AD-A151 384 RF DISCHARGE LASER STUDIES(U) POTOMAC RESEARCH INC ALEXANDRIA VA C P CHRISTENSEN 02 JUN 83 N00014-83-C-2022 1/1

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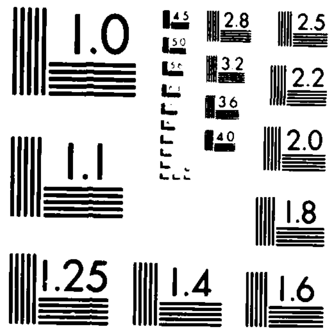

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POTOMAC PHOTONICS
P.O. BOX 4413
ALEXANDRIA, VA 22303

December 31,1982

Dr. N. Djeu
Code 6540
Naval Research Laboratory
Washington, DC 20375

REFERENCE: Monthly Progress and Status of Funds Report for NRL Contract N00014-83-C-2022, "RF Discharge Laser Studies".

Dear Dr. Djeu:

During the period 15 November 1982 - 14 December 1982 contract effort was primarily directed toward investigation of RF field penetration into a high-density, collisional plasma. This work was both experimental and theoretical.

Experimental. We have constructed an optical system which allows measurement of radial distribution of fluorescence in short lengths of glass tubing containing gases excited by our X-band microwave system. High spatial resolution (about 0.1 mm) has been demonstrated and use of a monochromator/OMA also allows good spectral resolution. The system has been used to investigate the temporal and spatial development of discharges in a 4mm diameter pyrex tube. Pure helium and XeF laser mixtures were used. The results of these measurements can be summarized as follows:

(1) Excitation is uniformly distributed across the tube during the first 50 to 100 nanoseconds abter breakdown.

(2) All spectral lines (neutral, ion, and excimer) show roughly the same time dependence at any fixed radial position.

(3) As the discharge progresses excitation occurrs only in a narrow band near the walls. The width of this band is typically a few tenths of a millimeter at atmospheric pressure but in creases so that the discharge fills the tube at pressures below 10 torr.

During these experiments we have also observed evidence of waveguiding of microwaves along the discharge tube and out of the enclosing waveguide. In addition we find that triggering of the discharge is often easier when the discharge tube is exposed to visible light.

Theoretical. Rough calculations suggest that the pronounced concentration of excitation near the walls which we observe experimentally is probably not due to nonlinear ionization or V-I characteristics of the gas as originally proposed. In an effort to better understand the physics of the discharge plasma we have carried out modelling calculations which begin from first principles (Maxwell's equations, momentum conservation, etc.) and which can be used to describe behavior of the plasma under a variety of discharge conditions. We have also uncovered a fairly large body of literature dealing with microwave/plasma interactions. A one-dimensional model of a plasma between dielectric sheets has revealed a number of interesting features:

(1) In addition to electromagnetic waves we also can excite plasma waves which are essentially hydrodynamic in the ionized medium. These waves have a very short wavelength and are highly damped.

(2) Generation of electron plasma waves produces sheath-like dark spaces near a dielectric surface. These regions are typically only a few microns in width.

(3) With the exception of these dark spaces the one-dimensional model predicts uniform excitation of the bulk of the plasma even when the plasma frequency far exceeds the microwave frequency. This is a result of our plasma being highly collisional.

Travelling wave and waveguiding effects cannot be treated by our 1D model: however, surface wave modes which confine all fields to a region near the dielectric/plasma interface have been observed in several experiments using geometries similar to ours. Although these experiments were carried out using collisionless (low pressure) plasmas similar phenomena may be occurring in our devices. We are currently modelling a plasma/dielectric "sandwich" using a two-dimensional approach which allows treatment of propagation effects.

STATUS OF FUNDS

As of December 14, 1982, approximately $3893 of contract funds have been expended. Remaining funds are $17183.

