NRL/MR/6681--93-7359

Soft X-ray Emission from Alexandrite Laser-Matter-Interaction

P. G. BURKHALTER

Dynamics of Solids Branch
Condensed Matter & Radiation Sciences Division

D. J. HARTER

Allied Signal, Inc.
Morristown, NJ 07960

E. F. GABL
P. BADO

MXR, Inc.
Dexter, MI

D. A. NEWMAN

SFA, Inc.
Landover, MD

July 15, 1993

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 15, 1993	

4. TITLE AND SUBTITLE

Soft X-ray Emission from Alexandrite Laser-Matter-Interaction

5. FUNDING NUMBERS

6. AUTHOR(S)

P.G. Burkhalter, D.J. Harter*, E.F. Gabl**, P. Bado**, and D.A. Newman***

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6681--93-7359

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

ARPA
3701 N. Fairfax Dr.
Arlington, VA 22203-1714

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Allied Signal, Inc., Morristown, NJ 07960
**MXR, Inc., Dexter, MI
***SFA, Inc., Landover MD

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

X-ray spectroscopy was used to quantify the plasma generated by a focused, Alexandrite laser as a potential alternative source in proximity lithography. An x-ray emission efficiency of 2 - 11% was determined by analysis of spectral data (10 - 14A) from transition-metal targets.

14. SUBJECT TERMS

X-ray spectroscopy
Proximity
Lithography

15. NUMBER OF PAGES

30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

SOFT X-RAY EMISSION FROM ALEXANDRITE LASER-MATTER-INTERACTION

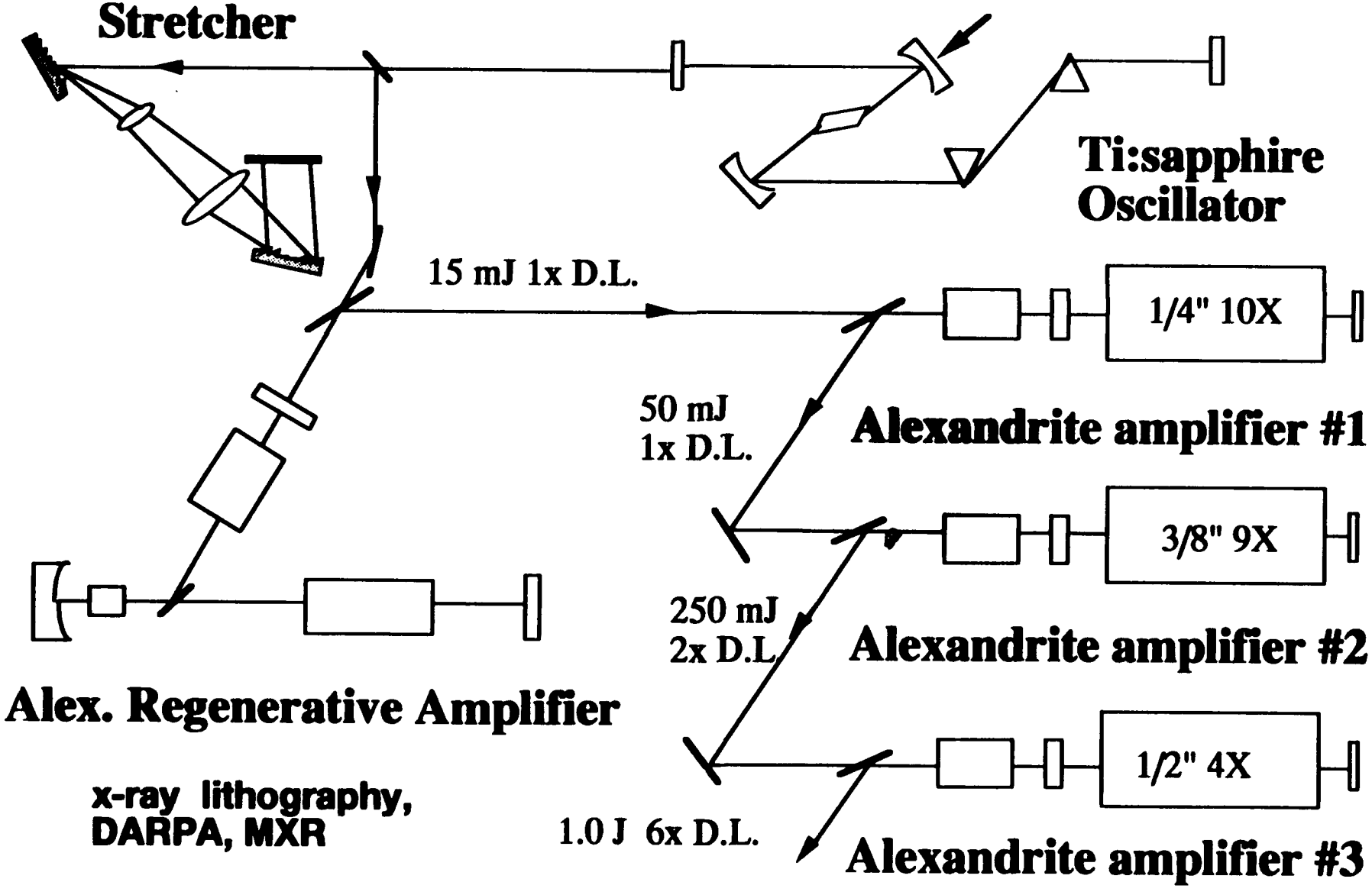
Manuscript approved June 6, 1993.

EXPERIMENTAL

A compact (table-top), focused Alexandrite (750 nm) pulsed-laser system generated soft x-ray emission from planar-metal targets. Quantitative x-ray spectroscopy (active and passive detection) and pinhole imagery were used to characterize the 10 - 14 Å region that is important for resist exposure in proximity x-ray lithography. X-ray data was collected from transition metal targets. The spectra, acquired on film, were densitometered and computer processed to obtain line intensities from the L-shell transitions in highly-ionized copper and iron plasma. Spectral data was also acquired from K-shell transitions in aluminum in order to compare the effects of less than 8 Å spectral wavelengths (>1.5 keV energy) as the more energetic x-rays have greater penetration in the lithographic process.

The 10 Hz Alexandrite laser system at Allied Signal employs a Ti: sapphire oscillator, a pulse-stretcher (grating-pair), and a three-stage Alexandrite regenerative amplifier stage. The laser can generate chirped pulses (0.75 ns) up to 1 joule. These pulses can be recompressed to shorter pulse widths with an additional grating pair. Spectral data was acquired with both single laser pulses and a train of widely-spaced (8-ns) laser pulses.

