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POPULATION INVERSION AND GAIN MEASUREMENTS FOR SOFT X-RAY-LASER DEVELOPMENT IN A MAGNETICALLY CONFINED PLASMA COLUMN

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MASTER

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POPULATION INVERSION AND GAIN MEASUREMENTS FOR SOFT X-RAY-LASER DEVELOPMENT IN A MAGNETICALLY CONFINED PLASMA COLUMN

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ABSTRACT

We present population inversion and gain measurements from an experimental investigation of possibilities to obtain high gain and lasing action in the soft X-ray region. Our approach to soft X-ray-laser development is based on rapid plasma cooling after the laser pulse by radiation losses, leading to fast recombination and collisional cascade into upper excited levels of CVI, for example, while the lower excited levels depopulate rapidly by radiative transitions, thus creating population inversions and gain. A ≈ 0.5 kJ CO_2 laser was focused onto a target of solid carbon or teflon; or CO_2, O_2, Ne gas, and the resulting plasma confined in a 50-90 kG magnetic field. Spectroscopic diagnostics with absolute intensity calibration were used to measure level populations. Population inversions were observed between the 4d and 3d levels in the lithium sequence ions: CIV, OVI, FVII, and NeVIII, and a gain of 0.1 (10%) was estimated for the OVI 4f-3d transition at 520Å. In experiments with a solid carbon target we observe relatively high CVI 182Å emission in the axial direction compared to the transverse direction, which if due to stimulated emission, would correspond to a gain of 4. Extension of these results to potential lasing transitions below 100Å will be discussed.

I. INTRODUCTION

Among the number of promising approaches toward the development of a soft X-ray laser (see Refs. 1-8, also review articles 9 and 10) is the idea of rapidly cooling a multi-Z, high density plasma to create a strongly nonequilibrium (recombination) regime. In such a plasma, rapid three-body recombination of totally stripped ions creates a high density of highly excited hydrogenlike ions. The lower levels are populated by collisional cascading processes and depopulated by radiative (spontaneous) transitions which are particularly fast for the first excited level. In this way a population inversion can occur for levels n=3 and 4 relative to level m=2. Gudzenko et al.,[11,12] who first pointed out the possibility of using a recombining plasma as a medium for lasing action in the X-ray region, suggested cooling the plasma by rapid adiabatic expansion. Irons and Peacock[13] first observed a population inversion in 1974 in hydrogenlike CVI on a transition in the soft X-ray region. The plasma was created by a laser beam interaction with a solid target, and a population inversion was observed during plasma expansion into the vacuum with an estimated single pass gain $G \approx 10^{-5}$. Elton and Dixon[14] in a similar experiment with a carbon target, but with plasma expansion into a gas, observed a population inversion due mainly to a charge exchange process. Bhagavatula and Yaakobi[15] reported a population inversion in H-like AℓXIII using a much more powerful laser. Significant gain in CVI at 182Å was observed by Pert et al.[16,17] during the free expansion of a carbon plasma created by the interaction of a laser beam with a 2-mm long, 4-μm diameter carbon fiber. Of course, in a rapidly recombining plasma a population inversion in the X-ray region can also be obtained in other ions, e.g., in Li-like ions between levels 4f or 5f and 3d, due to the fast radiative decay of level 3d as was pointed out by Silfvast et al.[18,19]

Recently, Jaeglé *et al.*[20] presented evidence for small single pass gain in Li-like AℓXI at 105Å (5f-3d transition). However, the free expansion makes it difficult to control the electron density and arrange optimum conditions for gain.

To avoid a rapidly decreasing plasma density and create a relatively uniform and long plasma column (single pass gain G is proportional to the length), it was proposed[21] to confine the plasma in a strong magnetic field and rely on radiation losses for fast cooling. In this proposal the plasma dimensions are well-suited to a practical laser with a large ratio of plasma length, ℓ, to radius, r ($\ell/r \geq 10^2$). Calculations[21] have shown that for such a plasma column heated by 0.5-1 kJ CO_2 laser (10-20 GW of power), CVI is the most suitable hydrogenlike ion to obtain lasing action in the soft X-ray region (to have the same gain in H-like oxygen a more powerful laser is needed). A CO_2 laser operation wavelength of 10.6 μm is appropriate for our experiment from the point of view of the optimum electron density. For the maximum radiative cooling (a strong function of the recombination rate) one would like to have an electron density n_e as high as possible (three-body recombination rates are proportional to n_e^2). However, for each transition under consideration for lasing action there is a limit for n_e above which collisional depopulation becomes faster than radiative decay. Above this limit collisions "thermalize" the population inversion and prevent gain. For example, for the CVI 3→2 transition the electron density should not exceed 10^{19} cm^{-3} (see Ref. 22). This also corresponds to the critical density for a 10.6 μm laser (at which the plasma frequency equals the laser frequency).

The main purpose of this paper is a presentation of the experiments indicating the effectiveness of radiation losses for plasma cooling, preliminary results on the enhancement of the CVI 182Å line intensity possibly due to stimulated emission, and an observation of population inversion in Li-like CIV, OVI, FVII, and NeVIII ions.

