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HIGH POWER, SHORT PULSE ULTRAVIOLET LASER FOR THE DEVELOPMENT OF A NEW X-RAY LASER

BY

L. MEIXLER, C.H. NAM, J. ROBINSON, W. TIGHE, K. KRUSHELNICK,
S. SUCKEWER, J. GOLDHAR, J. SEELY, AND U. FELDMAN

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PRINCETON
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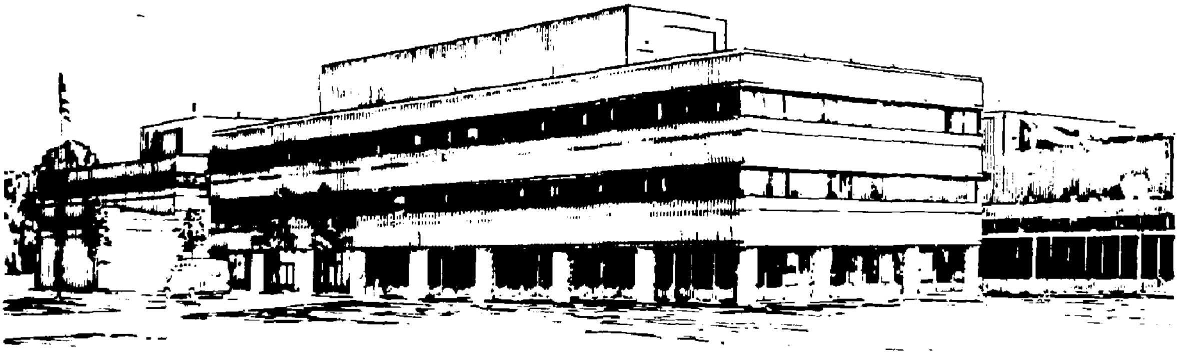

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High Power, Short Pulse Ultraviolet Laser for the Development of a New X-Ray Laser

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L. Meixler, C.H. Nam, J. Robinson, W. Tighe,
K. Krushelnick, and S. Suckewer,[a]
Princeton University, Plasma Physics Laboratory,
Princeton, New Jersey

J. Goldhar
University of Maryland, Maryland

J. Seely and U. Feldman
Naval Research Laboratory, Washington, D.C.

ABSTRACT

A high power, short pulse ultraviolet laser system (Powerful Picosecond-Laser) has been developed at the Princeton Plasma Physics Laboratory (PPPL) as part of experiments designed to generate shorter wavelength X-ray lasers. With the addition of pulse compression and a final KrF amplifier the laser output is expected to have reached 1/3-1/2 TW (10^{12} watts) levels. The laser system, particularly the final amplifier, is described along with some initial soft X-ray spectra from laser-target experiments. The front end of the PP-Laser provides an output of 20-30 GW (10^9 watts) and can be focussed to intensities of $\sim 10^{16}$ W/cm^2. Experiments using this output to examine the effects of a prepulse on laser-target interaction are described.

[a] Also at Mechanical and Aerospace Engineering Dept., Princeton University.

I. Introduction

It is our goal to demonstrate X-ray lasing significantly below 10 nm, perhaps as short as 1 nm. However, with present X-ray schemes (even those with extremely large pump lasers), these goals may be difficult to reach and new approaches may be required.

One approach, which we consider highly promising, is to use autoionizing metastable levels for storage of the pumping energy, as proposed by S. Harris [1] for 207 Å lasing in lithium. Other approaches are based on inner shell ionization and Auger transitions [2-5].

In a recombination laser X-ray scheme the input pump intensity scales as severely as λ^{-4}. That is, to reduce the wavelength by a factor of ten requires an increase in input laser power of four orders of magnitude. However, the pumping time required, τ, actually decreases as λ^{-2}. So, the practical approach to shorter wavelength emission should make use of short pulse length, high power lasers. This is what motivated our construction of the Powerful Picosecond-Laser (PP-Laser).

For a number of years C. Rhodes and his group [6] proposed the use of very high power density, short pulse lasers for multiphoton selective excitation of inner shell transitions in order to generate lasing in the 10 Å wavelength region. The PP-Laser effectively employs this approach.

II. First Stage of the System

The PP-Laser system which we developed [7], as well as systems developed by others [8-11], have a large number of system components. The first stage of our system consists of a short pulse dye oscillator/amplifier whose output is frequency converted to obtain a wavelength of 248 nm, and then amplified by two KrF amplifiers to obtain output energy in the 20 - 30 mJ range. A detailed block diagram of the system showing the first stage, the optional pulse compression, and the final KrF amplifier is given in Fig. 1.

The frequency-doubled (523 nm) output of the mode-locked Nd:YAG Laser is used to pump the cavity-dumped dye oscillator, providing an output which is approximately 1 ps at 647 nm. Residual 1.06 μm from the YAG laser is directed through a pulse slicer, amplified, frequency doubled and used to synchronously pump a three-stage dye amplifier. The output of the oscillator is delayed and then directed into this dye amplifier. Optionally, the pulse width of the picosecond pulse may be shortened to the 200-300 fs range with a fiber - grating compressor prior to amplification [12].

The noncompressed pulses, measured with an autocorrelator at the outputs of the dye oscillator, the dye amplifiers, and the second excimer amplifier, KrF II, (using the two photon fluorescence technique in Xe), were 1 ps, 1.3 ps, and 1.1 ps FWHM, respectively (Fig. 2). The corresponding compressed pulse at the output of KrF II, measuring 250 fs with the two photon fluorescence technique, is shown in Fig. 3.

The dye amplifier output is frequency doubled and then mixed with residual 1.063 μm to yield the desired 248 nm seed pulse for the KrF* excimer amplifiers. Without compression, the output beam from the second KrF* amplifier has focal spot intensities of $\sim 10^{16}$ W/cm^2. This constitutes the output from the first stage of the PP-Laser system. A photograph of the first stage, showing KrF amplifiers I and II in the foreground, is reproduced in Fig. 4.

Fig. 5 shows the intense spectral lines of hydrogen and helium-like ions of oxygen and carbon in the wavelength region of 15 to 45 Å. It is remarkable that the results look similar to the 1-2 keV high temperature tokamak plasmas, except that the lines are much broader [13].