1 Joule, 1 ns, 10 Hz alexandrite laser
5 to 3 amplifiers

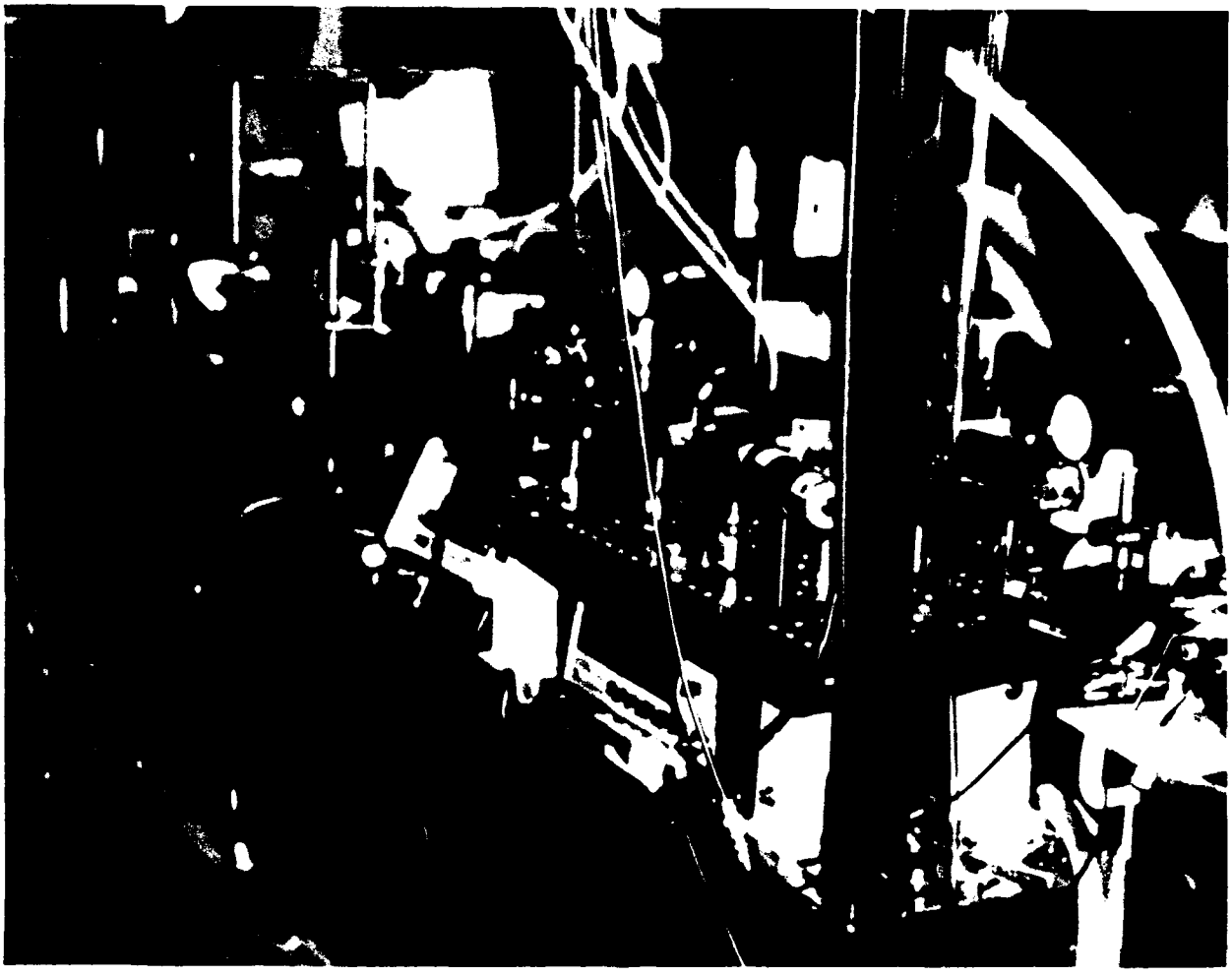


x-ray lithography,
DARPA, MXR

ALEXANDRITE FOCUSSED LASER

ALLIED-SIGNAL Corp.
Morristown, NJ

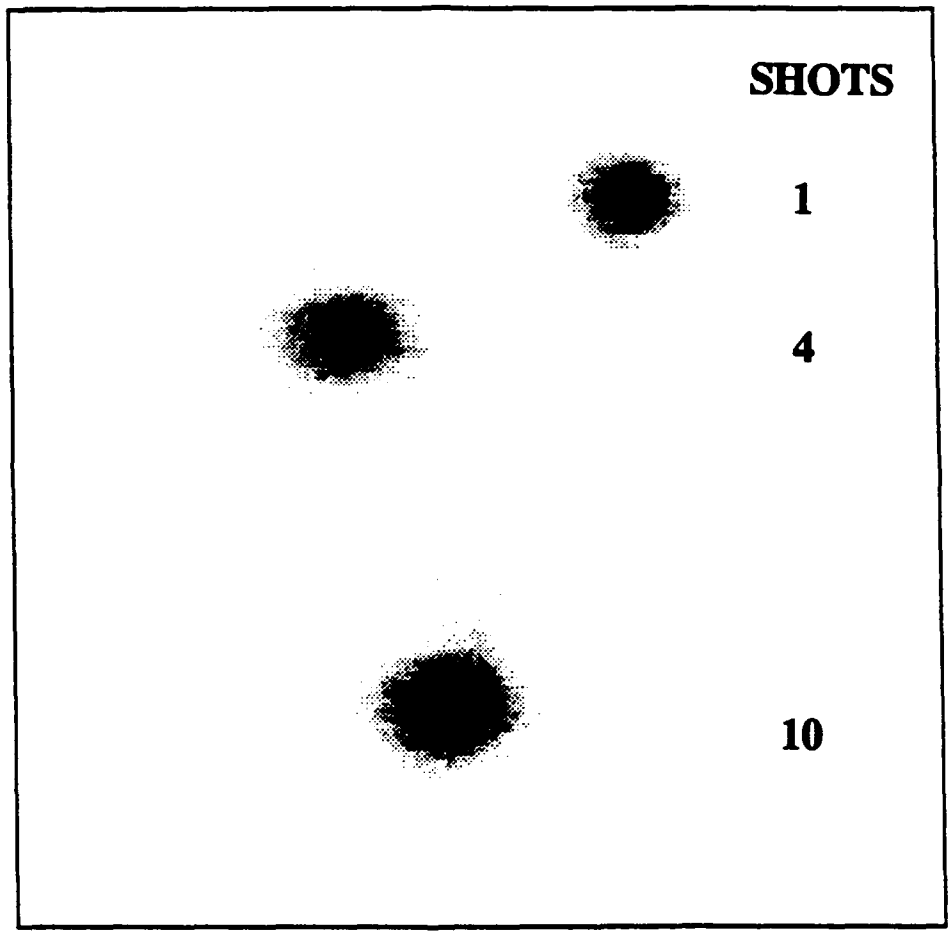
Wavelength:	**800 nm**
Pulse Energy:	**1 J**
Pulserwidth:	**3/4 ns**
Repetition Rate:	**10 Hz**



