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Progress Report on the Lawrence Livermore National Laboratory Soft X-Ray Laser Program

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DISCLAIMER

PROGRESS REPORT ON THE LAWRENCE LIVERMORE NATIONAL LABORATORY SOFT X-RAY LASER PROGRAM*

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ABSTRACT

Significant progress toward the goal of producing high power, high coherence x-ray lasers has been made. Lasing at wavelengths as low as 66 Å has been achieved in a nickel like laser scheme which is scalable to sub-44 Å wavelengths. In addition, x-ray laser cavities, x-ray holography, and an applications beamline have been demonstrated.

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INTRODUCTION

The Laboratory Soft X-ray Laser Program at the Lawrence Livermore National Laboratory Nova Laser Facility has been pursuing soft x-ray laser research with the goal of producing highly coherent, high power sub-44 Å lasers. A general review of this effort has been presented by D. Matthews et al.,[1] previously. Significant new progress has been made toward this goal since then. Spectrally resolved source size measurements have shown that the total output energy of the Ne-like Se laser is now greater than the calculated saturation output energy. Multi-pass amplification using the Se laser has also been demonstrated in a laser cavity. Lasing has been demonstrated in Ni-like Eu at wavelengths as low as 66 Å. This scheme is scalable to sub-44 Å wavelengths. Research on recombination laser schemes which are also scalable to shorter wavelengths has been initiated. An x-ray laser applications beam line has been constructed and used in a photo-ionization physics experiment. Finally, x-ray holography using an x-ray laser has been demonstrated for the first time.

NEON LIKE SELENIUM

The Ne-like Se laser is produced when a powerful optical laser pulse ionizes an exploding foil geometry target.[1,2] The population inversion is produced by both collisional excitation and dielectronic recombination during the optical laser drive pulse.[1,3] The typical irradiance on the foil is 5×10^{13} W/cm^2 of 0.5 μm light in a 500 ps gaussian pulse. This produces laser emission at five wavelengths ranging from 182 to 263 Å. The dominate emission occurs at 206 and 209 Å. The emission at these wavelengths is more than five orders of magnitude greater than the spontaneous emission levels. The laser source size has been measured to be 50 μm in diameter.[4] With this source size, the output energy of about 150 mJ from a 4 cm long laser have been shown to be greater than the predicted saturation output energy of 70 mJ.[4]

LASER CAVITIES

Laser cavity development is important for the improved efficiency, divergence, and coherence of soft x-ray lasers. For the first time, multi-pass amplification of a soft x-ray laser has been demonstrated.[5] The cavity consisted of a spherical multi-layer mirror and a flat multi-layer beamsplitter placed at either end of the Se laser. The spherical mirror was a Si/Mo multi-layer deposited on a glass substrate. The beamsplitter was a Si/Mo multi-layer deposited on a 400 Å silicon nitride substrate. The thin silicon nitride substrate has high soft x-ray transmission. The measured reflectivities at 206 Å were 20% for the spherical mirror and 15% for the beamsplitter. The measured beamsplitter transmission was 5%.

Both double pass and triple pass amplification experiments were conducted. A time resolved spectrometer was used to monitor the laser output from the cavity. In the double pass experiments, the second pass was about seven times more intense than the initial amplified spontaneous emission. In the triple pass experiments, the initial laser emission, the second pass due to reflection off the mirror, and the third pass due to reflection off the beamsplitter and the mirror were time resolved. The second pass was about 20 times more intense than the first pass, while the third pass was comparable to the first pass. The drop in the third pass output was due to the rapidly decreasing gain as a function of time late in the laser time evolution.

NICKEL LIKE LASERS

The scalability of laser schemes to shorter wavelengths is important for such applications as holography of biological specimens where the laser wavelengths need to be in the "water window" (44-23 Å). The Ne-like schemes are estimated to require drive laser intensities of more than 10^{16} W/cm^2. These intensities, over focal spots several centimeters in length necessary for saturation, are beyond the capabilities of current optical lasers. Nickel like lasers, however, will only require approximately 4 x 10^{14} W/cm^2 for lasing at 43 Å. The Ni-like laser is an analog to the Ne-like laser except 4-4 transitions are used as laser transitions instead of the 3-3 transitions in the Ne-like lasers. The 4-4 transitions in Ni-like ions have a shorter wavelength for a given ionization potential than the 3-3 transitions in Ne-like systems. This results in less power being required for lasing to be achieved. Lasing at 66 and 71 Å has been demonstrated in Ni-like Eu.[6] Evidence for gain at 50.5 Å has been obtained in Ni-like Yb. These experiments are discussed in more detail in Ref. 4 (these proceedings). Experiments using Ni-like W, with laser emission at 43 Å are planned.