III. Results from the First Stage of the Short Pulse Laser System

The output of the first stage (20-30 GW) was initially used in experiments with solid targets. Using a 3-m, high resolution XUV spectrometer [14], a number of spectra were recorded in the region from 10 to 300 Å. The highlights of the resulting spectra were the observation of highly ionized species (Fe XVI), Fig. 6, and very significant line broadening for certain transitions. The high resolution of the instrument can be seen from the narrowness of the LiII lines in Fig. 7. The observed broadening may be a result of either Stark broadening in a high density (> 10^{22} cm^{-3}) plasma or the extremely high electric field associated with the laser pulse (10 V/Å). Modelling, based on Stark broadening, indicated that in some cases a mixing of wave functions and subsequent emissions from otherwise forbidden transitions occurred, which could explain the observed asymmetry in certain lines (FVII 3d-2p, Fig. 8). This asymmetry, as was pointed out recently by K. Koshelev [15], may be the result of the contribution of satellite lines to the line intensities.

The effect of a prepulse [16] on the generation of plasma by a picosecond KrF* laser has been examined. The prepulse preceding the picosecond pulse arises from the amplified spontaneous emission (ASE) of the two KrF* amplifiers. The amount of prepulse energy is varied by changing the injection timing of the seed pulse. Even though the ASE signal is a factor of 10^4 times longer in duration and more than 10^5 times weaker in intensity than the main picosecond pulse, it nevertheless significantly changes the condition of interaction of the main pulse with the target.

The spectra shown in Figs. 9 (a), (b), and (c) were obtained with a teflon target at injection times of t = -3, 0, and +3 ns, respectively, in relation to time t = 0, when the laser (1 ps) pulse energy was at maximum. The estimated amount of prepulse energy in each case is 0.3, 7, and 15%, respectively, of the picosecond pulse energy. As the injection time is delayed (more prepulse), FVII lines become broader. Also, the forbidden transition 3p-2p of FVII gets stronger with increasing prepulse.

This implies that the FVII ions are created at higher electron density closer to the peak of the picosecond pulse as the prepulse increases. Furthermore, narrower line widths of FVII in the case of a weak prepulse (t = -3 ns, Fig. 9) mean that FVII ions in this case are created at a lower density. Since the plasma created by the picosecond KrF* laser freely expands, the observation of FVII ions at lower electron density implies that a significant part of the radiation from FVII ions is generated during the recombination phase after the laser pulse. It also implied that there existed a plasma with higher electron density and higher electron temperature earlier in time. This may be indicated by the presence of much stronger resonance lines of CV and CVI (observed in third order) for the case of weak prepulse (t = -3 ns) than those observed for a stronger prepulse (t = 0 ns). Thus, the initial plasma in the case of t = -3 ns is hotter than that at t = 0 ns or t = +3 ns.

The role of the prepulse can be modeled as follows. The prepulse is expected to create a low temperature plasma which will expand prior to the arrival of the picosecond pulse. As the amount and duration of prepulse increases, the number of ions interacting with the picosecond pulse will increase. Subsequently, the heat capacity of the plasma will increase with increasing prepulse because a larger number of particles are involved, with the result that the peak electron temperature will decrease. Therefore, a hotter plasma is created with less prepulse. This model is supported by calculations based on the observed spectral intensities and the linewidths of the Li-like FVII.

IV. Final KrF* Amplifier

Excimer laser research is being vigorously pursued [17] because of the advantages these lasers offer: they can amplify sub-picosecond pulses [18], their short wavelength allows the output pulse to be focussed to a relatively small spot size, and their relatively high pumping efficiencies allow multi-terawatt power densities to be delivered to targets with small laboratory size facilities.

The final KrF* excimer amplifier (KrF III) has as its seed pulse the 25 mJ, 248 nm output from the PP-Laser system first stage. The cross-sectional area of the laser cavity is 5 cm by 10 cm, and the active length is approximately 80 cm and is UV preionized by a row of 41 pins which span the length of the laser active region. Brewster's angle window mounts are used on each end of the laser to minimize reflection from the quartz windows. The amplifier unit consists of the laser body and its associated high voltage circuitry, contained in an aluminum enclosure to minimize EMI, and external high voltage power supplies and control electronics. Timing for the amplifier and for coordinating the entire experiment is derived from the PPPL-designed and constructed Fast Timing System and Master Timing System, which is locked to the 38 MHz clock derived from the mode locker of the Nd:YAG pump of the dye oscillator.

The main body of the amplifier is made of 1.25 inch thick G-10 epoxy fiberglass and the electrodes are made from 3/4 inch thick aluminum.

One electrode is machined from solid aluminum. The other electrode is similar, but has a slot milled into it with a layer of stainless steel screening over it to allow the UV from the preionizer pins to pass through. The basic electrical circuit configuration of the laser is the capacitive discharge circuit, similar to those found in nitrogen and CO_2 TEA lasers. The electrical circuits for excimer lasers, however, are characterized by very low inductance, very fast current and voltage rise-times, and very high peak currents because of the short lifetime of the excited gas molecules (∿20ns). This means that circuit geometry and component stresses are critical considerations in the development of a reliable laboratory-scale 1 J excimer laser. Figure 10 shows an end view of the amplifier. The preionization circuitry is shown along the top of the amplifier, and the main discharge capacitors are mounted close to the laser body along each side.

A series of tests were run on the KrF* final amplifier, first as an oscillator and later as an amplifier in the PP-Laser system. In the oscillator configuration, a 1.5-m radius spherical mirror was placed at one end of the laser and a 5% reflective flat window at the other end so that a laser cavity was formed. In this configuration tests were run to determine the optimal gas mix needed for maximum energy output. The highest output was achieved by using a mix of 50 torr krypton, 75 torr of 5% fluorine in a helium buffer gas mix and the balance composed of neon with the amplifier operated at 3 atm absolute. When the amplifier is part of the PP-Laser system, the amplifier is double passed. The pulse expands to fill the aperture as it traverses the amplifier on the initial pass, and is reflected by the 1.5-m spherical mirror and then slowly converges on its return trip before it is focussed onto the target. In this configuration, output energy of 1 J has been measured using a 20 ns seed pulse from the first two KrF* amplifiers, and energy levels in the range of 150-200 mJ (with $\sim$ 20% ASE) have been recorded using the compressed seed pulse. Some recent results indicated that ASE has been reduced to $\sim$10% for 120-170 mJ output.

V. Initial Spectroscopic Results with the Final KrF Amplifier

The plasma is monitored by a grazing incidence soft X-ray spectrometer, (SOXMOS) [13], which uses a microchannel plate detection system for increased sensitivity. Recently obtained spectra using the system with the large aperture final KrF* amplifier show results significantly different from the spectra obtained from the system without the final amplifier. The spectrum of Fig. 11a was obtained from 200 noncompressed shots from the first part of the system, at an energy of approximately 20 mJ each and pulse duration of $\sim$ 1 ps. The spectrum of Fig. 11b was obtained from 5 shots at 100 mJ with compressed ($\sim$ 300 fs) pulses. The latter spectrum shows an increase in line broadening and the onset of satellite lines in comparison to the former spectrum. Spectra are being analyzed presently and the results will be published elsewhere.