X-RAY PINHOLE IMAGES

for

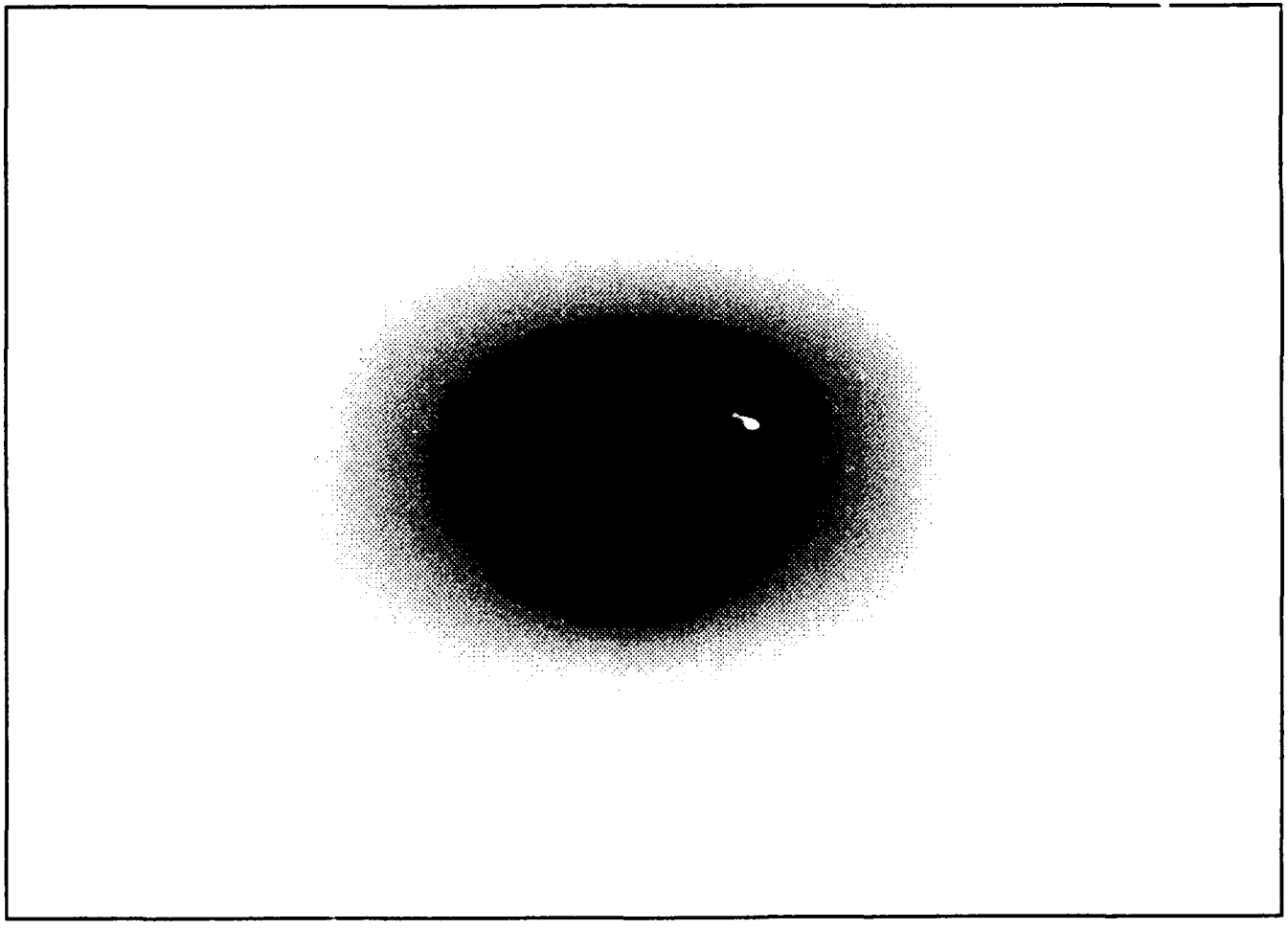
ALEXANDRITE LASER

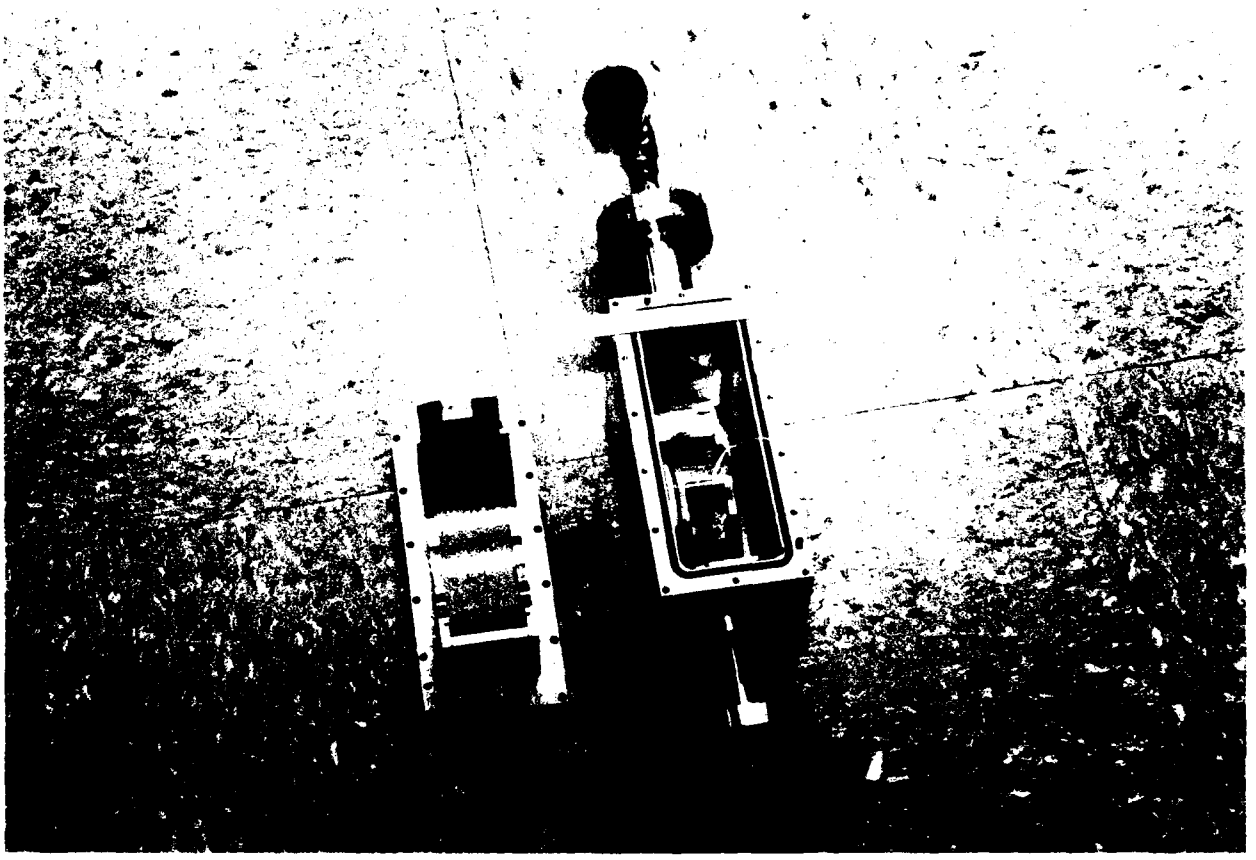

SHOTS
1
4
10

X-RAY EXPOSURE UNIFORMITY

Curved-Channel Plate Array Camera

Allied Signal, Shot 8, 22-Dec-1992

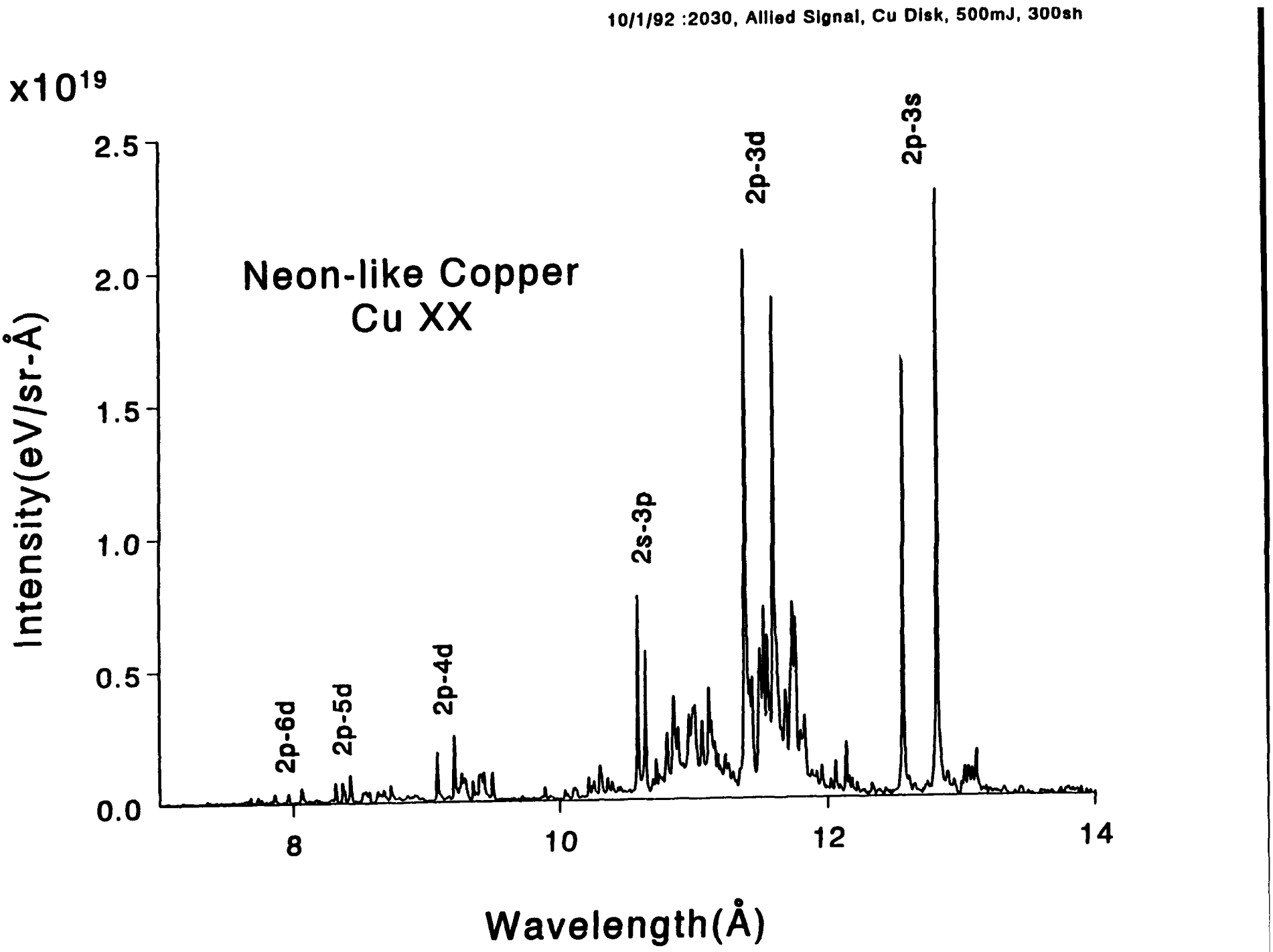


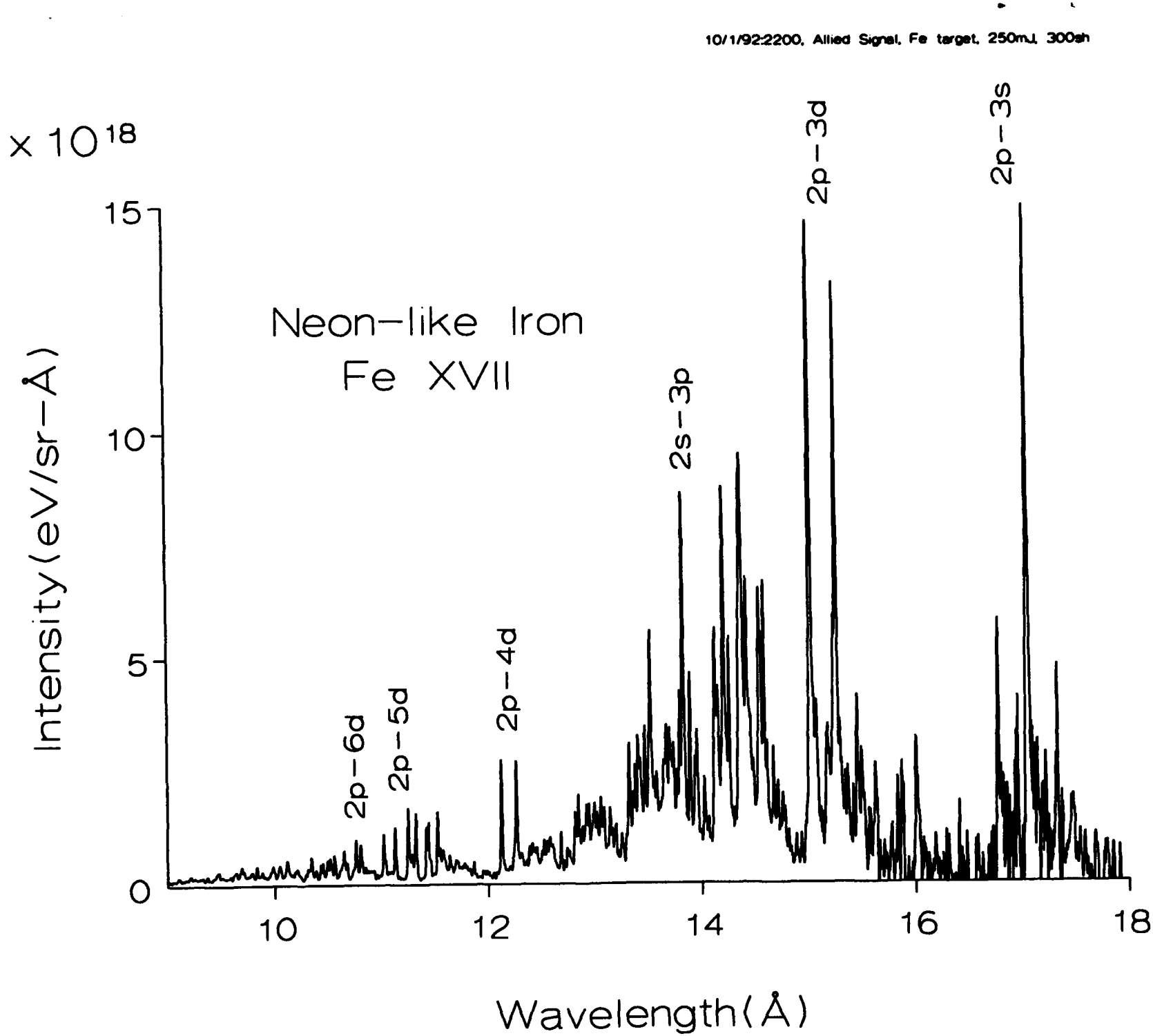


SPECTRA

