.8 microsecond period of excitation was somewhat longer than the 0.4 microsecond pulse duration typically used for laser excitation and tended to accentuate cumulative loss processes. Although the fluorescence similar to that shown in Fig. 5 suggested that measurable gain should be observed in the latter part of the excitation pulse, the probe beam is amplified only in the initial part of the excitation pulse and experiences loss in the latter part. This loss persists for a few tens of microseconds, disappearing on time scales corresponding to diffusion or cooling effects.

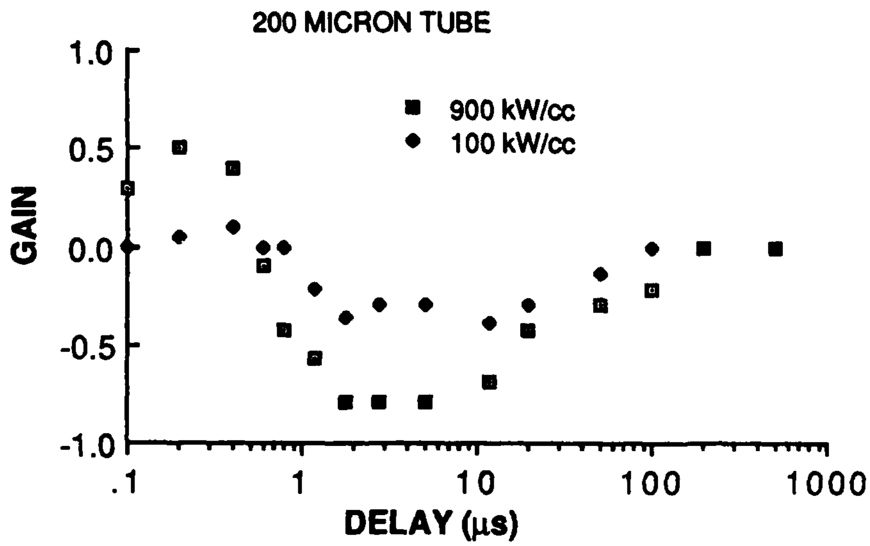
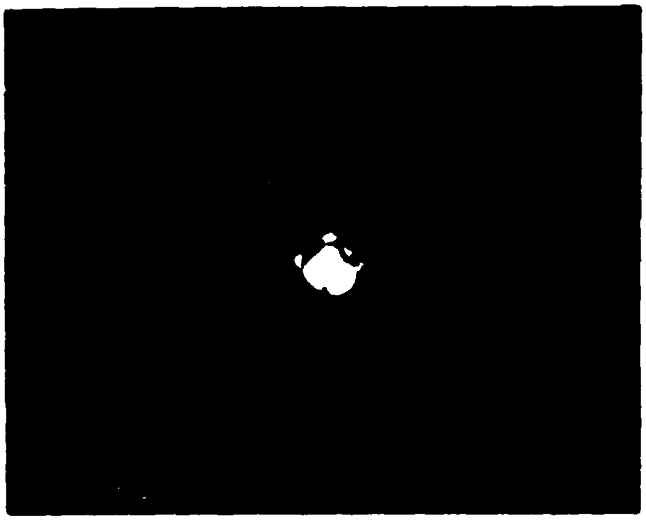


Fig. 9. Single pass gain -- $(P_{out} - P_{in})/P_{in}$ -- experienced by a 308 nm probe beam guided through a 200 micron discharge tube at various times during and after the discharge. The discharge gas at 40 psig was excited excited by a 1.8 microsecond, 915 MHz pulse at power levels of 900 kW/cc and 100 kW/cc. Probe delay was measured relative to the time of discharge initiation.

The transient loss experienced by the probe can be correlated with severe optical distortion of the probe beam emerging from the waveguide. Fig. 10 shows photographs of the probe beam transmitted through a 200 micron discharge tube at a time corresponding to the end of the 1.8 microsecond microwave pulse. Application of microwave power is seen to produce a substantial increase in the small scale structure and divergence of the probe beam. Since optical rays travelling at large angles of incidence to the tube walls experience high loss, optical distortion that produces output beams of increased divergence should also be expected to increase transmission losses.