Figures 12 and 13 show the results obtained with a compressed 100 mJ pulse on a teflon target. Figure 12 shows FVII lines which are very broadened and have significant intensity. Figure 13, which corresponds to ASE only shots, shows no significant spectra, indicating that the FVII lines are a consequence of the shortened picosecond pulse.

VI. Experimental Configuration for the New X-Ray Laser System

As mentioned earlier, the PP-laser has been developed as a high intensity pump source in the development of a shorter wavelength X-ray laser. In general, however, in order to obtain shorter wavelength emission, one must access transitions which arise from excited levels of highly ionized species. The laser characteristics required to produce the relatively long-lived ionization stage which is needed are very different from those needed to excite the short wavelength transition and to produce a population inversion. While a single laser might be able to perform these tasks, a two-laser approach [19], which separates these processes, promises to be more efficient.

The two-laser approach (Fig. 14) consists of the following elements: A high energy CO_2 or Nd:glass laser is fired onto a target to produce a plasma column. A 100 KG magnet is used to confine the plasma and provide the desired plasma conditions. The short pulse, high power laser is used at the appropriate time (the occurrence of the correct ionization state) to create the population inversion. The interaction is examined using various diagnostics, primarily the XUV spectrometer. All the essential elements for this experiment are now in place. Temporal synchronization between the lasers, the magnetic field, and the diagnostics has been verified. Higher output power from the lasers may prove necessary. This will be determined in the near future when initial target experiments will be performed.

VII. Conclusion

Initial tests of a high power, short pulse ultraviolet laser system have been conducted with a compressed laser pulse at 248 nm. Spectra of plasmas using teflon targets have been recorded and are being analyzed. The system has been working reliably and is capable of being synchronized to other lasers and diagnostics. Additional experiments will be performed to investigate the effects of the interaction of the powerful laser pulse on various targets.

Acknowledgements

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References

[1] S.E. Harris, "Proposal for a 207-Å Laser in Lithium," Opt. Lett. 5 (1980) 1.

[2] M.A. Duguay and P.M. Rentzepis, "Some Approaches to Vacuum UV and X-Ray Lasers," Appl. Phys. Lett. 10 (1967) 350

[3] E.J. McGuire, "Soft X-Ray Amplified Spontaneous Emission via the Auger Effect," Phys. Rev. Lett. 35 (1975) 844.

[4] H.C. Kapteyn, R.W. Lee, and R.W. Falcone, "Observation of a Short-Wavelength Laser Pumped by Auger Decay", Phys. Rev. Lett. 57, 2939 (1986).

[5] W.T. Silvast and O.R. Wood, "Photoionization Lasers Pumped by Broadband Soft X-Ray Flux from Laser-Produced Plasmas," J. Opt. Soc. Am. B 4 (1987) 609.

[6] A. McPherson et al., "Studies of Multiphoton Production of Vacuum-Ultraviolet Radiation in the Rare Gases," J. Opt. Soc. Am. B 4 (1987) 595.

[7] W. Tighe et al., "High Power Picosecond Laser System at 248 nm," Rev. Sci. Instrum 59 (10) (1988) 2235-2240.

[8] S. Watenabe, A. Endoh, M. Watenabe, N. Sarukura, "Multiterawatt Excimer Laser System," Optical Society of America Proceedings on Short Wavelength Coherent Radiation: Generation and Application. Vol 2 (R. Falcone and J Kirz), eds Optical Society of America, Wash, D.C. 1989 (in press).

[9] A.P. Schwarzenbach et al., "Sub-picosecond KrF Excimer-Laser Source," Opt. Lett. 2 (1986) 499.

[10] O. Willi, G. Kiehn, J. Edwards, U. Barrow, R. Smith, "Observations of High Density Plasmas produced with a Picosecond High Power KrF Laser," Optical Society of America Proceedings on Short

Wavelength Coherent Radiation: Generation and Application. Vol 2 (R. Falcone and J. Kirz), eds Optical Society of America, Wash, D.C. 1989 (in press).

[11] P.H.Y. Lee, D. Casperson, G. Schappert "Search for X-rays Generated by Collisionless Multiphoton Processes," Optical Society of America Proceedings on Short Wavelength Coherent Radiation: Generation and Application. Vol 2 (R. Falcone and J Kirz), eds Optical Society of America, Wash, D.C. 1989 (in press).

[12] This work was done in conjunction with J. Fujimoto, M.I.T.

[13] J.L. Schwob et al., "High Resolution Duo-Multichannel Soft X-Rav Spectrometer for Tokamak Plasma Diagnostics," Rev. Sci. Instrum. 58 (9) 1601 (1987).

[14] C.H. Nam et al., "Observation of Asymmetric Stark Profiles from Plasmas Created by a Picosecond KrF Laser," Phys. Rev. Lett. 59 (1987) 2427.

[15] K.N. Koshelev, "Asymmetric Line Profiles of Highly Charged Ions in Dense Plasmas and Dielectronic Satellites," J. Phys. B 21 593.

[16] C.H. Nam, "Spectroscopic Studies of Plasmas Created by a Powerful Picosecond KrF* Laser," Ph.D. Thesis, Princeton University, April 1988.

[17] A. Endoh et al., "Picosecond Amplification in Wide-Aperture KrF Lasers," Opt. Lett. 12 (11), 906 (1987).

[18] S. Szatmari et al., "Picosecond Gain Dynamics of KrF*," Appl. Phys. B 33 (1984) 219-223.

[19] S. Suckewer et al., "Recent Progress in Soft X-Ray Laser Development at Princeton," J. Phys., Colloque C6, Supplement AU No DD, Tome 47, Oct. 1986.

Figure Captions

Fig. 1: Picosecond Laser System - block diagram.

Fig. 2: Autocorrelation traces of noncompressed pulses.

Fig. 3: Compressed pulse at the output of the second KrF* amplifier.

Fig. 4: First stage of Powerful Picosecond Laser System showing first and second KrF amplifier.

Fig. 5: Densitometer trace of the spectrum from a G-10 target showing transitions in H-like and CVI and OVIII, He-like CV and OVII, and Li-like SiXII.

Fig. 6. Iron spectrum showing Na-like Fe XVI and Mg-like Fe XV.

Fig. 7: Densitometer trace of the spectrum from a 1500-Å LiF coating on aluminum target showing transitions in He-like Li II.