II. EXPERIMENTAL ARRANGEMENT

The experimental setup is presented in Fig. 1. Four Lumonics 620 TEA CO_2 laser units in oscillator-amplifier configuration were used for plasma heating. The two oscillator units were operated broad-band with a reduced N_2 component in the gas mix in order to remove the "tail" appearing in the laser output after the main pulse. A reflection from the output window of the last amplifier was focused to an intensity monitor (marked on Fig. 1 as Laser Beam Detector) consisting of a thermopile and a photon drag detector which provided a record of laser energy and power. The output energy could be varied in the 0.2÷0.7 kJ range by operating with two, three, or four laser units. The output pulse was 75 nsec FWHM duration. The laser beam was focused by a 2.84 m focal length NaCℓ lens to an evacuated target chamber inside a solenoidal magnet. The laser focal spot size was 1 mm in diameter with a corresponding intensity of $(0.3-1) \times 10^{12}$ watts cm^{-2}. A magnetic field of up to 90 kG was used to confine the plasma (maximum available magnetic field: 150 kG) and was essentially static over the plasma lifetime. For the case of gaseous targets the gas was puffed into the target chamber by a fast valve. Gas puffing provides a decreasing pressure gradient in the backward direction with respect to the laser beam and prevents the formation of a backward going shockwave[23] which would decrease the efficiency of the laser-plasma coupling. The gas volume was limited by discs -- one with a 2-mm orifice to decrease gas flow in the direction to the axial spectrometer (see Fig. 2) and the second one with a 10- or 15-mm orifice at a distance of ℓ = 5 or 10 cm upstream from the first one (towards the CO_2 laser) to provide a high gas pressure gradient near the laser focus. The gas density was monitored at different distances along the axis with a calibrated piezoelectric probe of rise time 2 μsec. In Fig. 2 there is also shown a solid target with a 1-mm hole in the center. For this a plasma column was created along the axis through the hole. With a magnetic field of $B \geq 50$ kG, the plasma column was well-confined and the length of the column was $\ell \simeq 5$ cm as monitored by the streak camera.

Inverse bremsstrahlung is expected to be the main heating process for plasmas created from both gaseous and solid targets, as in a number of experiments related to the thermonuclear fusion program (Refs. 23-26). In these experiments peak electron temperatures in the range of 100 - 400 eV and electron densitites in the range of (1-3) x 10^{18} cm^{-3} were generated by a 200 - 300 J, 60 - 70 nsec CO_2 laser in a plasma confined by a magnetic field.[25,26]

In the present experiment mainly carbon targets were used, although a few experiments were done with a teflon target (for observation of fluorine spectra, particularly Li-like FVII spectra) and an aluminum target (for Li-like AℓXI). The primary plasma diagnostic instruments were an array of six spectrometers as shown in Fig. 1. A system of beam splitters was set up so that the grazing incidence VUV instruments and absolute intensity calibrated air monochromators viewed the same region of the plasma in order to facilitate "branching ratio" intensity calibration of the VUV instruments (Fig. 2). A grazing incidence glass "bent mirror"[27] was used to improve the sensitivity of the axial VUV instrument situated 3 m from the plasma. For the work reported here, the VUV data were recorded on photographic plates with 1-20 laser shots per exposure. The 0.6 m air spectrograph provided spectral and spatial resolution across the plasma diameter. An absolute intensity calibration for the three 0.5 m air monochromators was performed using a standard tungsten strip lamp and an NBS mini-argon arc lamp (the arc lamp was used in the 2000-3000Å region). The instrumental resolution was set at 1.9Å and a wavelength calibration was performed before each data run using an Hg lamp.

A series of plastic light guides was set up, one leading from each viewport in the magnet to an array, with additional light guides for position calibration. This array was photographed by a streak camera on each laser shot and provided an overall view of the space and time development of the plasma as indicated by visible emissions.

The data were recorded by two Tektronix 7912 and six LeCroy 2256 Transient Digitizers.

III. EFFECTIVENESS OF RADIATION COOLING

In the first series of experiments,[28] an absolute intensity calibrated 0.5 m spectrometer and 0.6 m spectrometer (both for the 2000- 000Å spectral range) were used for monitoring, respectively, the time evolution and space distribution of CVI emission lines from $7 \to 6$ (3434Å) and $8 \to 7$ (5291Å) transitions. Lines of carbon and oxygen ions of lower ionization stages were also recorded. In Fig. 3 are shown spectra near the CVI 3434Å line for B=0 and B=50 kG for a gas (CO_2) target of pressure $p \approx 2$ Torr. The vertical direction in the spectra represents a transverse section of the plasma near the CO_2 laser focus. It can be seen that the CVI is confined within a column radius $r \lesssim 1.2$ mm by the magnetic field at 50 kG. With such a magnetic field the peak intensity of the CVI 3434Å line increased three times in relation to B=0 and the decay time decreased from 400 nsec (B=0) to 200 nsec (B=50 kG) as can be seen at the bottom of Fig. 3. This line emission peaked at 200 nsec after the peak of the laser pulse during the plasma recombination stage. For a higher magnetic field (B=90 kG, Fig. 4), the decay time becomes even shorter (100 nsec) and the radius of the hot part of the plasma column becomes $r < 0.9$ mm. The data in Figs. 3 and 4 indicate that recombination in the high density plasma confined by the magnetic field is much faster than the recombination in the zero field free expansion case. In the free expansion case, the electron density and hence recombination rate and excited level populations are lower leading to a reduced radiative cooling rate, and the difference is not compensated for by cooling due to adiabatic expansion. One caveat to this interpretation is the existence of a potential OVI emission line also at 3434Å. In the VUV region of the spectrum the CVI and OVI lines are well separated, so this problem will be eliminated in the near future when the VUV instruments are converted to the photoelectric mode.

IV. MEASUREMENTS OF POPULATION INVERSION AND GAIN

In the next series of experiments, we concentrated on measurements of line radiation in the soft X-ray region using the two vacuum ultraviolet (VUV) spectrometers. One spectrometer monitored line radiation from the plasma column along the axis (axial instrument) and the second one along the diameter of the column (transverse instrument). Two differential pumping stations isolate these instruments from the target chamber. A system of beam splitters enables absolute intensity calibrated 0.5 m air monochromators to view the same points of the plasma. In this way, we can calibrate the VUV instruments for absolute intensities by the method of branching ratios. The optical arrangement of the experiment and target assemblies were already presented in Fig. 2.