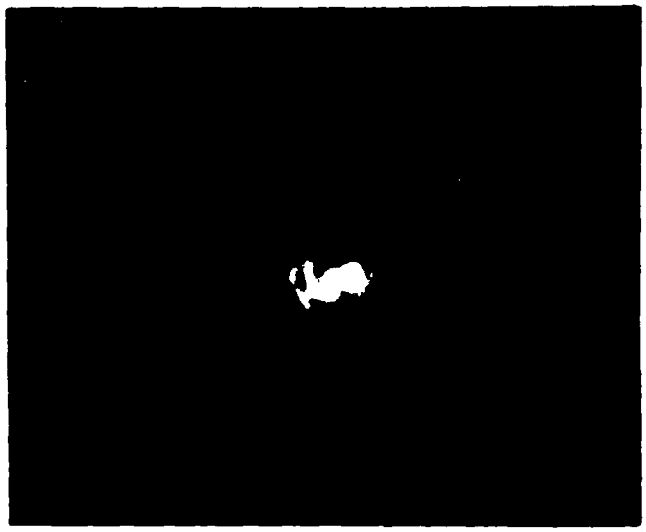
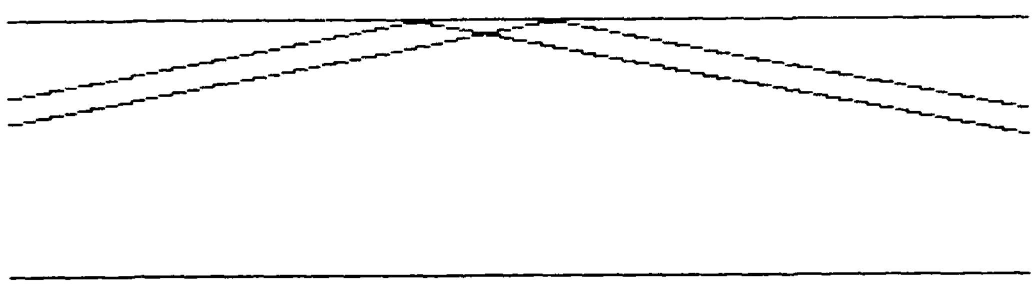
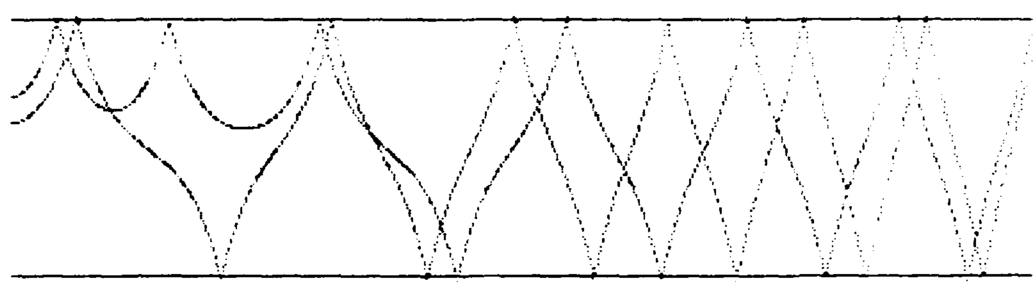


Fig. 10. Transverse structure of the probe beam after transmission through a 200 micron discharge tube operated at a pressure of 40 psig at a delay time corresponding to the end of a 1.8 microsecond microwave pulse. Left- no excitation. Right- microwave excitation at approximately 900 kW/cc.