Fig. 8: Fluorine spectrum obtained with teflon target.

Fig. 9: Fluorine and carbon spectra in the wavelength region 90-130 obtained with teflon target. The injection time of the picosecond pulse in each case (a) $t = -3$ nsec, (b) $t = 0$ nsec, and (c) $t = +3$, respectively.

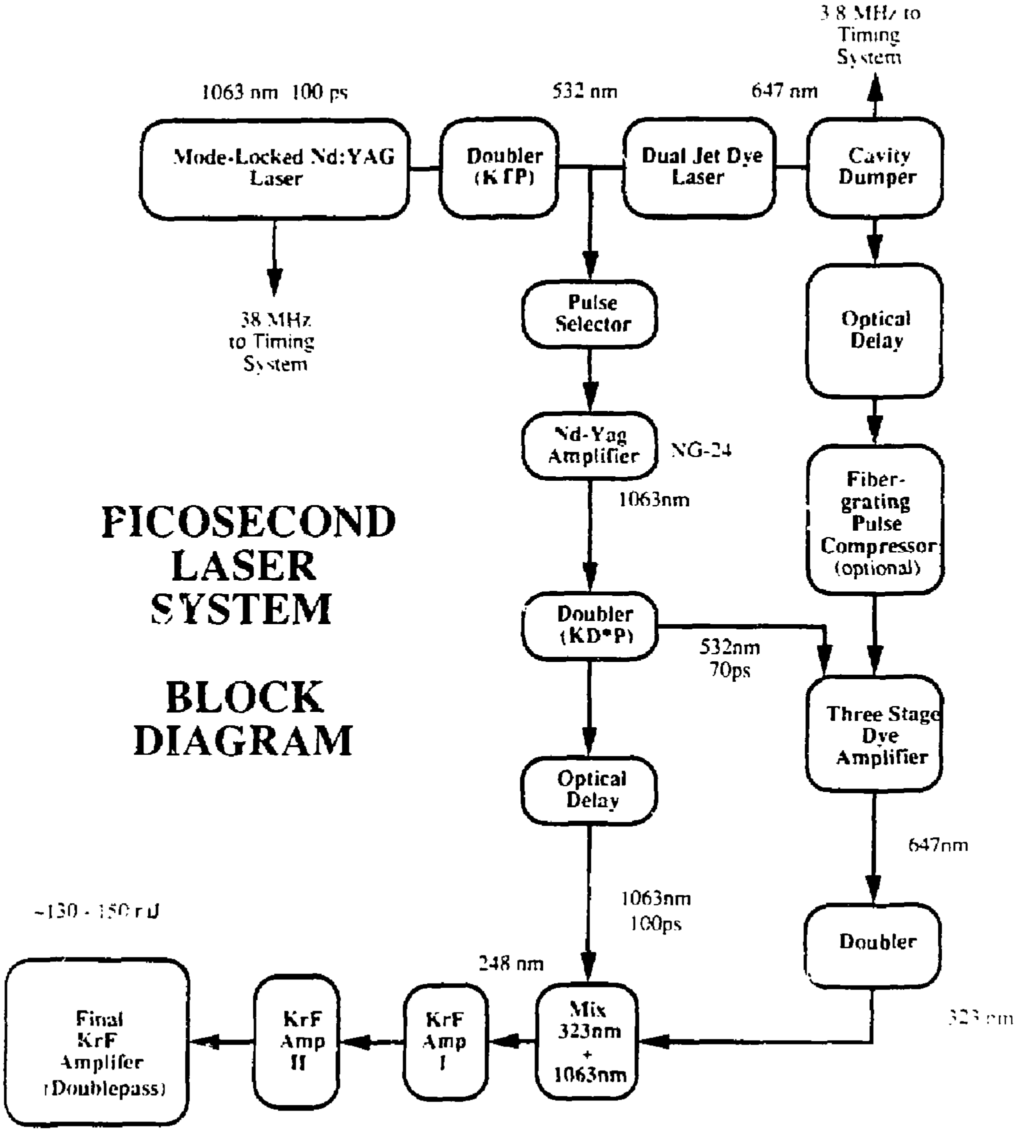
Fig. 10: End view of KrF* amplifier.

Fig. 11: Carbon spectrum obtained with teflon target. (a) 200 shots with $\Delta t \sim 1$ ps, (b) 5 shots at 100 mJ with $\Delta t \sim 300$ fs.

Fig. 12: Fluorine and carbon spectra obtained with teflon target.

Fig. 13: ASE ($E = 20$ mJ) only output from final KrF amplifier - teflon target.

Fig. 14: Schematic of arrangement of "Two-Laser Approach" to X-ray laser development.


PICOSECOND
LASER
SYSTEM
BLOCK
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Mode-Locked Nd:YAG Laser
38 MHz to Timing System
Doubler (KTP)
532 nm
Dual Jet Dye Laser
647 nm
Cavity Dumper
3.8 MHz to Timing System
Optical Delay
Fiber-grating Pulse Compressor (optional)
Pulse Selector
Nd-Yag Amplifier
NG-24
1063nm
Doubler (KD*P)
532nm
70ps
Three Stage Dye Amplifier
647nm
Optical Delay
1063nm
100ps
Doubler
323 nm
248 nm
Mix 323nm + 1063nm
KrF Amp I
KrF Amp II
Final KrF Amplifer (Doublepass)
~130 - 150 mJ

Fig. 1

88X3279

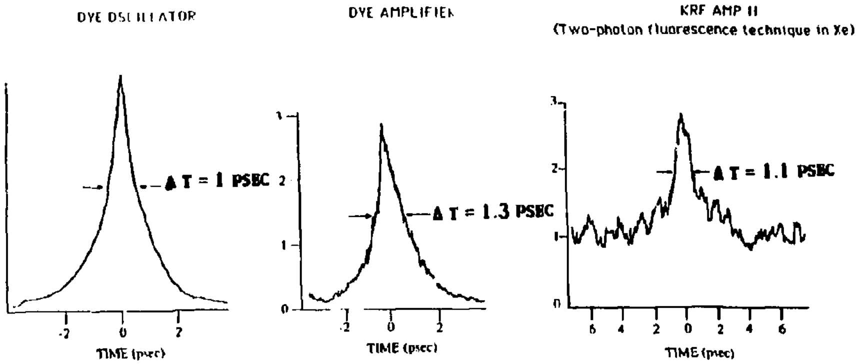

Fig. 2

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COMPRESSED PULSES

Output from KrF Amp II of PP-laser

(Two photon fluorescence technique in Xe)