Population inversions were observed in Li-like spectra obtained by focusing the laser beam on gas or solid targets. The Li-like sequence has an energy structure similar to the one presented in Fig. 5 for OVI. In Fig. 6a is shown the OVI spectrum in the region 100–180Å obtained by using a CO_2 gas target with a pressure p ≈ 3.5 Torr and magnetic field B=50 kG. The effect of self-absorption on the line intensities was estimated by measurements of the intensity ratio of the fine structure components of the 3d-2p transition (172.934Å, 173.082Å), the strongest transition in the OVI spectrum. This ratio was close to the theoretical one for an optically thin plasma, and hence allowed us to neglect self-absorption in level population measurements. The intensity ratio of the OVI 129Å (4d-2p) and OVI 173Å (3d-2p) lines indicates a population-inversion for levels 4d and 3d. Also a population inversion may be seen for levels 4p and 3p from the intensity ratio of the OVI 115Å (4p-2s) and the OVI 150Å (3p-2s) lines. Preliminary estimation of the population inversion for these levels was $n_{4d}/n_{3d} \approx 8$ and $n_{4p}/n_{3p} \approx 2$ ($n_k=N_k/g_k$ where N_k is the population density of level k and g_k is the statistical weight).

In order to measure the gain, the absolute population of OVI 3p level was determined by measurements of the absolute intensity of the OVI 3811Å (3p-3s) transition by a calibrated 0.5 m air spectrometer simultaneously with a VUV plate exposure. The 3811Å intensity was $3.6 \times 10^{+19}$ photons cm^{-2} sec^{-1} sr^{-1} corresponding to a 3p sublevel population $n_{3p} = 2.2 \times 10^{12}$ cm^{-2}. The relative populations of the 3p, 3d, and 4d levels obtained from the OVI 150Å, 173Å, and 129Å emissions recorded on the VUV plate could thus be put on an absolute scale and the sublevel population difference $n_{4d} - n_{3s}$ determined to be 5.5×10^{11} cm^{-2}. The 4d and 4f levels have a very small energy separation (0.02 eV) and we assume their sublevel populations to be equal. The Stark effect is expected to be the more dominant broadening mechanism for the OVI 520Å line (4f – 3d transition), and the line width was estimated by scaling the results of Kepple and Griem[26] for the CVI 3434Å (7-6) transition by

$n_\ell + 1/2$ where n_ℓ is the principal quantum number of the lower level of the transition. The result for an electron density of $n_e = 10^{18}$ cm^{-3} is 0.1Å (FWHM). The gain of the OVI 520Å transition based on a 0.1Å Stark width is calculated to be G ≃ 0.1. We should emphasize here that this measurement was preliminary without any special attempt to maximize gain. The result is subject to some uncertainties with regard to the variation of the sensitivity of the VUV spectrograph with wavelength, but does represent a time integrated measurement. The peak gain at 520Å is expected to be much higher. The inversion diminished when we cooled the plasma too much during the heating period by adding 5% Xe (Fig. 6b). Such strong cooling prevented the creation of a high enough density of OVII ions which are the source of the OVI population inversion during the period of fast recombination. However, in the case of CIV ions such additional cooling is not particularly negative during the heating period because the temperature of maximum abundance of CV is significantly lower than for OVII, and during the cooling period Xe increases the rate of radiative cooling. In Table I are shown the measured population inversions for Li-like ions from CIV to NeVIII with wavelengths λ of the potential lasing transitions in a plasma column confined by a 50 kG magnetic field.

Our most interesting results for soft X-ray laser development have been obtained in H-like CVI (Fig. 7). In this figure are presented axial and transverse emission spectra in the vicinity of the CVI 182Å and CVI 33.7Å lines from a carbon target with 1-mm hole and with applied magnetic field B=50 kG. It can be seen that the CVI 182Å line (3→2 transition) intensity as compared to, e.g., the CVI 33.7Å line (2→1 transition) intensity is more than an order of magnitude stronger in the axial direction than in the transverse direction. If this enhancement of 182Å line is by stimulated emission (which still needs to be proven in future experiments), it would correspond to a gain of $G \approx 4$. [This follows from the relationship between axial (stimulated, I_{stim}) and transverse (spontaneous, I_{spon}) line intensities: $[I_{stim}/I_{spon} = (e^G - 1) / G.]$. Observation of the time evolution of the line intensities in the axial and transverse direction; modification of the plasma conditions to change the intensity ratio of the 182Å and 33.7Å lines; and measurements of the population of the CVI levels n=2, 3, and 4 are planned for confirmation of this gain.

We are also planning to investigate conditions for X-ray laser development in the spectral region below 100Å using hydrogenlike ions. Analysis of levels populations in CVI, OVIII, and NeX versus plasma parameters should allow us to predict the conditions required for the creation of population inversions and high gain in the H-like isoelectronic sequence for higher Z elements in addition to the Li-like sequence discussed earlier.

V. SUMMARY

The first series of experiments have shown that a magnetic field of order $B \approx 90$-100 kG can well-confine highly ionized ions (e.g., CVI, OVI) within a radius of $r < 1$-mm in a column ℓ=5-10 cm long.

Preliminary measurements of line radiation using two vacuum ultraviolet (VUV) spectrometers have shown strong enhancement of CVI 182Å line intensity emitted in the axial direction in comparison to the intensity of this line measured in the transverse direction (182Å line intensity was measured relative to the CVI 33.7Å $2 \rightarrow 1$ resonance transition). This enhancement suggested quite high, single pass gain. A plasma column was created by focusing the laser beam on the edge of a 1-mm hole in a carbon disc target and the plasma extended through the hole along the magnetic field B=50 kG.