Yours very truly,

C. Paul Christensen

C. Paul Christensen

Letter on file

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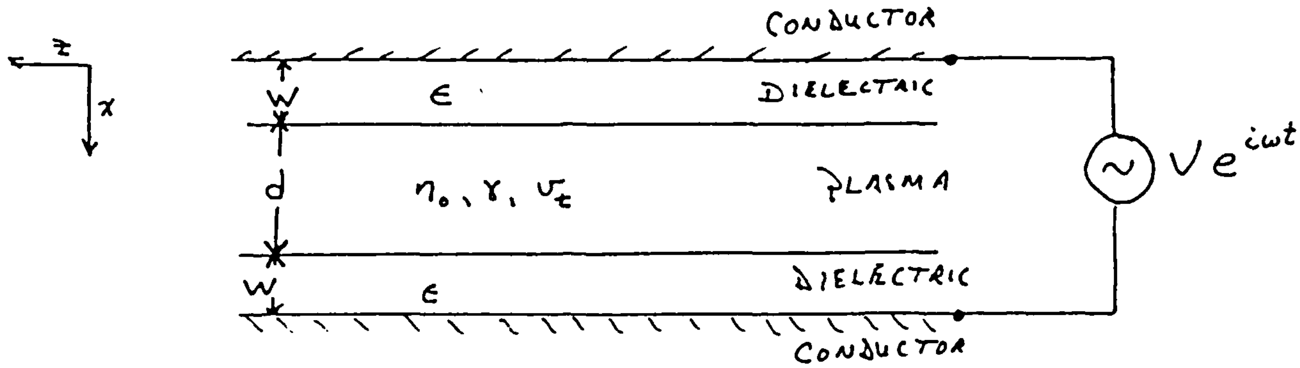
PLASMA FILLED CAPACITOR



ASSUMPTIONS

(1) Spatial variation of all parameters in the z direction is neglected.

(2) Only fields in the x direction are considered.

(3) The plasma is modelled as mobile electrons in a uniform sea of immobile positive ions. The electrons are assumed to have a random thermal velocity, v_t, an unperturbed density, n_o, and to collide with neutral species in the plasma at a rate, γ.

MODEL

With the above assumptions the electric fields and particle densities in the plasma can be modelled (references 1,2,3) using the following three equations:

Particle conservation--

$$\frac{d n_e}{dt} + \nabla \cdot n_e \bar{v}_e = 0 \qquad (1)$$

Momentum conservation--

$$m n_e \left[\frac{\partial \bar{v}_e}{\partial t} + \bar{v}_e \cdot \nabla \bar{v}_e \right] + e n_e \bar{E} + m n_e \bar{v}_e \gamma + m v_t^2 \nabla n_e = 0 \qquad (2)$$

Poisson's Equation--

$$\nabla \cdot \bar{E} = (n_e - n_o) \frac{e}{\epsilon_o} \qquad (3)$$

ELECTROMAGNETIC WAVES

Define $n = n_e - n_0$. It is clear by inspection that a solution of (1), (2), and (3) exists for which n = 0. In this case the medium behaves like a lossy dielectric with dielectric constant, ϵ , and conductivity, σ , given by

$$\epsilon = 1 - \frac{\omega_p^2}{\omega^2 + \gamma^2} \tag{4}$$

$$\sigma = \epsilon_0 \gamma \frac{\omega_p^2}{\omega^2 + \gamma^2} \tag{5}$$

where

$$\omega_p^2 = \frac{n_0 e^2}{m \epsilon_0} \tag{6}$$

PLASMA WAVES

If the electron density is allowed to fluctuate and we assume

$$n_e - n_0 = n \, e^{i(kx + \omega t)}$$

$$E(x) = E \, e^{i(kx + \omega t)}$$

$$v_e(x) = v \, e^{i(kx + \omega t)}$$

equations (1) - (3) become

$$i\omega n + ik n_0 v = 0 \tag{7}$$

$$(i\omega + \gamma) v + \frac{eE}{m} + \frac{v_t^2}{n_0}(ik) n = 0 \tag{8}$$

$$ikE = \frac{ne}{\epsilon_0} \tag{9}$$

These equations have a nonzero solution only if

$$k^2 = \frac{\omega_p^2 - \omega^2 + i\omega\gamma}{v_t^2} \tag{10}$$

The electron drift velocity is found from (7) and (9) to be

$$v = -\frac{i\omega}{\omega_p^2} \cdot \frac{eE}{m} \tag{11}$$

Note that E and v are always out of phase so that no net energy is transferred from the electric field to the electrons even in the presence of collisions. This effectively an acoustic wave in the electron sea.