Optical distortion induced by the discharge can be produced by thermal effects that generate transverse density gradients in the laser gas mixture or by gradients in the density of various species like HCl, H, Cl, or ions induced by the discharge plasma. We have found that thermal effects alone are adequate to produce significant distortion. A simple ray tracing computer program has been developed to model optical propagation inside a hollow tube filled with a medium that exhibits a parabolic index variation in the transverse dimension. This model is an extension of an approach used by Tien, et. al. [4] to study beam propagation in gas lenses. The program assumes a parabolic temperature profile in the tube and computes transverse gradients in the gas density given the microwave energy deposition. It then begins with an input beam with divergence determined by the tube bore and uses the paraxial ray equation to plot ray paths on the screen of a Macintosh computer. Figure 11 demonstrates the perturbations in ray propagation in a 200 micron tube that can be expected after microwave excitation at a level of 100 kW/cm^3 for a period of 500 nanoseconds. This level of excitation would produce optical gain of about 1% per centimeter in XeCl. At lower excitation levels optical distortion builds up more slowly, and density gradients produce a smaller effect in configurations in which rays propagate at a high angle to the optical axis.



(a) No excitation



(b) 600 ns, 900 kW/cm^3 pump.

Fig. 11. Distortion of guided 308 nm rays in a hollow planar waveguide filled with helium. Horizontal lines correspond to top and bottom waveguide surfaces.

In high-repetition-rate operation optical distortion is expected to produce increased loss when the pulse repetition rate substantially exceeds the cooling rate of the laser gas. Very rapid cooling rates can be achieved with small bore tubes, however. Fig. 12 shows optical transmission of the probe beam through a 100 micron tube as a function of delay after excitation. Data was collected for both single pass and double pass configurations. For the double pass arrangement a dielectric mirror was placed 3 mm from the tube end and aligned for maximum transmission. Onset of measurable loss occurred somewhat earlier in the two-pass configuration, probably due to the strong influence that beam divergence has upon the mirror-tube coupling loss.

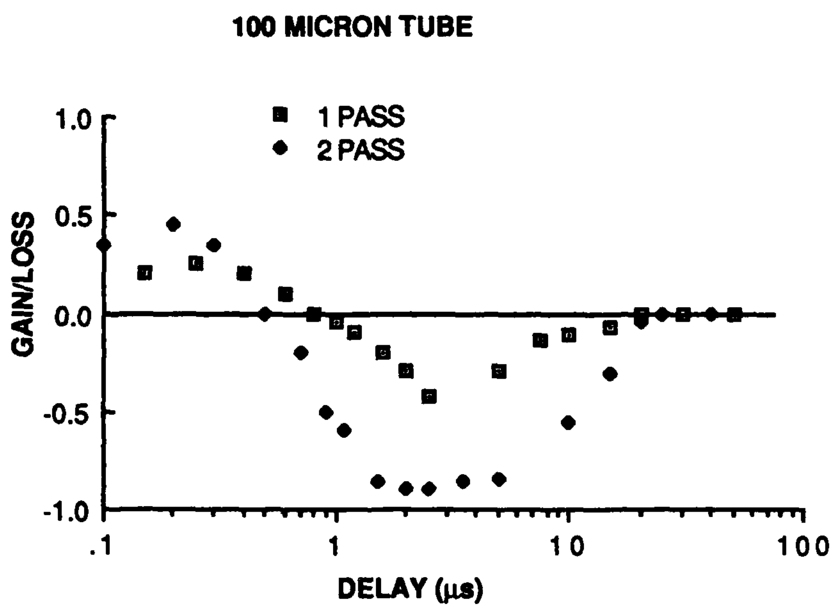


Fig. 12. Gain and loss experienced by the probe beam passing through a 100 micron discharge tube with 40 psig of laser gas excited at approximately 400 kW/cm^3 for a period of 1.8 microseconds. Probe delay is measured relative to the onset of excitation.