In a separate experiment, observation of line radiation of Li-like ions in the VUV spectral region indicated population inversions between levels n=4 and m=3 for ions from CIV to NeVIII. Estimated average gain for OVI 4f-3d transition (520Å) was $\bar{G} \approx 0.1$ which suggested much higher peak gain, although no attempt has been made yet for the optimization of the population inversion for any of these Li-like ions.

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REFERENCES

1 M.A. Duguay and M.P. Rentzepis, Appl. Phys. Lett. 10, 350 (1967).

2 R.A. McCorkle, Phys. Rev. Lett. 29, 982 (1972).

3 R.C. Elton, Appl. Opt. 14, 2243 (1975).

4 A.V. Vinogradov and I.I. Sobelman, Sov. Phys. JETP 36, 1115 (1973).

5 A.A Ilyukhin, G.V. Peregudov, E.N. Rogozin, I.I. Sobelman, and V.A. Chirkov, Soc. Phys. JETP 25, 535 (1977).

6 T.C. Bristow, M.J. Lubin, J.M. Forsyth, E.B. Goldman, and J.M. Soures, Opt. Commun. 5, 315 (1972).

7 S. Harris, Opt. Lett. 5, 1 (1980).

8 E. Ya. Kononov, K.N. Koshelev, Yu. A. Levykin, Yu. V. Sidelnikov, and S.S. Churilov, Sov. J. Quantum Electron. 6, 308 (1976).

9 R.W. Waynant and R.E. Elton, Proc. IEEE 64, 1059 (1976).

10 F.V. Bunkin, V.I. Derzhiev, and S.I. Yakovlenko, Sov. J. Quantum Electron. 11, 981 (1981).

[11] L.I. Gudzenko and L.A. Shelepin, Sov. Phys. JETP 18, 998 (1964); Sov. Phys. Dokl 10, 147 (1965).

[12] L.I. Gudzenko, L.A. Shelepin, and S.I. Yakovlenko, Sov. Phys. USP. 17, 848 (1975).

[13] F.E. Irons and N.J. Peacock, J. Phys. B 7, 1109 (1974).

[14] R.H. Dixon and R.C. Elton, Phys. Rev. Lett. 38, 1072 (1977).

[15] V.A. Bhagavatula and B. Yaakobi, Opt. Commun. 24, 331 (1978).

[16] R.J. Dewhurst, D. Jacoby, G.J. Pert, and S.A. Ramsden, Phys. Rev. Lett. 37, 1265 (1976).

[17] D. Jacoby, G.J. Pert, S.A. Ramsden, L.D. Shorrock, and G.J. Tallents, Opt. Commun. 37, 193 (1981).

[18] W.T. Silfvast, L.M. Szeto, and O.R. Wood, II, Appl. Phys. Lett. 39, 212 (1981).

[19] W.T. Silfvast and O.R. Wood, II, "Recombination Lasers in the VUV," in Laser Technique for Extreme Ultraviolet Spectroscopy, edited by T.J. McIlrath and R.R. Freeman (AIP, N.Y., 1982), p. 128.

[20] G. Jamelot, P. Jaeglé, A. Carillon, A. Bideau, C. Möller, H. Guennon, and A. Sureau, in Proceedings of the International Conference on Lasers 81, New Orleans, LA, 1981, p. 178.

[21] S. Suckewer and H. Fishman, J. Appl. Phys. 51, 1922 (1980).

[22] R.C. Elton, J.F. Seely, and R.H. Dixon, "Population Density and VUV Gain Measurements in Laser-Produced Plasmas," in Laser Technique for Extreme Ultraviolet Spectroscopy, edited by T.J. McIlrath and R.R. Freeman (AIP, N.Y., 1982) p. 277.

[23] T.K. Chu and L.C. Johnson, Phys. Fluids 18, 1460 (1975).

[24] A.L. Hoffman and E.A. Crawford, J. Appl. Phys., 29, 3219 (1978).

[25] W. Halverson, N.G. Loter, W.W. Ma, R.W. Morrison, and C.V. Karmendy, App. Phys. Lett. 32, 10 (1978).

[26] N.G. Loter, W. Halverson, and B. Lax, J. Appl. Phys. 52, 5014 (1981).

[27] J.H. Underwood, Space Sci. Instrum. 3, 259 (1977).

[28] S. Suckewer, L.C. Johnson, K. Sato, A. Semet, C.H. Skinner, and D. Voorhees, Princeton Plasma Physics Laboratory Report No. PPPL-1896, 1982.

Table I. Population Inversion in Li-like Ions

Conditions	B(kG)	Ion	Population 4d:3d	λ (Å) 4f-3d
2.4 Torr CO_2 +5% X_e	50	CIV	4.3:1	1168Å
Carbon Target	50	CIV	2.1:1	1168Å
3.5 Torr CO_2	50	OVI	8.3:1	519.6Å
Teflon (CF_4)	50	FVII	1.2:1	381Å
Neon	50	NeVII	3.7:1	292Å

FIGURE CAPTIONS

FIG. 1 Schematic of experimental arrangement.

FIG. 2 The optical arrangement of the experiment and target assemblies.