BOUNDARY CONDITIONS IN THE CAPACITOR

At x = w

$$\epsilon\, E_x(x = w-) = E_x\,(x = w+) \tag{12}$$

$$v\;(x = w) = 0 \tag{13}$$

and similar relationships exist at x = w + d. These boundary conditions are discussed in reference 2, p. 287 and are appropriate for a warm plasma $(v_t^2 > 0)$

FIELDS IN THE CAPACITOR

In the dielectric portions of the capacitor the fields must be spatially invariant, and by symmetry the fields in regions 1 and 2 must be equal. Consequently we assume

$$E = \left[E_+ e^{ikx} + E_- e^{-ikx} + E_c \right] e^{i\omega t} \qquad \text{(plasma)}$$

$$E = E_d\, e^{i\omega t} \qquad \text{(dielectric)}$$

Imposing the boundary conditions gives

$$E_- e^{-ikw} = E_+ e^{ik(w+d)} \qquad (14)$$

$$\epsilon E_d = E_c \left(1 - \frac{\omega_p^2}{i\omega(i\omega+\gamma)} \right) \qquad (15)$$

$$E_+ e^{ikw} = \frac{-\omega_p^2}{i\omega(i\omega+\gamma)} \frac{E_c}{1+e^{ikd}} \qquad (16)$$

VOLTAGE ACROSS THE PLASMA REGION

Integration of electric fields in the plasma along the x direction gives the voltage across the plasma,

$$V_p = E_c \left[d + \frac{2\omega_p^2}{\omega k(i\omega+\gamma)} \tan(kd/2) \right] \qquad (17)$$

Voltage across the entire capacitor can therefore be related to the electromagnetic field amplitude in the plasma by

$$V = E_c \left[\frac{2w}{\epsilon} + d - \frac{2\omega_p^2}{i\omega(i\omega+\gamma)} \left(\frac{2w}{\epsilon} + i\frac{\tan(kd/2)}{k} \right) \right] \qquad (18)$$

ENERGY DEPOSITION IN THE PLASMA

Since all power is deposited in the plasma via electron collisions we can write

$$P = n_0 m |v|^2 \gamma \qquad (19)$$

Power deposition at any point in the plasma can thus be found by using the known fields in (1) - (3) to find electron drift velocities. For simplicity here we consider only plasma regimes appropriate to excimer lasers. In this case electron collisions occur about every picosecond and the electron density is about $10^{14}/cm^3$. For x-band microwave excitation we thus have

$$\gamma = 10^{12}/sec$$
$$\omega_p = 5\times10^{11}/sec$$
$$\omega = 6\times10^{10}/sec$$

Under these conditions (10) shows that plasma waves are damped in about one Debye length, ω_p/v_t, which is just a few microns for electron temperatures of a few eV.

$$k = \beta + i\alpha = \frac{\omega_p}{v_t}\left(1 + \frac{i\omega\gamma}{\omega_p^2}\right)^{1/2}$$
$$\alpha \cong \beta \cong \frac{\omega_p}{v_t}\left(\frac{\omega\gamma}{\omega_p^2}\right)^{1/2} .$$

The spatial distribution of deposited power is found from (19) to be

$$P = \frac{\omega_p^2}{\gamma}\epsilon_0 |V|^2 \frac{\left|1 - e^{(\alpha - i\beta)(x-w-d)} - e^{-(-\alpha+i\beta)(x-w)}\right|^2}{\left(\frac{2w}{\epsilon}+d\right)^2 + \left(\frac{\omega_p^2}{\omega\gamma}\right)^2\left(\frac{4w}{\epsilon}\right)^2} \qquad (20)$$

Except for a dark region near the boundaries excitation of the plasma is spatially uniform. The bulk of the plasma is excited at a level identical to that which would be calculated by modelling it as a lossy dielectric with conductivity given by (5) and dielectric constant = 1.

REFERENCES

1. F. F. Chen, "Introduction to Plasma Physics", Plenum Press(New York, 1974) p. 75.

2. V. Atanassov, J. Plasma Physics 25, 285(1981)

3. D. Lepechinsky and J. Tataronis, J. Appl. Physics 42, 3965(1971)

POTOMAC PHOTONICS

P.O. BOX 4413

ALEXANDRIA, VA 22303

(703) 960-4206

January 25, 1983

Dr. N. Djau
Code 6540
Naval Research Laboratory
Washington, DC 20375

REFERENCE: Monthly Progress and Status of Funds Report for NRL Contract N00014-83-C-2022, "RF Discharge Laser Studies".