Recovery of optical homogeneity was observed on time scales of 10 - 20 microseconds in the 100 micron tube. This is significantly faster than the observed rates for the 200 micron tube and

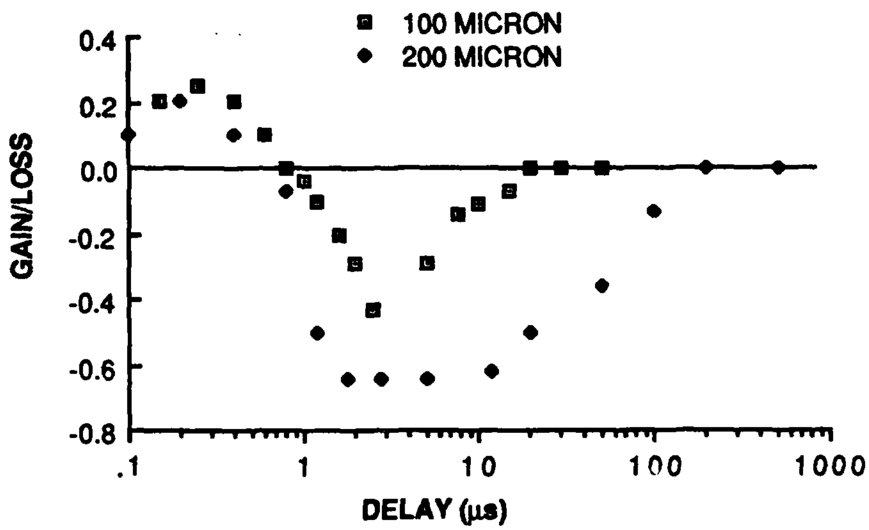


Fig. 13. Comparison of gain and loss experienced by the probe in a single pass through tubes of 100 micron and 200 micron diameter excited at approximately 400 kW/cm^3 for a period of 1.8 microseconds.

reflects the four-fold increase in diffusion and cooling rates in the smaller tube. Fig. 13 directly compares gain and loss observed with the 100 micron and 200 micron tubes under similar excitation conditions.

Laser Experiments

To further explore the XeCl recovery kinetics relevant to high duty factor operation double pulse laser experiments were carried out using an oscillator cavity with two identical gain sections like that sketched in Fig. 14. The 40 cm rectangular discharge tube was characterized by a 0.2 mm x 2 mm bore and each of the two sections was excited by a 3.0 GHz magnetron. Using high reflectivity mirrors, each section could provide about 3 times the optical gain required to reach threshold. A delay generator was inserted into the control circuitry to allow one section to be fired after the other with a variable time delay.

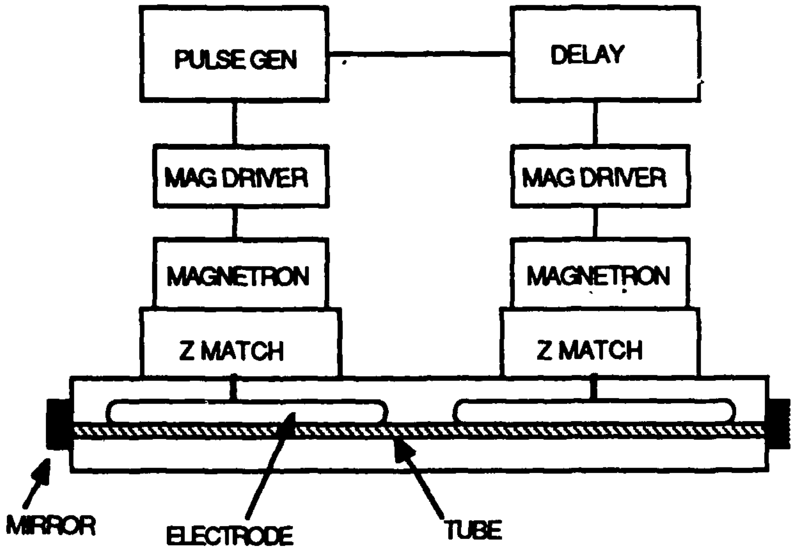


Fig. 14. A two-section XeCl laser using a 0.2 x 2 mm discharge tube and excited by dual 3 GHz magnetrons.

Amplitude of the second laser pulse was observed as a function of delay between pulses, and the results are plotted in Fig. 15. Since only the first pulse was properly synchronized with the 30 kHz preionizer voltage, some variation in the second pulse amplitude was found to be related to improper preionization.