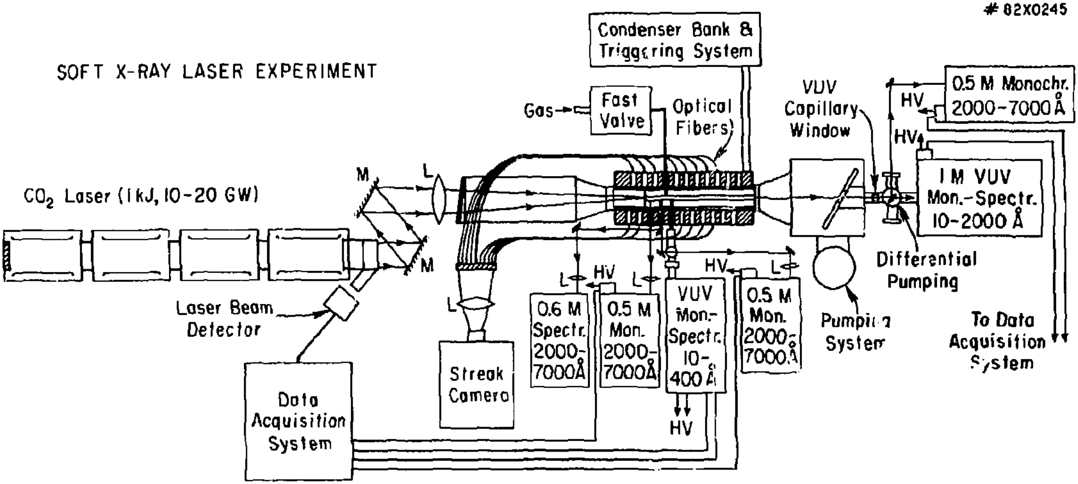
FIG. 3 Plasma spectrum near CVI 3434Å line and time evolution of the intensities of this line for magnetic fields B=0 and B=50 kG.

FIG. 4 Plasma spectrum near CVI 3434Å line and its intensity evolution for B=90 kG.

FIG. 5 Diagram of OVI levels.

FIG. 6 OVI spectra in the 100-180Å region (a) with inversion, and (b) without inversion.

FIG. 7 Axial and transverse emission spectra in the vicinity of the CVI 182Å and CVI 33Å lines.

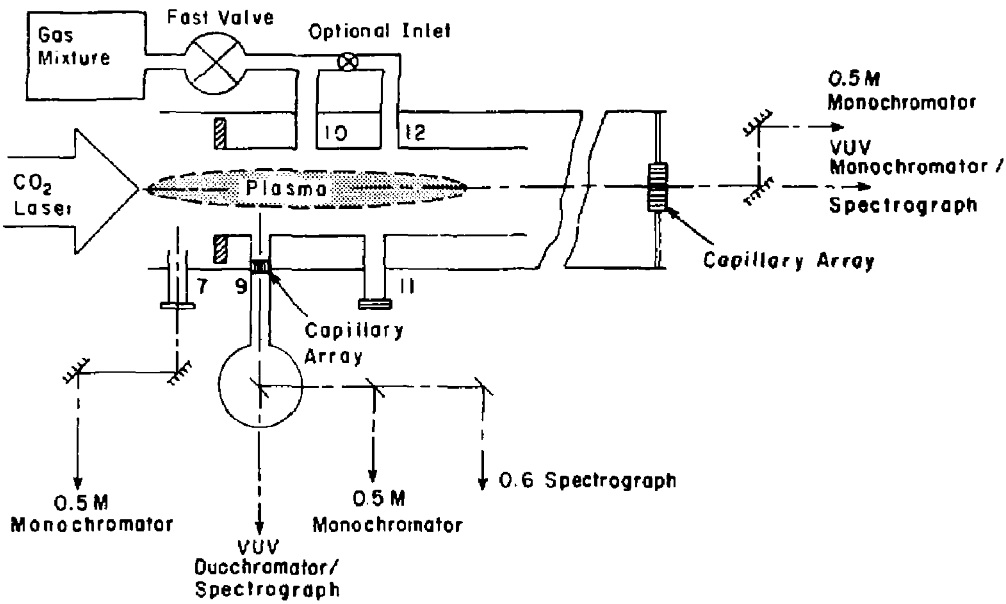


SOFT X-RAY LASER EXPERIMENT
82X0245
Condenser Bank & Triggering System
Gas
Fast Valve
Optical Fibers
VUV Capillary Window
0.5 M Monochr. 2000-7000 Å
HV
HV
1 M VUV Mon.-Spectr. 10-2000 Å
CO_2 Laser (1 kJ, 10-20 GW)
M
L
M
Laser Beam Detector
L
Streak Camera
L
HV
L
0.6 M Spectr. 2000-7000Å
0.5 M Mon. 2000-7000Å
VUV Mon.-Spectr. 10-400 Å
HV
L
0.5 M Mon. 2000-7000Å
HV
Differential Pumping
Pumping System
To Data Acquisition System
Data Acquisition System

