Section 3
X-RAY LASER EXPERIMENTS

The extension of the laser into the x-ray range has long been the tantalizing objective of many research efforts. During the last twenty years, numerous papers have been published on a large variety of potential pumping schemes.[1] The enthusiasm for these studies has waxed and waned over this time, and although there have been overly optimistic claims which have not withstood the test of independent replication and close scrutiny, the objective has remained as unattainable as ever. The most publicized attempts to date, and those that have received the most attention, have been those x-ray laser schemes which employ high-power lasers to produce dense plasmas of highly stripped ions, in a geometric configuration designed to allow temporary population inversion to occur in the recombining plasma. Population inversion has been observed in recombining C, O, and Al plasmas.[2-4] The latter work, performed with the GDL laser system at the University of Rochester with both circular and line focus conditions, used targets in which the plasma was cooled by the interjection of a secondary metal foil in close proximity to the laser plasma. Studies of this approach continue.

Since the summer of 1982, preparations have been under way at both LLE and LLNL to investigate another approach to x-ray lasers. The basis of this approach is the use of x rays from a laser-produced plasma to pump specific transitions in a gaseous plasma or medium. This approach has been considered by a number of workers in the past, but has, up to the present, undergone little experimental

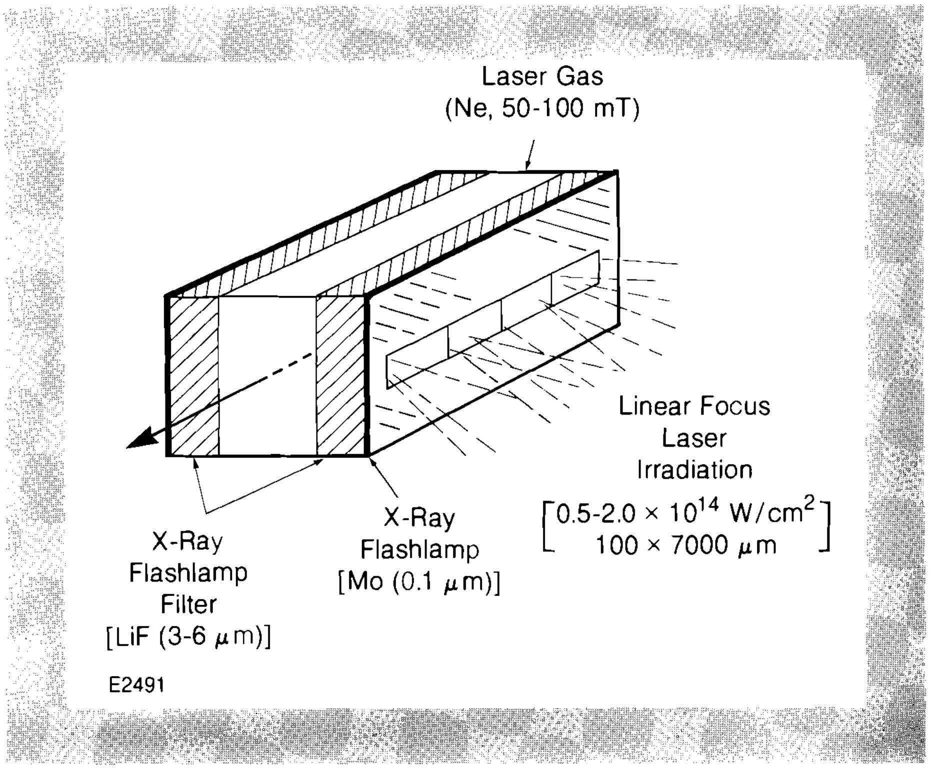

Fig. 21
Schematic of target configuration for laser-pumped, photo-absorption x-ray laser.

investigation.[5] Complex computations of this approach, using detailed hydrodynamic and atomic physics codes, have recently been made by Hagelstein.[6]