Dear Dr. Djeu:

During the period 15 December 1982 - 14 January 1983 contract effort emphasized analysis of RF field penetration into plasma slabs bounded by dielectric sheets. Some of this material was presented at the Conference on Excimer Lasers held January 10 - 12 at Lake Tahoe, Nevada.

TECHNICAL REPORT

The preceding report presented a one-dimensional analysis of wave penetration into a plasma sandwiched between two dielectric sheets. This work has been extended to include two-dimensional travelling wave effects. The results of the analysis suggest that our RF discharge experiments may be complicated by the presence of surface waves at the plasma/dielectric boundary and by the existence of modes of propagation in which the electric field in the plasma is essentially polarized parallel to the direction of propagation. Past experience has shown that this field polarization is not conducive to uniform excitation of the laser medium, although our linearized model cannot show discharge collapse. Our analysis indicates that modes with this polarization cannot exist below a cutoff frequency which depends upon the discharge geometry and the plasma conductivity.

We have also shown that parallel plate transmission line structures can support a TEM-like mode which propagates at all frequencies, and in which the electric fields in the plasma are in the transverse direction. Penetration of the plasma by this lowest order mode should be limited only by skin depth effects.

A detailed description of the approach used in the modeling effort and a summary of pertinent results is attached.

STATUS OF FUNDS

As of January 14, 1983 approximately $8100 of contract funds have been expended. Remaining funds are $12,975.

Yours very truly,

C. Paul Christensen

C. Paul Christensen

POTOMAC PHOTONICS
P.O. BOX 4413
ALEXANDRIA, VA 22303

February 28, 1983

Dr. N. Djeu
Code 6540
Naval Research Laboratory
Washington DC 20375

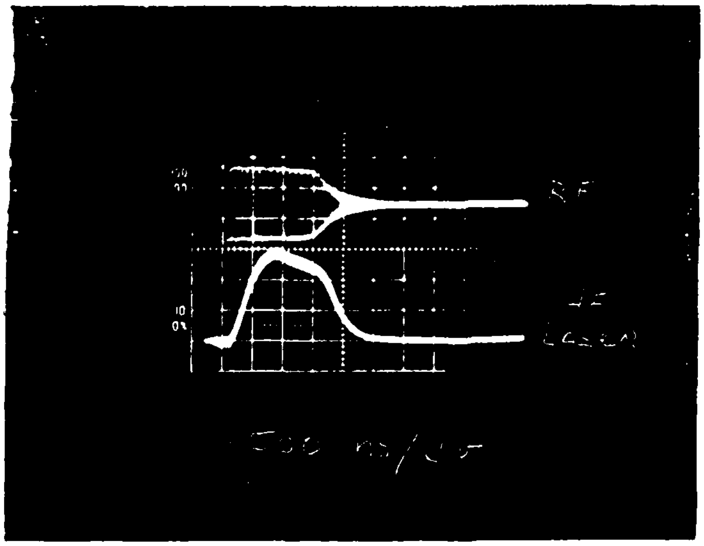
REFERENCE: Monthly Progress and Status of Funds Report for NRL Contract N00014-83-C-2022, 'RF Discharge Laser Studies".

Dear Dr. Djeu:

During the period 15 January 1983 - 14 February 1983 effort on the contract was directed toward fabrication of a laser head for investigation of hydrogen halide transfer lasers using the 200 MHz pump source and reassembly and upgrading of the 1.2 GHz magnetron source.

TECHNICAL REPORT

The laser head used for 200 MHz excitation of XeF has been modified to allow placement of the laser mirrors within a few millimeters of the 1 mm dia. discharge tube. This was done to reduce mirror coupling losses to a negligable level. The impedance matching network has also been changed to allow easier and more repeatable adjustment. An HF chemical laser gas mixture ($He:SF_6:H_2$ = 60:3:1) has been discharged in this device, and laser output has been observed at pressures extending to 1 atmosphere. The attached photograph shows a typical RF excitation pulse and laser output pulse. After a brief characterization of the chemical system we will proceed to investigation of H_2 - HF and H_2 - HCl transfer systems.



Work on the 1.2 GHz magnetron system has included installation of a thyratron to switch the PFN, reconfiguration of the waveguide support structure to allow full isolation of the magnetron from mechanical stresses on the output waveguide, and connection and check-out of oil flow and oil temperature sensors. The new magnetron is ready for test, but the system will be inspected by Irwin Olin (who has responsibility for a large L-band radar at CBD) before turn-on.