RECOMBINATION LASERS

Recombination lasers such as those demonstrated by Suckewer, et al.,[7] and Key et al.,[8] have simple atomic physics and a rapid scaling to short wavelengths. Hydrogen like Al has predicted gains of 5 cm^{-1} on the 3-2 transition at 39 Å using a drive laser intensity of 3 x 10^{15} W/cm^2. The output pulse length is predicted to be 10 ps in duration.[9] Lithium like Cr is predicted to also have laser emission at 39 Å with a drive laser power of 3 x 10^{14} W/cm^2. Ionization balance and spectral identification experiments are underway as a preliminary step to producing sub-44 Å lasing using recombination laser systems.[10]

APPLICATIONS BEAMLINE

The Se x-ray laser wavelengths (~200 Å), pulselength (~200 ps) and output energy (0.5 mj) are well matched to test the population inversion physics for a 372 Å photo-ionization laser in Na^{+1} proposed by W. Silfvast and O. Wood.[11] In order to utilize the Se laser, an applications beam line was constructed to collimate, relay, and focus the x-ray laser beam into a Na cell.[12] A schematic drawings of the system is shown in Fig. 1. The beamline consisted of two spherical multi-layers and a thin Al filter. The spherical mirrors had a peak reflectivity of ~26% at 208 Å and a radius of curvature of 4 meters. The narrow bandpass (~10%) of the mirrors was used to eliminate the background emission due to the non-lasing processes. The 1000 Å thick Al filter was used to eliminate stray 0.5 μm visible light from the drive laser scattered by the Se exploding foil target. A measured spot size of

300 μm in diameter was obtained using this optics system. This measurement was done with the optics slightly defocused. This spot size is consistent with a spot size of 100 μm in diameter, at best focus. The Se laser beamline has been used in a preliminary photo-ionization experiment with Ar.[13] Experiments with Na are planned.

HOLOGRAPHY

X-ray holography offers the possibility of obtaining high resolution (<500 Å) three-dimensional images of live biological specimens on timescales short compared to biological processes. This requires high power, highly coherent, sub-44 Å lasers. With the demonstration of Ni-like lasers, the demonstration of laser cavities, and the possibility of oscillator-amplifier x-ray laser chains,[14] such high quality lasers may soon be available for holography of biological specimens. As a first step toward the goal of making holograms of biological specimens, a proof of principle x-ray laser holography experiment has been demonstrated.[15]

The Se laser at 206 and 209 Å was used in a modified Gabor geometry. A schematic of the system is shown in Fig. 2. An ultra-smooth (<1 Å rms), ultra-flat (<λ/100) narrow bandpass multi-layer mirror is used to relay the x-ray laser beam to the holography object. The narrow bandpass (10%) eliminates high energy background. Kodak 101 x-ray film was used as a detector. An Al filter was used to protect the film from stray light. The primary object was an 8 μm diameter carbon fiber.

The results are shown in Fig. 3. The top portion shows a false gray scale image of the hologram fringe pattern obtained from the wire with the film response deconvolved numerically. The middle portion shows the average intensity across the data as a function of position, the bottom portion shows a calculated fringe pattern for the wire. Agreement is quite good except at large distances from the center of the hologram where the spatial frequency of the fringes is too high compared to the spatial resolution of the film. Holograms of three-dimensional gold bar figures were also obtained and reconstructions using a He-Ne laser were successfully produced. Alternative holography systems which offer potentially higher resolutions are being pursued. Requirements for making holograms of biological specimens with sub-44 Å lasers are also being studied.

CONCLUSIONS

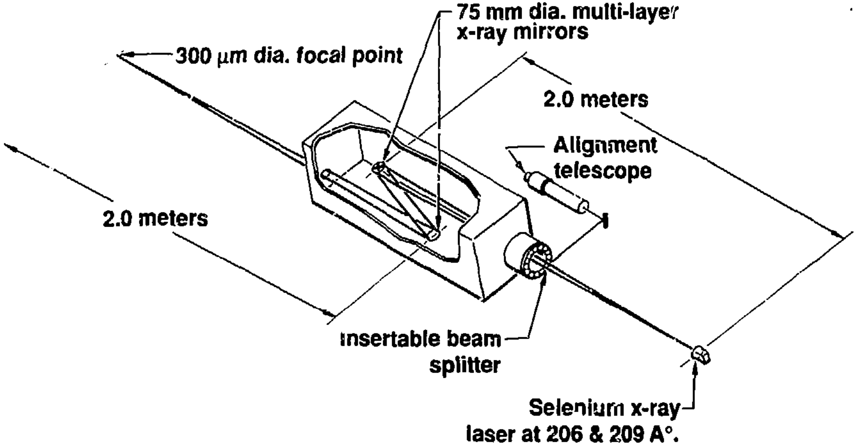
The LLNL soft x-ray laser program is now focusing on the development of sub-44 Å laser schemes which can be scaled to high power and high coherence. The technologies for this, such as cavities, oscillator amplifier designs, and x-ray optics are being developed. There is also an initial effort in developing x-ray laser holography as a useful tool in high resolution microscopy.