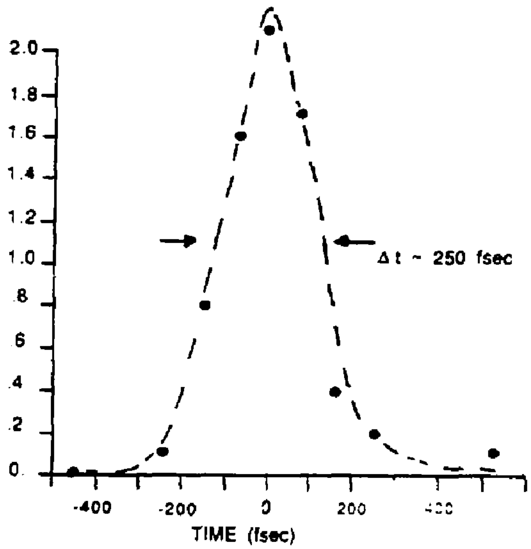


Fig. 3

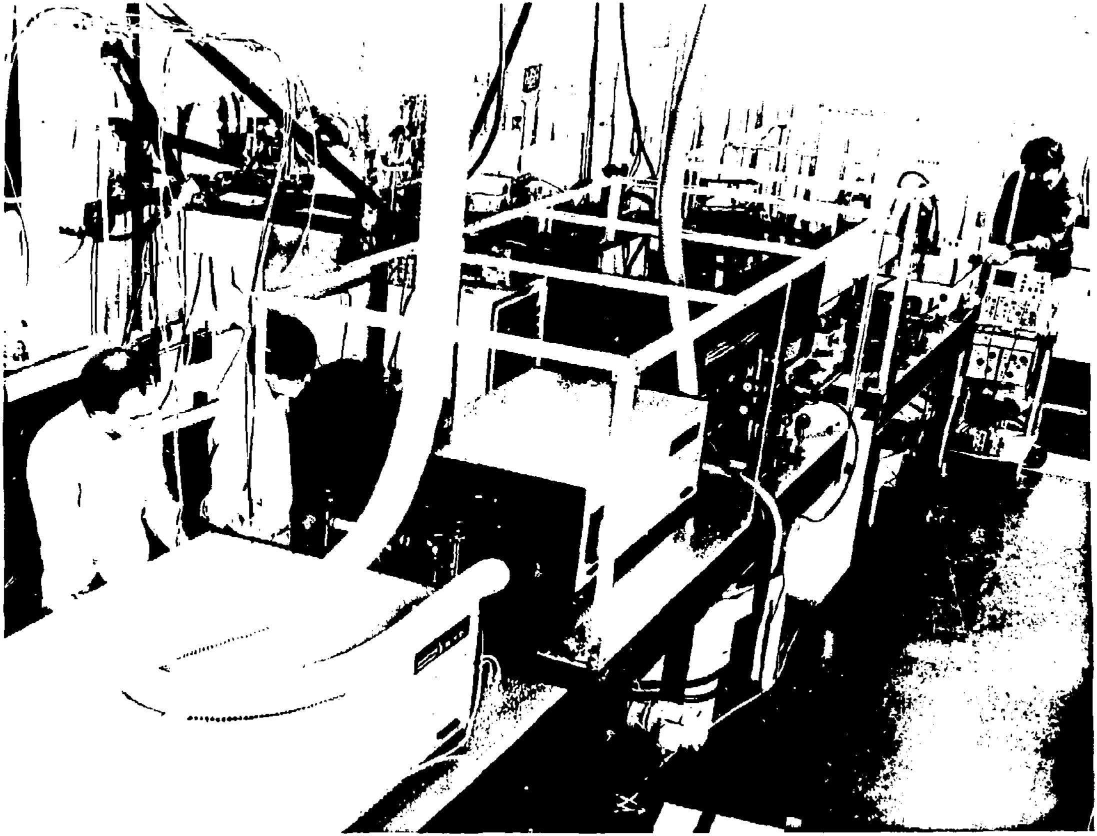
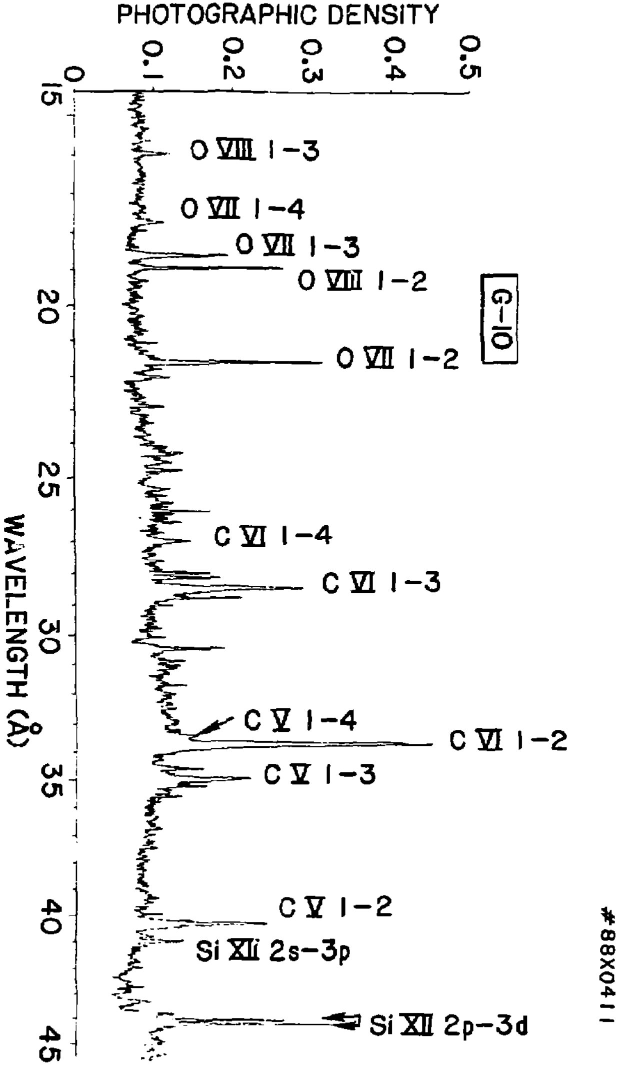


