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PPPL--2567

DE89 004628

Gain Measurements at 182 Å in C VI Generated by a Nd/Glass Laser

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Abstract

We present recent gain measurements in C VI at 182 Å for a soft x-ray amplifier produced by a line-focused glass laser(1.053 μm) on a solid carbon target. The maximum gain measured was 8 ± 1 cm^{-1} in the recombining plasma column with additional radiation cooling by iron impurities.

Recent research in soft x-ray laser development is progressing in the direction of obtaining shorter wavelengths. Significant advances are also being made in the XUV region. Much attention is being devoted to the first applications of these lasers. The possibility of using soft x-ray lasers for the microscopy of living cells has stimulated work to develop x-ray lasers operating in the wavelength region 23.3 Å to 43.7 Å, the so-called water window.[1] Impressive advances in longer wavelength XUV lasers, such as the one recently demonstrated at 1089 Å,[2,3] have significant potential applications in chemistry. An important point, however, that is rarely discussed, is the laser energy required for these applications. For instance, in order to record a high resolution image of a biological cell on photo-resist, a substantial laser beam energy is required. This is a significant concern in our current soft x-ray microscopy experiments,[4] even for the maximum output energy of our current 182 Å laser.[5]

We have, therefore, dedicated a significant effort to increase the energy of the 182 Å soft x-ray laser. One approach has been to develop additional amplifiers. This technique can also be applied to the shorter wavelength region where our current goals include the generation of lasing action both near 100 Å, using ions in the Li-like sequence,[6] and down to 10 Å, using a powerful picosecond laser for selective excitation.[7]

In this paper we present the first step in developing such amplifiers by the generation of gain in C VI at 182 Å using a Nd glass laser beam brought to a line focus on a solid carbon target in a strong magnetic field (field lines parallel to the line focus).

The role of the magnetic field is less important here than in our work in generating gain at 182 Å using a CO_2 laser point-focused along the magnetic field axis because of much higher initial electron density for 1 μm than for the 10 μm CO_2 laser. However, in the future, we plan to combine this amplifier with our CO_2 laser-pumped, magnetically confined soft x-ray laser; so, it is necessary that the Nd/glass laser pumped amplifier also work in a magnetic field and have a similar transverse dimension.

In the experiments the maximum laser energy used was 40 J, limited by the area of beam input optics, and the pulse duration was 3 nsecs. The 2 in. diameter laser beam was line-focused onto the cylindrical target by the combination of a 67 cm focal length spherical lens and 450 cm focal length cylindrical lens (Fig. 1). The dimensions of the line focus were ~ 100 μm by 5 mm. The length of the line focus was limited by the size of the magnet port. One of features of the target system is the capability of rotating the target so that for every shot a fresh target surface is exposed by the laser. A similar feature was obtained in the experiments performed by Jaeglé *et al.*[8] by translating a plane aluminum target. Gain was measured by changing the target length and hence the plasma length, as shown in Fig. 1. Another feature was the stainless steel blade 0.8 mm in front of the target. The 0.25 mm thick stainless steel blade is placed 0.8 mm away from the target surface. The function of the blade was to provide an additional cooling source: fully stripped carbon ions in the laser-produced plasma interact with the blade and cool down rapidly through thermal conduction and line radiation. Experiments with a target lacking the stainless steel blade showed significantly lower gain. A limited spatial region is selected by a slot in a mask 1.5 cm away from the target in the axial direction and viewed by the axial

XUV spectrometer. For the data presented below, the slot size was 0.8 × 2 mm and the near edge of the slot was 0.5 mm away from the target surface. Experiments in which the distance from the edge of the slot to the target surface was varied indicated a favorable condition for high gain in this region.

