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RESONANTLY-PUMPED SOFT-X-RAY LASER USING ICF DRIVERS

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INTRODUCTION

The problem of developing a laser with a transition frequency in the EUV or soft X-ray regime is challenging, due primarily to the difficulty in developing an inversion on a line with appreciable gain under experimentally accessible conditions, and in part to the large local power requirements involved. The development of EUV and soft X-ray lasers would lead to advances in spectroscopy due to the potential for high brightness and narrow line width of the lasing radiation. There may be practical applications for a soft X-ray laser in the area of semiconductor photolithography. Short wavelegth holography may prove to be useful, assuming in both cases that the output laser radiation is sufficiently powerful, coherent and economical, and that production of the laser radiation can be carried out in a practical manner.

In this paper, we shall be concerned with some aspects of laser design relating to experiments planned for the NOVETTE laser system at Livermore in early 1983. The experiments are aimed at testing

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several resonantly-pumped lasers with transition energies between 42.3 eV and 153 eV. These experiments follow several years of theoretical work, a set of flashlamp characterization experiments performed on the SHIVA laser system (LLNL) in December, 1981, and some high precision spectroscopic studies carried out at KMS during the summer of 1982. We shall attempt to give an account of some of the major physics design issues as the relate to the experiments, and review some of the numerical simulations that have been carried out so far.

The present approach was originally proposed by Vinogradov et al (1975), who described resonant pumping (along with several other types of schemes) and presented a set of candidate resonances. Of primary interest is the Na X ($1s^2$-$1s2p\,^1P$) / Ne IX ($1s^2$-$1s4p\,^1P$) resonance with a mismatch of 0.46 eV, which, among others, is considered here. Norton and Peacock (1975) proposed and analysed a resonantly-pumped scheme involving C VI pumping C V, and Apruzese et al (1978) discuss the Si XIII/Al XII resonance. Bhagavatula (1980) describes theoretical and experimental work on resonantly pumped schemes (including a C VI/Mg XII resonance). Alley et al (1981) have carried out calculations of resonantly pumped helium-like systems at higher Z.

The designs described in this paper are based on work reported in Hagelstein (1981), and represent an improvement over designs described in that work. In particular, it was assumed that suprathermal electrons dominate the laser medium (at 6×10^{14} W/cm^2 of 1.06μ light incident on the flashlamp, this is a real possibility). At lower incident laser intensity and with frequency-doubled light (NOVETTE will be frequency-doubled for these experiments), the cooler thermal electrons dominate the free electron distribution, leading to much higher laser gain and fewer hydro-related problems.

Earlier works relied heavily on the use of K shell / K-shell resonances, as the K-shell lines are quite bright, their positions known accurately, and the physics of one- and two- electron systems are understood better than other atomic systems. The only precise resonance of this type at low Z is the Na X / Ne IX coincidence mentioned above. Bhagavatula (1980)

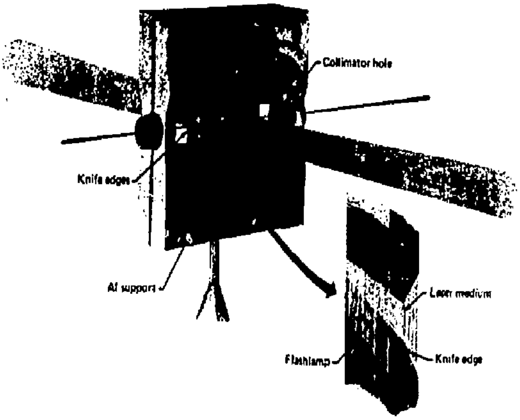

Figure 1. Proposed laser target for NOVETTE soft X-ray laser. Laser medium (which contains neon or fluorine) is a gas between flashlamp and filter systems.

is an exception; he proposed using 1-2 transitions to pump 2-4 lines in ions with twice the effective nuclear charge. We have focused on another approach, which involves using the strong 2-3 lines of 3-10 electron systems to pump the 1-3 and 1-4 transitions in low X helium-like and hydrogenic systems. We have also carried out the design and analysis of targets implementing such schemes much further than in previous works.

DESIGN ISSUES

The basic target consists of low density ($\sim 10^{18}/cm^3$) gas surrounded by flashlamp and filter systems which produce X-rays upon irradiation by $\sim 3 \times 10^{14}$ W/cm^2 100 ps frequency-doubled Nd (1.06μ) light (see Figure 1). The idea is to transiently strip the lasing element (neon, fluorine) down to the helium-like or hydrogen-like sequence, and then resonantly pump a 1-3 or 1-4 transition with line radiation produced in the flashlamp.

Table 1. Partial List of Candidate Coincidences

Lasant line			Pumping ion and line	λ(Å)	gf	Reference
F VIII	$1s^2$-$1s4p\ ^1P$	13.782	Be-like Cr $2p^2\ ^3P_2$-$2p3d\ ^3D_3$	13.779	3.42	Spector et al (1980)
Ne IX	$1s^2$-$1s4p\ ^1P$	11.000	He-like Na $1s^2\ ^1S_0$-$1s2p\ ^1P_1$	11.003	0.72	Scofield (1975)
			N-like Ni $1s^2p^3\ ^2D_{5/2}$-$2s^2p^2\ (^3P)3d\ ^2F_{7/2}$	11.00	0.97	Fawcett & Hayes (1975)
F IX	1s-3p	12.643	Ne-like Ni $2s^2p^6\ ^1S_0$-$2s^2p^5\ (^2P_{1/2})\ 3d\ ^3D_1$	12.654	0.83	Boiko et al (1978)
	1s-3p	12.645	Be-like Mn $2p^2\ ^1D_2$-$2p3d\ ^1F_3$	12.643	4.60	Boiko et al (1977)
F VIII	$1s^2$-$1s5p\ ^1P$	14.458	B-like Cr 2p-3d (unident.)	~14.46		

The B-like Cr line was observed in the December SHIVA shot by D. Matthews and L. Koppel. The KMS group verified that it is near coincidence.