Fig. 4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25
30
35
40
45
G–10
O VIII 1–3
O VII 1–4
O VII 1–3
O VIII 1–2
O VII 1–2
C VI 1–4
C VI 1–3
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C V 1–3
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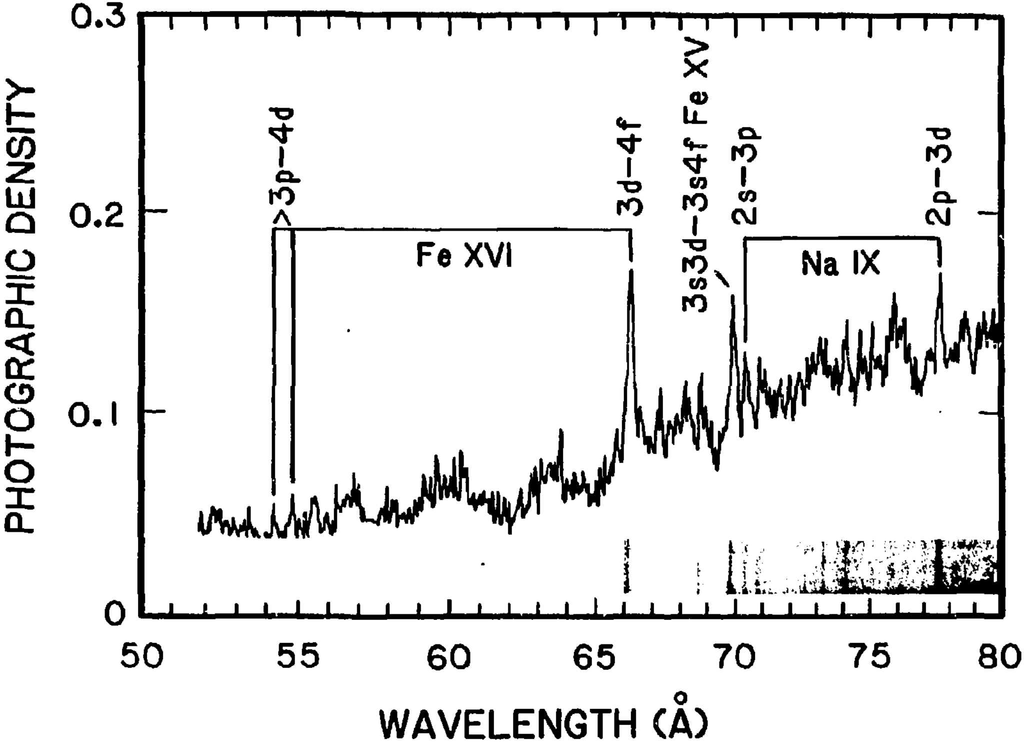
Fig. 5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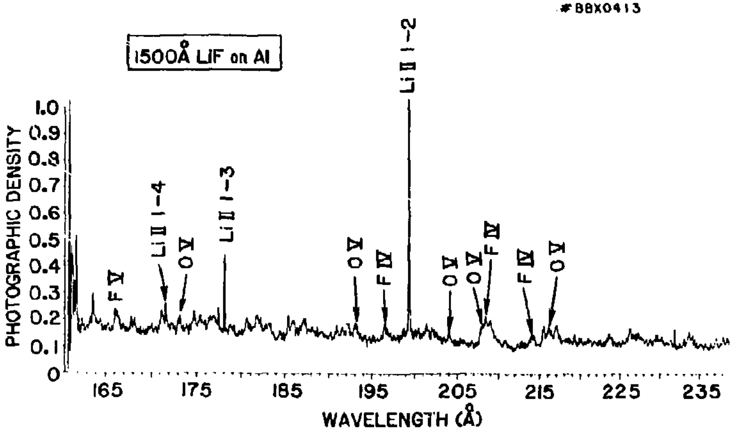
3d–4f
3s3d–3s4f Fe XV
2s–3p
Na IX
2p–3d

Fig. 6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0.3
0.4
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0.6
0.7
0.8
0.9
1.0
F V
Li II 1-4
O V
Li II 1-3
O V
F IV
Li II 1-2
O V
O V
F IV
F IV
O V
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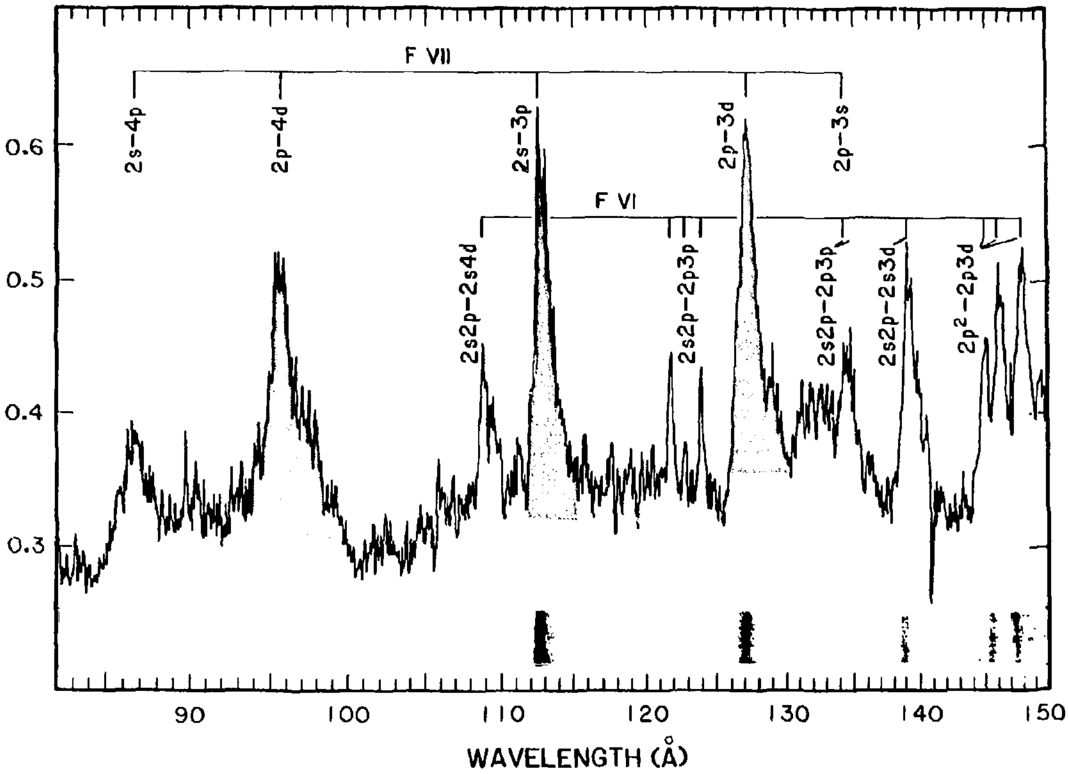
175
185
195
205
215
225
235
WAVELENGTH (Å)