Fig. 2 shows the experimental data recorded with an axial grazing incidence soft x-ray spectrometer. The angle of incidence was 88 degrees and intensities of multiple orders were negligible. It was equipped with a 1200 grooves/mm grating at a blaze angle of 1 degree and a multichannel detector. The intensity dependence of the C VI 135 A, C VI 182 A, and C V 186 A lines with respect to the plasma length are shown. The data were obtained with 25 J of laser energy and the stainless steel blade and the slot dimensions as described above. The magnetic field was 50 kG. In the experiments it was found that the variation of laser intensity over the line focus limited the length of the plasma, over which gain medium could be achieved, to about 3 mm. The weaker laser intensity beyond the central 3 mm long region of the line focus did not create the same plasma conditons as in the central region, and the outside region absorbed the C VI 182 A emission radiated from the central 3 mm long region. The plasma lengths were 1, 2, and 3 mm. Emission by iron is clearly seen in the spectra. The 182 A line from C VI is blended with a similar wavelength line from iron. The line intensity of Fe XI 182 A is known to be about the same as that of Fe XI 179 A,[9] hence, the small contribution of Fe XI 182 A can be estimated and subtracted. In Fig. 3, the corrected line intensities of C VI 182 A (integrated over time and frequency) are plotted with respect to the plasma length. The data have been fitted by the formula[10]

$$I \sim \frac{(e^G - 1)^{\frac{3}{2}}}{(Ge^G)^{\frac{1}{2}}}, \tag{1}$$

for the output intensity of a Doppler-broadened, homogeneous source of amplified spontaneous emission of gain-length product G. This formula is correct in both the small and large gain-length limits. The theoretical gain curve of g = 8.1 cm^{-1} is drawn. It can clearly be seen that the C VI 182 Å line increases exponentially and the C VI 135 Å line linearly with the plasma length.

In conclusion, we have demonstrated a high gain of 8 ± 1 cm^{-1} at 182 Å in C VI using the newly developed carbon target system pumped with a 25 J, 3 ns Nd glass laser. We plan to combine this amplifier with the present soft x-ray laser of 182 Å in a CO_2 laser-produced, magnetically confined carbon plasma.

We thank H. Furth and W. Tighe for very helpful discussions. We greatly acknowledge D. Voorhees, G. Drozd, D. Dicicco, and B. Micholvic for their technical support of making the new system and providing the length-varying cylindrical target. G. Umesh wishes to acknowledge the government of India for supporting him with a post-doctoral fellowship.

This work was supported by the U.S. Department of Energy, Advanced Energy Projects of Basic Energy Sciences, the U.S. Air Force Office of Scientific Research, and NRL/SDIO.

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Figures

FIG. 1. The rotatable target system.

FIG. 2. Experimental spectra obtained by XUV spectrometer for different plasma lengths, 1, 2, and 3 mm.

FIG. 3. Plot of intensities of C VI 182 Å and 135 Å vs. plasma length. The dotted line is a theoretical gain curve of 8.1 cm^{-1}. It was taken with 25 J of laser energy and the magnetic field strength of 50 kG.

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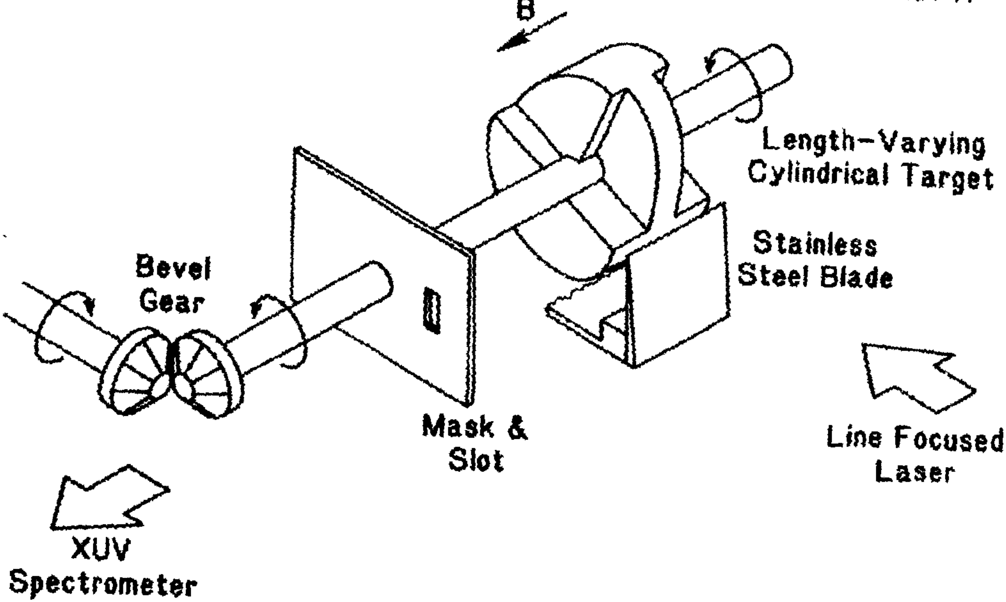