REFERENCES

1. D. Matthews, et al., J. Optical Soc.
2. D. Matthews, et al., Phys. Rev. Lett. 54, 110 (1985).
3. M. Rosen, et al., "On the Dynamics of Collisional Excitation X-ray Lasers," to be published.
4. D. Whelan, et al., these proceedings.
5. N. Ceglio, et al., "Multi-pass Amplification of Soft X-rays in a Laser Cavity," submitted to Optics Letters.
6. B. MacGowan, et al., "Demonstration of Soft X-ray Amplification in Nickel-like Ions," submitted to Phys. Rev. Lett.
7. S. Suckewer, et al., Phys. Rev. Lett. 55, 1753 (1985).
8. M. Key, et al., J. de Physique, C6, 71 (1985).
9. D. Eder, et al., "Recombination X-ray Lasers Using H-like Magnesium and Aluminum," submitted to JOSA B.
10. C. Keane, et al., to be published.
11. W. Silfvast, et al., "Short Wavelength Coherent Radiation: Generation and Applications," D. Atwood and J. Bokor, eds. (AIP, NY, 1986).
12. D. Nilson, et al., to be published.
13. W. Silfvast, O. Wood, et al., to be published.
14. M. Rosen, et al., Comm. Plasma Phys. Controlled Fusion, 10 245 (1987).
15. J. Trebes, et al., submitted to Science.

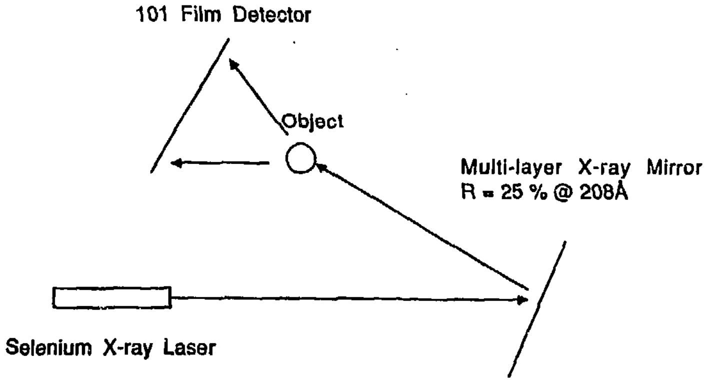
FIGURE CAPTIONS

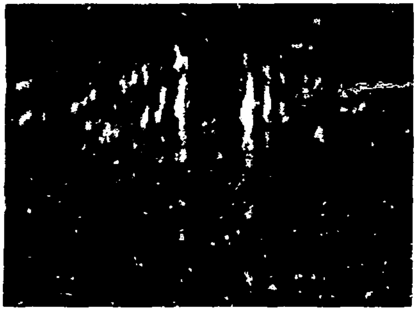
1. Schematic of the x-ray laser application beamline.
2. Schematic arrangement of the modified Gabor holography geometry showing the narrow bandpass x-ray mirror.
3. Upper -- fringe pattern from hologram of 8 μm wire. Middle -- average intensity as a function of position in the fringe pattern. Lower -- calculated intensity as a function of position for a hologram of an 8 μm wire.

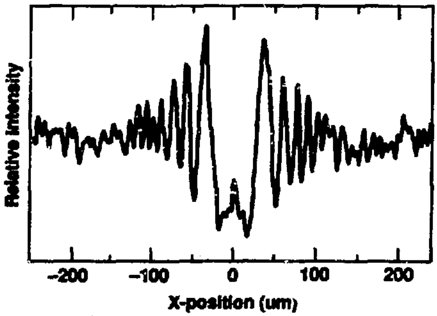


- Two multi-layer mirrors focus the x-ray laser to a 300 μm dia. point.

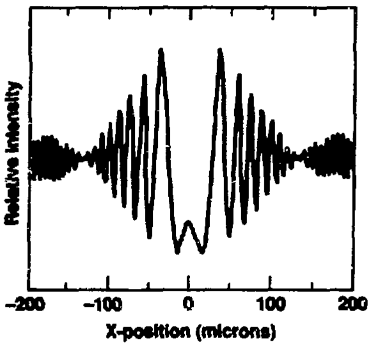
- The laser can be pointed with a 75 μrad accuracy with this mirror configuration.


101 Film Detector
Object
Multi-layer X-ray Mirror
R = 25 % @ 208Å
Selenium X-ray Laser





Relative Intensity
-200
-100
0
100
200
X-position (um)



Relative Intensity
-200
-100
0
100
200
X-position (microns)