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MODELING THE ENERGY DEPOSITION IN THE AURORA KrF LASER AMPLIFIER CHAIN

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ABSTRACT

Monte Carlo calculations model the energy depositions by highly energetic electron beams into the cavities of the four KrF laser amplifiers in the Aurora chain. Deposited energy density distributions are presented and studied as functions of e-beam energy and gas pressure. Results are useful for analyzing small signal gain (SSG) measurements and optimizing deposition in future experiments.

INTRODUCTION

The KrF laser is a potential driver for inertial confinement fusion (ICF), and as part of the ICF program at Los Alamos, a large KrF laser system, called Aurora,¹ is under construction. Aurora consists of a front-end KrF laser resonator and a chain of four electron-beam pumped KrF laser amplifiers, whose names are abbreviated by SAM, PA, IA, and LAM. (See Fig. 1; more details of the design appear in Fig. 2 of Ref. 1.) Compression of the laser output pulse to 5 ns is achieved¹ by angular multiplexing (not illustrated in Fig. 1). The amplifiers have rectangular cavities 1-3 m in length (see Table I) with extraction volumes between 12 ℓ and 2100 ℓ .

Figure 1. Simplified schematic of the Aurora laser chain.

TABLE I Model Parameters for E-Beam Pumping

Property \ Laser	SAM	PA	IA	LAM	Average
Cavity Dimensions					
Width, A_x	22.2	31.5	53.3	107.0	13.0
Height, A_y	19.05	30.0	56.0	106.0	10.0
Length, A_z	120.0	320.0	320.0	280.0	100.0
Pumped height, A_{yp}	12.0	20.0	40.0	102.0	10.0
Pumped length, A_{zp}	100.0	280.0	280.0	208.0	2.0
Materials					
Foil (thickness, mil)	Ti(2)	Ti(2)	Ti(2)	Ti(1)	Rapton(2)
Walls	Cu	Cu	Cu	Cu	Al
Ends	SiO ₂	SiO ₂	SiO ₂	SiO ₂	CaF ₂
Gas Pressure (Torr)	900	750	400-1400	700	380-1520
χ_{comp} , Kr/F ₂ (balance Ar)	10/0.4	10/0.4	20/0.4	10/0.4	4/0.3
No. of pumped sides	1	1	1	2	1
E-beam energy (keV)	320	520	400-900	660	275
Appl. mag. field (kG)	0	1.2	1.2	1.6	4.0

MODELING METHODS

We have used a Monte Carlo code that originally modeled electron energy deposition in e-beam pumped CO₂ lasers². The generic configuration for each of the four laser amplifiers (Fig. 2) includes a rectangular cavity containing a Kr/F₂/Ar gas mixture, surrounded by six solid volumes. In present notation x measures distance (in the cavity) from the inner edge of the foil, $y = 0$ at half the height of the cavity, and $z = 0$ at the midpoint between end pieces.

Figure 2. Geometrical configuration of modeled lasers.

Calculations are accomplished in two stages. The first stage employs the "microscopic" physics of collisions and generates, for each material within the seven volumes, a data file consisting of (i) probability distribution functions for electron scattering into various angles and (ii) distribution for electron energy loss per unit path length (stopping power). For electron scattering, Monte Carlo techniques are used, assuming a "shielded Coulomb" form of the cross section with a shielding angle specified by Molière's formula^{2,3}. For the energy loss, the straggling distribution follows Landau's theory, with the mean loss rate normalized to Bethe's formula.³

The second stage models the "macroscopic" deposition using as input the physical dimensions of the laser, the applied fields, and the gas density. The Monte Carlo technique follows many electron trajectories, with each trajectory consisting of small substeps. Within each substep the relativistic equations of motion are time-integrated, including effects of Lorentz forces from the applied fields and the continuous stopping-power force. Scattering occurs at the end of each substep. Output from the second stage consists of fractional absorptions in the objects surrounding the cavity and a three-dimensional density function for the energy (per electron) deposited in the gas. The energy is accumulated at 51 positions (including the end points) in each dimension, and the complete density function is the collection of evaluations in the $(51)^3$ sub-volumes. Summation over one or two dimensions allows a graphical routine to illustrate the density by a curve in one dimension, or to represent the distribution in two dimensions by a contour plot.

The Monte Carlo energy per electron deposited in the gas, W_g , is an integral of the density function over three dimensions. W_g is related to the average energy density deposited in the gas, E_d , by the approximate formula,

$$E_d = W_g I_b \Delta t / v, \quad (1)$$

where I_0 is the electron beam current, Δt is the duration of the input pulse (here taken to be fwhm), and v is the volume of the cavity.

The present code has modeled a small signal gain (SSG) experiment at the Avco Everett Research Laboratory.⁴ The cavity of their KrF laser resonator was much smaller than those of our amplifiers (see Table I), and their e-beam operated at lower energy than ours. Our calculated one-dimensional distributions are in good agreement with their (normalized) data presented in Fig. 7 of Ref. 4. (Our x-direction is equivalent to z in their notation.)

RESULTS

The energy distributions for the Aurora amplifiers are plotted within the cavity dimensions specified in Table I. Fig. 3 refers to gain probe experiments on the SAM laser, in which four probe beams were aligned parallel to the z-axis

Figure 3 Deposition profiles in y at the two x -coordinates of gain probes. Dashed lines show top and bottom edges of the foil. Dotted lines mark aperture edges. Heavy dots indicate the gain probe lasers.

and were placed at the following (x,y) coordinates (in cm) $(7.8, 0)$, $(15.3, 0)$, $(15.3, \pm 4.5)$. SSG coefficients of 3.6, 1.8, 1.6, and 1.6 %/cm were measured at the four respective positions. The two y -profiles were obtained by integrating the 3-dimensional distribution over z , with x fixed at the sub-interval center nearest the probe position. Reflection symmetry was imposed about $y=0$ to reduce statistical noise. Calculated relative energy absorptions at the positions of the gain probes are in excellent agreement with the observed ratios of gains.