from

ALEXANDRITE LASER


10/1/92 :2030, Allied Signal, Cu Disk, 500mJ, 300sh
x10^19
Neon-like Copper
Cu XX
Intensity(eV/sr-Å)
Wavelength(Å)
2.5
2.0
1.5
1.0
0.5
0.0
8
10
12
14
2p-6d
2p-5d
2p-4d
2s-3p
2p-3d
2p-3s


10/1/92:2200, Allied Signal, Fe target, 250mJ, 300sh
x 10^18
Intensity(eV/sr-Å)
Neon-like Iron
Fe XVII
2p-6d
2p-5d
2p-4d
2s-3p
2p-3d
2p-3s
0
5
10
15
10
12
14
16
18
Wavelength(Å)

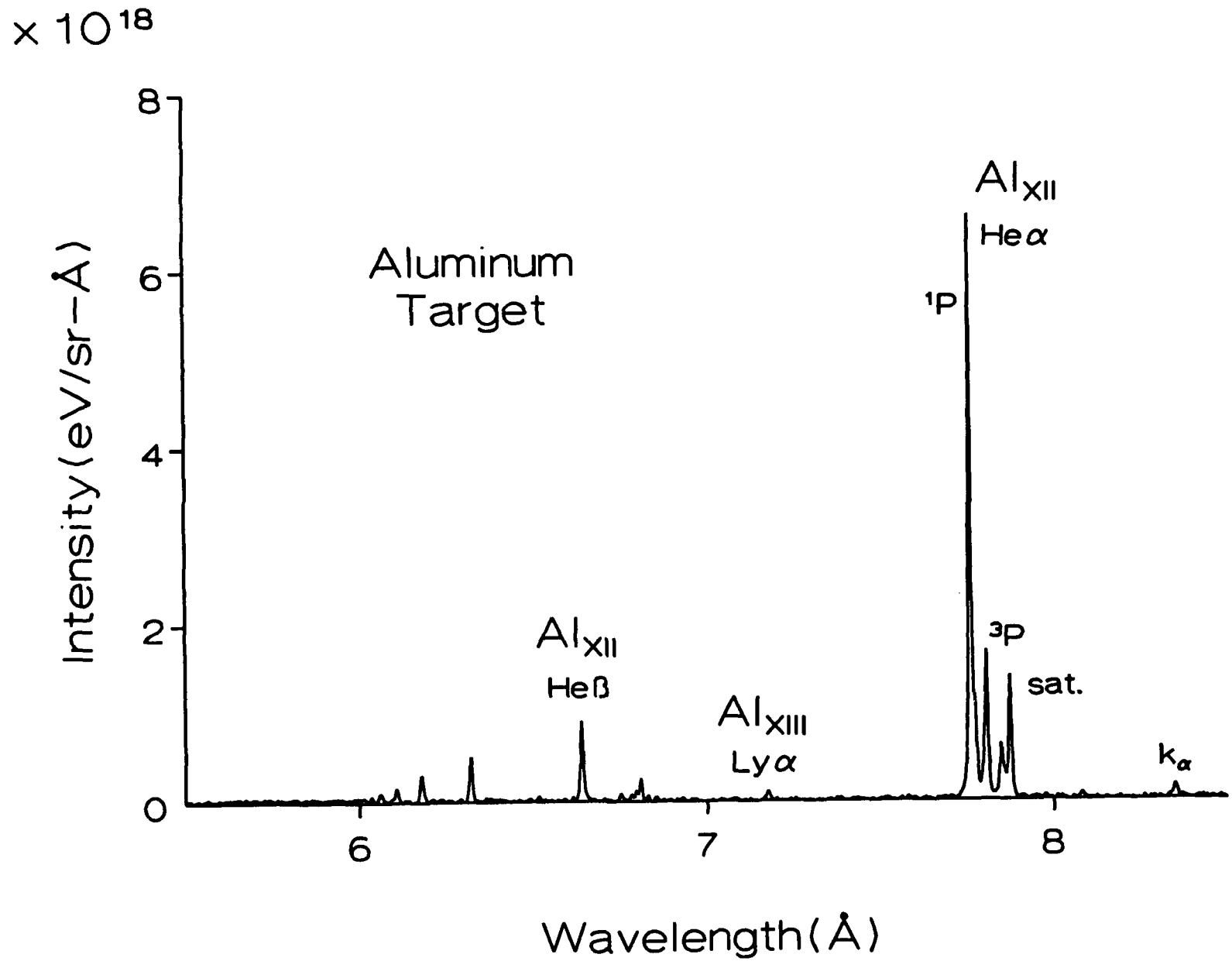

x 10^18
8
6
4
2
0
Intensity (eV/sr-Å)
Aluminum
Target
Al XII
Heα
1P
Al XII
Heß
Al XIII
Lyα
3P
sat.
kα
6
7
8
Wavelength (Å)

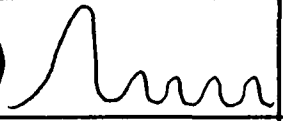
Table I. X-Ray Spectral Intensities Generated by Alexandrite Laser.