STATUS OF FUNDS

As of February 14, 1983 approximately $11,385 of contract funds have been expended. Remaining funds are $9691.

Yours very truly,

C. Paul Christensen

C. Paul Christensen

POTOMAC PHOTONICS
P.O. BOX 4413
ALEXANDRIA, VA 22303

March 28, 1983

Dr. N. Djeu
Code 6540
Naval Research Laboratory
Washington DC 20375

REFERENCE: Monthly Progress and Status of Funds Report for NRL Contract N00014-83-C-2022, "RF Discharge Laser Studies".

Dear Dr. Djeu:

During the period 15 February 1983 - 14 March 1983 project effort has emphasized investigation of nonchemical HF laser excitation using the 200 MHz RF source. Gas mixtures composed of He, H_2, and HF at pressures in the 100 to 700 torr range were used in these experiments. Laser operation has not been achieved although pump levels similar to those used by Osgood, et. al. have been used. Radial uniformity of the discharge fluorescence appears to be relatively good throughout this pressure range. Lack of success in these experiments may be due to HF absorption in about 20% of the discharge tube that remains unexcited, to losses associated with waveguiding in the 1mm Al_2O_3 tube, and to low optical gain. In the coming month techniques for cooling the discharge medium and for reducing the discharge dead space will be explored.

In addition to the above work break-in conditioning of the L-band magnetron has been carried out. The magnetron filiment has been operated at slowly increasing current levels for more than 8 hours with no evidence of difficulty, and the tube is now ready for RF tests.

STATUS OF FUNDS

As of 14 March 1983 approximately $14,600 of contract funds have been expended. Remaining funds are $6476.

Yours very truly,

C. Paul Christensen

C. Paul Christensen

POTOMAC PHOTONICS
P.O. BOX 4413
ALEXANDRIA, VA 22303

May 5, 1983

Dr. N. Djeu
Code 6540
Naval Research Laboratory
Washington, DC 20375

REFERENCE: Monthly Progress and Status of Funds Report for NRL Contract N00014-83-C-2022 "RF Discharge Laser Studies".

Dear Dr. Djeu:

During the period 15 March 1983 - 14 April 1983 contract effort was expended on fabrication of a cooled discharge structure for use with the 200 MHz source and upon RF testing of the high-power magnetron system.

Cooled Discharge Structure. Parts for a discharge structure which can be cooled by chilled vapors or liquids have been fabricated and are ready for assembly. The configuration to be used provides for thermal insulation of the discharge region from the RF feed line and suppression of moisture condensation on the laser windows.

Magnetron Tests. RF testing of the L-band magnetron has been carried out, and more than 2 MW of peak power has been obtained. A waveguide-to stripline transition has been fabricated which is capable of delivering 94% of the magnetron output to a stripline load. A substitution calorimeter which allows direct calibration of RF power monitors also has been constructed.

Generation of full output power by the magnetron requires cathode voltages near 75kV. The tube now arcs at about 50 kV although this level increases slowly as it breaks in. A larger power supply is being installed to allow higher repetition rate operation and faster break-in.

STATUS OF FUNDS

As of 14 April 1983 approximately $19100 of contract funds have been expended. Remaining funds are $1977.

Yours very truly,

C Paul Christensen

C. Paul Christensen

POTOMAC PHOTONICS
P.O. BOX 4413
ALEXANDRIA, VA 22303

June 2, 1983

Dr. N. Djeu
Code 6540
Naval Research Laboratory
Washington, DC 20375

REFERENCE: Monthly Progress and Status of Funds Report for NRL Contract N00014-83-C-2022 "RF Discharge Laser Studies".

Dear Dr. Djeu:

During the period 15 April 1983 - 14 May 1983 contract effort was limited to 53 hours due to early depletion of contract funds. Work was carried out on assembly of a cooled 200 MHz discharge structure and upgrading of the modulator/pulse forming network for the L-band magnetron to allow higher repetition rate operation and faster break-in. The modulator is now capable of 20 pps repetition rates. A diode stack has been installed to reduce reverse voltage backswing on the thyratron, and a larger high voltage supply has been installed. The magnetron now generates 3 MW pulses of 500 ns duration.