Fig. 1

83x0005

OPTICAL ARRANGEMENT



TARGET ASSEMBLIES

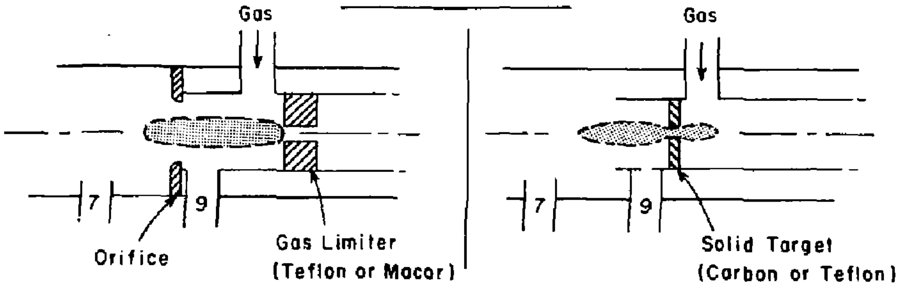
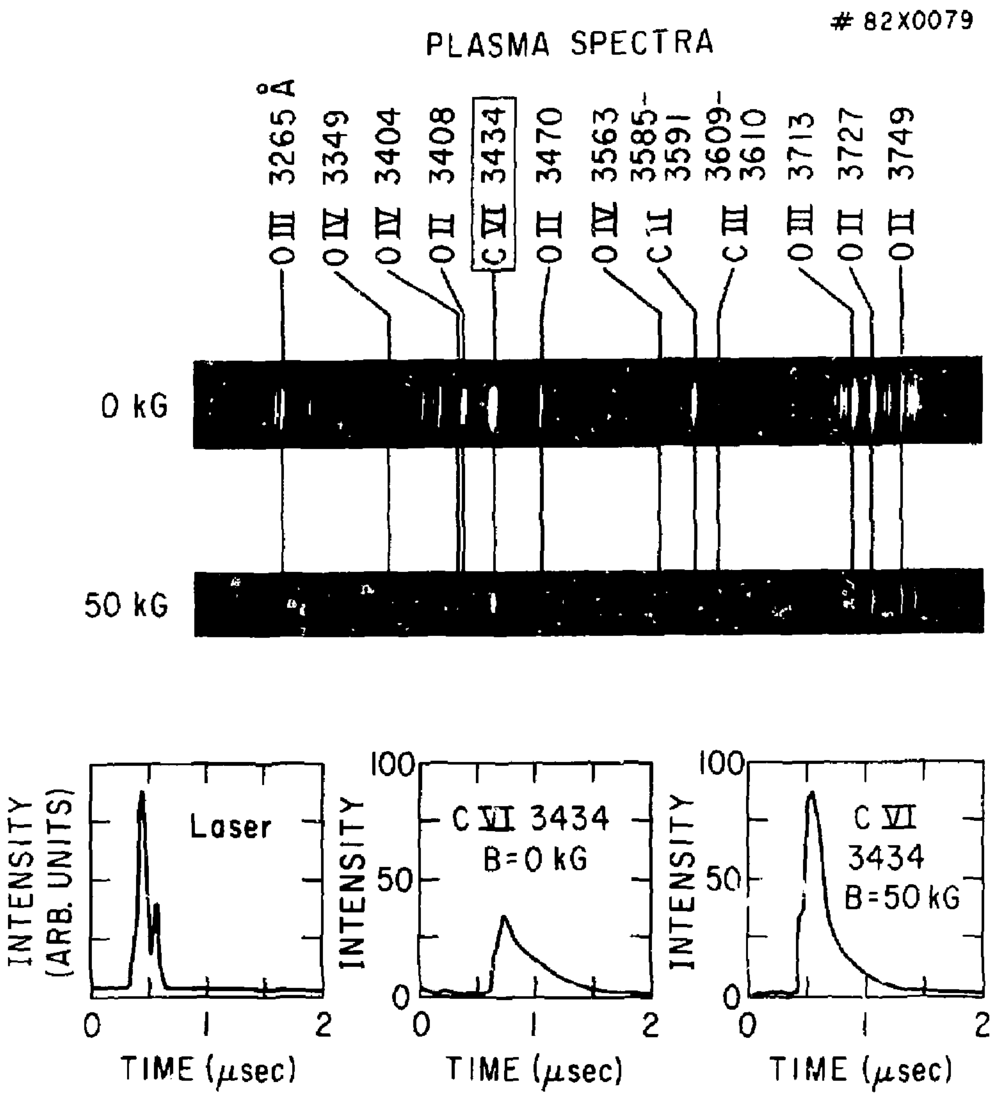


Fig. 2



82X0079
PLASMA SPECTRA
O III 3265 Å
O IV 3349
O IV 3404
O II 3408
C VI 3434
O II 3470
O IV 3563
C II 3585-3591
C III 3609-3610
O III 3713
O II 3727
O II 3749
0 kG
50 kG
INTENSITY (ARB. UNITS)
Laser
TIME (μsec)
INTENSITY
C VI 3434
B=0 kG
TIME (μsec)
INTENSITY
C VI 3434
B=50 kG
TIME (μsec)