Fig. 1

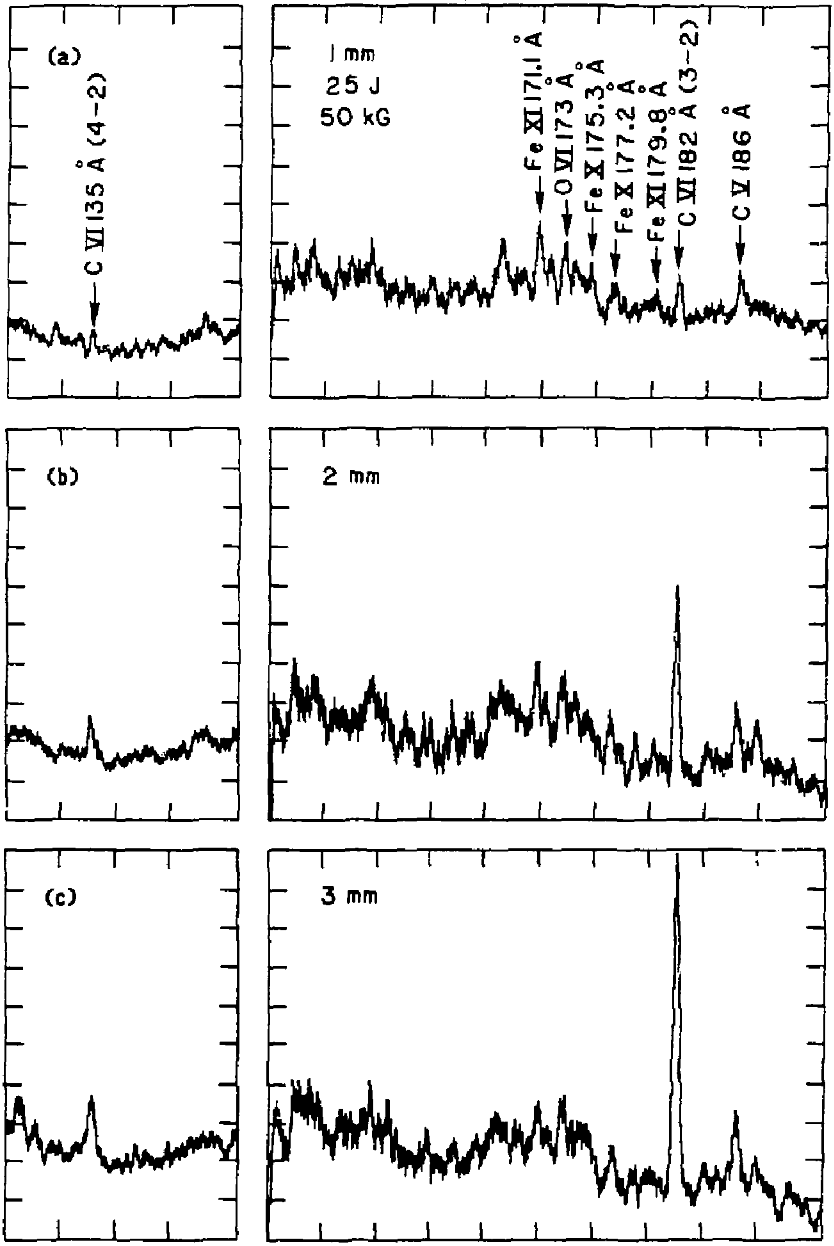
(a)
C VII 135 Å (4−2)
1 mm
25 J
50 kG
Fe XI 171.1 Å
O VI 173 Å
Fe X 175.3 Å
Fe X 177.2 Å
Fe XI 179.8 Å
C VI 182 Å (3−2)
C V 186 Å
(b)
2 mm
(c)
3 mm