Target Material	Shot Sequence	Number of Shots	Spectral Range Angstrom	Integrated Intensity eV/sr	Output Joules into 2π	Output mJ/shot into 2π	η, %
Cu	10/1/92:1400	400	7-14	$1.89 \bullet 10^{18}$	1.9	4.8	1.9
	10/1/92:1500	270	7-14	$3.74 \bullet 10^{18}$	3.8	14.1	2.8
	10/1/92:1630	300	7-14	$3.75 \bullet 10^{18}$	3.8	12.7	2.5
	10/1/92:2030	300	7-14	$4.98 \bullet 10^{18}$	5.0	16.7	3.3
Fe	10/1/92:2130	300	9-18	$7.86 \bullet 10^{18}$	7.9	26.3	5.3
	10/1/92:2200	300	9-18	$8.54 \bullet 10^{18}$	8.6	28.7	11.5

X-RAY SPECTRAL DATA

for LASER PULSE TRAIN

Soft X-Ray Output

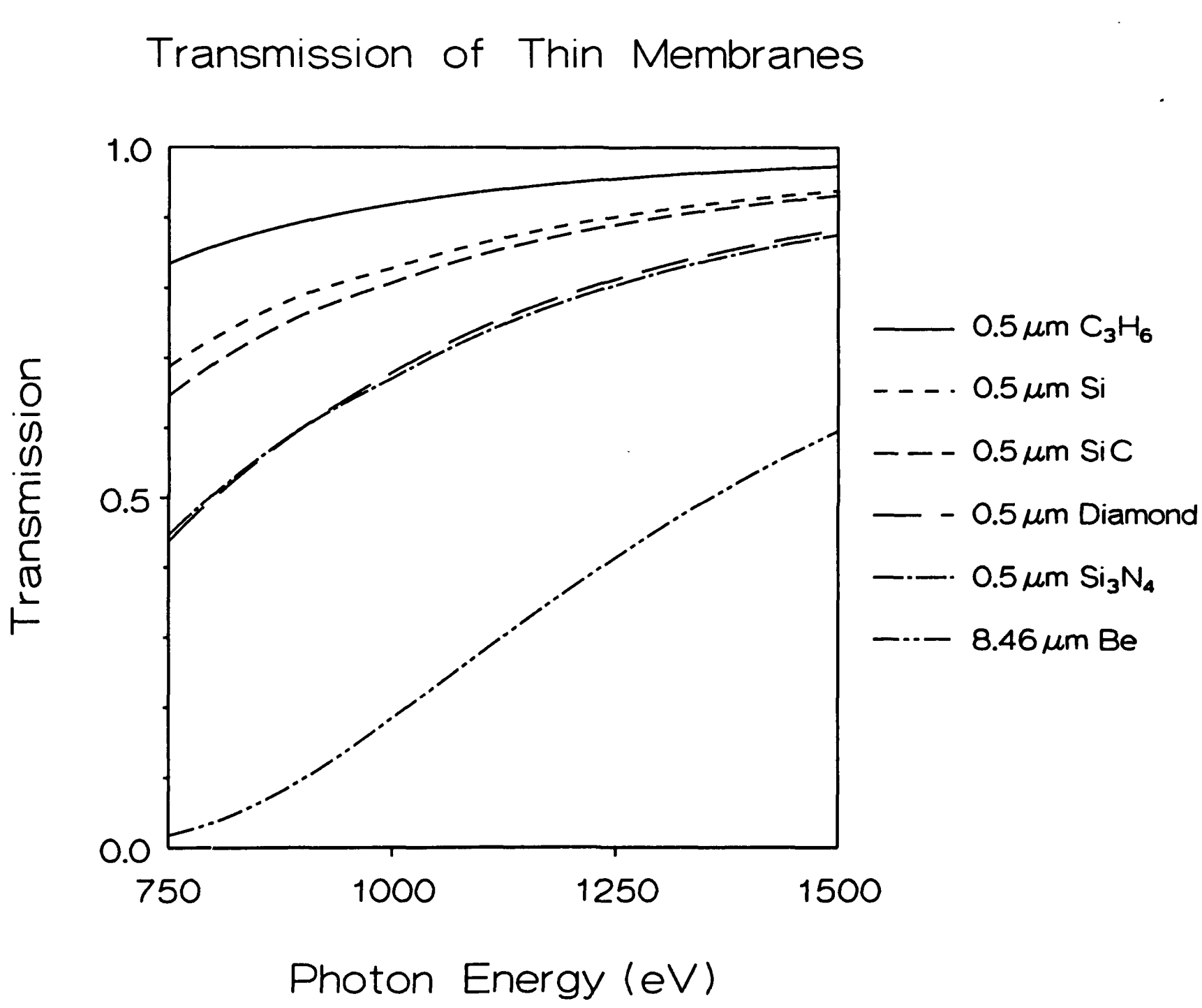
Data Group	Energy on Copper Target	Number shots	X-Ray Intensity (eV/sr)	Pulse Shape	Emission Comparison
Oct.	1/2 J	300	$4.8 \cdot 10^{18}$	a) 	unity
Dec.	1 J	120	$1.1 \cdot 10^{18}$	b) 	less by 2x
Dec.	2/5 J	120	$0.46 \cdot 10^{18}$	c) 	less by 4x

a) single pulse 3/4 ns width
b) train of pulses with 1 J leading edge
c) train of equal-intensity pulses separated by 8 ns