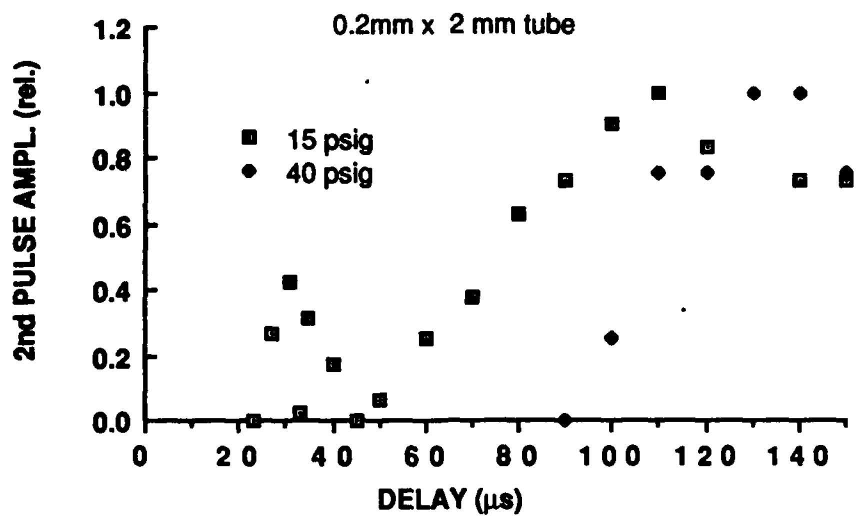


Fig. 15. Double pulse excitation of the two-segment laser. Amplitude of the second pulse showed the effect of asynchronism with the preionizer as well as recovery of the gain medium.

These experiments revealed recovery rates for the laser medium that are reasonably consistent with those obtained from the amplifier experiments. Substantially faster recovery was observed at lower operating pressure again suggesting that an important role is played by diffusion and cooling processes. The data suggest that repetition rates of 10 - 20 kHz should be achievable with a tube of these dimensions.

Estimates of Waveguide Loss.

There are three major contributions to intracavity loss in ultraviolet waveguide devices: (a) waveguiding losses associated with the cold discharge tube, (b) losses introduced by the discharge, and (c) mirror coupling losses. Waveguiding losses in the unexcited tube and mirror coupling losses are difficult to measure directly since they are typically fairly small and strongly depend upon the nature of the propagating modes. These losses typically must be inferred from laser operating parameters.

Laser experiments were attempted with the 200 micron round capillary tubes used in the fluorescence measurements. Although oscillation was achieved and the device could be operated at pulse repetition rates of several kilohertz, there immediately was evidence of high optical cavity loss. This laser required pump levels of the order of 1 MW/cm^3 to reach threshold -- several times that of the rectangular tube 3 GHz laser above. The laser output pulse duration, less than 200 nanoseconds, was relatively short and also suggested the presence of high cavity loss. Attempts to directly measure waveguiding loss yielded an estimate of 40% per pass.

The source of optical loss in the round discharge tubes has not been identified. Examination of the tubes under an optical microscope did not reveal evidence of inner wall roughness. Possible explanations are that the tube bending losses were excessive due to mounting difficulties previously described or that the inner bore diameter varies rapidly along the tube length.

Intracavity loss for the 3 GHz, 40 cm laser with 200 micron x 2 mm discharge tube could be estimated from the gain provided by the discharge at threshold early in the excitation pulse. Relative levels of gain at threshold were measured by observing the sidelight fluorescence. A calibration factor relating gain to fluorescence was then determined by observing fluorescence at threshold under with two different output couplers -- a 60% transmitting flat and a 3% transmitting flat. A 1 meter total reflector was used in conjunction with the two couplers to produce a stable resonator mode in the unguided, 2 mm, dimension. Intracavity losses under lasing conditions were estimated at 8% per pass. These losses should be dominated by waveguiding and mirror coupling losses for the 0.2mm x 2 mm tube and absorption by xenon excited states and other species in the discharge. Absorption by excited species is expected to be of the order of 4% per pass[5], although this estimate is necessarily crude. This leaves about 4% per pass for waveguiding and cavity losses. To compare this measurement with theoretical estimates we have used the analysis of Degnan[6] to calculate coupling losses for the laser mirrors. At a spacing of 3 mm from the end of the tube each mirror introduces a coupling loss of 1.1% for the lowest order transverse mode. Waveguiding losses for the lowest order mode in a perfect planar waveguide of 0.2 mm cross section can be shown to be 1.9% per pass[7]. .Thus for ideal conditions in a cold cavity single pass losses of 3.0% per pass might be expected.