Fig. 7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2s2p−2p3p
2s2p−2s3d
$2p^2-2p3d$
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0.3
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110
120
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140
150
WAVELENGTH (Å)

Fig. 8

88X3281

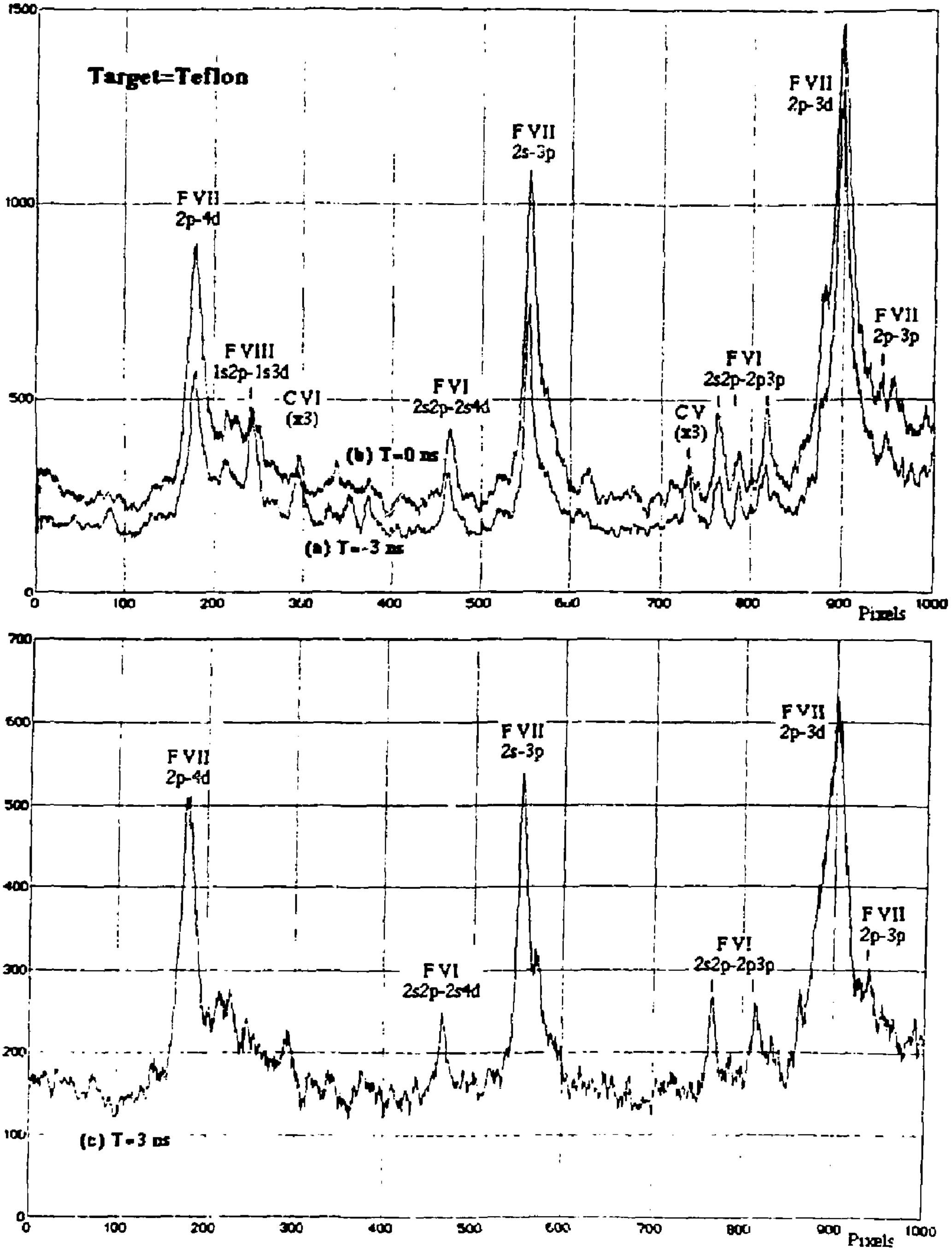


Fig. 9

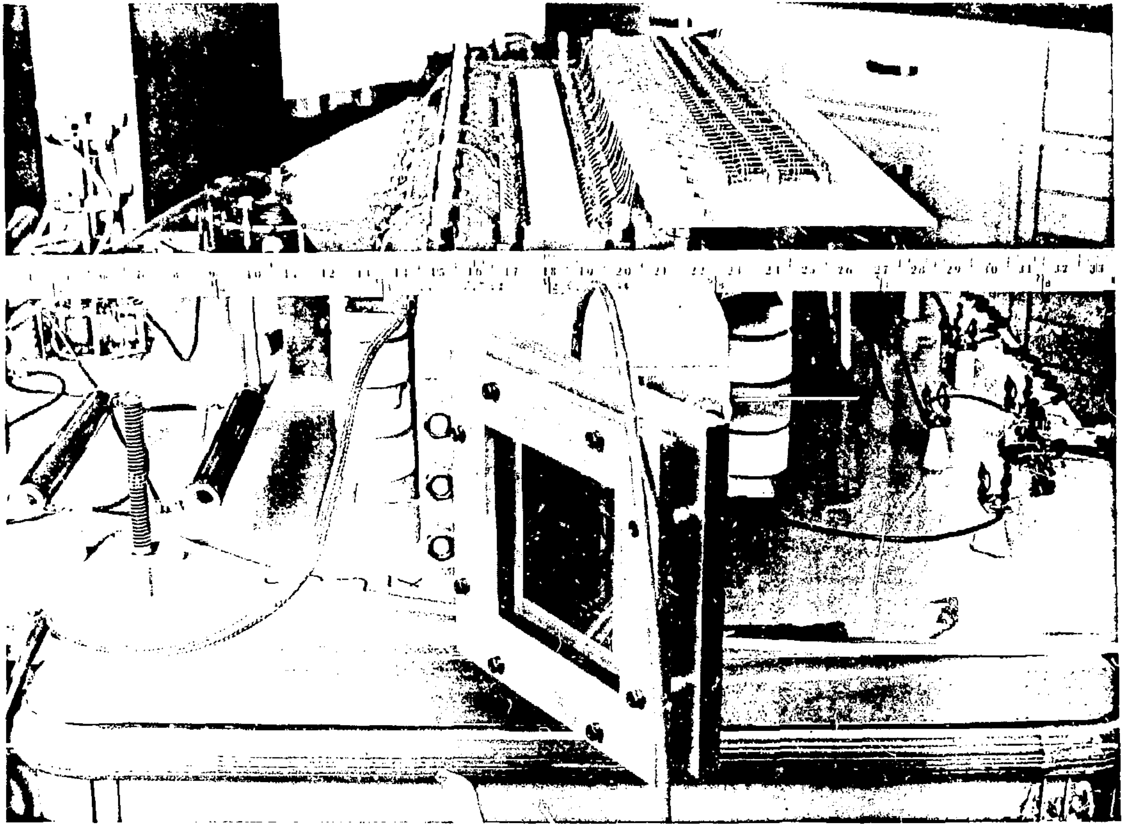
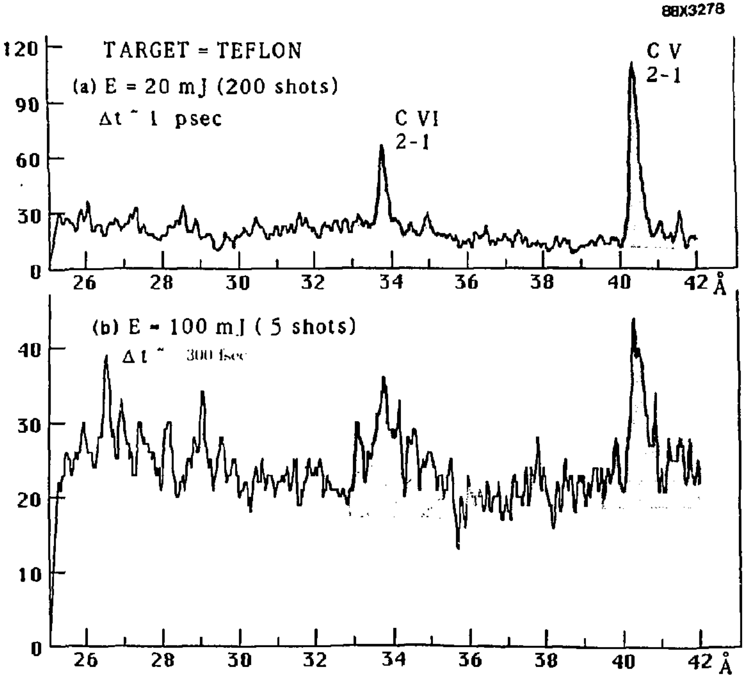