X-RAY SOURCE TRANSMISSION for LITHOGRAPHY

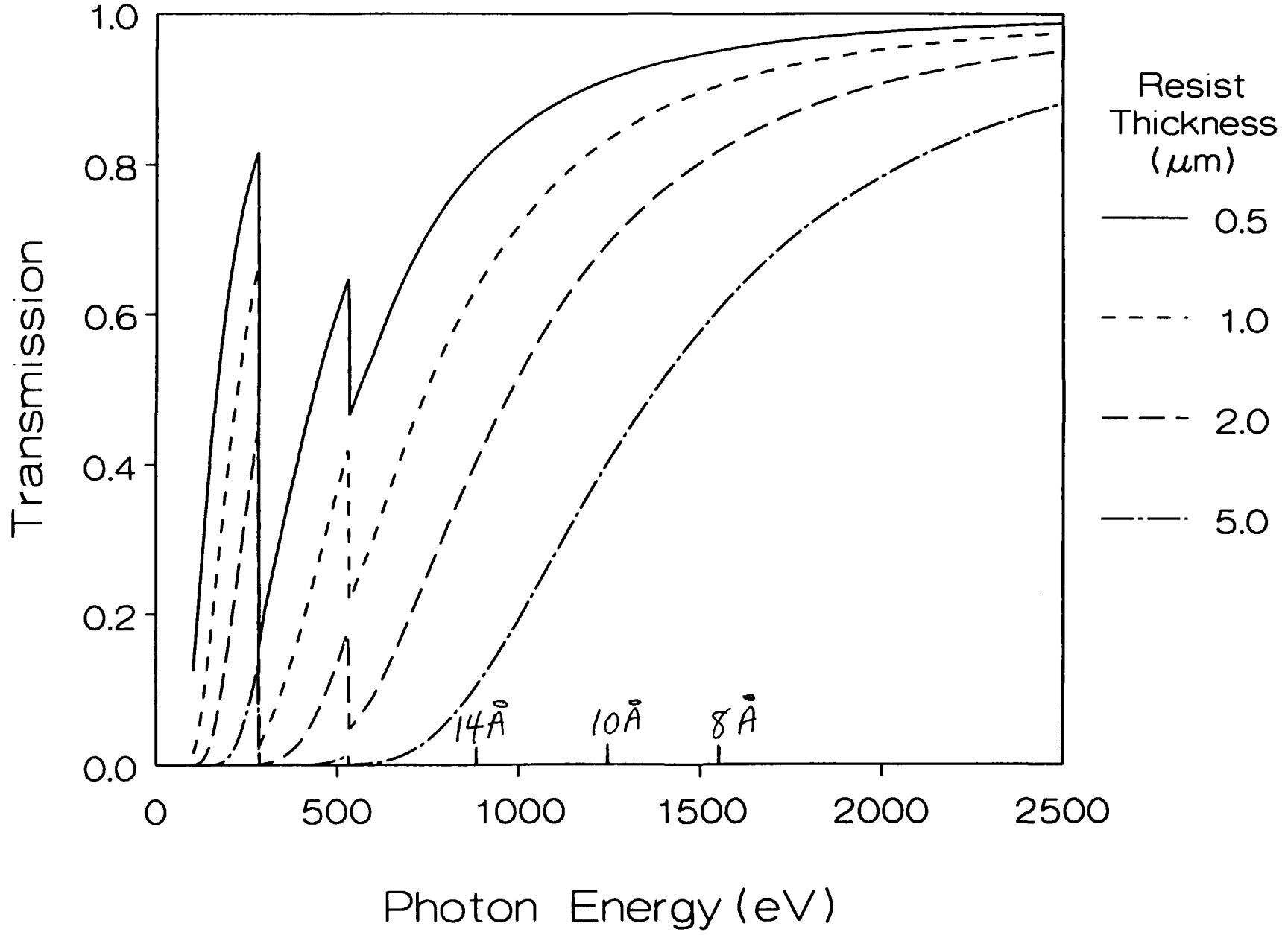
A. X-RAY MASKS + SUBSTRATE

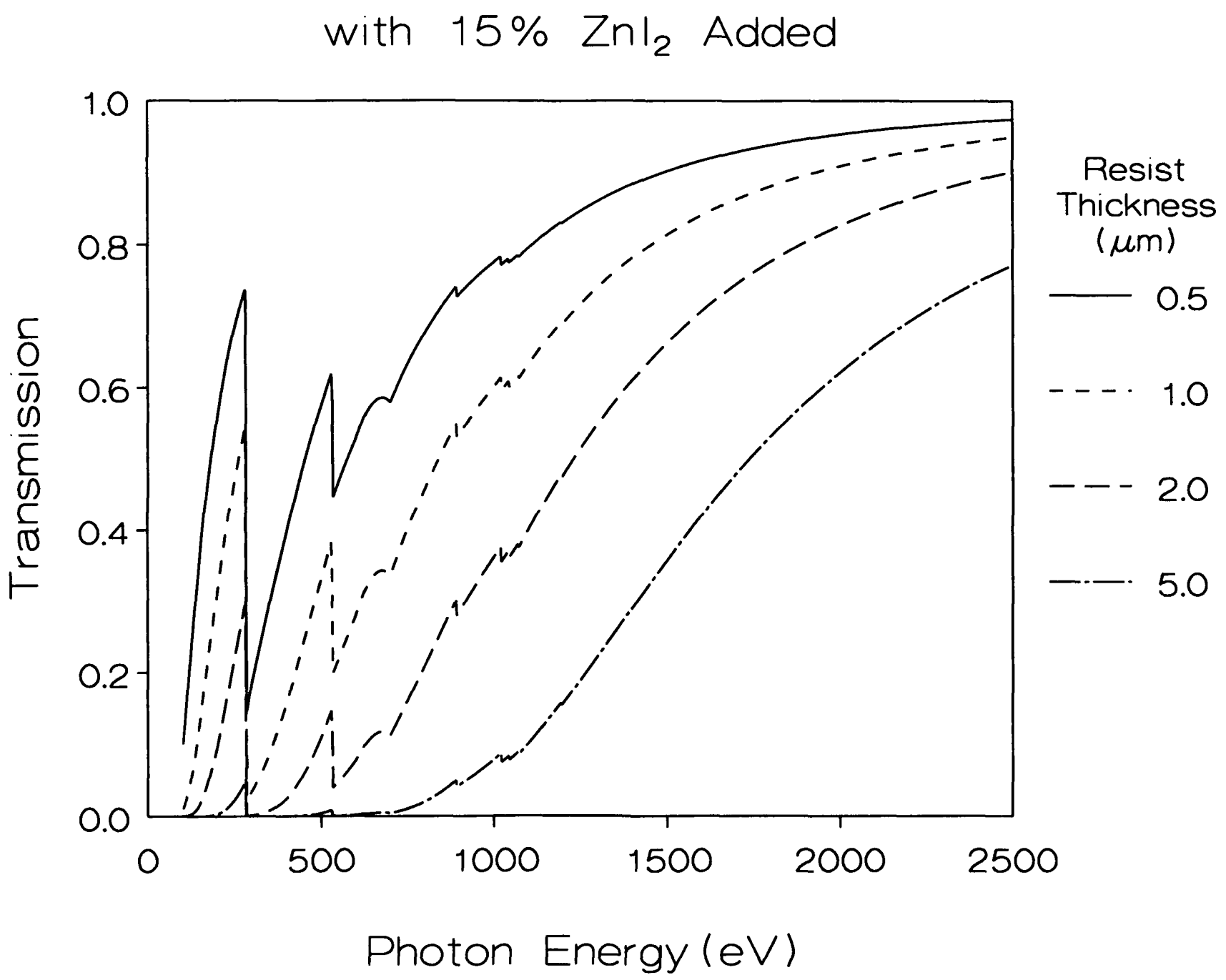
B. X-RAY RESISTS


Transmission of Thin Membranes
1.0
0.5
0.0
Transmission
750
1000
1250
1500
Photon Energy (eV)
0.5 μm C3H6
0.5 μm Si
0.5 μm SiC
0.5 μm Diamond
0.5 μm Si3N4
8.46 μm Be

Soft X-Ray Spectral Transmission

Spectrum	Region (Å)	Source Strength (eV/sr)	Helium Path 1atm 20-cm	Substrate Mask, SiC 1-μm	Substrate Mask, SiC 2-μm	Helium Path & Substrate 1-μm	Helium Path & Substrate 2-μm
Cu L	7-14	$4.0 \cdot 10^{18}$	84%	63%	40%	53%	33%
Fe L	8-17	$9.9 \cdot 10^{18}$	71%	43%	18%	30%	12%


X-Ray Transmission for PMMA
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
Photon Energy (eV)
14Å
10Å
8Å
Resist Thickness (μm)
0.5
1.0
2.0
5.0


X-Ray Transmission for PMMA
with 15% ZnI_2 Added
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
Photon Energy (eV)
Resist
Thickness
(μm)
0.5
1.0
2.0
5.0