The general configuration of these types of x-ray laser experiments is indicated by the illustration in Fig. 21. A simple type of target consists of a rectangular gas-cell clad, preferably on both sides, with an x-ray filter and flashlamp assembly, the latter being irradiated by the laser beam or beams in line focus configuration. The close proximity of the flashlamp ensures good geometric coupling of the resulting x-ray emission to the laser medium; the thin x-ray filter prevents harmful spectral components of the flashlamp emission from detrimentally pumping the laser medium. The subsequent production of a transient population inversion in the gaseous or plasma medium may permit amplified spontaneous emission to be generated along the axis of the rectangular cell of the laser medium.

In this generalized approach to the application of laser-produced x rays to pump x-ray laser media, the emphasis has been on two specific schemes. In the first, x-ray line emission from specific transitions of highly ionized states in the x-ray flashlamp pump transitions in the x-ray laser medium. This approach can potentially demonstrate high gain for relatively high x-ray laser energies (i.e., short wavelengths), but does require exceedingly high tolerances in the degree of spectral overlap between the pumping radiation and the transition to be inverted. Investigations of this scheme are currently under way at Lawrence Livermore National Laboratory utilizing the new two-beam laser system, NOVETTE.[7] NOVETTE is capable of producing $\sim 10^{14}$ W/cm^2 in line focii having dimensions of $100 \times 20{,}000$ microns.

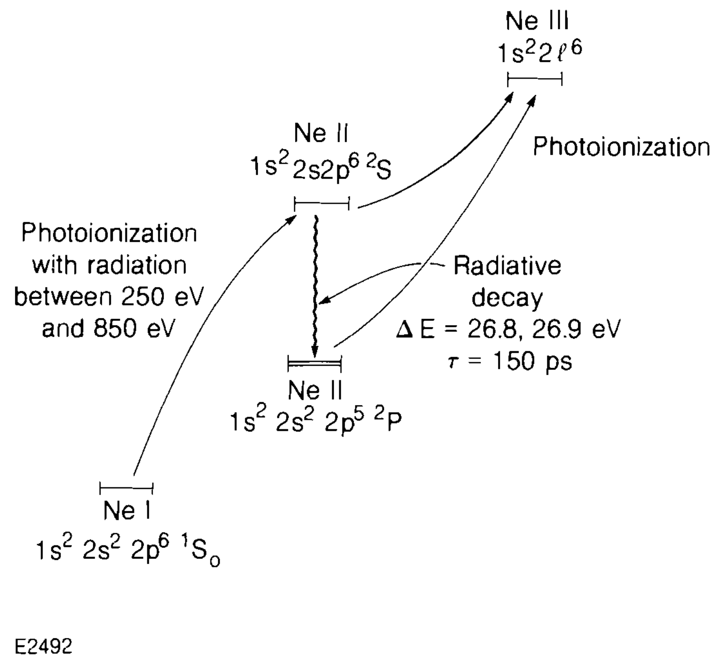

Fig. 22
NeII photoionization-pumped lasing scheme (from Ref. 6).

The second scheme employs a different pumping scheme in which broadband x-ray emission in the range 300-800 eV photoionizes a cool gaseous medium. An example of this pumping scheme is illustrated in Fig. 22. In this particular case, rapid photoionization of NeI to NeII is created, such that there is a transient population inversion between the 2p and 2s states of NeII. From previous experimental measurements (Wuillermier[8]), it is known that the photoionization cross section for the 2p level is greater than that for the 2s level for x-ray emission in the 300-800 eV range. Although this approach does not depend on precise spectral overlap between the x-ray pump radiation and the medium to be pumped, it does require that the x-ray medium remain un-ionized prior to photoionization by the soft x-ray emission. Well-controlled focus conditions are required to ensure that the x-ray medium is not subject to electron or x-ray preheat prior to irradiation by the soft x-ray source. The magnitude of the population inversion is predicted to be critically dependent upon rapid photoionization of the two states; therefore ultra-short pulse irradiation of the laser flashlamps is required. Experiments designed to investigate this approach are currently being conducted on the OMEGA facility. Eight beams of OMEGA, those in clusters 5 and 2, were converted to line focus conditions, each beam providing a line focus of 1.6 mm in length and 100 μm in width at 1054-nm wavelength. Four beams from each cluster are aligned end-on to provide a total irradiated focal area of 100 μm by 7000 μm (Fig. 23). These experiments require the shortest pulses which OMEGA can safely provide. The OMEGA system is operating with 50-ps (FWHM) pulses and an energy of 20 J per beam;