Fig. 3

83X0466

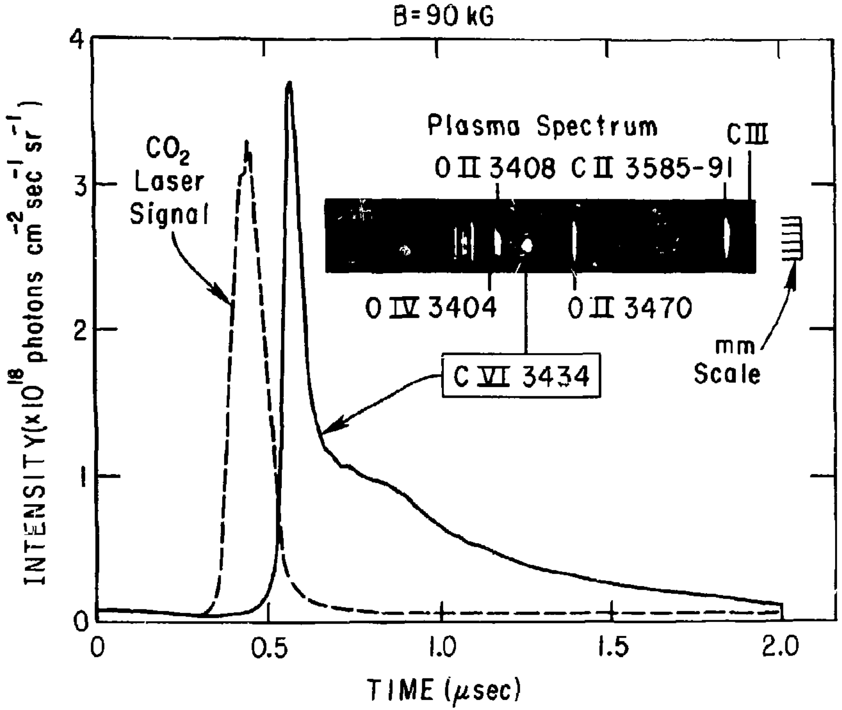


Fig. 4

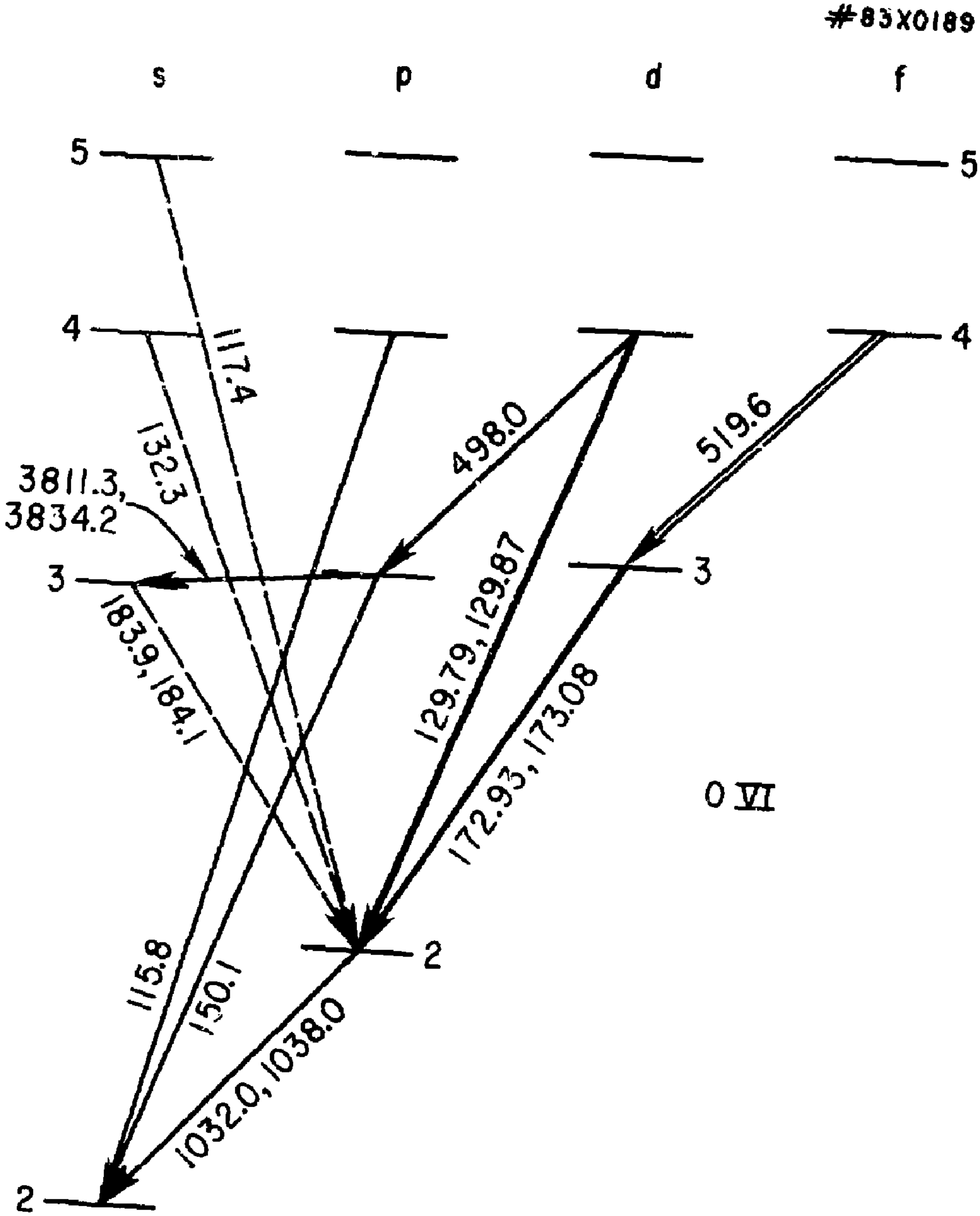
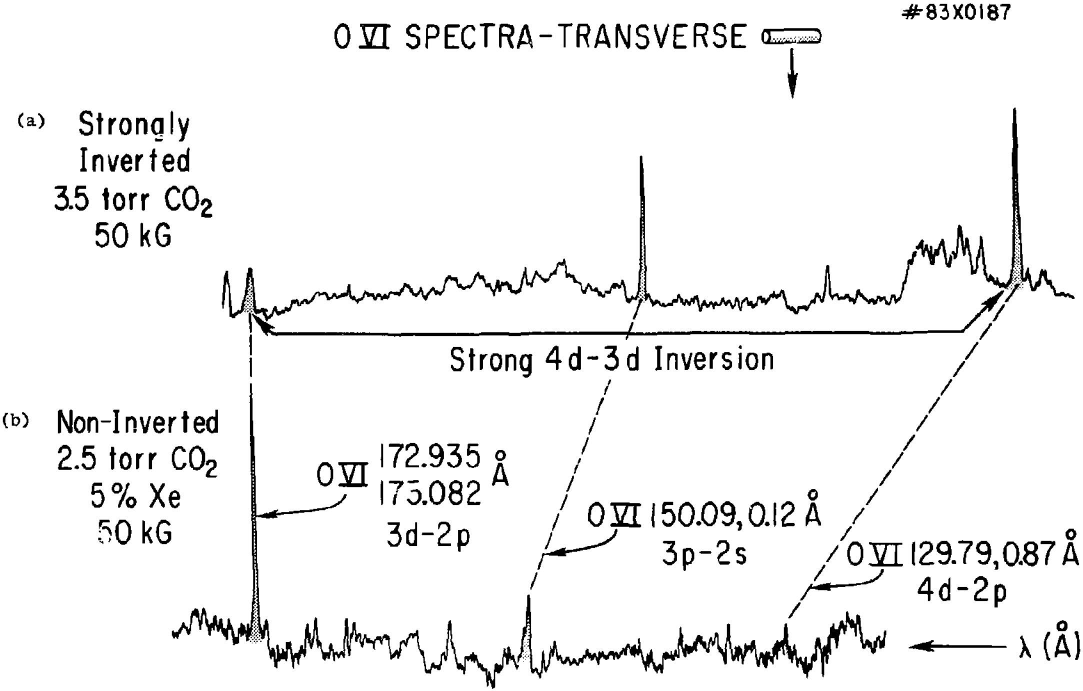