The accuracy of these measurements leaves something to be desired, but it appears that waveguiding losses are not far from theoretical estimates in this tube. This measured low loss demonstrates that ultraviolet waveguides of small bore can be constructed, and can be constructed with fairly simple techniques. The fact that reasonably low waveguiding losses can be achieved with simple redrawn glass tubing could have significant implications for excimer waveguide fabrication.

VI. CONCLUSIONS

The experiments carried out under Phase I show that unique and useful laser sources with a new range of operating characteristics can be constructed by extending current waveguide excimer technology. Waveguide excimer devices are particularly well suited to operation with relatively long pulse durations and ultrahigh pulse repetition rates. This combination of parameters can be accomplished with a simple structure requiring little or no gas flow and with the extended shelf and operating lifetime associated with all-ceramic construction. Waveguide excimer technology clearly offers the most promising current approach to efficient generation of quasi-cw ultraviolet radiation.

Gain Recovery.

The Phase I effort has demonstrated that both halogen donor recombination and thermal processes influence laser recovery kinetics, but that both effects are quite predictable. Recovery of optical homogeneity of the active medium is strongly influenced by the dimensions of the discharge tube, and extremely fast recovery can be achieved with tubes of small dimension. Halogen donor recombination is found to occur on time scales comparable to that of index recovery, and wall recombination begins to play an increasingly important role in tubes with bores with bores of less than 100 microns.

Pulse Repetition Rate.

Prior experiments[2] have shown that pulse repetition rates of 8 kHz can be achieved with 500 micron discharge tubes. Recovery data collected in Phase I suggests that repetition rates of tens of kilohertz are achievable with 200 micron tubes and that repetition rates of 50 to 100 kHz should be possible with 100 micron tubes. The ultimate limit on pulse repetition rate will be imposed by waveguiding losses associated with very small waveguide bores. This in turn will be a function of fabrication materials and techniques. One can envision hollow uv waveguides with multilayered reflecting walls that could exhibit low loss at very small bore dimensions. With simple quartz guides losses are manageable for bore diameters down to about 50 microns. Consequently, repetition rates of several hundred kilohertz seem possible without use of complicated waveguide designs.

Optical Pulse Duration

Fluorescence data collected in Phase I showed that the excimer gas can produce useful gain for periods of several microseconds. However, optical distortion limits the net optical gain of the waveguide to periods of about 1 microsecond. Longer gain duration could be achieved in guides in which diffusion and cooling time constants are of the order of a microsecond or less. This would require guide dimensions of 15 to 20 microns. We think that discharge excitation of tubes this size could be accomplished, but special waveguide configurations with highly reflecting walls would be required to reduce waveguide losses to a useful level. Consequently, although cw operation may not be impossible, the simpler problem of ultrahigh-repetition-rate operation probably should be addressed first.

Intracavity Losses With Small Bore Tubes

Intracavity losses measured in Phase I for the 200 micron rectangular bore tube showed that, at least for these dimensions, waveguides formed from redrawn tubing can provide reasonably low optical loss in the ultraviolet. These experiments also emphasized the importance of mirror coupling losses for waveguides of small bore. For waveguide bores smaller than 100 microns the required mirror/waveguide separation for large curvature mirrors will become extremely small, and alternate mirror configurations[6] will be required to minimize coupling loss.

VII. REFERENCES

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