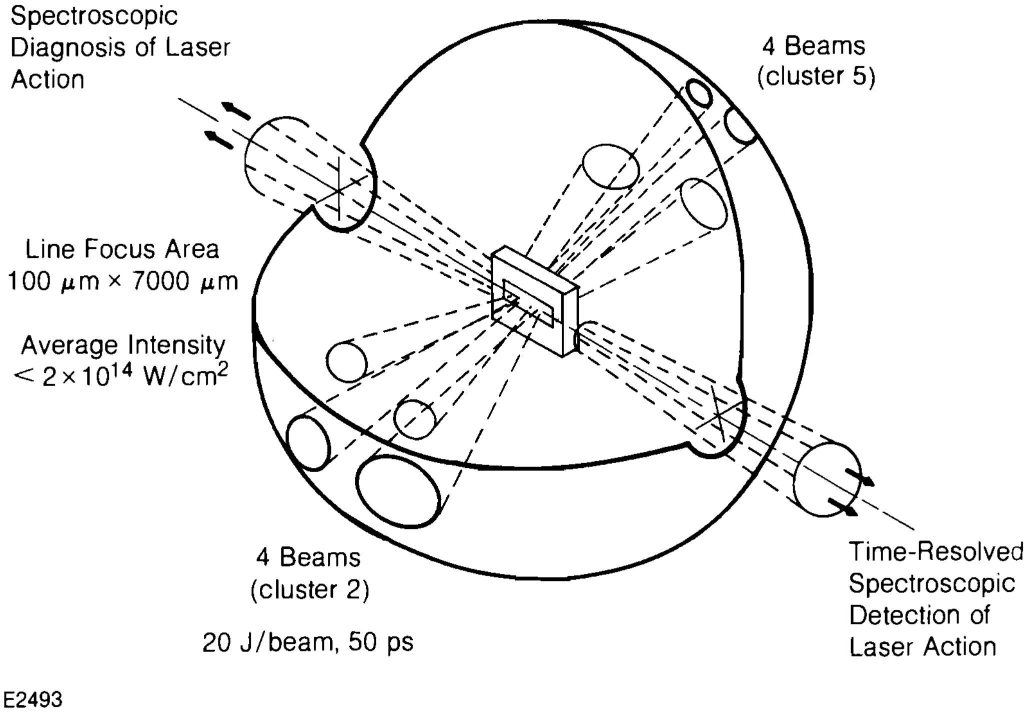

Fig. 23
Line-focus irradiation geometry on OMEGA.

thus, an average intensity in the line focus of $\sim 2\times10^{14}$ W/cm^2 is produced. Significant new problems of alignment are created in these types of experiments. The eight individual line-focused beams must be aligned in the correct position relative to one another, on a common axis. In addition, this axis must also be colinear with the axis of the target and the axes of the various diagnostics used to analyze the output of the target. For the current experiments, the individual beams have to be positioned to an accuracy of approximately 50 μm on the target axis, which itself has been aligned to within 10^{-2} rad of the XUV spectrometers deployed to analyze the output of the target.