In order to make X-ray laser of this type, one must arrange to have a coincidence present (a flashlamp line must overlap with the lasant line to within abou 3mÅ), with the pump line achieving a brightness close to 0.01 photons/mode (modal photon density equals occupation number--i.e.), $1/(e^{h\nu/kT}-1)$ for a blackbody). One must ensure that the neon or fluorine strips down to the helium-like sequence by the time the flashlamp is brightest, and that the walls do not cave in and ruin the laser medium before lasing has occured.

The major candidates for coincident pairs for the January NOVETTE experiments are given in Table 1. The references correspond to the various wavelengths measured for the pump lines. During the summer of 1982, a group of KMS (including G. Charatis, P. Rockett, and P. Burkhalter) conducted very high resolution coincidence experiments to verify these and other proposed resonant pairs. The analysis of the data is difficult due to the presence of substantial bulk Doppler shift of the lines and, as this paper is being written, the final results are not yet available.

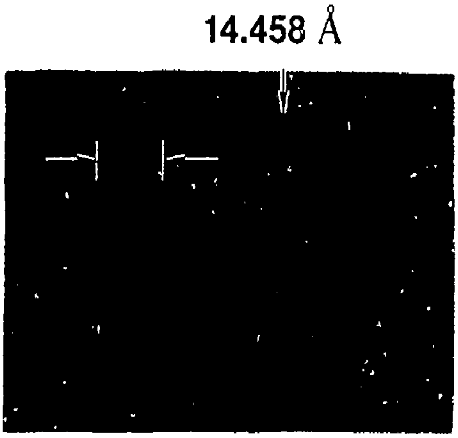

Figure 2. Example of KMS data for line coincidence experiment (with permission from KMS). The top line is the $1s^2$-$1s3p\,^1P$ line of F VIII and the botton trace is Cr near the 2p-3d B-like lines.

The brightness of the pump lines is a major issue, as the laser gain is linear in the pump strength at the present pump intensities. The flashlamps consist of a parylene layer (0.35μ) with an outer thin metal coating (500 A) of the pump metal. The metal faces the laser and produces a rich spectra when irradiated. In the simulations, the laser gains for the different schemes are comparable, and peak gains are calculated to be between 10 and 20 cm^{-1}, assuming that the pump line is resonant and has a strength of .01 photons/mode. The target is 1.4 cm long, and saturation is reached near 12 gain lengths. The most robust of the targets might reach saturation at 0.005 photons/mode pump, and signals may be measured at half of that. Simulations has been carried out on a benchmark target (Fe/CH) at 2×10^{14} W/cm^2 in the red (1.06μ, 100 psec), and the strongest lines of the spectra are calculated to have peak intensities near .01 photons/mode. In December of 1981, several candidate flashlamps were irradiated to determine the absolute pump intensities (these experiments were done by D. Matthews, M. Campbell, G. Tirsell, R. Kauffman, and Lou Koppel and will be reported elsewhere). The spectrographs record output energy modulo instrument and source broadening, and the intensity may be inferred given assumptions about line width and time history. The corresponding experimental numbers appear to be between .005 and .01 photons/mode in the brightest spectra. The candidate pump lines for pumping the laser are less intense, and seem to be in the .001 - .005 photons/mode range. Their calculated values are somewhat higher. The conclusion drawn is that one needs to pump much harder. For the NOVETTE soft X-ray laser experiments, the irradiation intensity will be near 3×10^{14} W/cm^2 in the green (0.53μ).

We have so far discussed briefly the spectroscopy and brightness issues. The timing of the transient ionization and hydrodynamic collapse are also important issues, and have not yet received attention experimentally. In the case of the transient ionization, we have relied on numerical simulation using XRASER and a 100 level atomic model. The code and model have been described elsewhere (Hagelstein (1981)), and suffice it to say here that it solves the time-dependent population kinetics, temperatures and line transfer in 1-D and 2-D in the PRD approximation. The continuum radiation field is taken from the flashlamp simulations, and is used to drive the kinetics. The ionization of the laser gas is due to photoionization and electron collisional processes, and the helium-like sequence is reached near the peak of the input laser pulse. Substantial hydrogenic population builds up late into the problem. These predictions have not been tested experimentally, and if the gas is for whatever reason slow in ionizing, the lasers will not work. In the case of the hydrogenic ion lasers, we have allowed in the target design some extra time in anticipation of the later arrival of hydrogenic ions.

The issues involved in the atomic physics and kinetics of the laser states has been described elsewhere as well, but it is worth adding that the low energy (4-3) lasers will be optically thin on the 1-4 line (at 5×10^{17}/cm^3 neon or fluorine), while the 3-2 lasers will be in a regime where 1-2 trapping is important ($1\text{-}2 \times 10^{18}$/cm^3 for the He-like and 8×10^{18}/cm^3 for the H-like). Some additional gas (CD_4) will be added to the laser gas for the 3-2 He-like laser to increase 3p-3d electron collisional coupling.

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