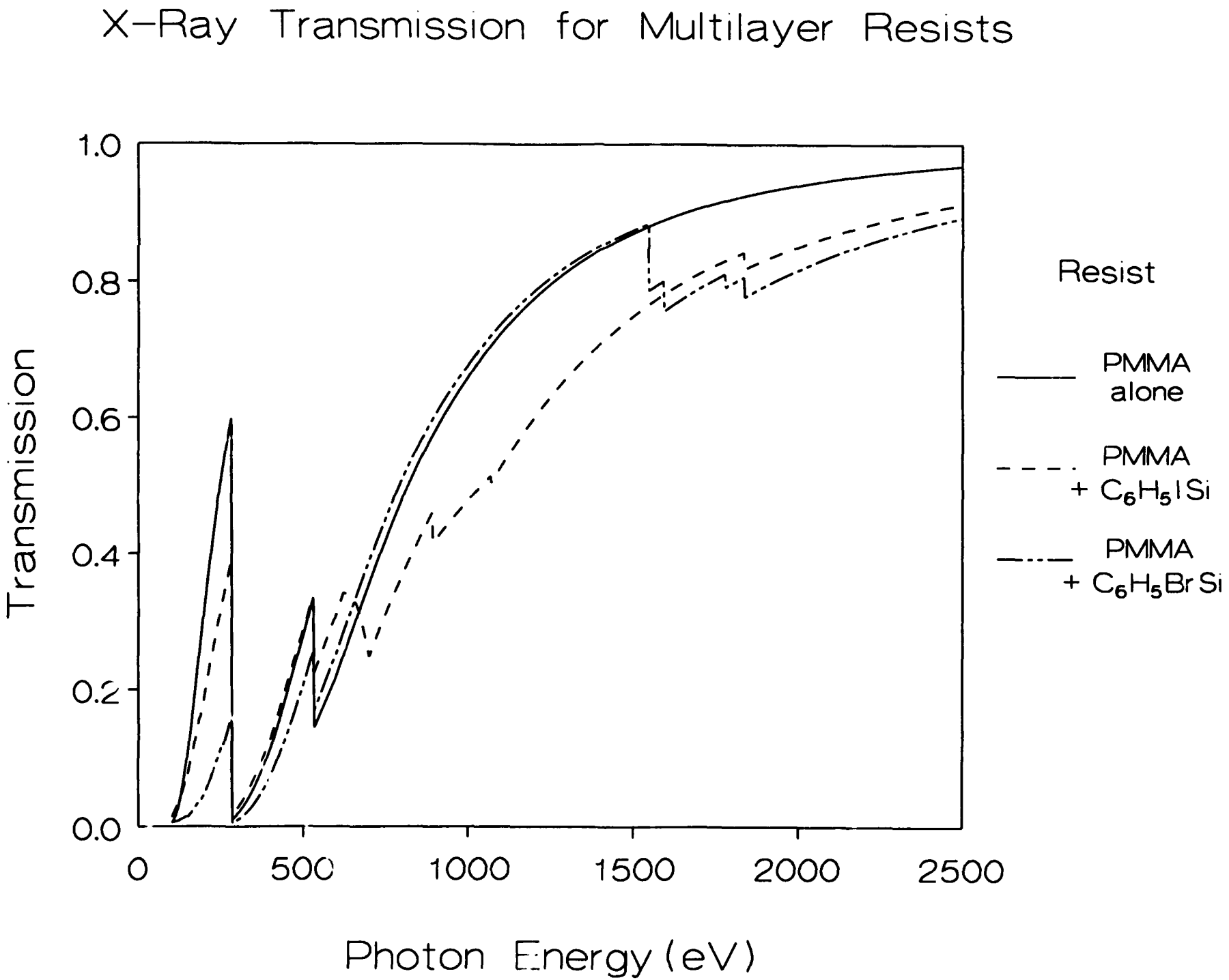

X-Ray Transmission for Multilayer Resists
Transmission
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
Photon Energy (eV)
Resist
PMMA alone
PMMA + C6H5ISi
PMMA + C6H5BrSi

Table II. Soft X-Ray Transmission.

Target Material	Source Emission (J/sr)	Mask Substrate (J/sr)	Resist PMMA (J/sr)
Aluminum	0.037	0.024	0.022
Copper	0.648	0.415	0.324
Iron	1.411	0.673	0.444

Table III. Soft X-Ray Absorption.

Target Material	Resist Exposure (J/cm^2)	ENERGY ABSORBED IN RESIST		
		PMMA (J/cm^2)	+15% ZnI (J/cm^2)	Multilayer (J/cm^2)
Aluminum	$6.00 \cdot 10^{-5}$	$4.84 \cdot 10^{-6}$	$8.45 \cdot 10^{-6}$	$1.23 \cdot 10^{-5}$
Copper	$1.04 \cdot 10^{-3}$	$2.29 \cdot 10^{-4}$	$3.63 \cdot 10^{-4}$	$4.67 \cdot 10^{-4}$
Iron	$1.68 \cdot 10^{-3}$	$5.72 \cdot 10^{-4}$	$7.13 \cdot 10^{-4}$	$9.23 \cdot 10^{-4}$

SUMMARY

The diagnostic instrumentation included filtered-PIN diodes, a diffraction-crystal spectrograph, and a film-recording x-ray pinhole camera. The x-ray spectrograph utilized a curved-KAP crystal.

An x-ray spectrum was recorded from a copper target. The most distinct and intense lines originate from transitions to the L-shell in neon-like copper. Spectral lines occur in the 8 - 14 Å region; however, the strongest lines are 2 - 3 level transitions in the 10 - 14 Å range from fluorine-like Cu XXI and Neon-like Cu XX. For the iron data, the same spectral transitions as in copper are generated but are shifted 3 - 4 Å to longer wavelength.

The x-ray output energy was determined assuming uniform emission over 2 π for the plasma generated at the surface of the planar targets. The soft x-ray conversion efficiency of the focused-laser beam was found to range from 1.9% at ¼ J to 3.2% at ½ J integrated over the 10 - 14 Å spectral region with an average efficiency of 2.5% for both copper and iron plasma. The total x-ray emission read in the 7 - 18 Å region is stronger for the iron targets by a factor of 3 because of the intense emission between 14 and 18 Å in neon-like Fe XVII. A soft x-ray conversion efficiency of greater than 10% was recorded for a ½ J iron target shot.

CONCLUSIONS

- **SOURCE STRENGTH**

  Alexandrite laser yields highest efficiency from iron target (L-spectrum) and lowest from aluminum (K-spectrum); however, copper has good L-shell spectral output in the 10 - 14 Å region.

- **LITHOGRAPHIC CONSIDERATIONS**

  Soft X-ray spectral transmission and absorption calculations revealed that the energy deposition into high-Z loaded PMMA resists can achieve greater than 45% soft x-ray deposition for copper and iron L-spectrum but only 20% for the energetic aluminum spectral distribution