The x-ray laser experiments on OMEGA are composed of three distinct parts. Initially we performed test experiments in order to (a) determine the quality of the line focus, (b) activate a large number of new diagnostics, and (c) perfect methods for target and beam alignment. Figure 24 shows an x-ray pinhole camera image of the four-beam line focus demonstrating the degree of alignment and focusing of the individual beams. Figure 25 shows a high-resolution optical image of the $2\omega_0$ emission from the focal region of the overlap of two beams. Microscopic structure emanating away from the focal region is clearly visible; this is suggestive of the existence of microscopic plasma or filamentary structures.

This phase of the program was followed by a short series of experiments to analyze the x-ray performance of the x-ray flashlamp

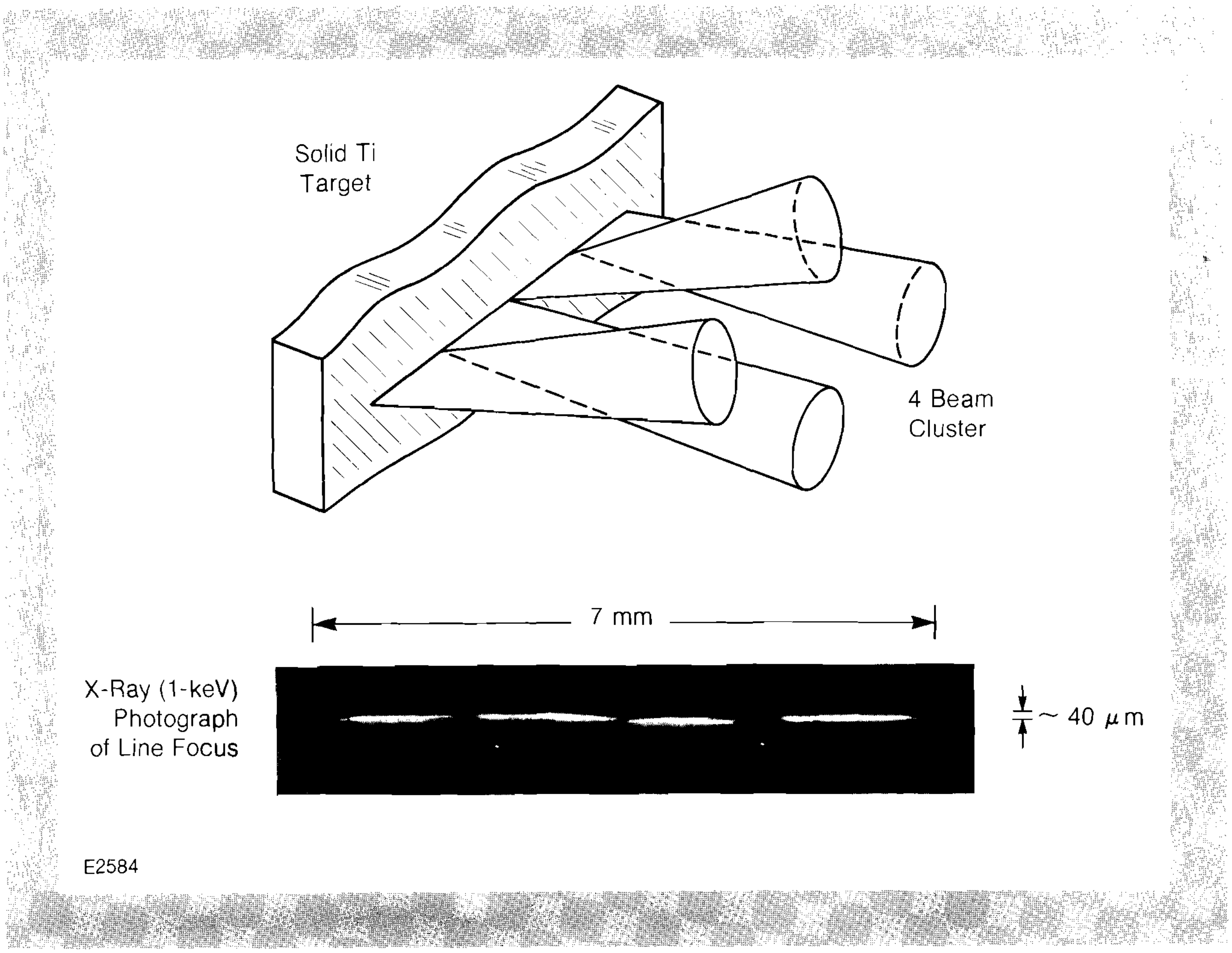

Fig. 24
X-ray pinhole camera image of four-beam line focus on OMEGA.