Figure 4 shows one-dimensional (twice integrated) distributions across the cavity of the PA laser. The degradation of pumping in the y direction is gradual near ± 10 cm (the edges of the foil), rather than abrupt, and only the central 10 cm interval is nearly uniformly pumped. Figure 5 gives the contour plot for the xy -distribution. Here the three dimensional density function was smoothed, symmetrized about $y=0$, and summed over the z -direction.

PA Model: Electron Energy Density Distributions
in One Dimension

Figure 4

Deposited Energy Density (ϵ, y) for the PA Laser

Figure 5: A smoothed (symmetrized) two-dimensional energy distribution function. The ten contours are evenly spaced in the deposited (over integrated) density 0.04 0.06 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 keV/electron-cm².

Figure 6

Electron energy deposition in the cavity of the 1A laser is modeled as a function of the e-beam energy (W_b) and gas pressure (P) in Fig. 6. Contours were derived from the values of W_g calculated at 36 points in the (P, W_b)-plane corresponding to $P = 400, 600, \dots, 1400$ Torr and to $W_b = 400, 500, \dots, 900$ keV. At each point the average energy density, E_d , was obtained from Eq. (1), using the Child-Langmuir law^{6,6},

$$I_b \propto W_b^{1.5}, \quad (2)$$

Figure 7 Families of one-dimensional deposited energy distributions for the LAM laser

addressed. For example, in Table II, calculated absorptions by the first and second foils indicate that, on the average, an electron deposits substantially less energy in the second foil than in the first. Therefore, the stress at a given foil is not greatly increased by the incidence of a second e-beam (from the opposite side of the cavity).

to scale the beam current, whose value of 97 kAmp was deduced at $W_b = 520$ keV from results of kinetics calculations⁷ and a measurement of SSG.

The LAM laser is the largest in the Aurora chain, and is designed for symmetrical 2-sided pumping to enhance uniform deposition across the 1 m width of its cavity. Table II gives the relative energies absorbed in the cavity and surrounding volumes, for single-sided pumping. Because of the magnetic field, the end pieces (see Fig. 2) are too far from the foil to absorb electrons. Figure 7 shows one-dimensional (twice integrated) energy distributions within the cavity as a function of the e-beam energy and gas pressure. Each curve for two-sided pumping is the superposition of the one-sided pumping curve with its reflection about the central value of x .

DISCUSSION

Parametric studies, such as Table II, reveal trends in relative energy absorptions in the seven volumes of Fig. 2 and guide future experiments to optimize pumping conditions. Column 3 of Table II is the gas pumping efficiency. Presently the LAM has the most efficient deposition of the four amplifiers (primarily because of its cavity width), as approximately 80% of the electron energy is absorbed by the gas. In the three smaller lasers, the fractions are typically 30–40% for the SAM and 40–45% for the PA and IA. Contours of pumping performance for the IA, in Fig. 6, were derived from calculated fractional electron energies deposited in the gas. Other practical questions are

TABLE II. Monte Carlo Electron Energy Deposition for the LAM Laser

P _t (Torr)	V _b (keV)	Fractional Absorptions of Energy per Electron					V _a c (keV)
		Gas	1st Foil	2nd Foil	Top. bott.	Losts	
600	400	0.815	0.112	0.000	0.008	0.066	326
	500	0.833	0.082	0.004	0.012	0.070	417
	600	0.823	0.058	0.023	0.015	0.080	494
	700	0.773	0.047	0.035	0.018	0.128	541
900	400	0.815	0.113	0.000	0.007	0.066	326
	500	0.841	0.080	0.000	0.010	0.068	421
	600	0.870	0.058	0.000	0.014	0.058	522
	700	0.870	0.046	0.006	0.018	0.060	522

*Each row represents calculation of 20300 independent electron trajectories

*T=295°K is assumed for calculating densities

*This is the product of entries in the second and third columns of this table.

*Electrons are lost to the vacuum either by backscatter from the first foil or by penetration of the second foil. By assumption, 50% of such electrons (selected randomly) are lost.

On the subject of detailed energy density in the gas, the close agreement between SSG measurements and calculated deposition for the SAM laser suggests that Monte Carlo distributions faithfully indicate regions of relatively high gain in the cavity. In particular, the contours in Fig. 5 should accurately characterize the SSG in the PA laser. Figure 7 shows that the energy distribution (and gain) in the cavity can be very sensitive to beam energy and gas pressure. Finally, deposited energy densities E_d , and temporal pulse shapes, provide the power input to time-dependent kinetics calculations of SSG and laser extraction.⁷ A future application will be to model the spatial profiles of beam intensity at the exit aperture of each laser amplifier in the Aurora chain.

REFERENCES

- 1 L A Rosocha, J A Hanlon, J McLeod, M Kang, B L Kortegaard, M D Burrows, and P S Bowling, Fusion Technol 11, 497 (1987)
- 2 J C Comly, W T Leland, C J Elliott, A M Hunter, and M J Kircher, IEEE J Quantum Electron QE17, 1786 (1981)
- 3 M J Berger, Meth Comp Phys 1, 135 (1963)
- 4 A Mandl, D Klimek, and J H Parks, J Appl Phys 55, 3940 (1984)
- 5 C D Child, Phys Rev Ser I, 32, 492 (1911)
- 6 I Langmuir, Phys Rev Ser II, 2, 450 (1913)
- 7 S J Czuchlewski, D E Hanson, B J Krohn, A R Larson, and E T Salesky, Fusion Technol 11, 560 (1987)