Fig. 2

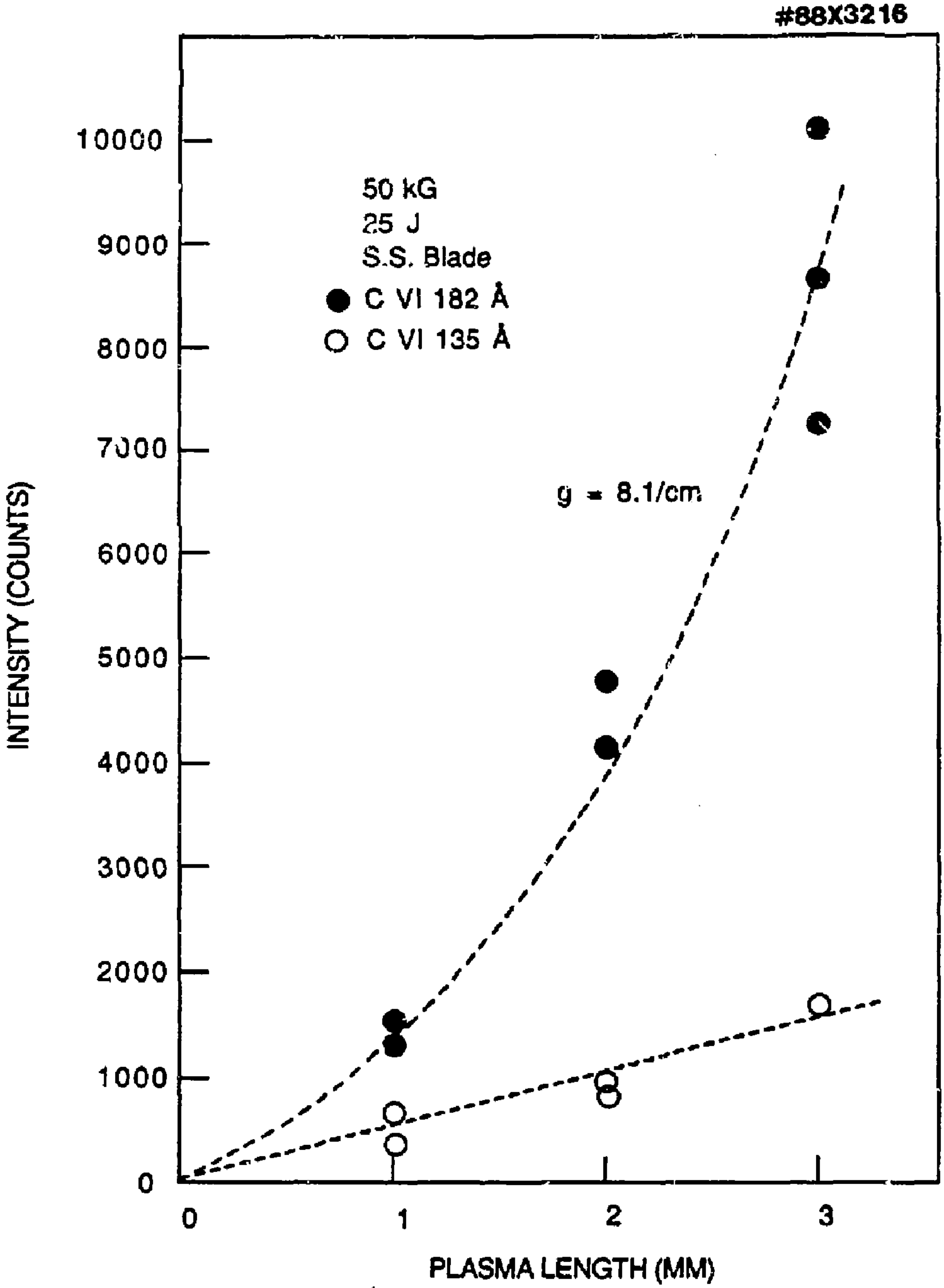
#88X3216
50 kG
25 J
S.S. Blade
C VI 182 Å
C VI 135 Å
g = 8.1/cm
INTENSITY (COUNTS)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
PLASMA LENGTH (MM)

Fig. 3