Fabrication of all components of the 200 MHz cooled discharge structure has been completed, and this device will be available for test at the beginning of the new contract period.

STATUS OF FUNDS

All contract funds have been expended.

Yours very truly,

C. Paul Christensen

C. Paul Christensen

FINAL TECHNICAL REPORT

NRL Contract: N00014-83-C-2022, "RF Discharge Laser Studies"

Date: June 2, 1983

Submitted by: C. P. Christensen, Potomac Photonics CPC

NRL contract N00014-83-C-2022 comprised a three man-month effort distributed over the period 15 November 1982 - 14 May 1983. Progress was made on several fronts and is summarized below.

High-Power Magnetron Source. A 1.3 GHz magnetron source was assembled and RF tested. This source is now capable of producing 3 MW pulses of 500 ns duration at a 20 Hz repetition rate. A transition suitable for use at high power has been constructed which transfers power from L-band waveguide to a 50 ohm stripline with 94% efficiency. A DC substitution calorimeter using stripline geometry has been fabricated and used to directly measure average RF power. Using this calorimeter directional couplers have been calibrated, and a system for real-time monitoring and display of microwave power delivered to an RF discharge has been assembled. Finally, a 1.3 GHz discharge structure has been designed and is under construction.

Hydrogen Halide Laser Experiments: Using the 200 MHz source experiments have been initiated which will investigate the feasibility of RF excitation of nonchemical hydrogen halide lasers. HF chemical laser operation has been demonstrated in $He/H_2/SF_6$ mixtures with a discharge structure similar to that employed in excimer laser experiments. However, efforts to demonstrate nonchemical laser operation using $He/H_2/HF$ and He/HF mixtures were unsuccessful. In order to increase optical gain in the nonchemical system a cooled discharge head has been fabricated. Testing of the cooled device will be carried out in the next contract period.

Discharge Plasma Modeling. A detailed analysis of the linear interaction of electromagnetic radiation with a uniform plasma confined between two dielectric sheets has been conducted. This analysis suggests that:

1. Both electromagnetic and electron hydrodynamic waves can propagate in the laser discharge plasma.

2. Electron hydrodynamic waves can produce sheath-like effects at the plasma boundaries.

3. In collisional (high-pressure) plasmas electromagnetic wave penetration is typically limited only by the skin effect.

4. Surface waves can exist at the boundaries of both collisional and noncollisional plasmas.

5. "Sandwich" discharge structures (dielectric/plasma/dielectric) can support a number of propagating modes. Some of these modes exhibit electric field configurations which are not expected to produce homogeneous discharges.

Fluorescence Measurements. An optical system was constructed which allowed measurement of radial distribution of fluorescence in short tubes excited by X-band microwaves. High spatial, spectral, and temporal resolution were obtained using a high quality optical system and an OMA. Several neutral and ion lines and excimer bands were studied in XeF laser mixtures and in pure helium. Particular attention was given to the ratio of ion fluorescence to neutral fluorescence and its spatial and temporal variation. British investigators have used this ratio to track large changes in electron density in a pulsed DC discharge. Our measurements, however, reveal little spatial or temporal variation in the relative amplitude of ion lines after breakdown. This observation shows that there are transverse variations in electric field in the discharge plasma. The plasma analysis described in the preceding paragraph has shown that these transverse field variations cannot be explained by the skin effect, and the responsible mechanism has not been identified.

Summary and Conclusions. Work conducted under this contract has resulted in availability of a new high-power RF source, construction of a cooled discharge structure, preliminary hydrogen halide experiments, theoretical analysis of the discharge plasma, and detailed observations of discharge fluorescence. At the end of the contract period the status of NRL RF discharge experiments, from the perspective of this investigator is as follows:

1. For the first time since initiation of RF discharge investigations in 1979 the experiments are not limited by lack of good RF sources. A much larger portion of the experimental effort should now be available for the study of problems associated with the laser media.

2. The mechanisms responsible for transverse inhomogenieties in the discharge are still not well understood. Some fundamental work needs to be done on this problem since it seems to be an important limiting factor in some of the experiments.

3. In addition to excimer, HgBr, and CO_2 several new laser systems have emerged which merit investigation. These include nonchemical hydrogen halides, Ar-Xe, and xenon dimer. If fundamental processes can be understood and controlled the RF discharge may become a broadly applicable excitation technique.

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