#83X0189
s
p
d
f
5
5
4
4
3
3
2
2
117.4
132.3
3811.3,
3834.2
498.0
519.6
183.9, 184.1
129.79, 129.87
172.93, 173.08
O VI
115.8
150.1
1032.0, 1038.0

Fig. 5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O VI SPECTRA-TRANSVERSE
(a) Strongly Inverted
3.5 torr CO2
50 kG
Strong 4d-3d Inversion
(b) Non-Inverted
2.5 torr CO2
5% Xe
50 kG
O VI 172.935 Å 173.082
3d-2p
O VI 150.09, 0.12 Å
3p-2s
O VI 129.79, 0.87 Å
4d-2p
λ (Å)

Fig. 6

#83X0188

STRONG AXIAL EMISSION OF C VI 182.17 Å (Hα)

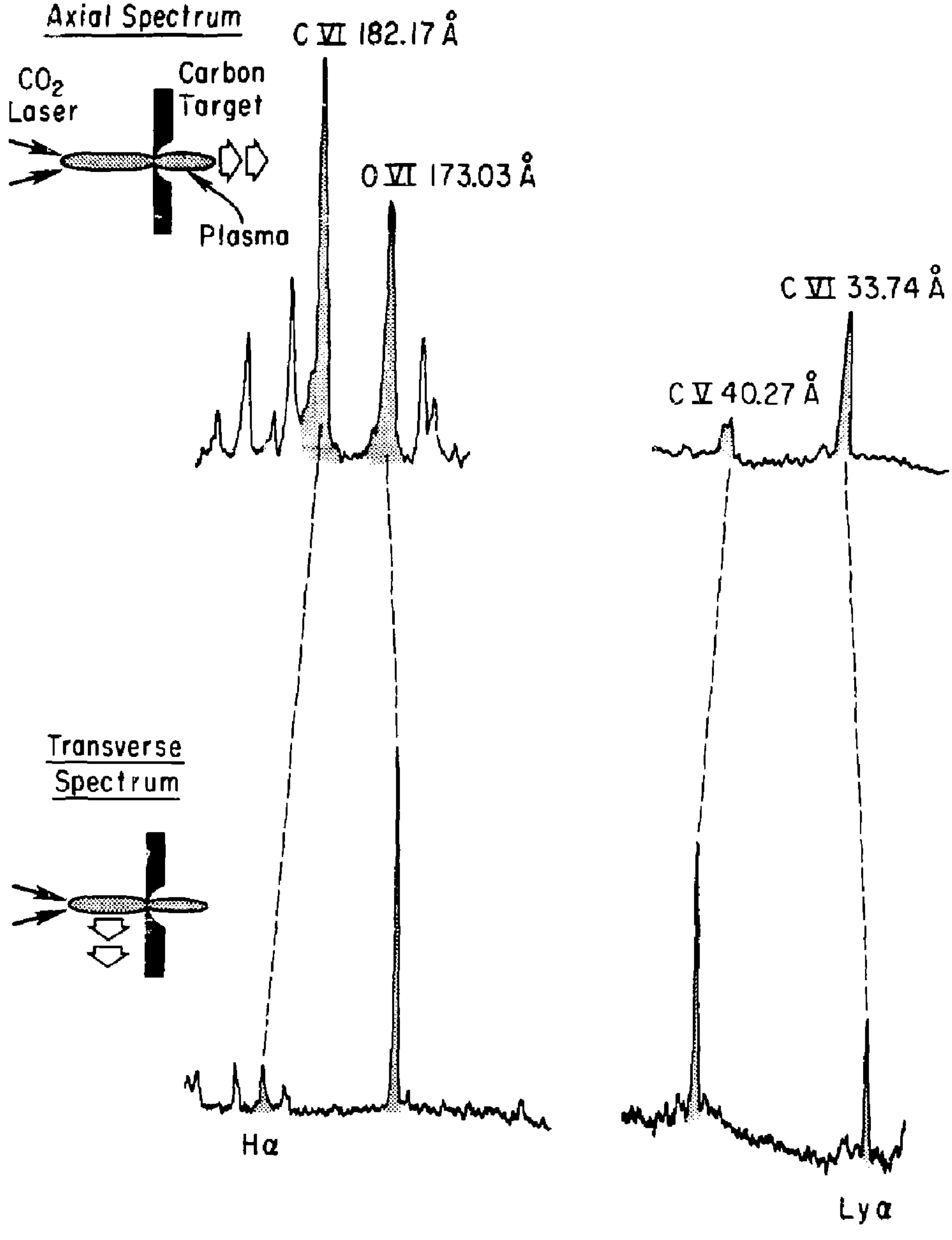

Fig. 7

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