and filter assemblies. Finally, a series of experiments was performed on integral gas-filled targets, to examine the performance and potential of this approach to x-ray lasers. Detailed results from these experiments will be presented and analyzed in a future issue of LLE Review.

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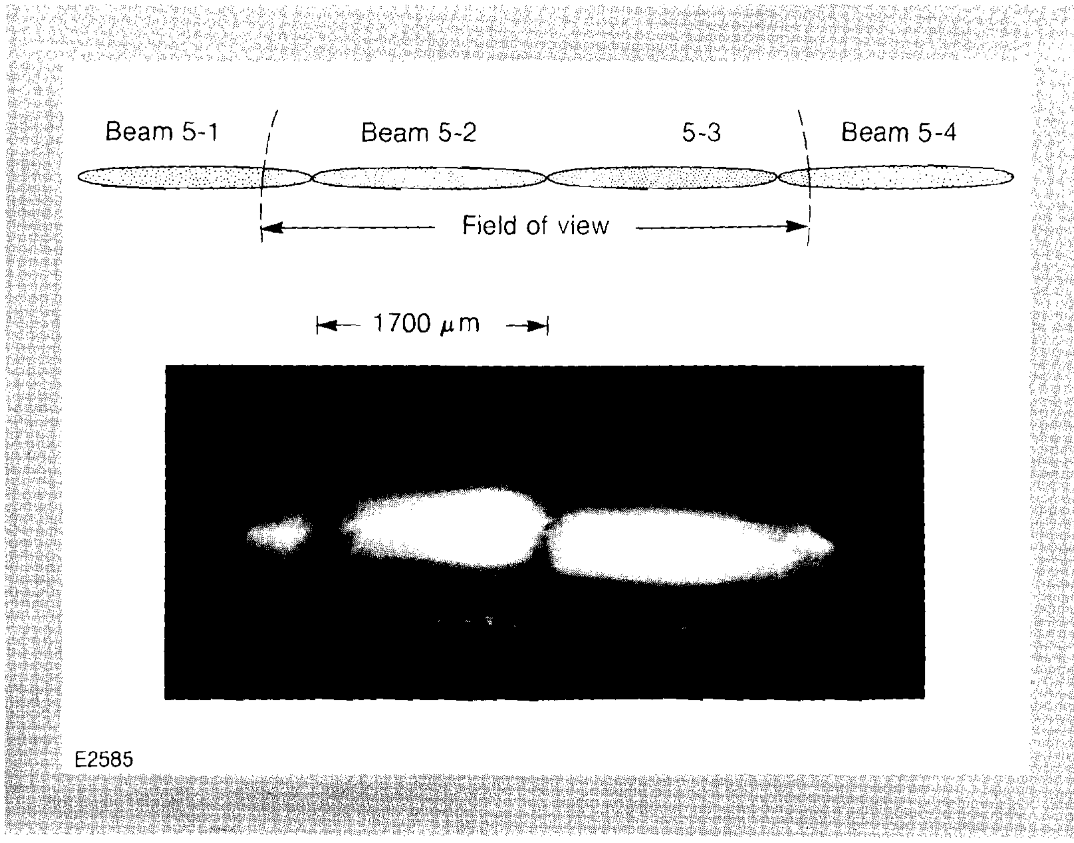

Fig. 25
Image of $2\omega_0$ emission from OMEGA line-focus experiment showing the region of overlap of two beams.

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