Fig. 10



Carbon spectrum obtained with the teflon target
(a) E = 20 mJ (b) E = 100 mJ

Fig. 11

88X3282

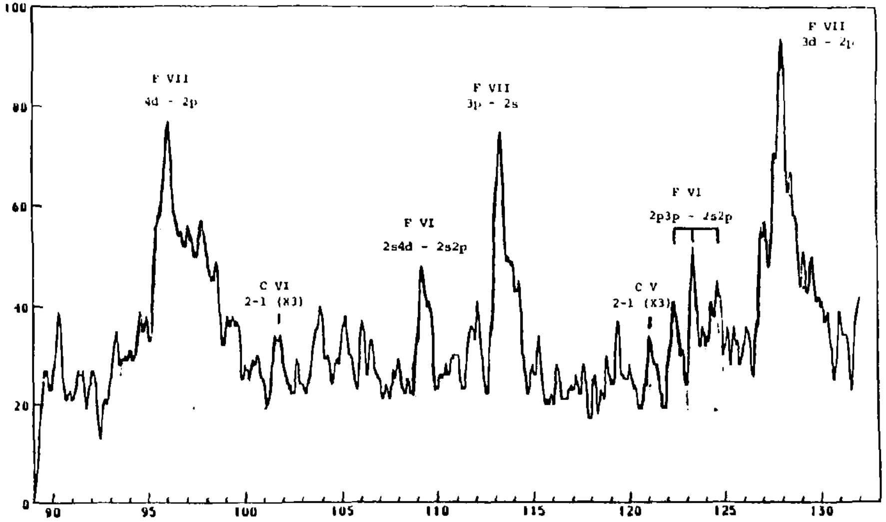


Fig. 12

B8X3280

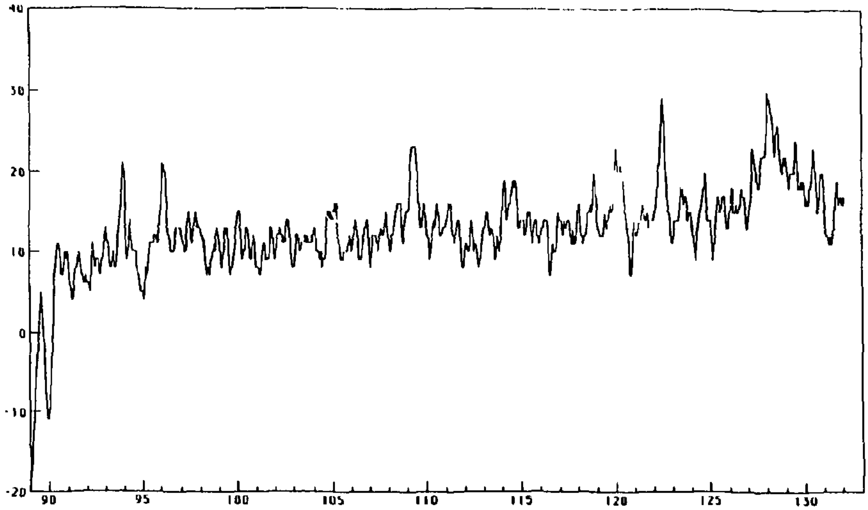
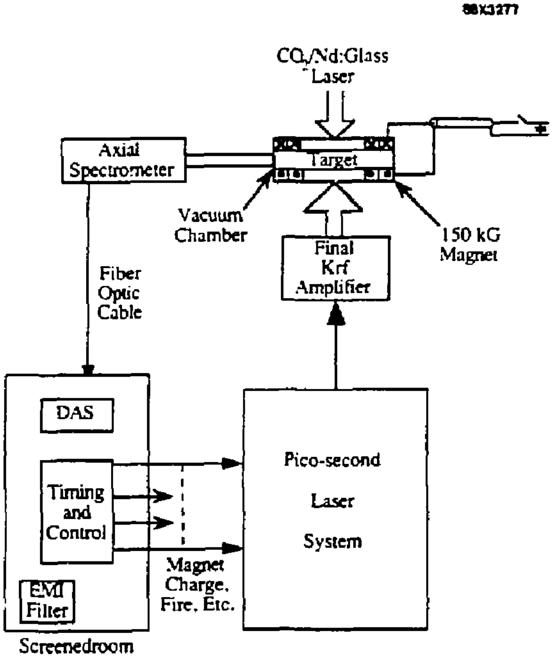


Fig. 13



New Xray Laser System Block Diagram

Fig. 14

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