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Evaluation of the Potential to Upgrade the Sandia Atomic Iodine Laser SAIL-1 to Higher Output Energies

Merle E. Riley, Richard E. Palmer

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EVALUATION OF THE POTENTIAL TO UPGRADE THE SANDIA ATOMIC
IODINE LASER SAIL-1 TO HIGHER OUTPUT ENERGIES

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ABSTRACT

The predicted output energy of the Sandia Atomic Iodine Laser SAIL-1 is given for various numbers of preamplifier stages and for various small signal gains in each stage. Additional possibilities for further increasing the output energy are given.

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I. Introduction

The atomic iodine laser is capable of producing output powers equal to 1 TW and output energies of several hundred joules.^{1,2} The atomic iodine laser at Sandia Laboratories, SAIL-1, is a moderate-sized system consisting of an oscillator, a preamplifier, and a final main amplifier. In its present form, it has produced output energies of 10 J with output powers of 30-40 GW. If the output energy were somewhat higher, SAIL-1 could be an extremely useful research tool in the study of laser plasma interactions. The purpose of this report is to evaluate the expected energy output from SAIL-1 for various numbers of additional preamplifier stages and for various gains in each stage.

In Section II the theoretical bases used to calculate the expected energy output are discussed. The results for many different system configurations are given in Section III. Section IV deals with a number of limiting conditions relating to beam quality and spurious outputs such as prelude and amplifier self-oscillation. Section V mentions a few possibilities to increase the energy output even further, i.e. a two-line oscillator, improved pumping, and the use of cassegrainian optics.

II. Theory

A. Two-Level Radiation Transport Equations

An accurate description of the amplification of subnanosecond pulses in the atomic iodine system requires the Maxwell-Bloch theory, since the pulsewidth and the medium coherence decay time are comparable.³ However, if the pulsewidth is on the order of a nanosecond or longer, the Maxwell-Bloch equations can be approximated by the photon rate equations. Moreover, in most of the circumstances of interest here, the medium behaves like a two level atomic system with level degeneracy. The rate equations describing the evolution of the pulse and the medium are

$$\left(\frac{\partial}{\partial z} + \frac{1}{c} \frac{\partial}{\partial t} \right) I = \frac{\partial I}{\partial z'} = \sigma_{se} I n$$

(1)

$$\frac{\partial n}{\partial t} = \frac{\partial n}{\partial t'} = -b \frac{I}{h\nu} \sigma_{se} n .$$

$I = I(z, t)$ is the intensity in units of power per area; z is axial distance; t is time; $t' = t - z/c$ is the retarded time variable with $z' = z$; n is the inversion number density, defined in terms of the upper (U) and lower (L) level densities as $n = g_U n_U / g_L$; g_U and g_L are the degeneracies; $b \equiv 1 + g_U/g_L$; σ_{se} is the stimulated emission cross section for the $U \rightarrow L$ transition. By appropriate scaling of the dependent variables I and n , the nonlinear partial differential equations take the form

$$\frac{\partial y}{\partial z'} = xy , \quad \frac{\partial x}{\partial t'} = -xy ,$$

which have the general solution first presented by E. O. Schulz-DuBois and Bellman, Birnbaum, and Wagner:^{4,5}

$$x = -\frac{\partial \phi}{\partial z'}, \quad y = \frac{\partial \phi}{\partial t'}$$

$$\phi = \ln(F(t') + G(z')) .$$

F and G are arbitrary functions that are determined by the initial conditions. The pulse shape is not of particular interest here, so the time-integrated intensity, or flux,

$$F = \int_{-\infty}^{\infty} dt I ,$$

which is in units of energy per area, is used. One can show that the output flux from an amplifier of small signal gain $G^{ss} = \exp(n \sigma_{se} L)$, is given by

$$F_{out} = F_s \ln \left[G^{ss} (\exp(F_{in}/F_s) - 1) + 1 \right] . \quad (2)$$

F_{in} is the incident flux and F_s is the saturation flux:

$$F_s \equiv \frac{h\nu}{b\sigma_{se}} . \quad (3)$$

Various limits and forms of eq. (2) are useful for amplifier analysis.

First of all, there are the small signal and large signal limits:

$$F_{out} = G^{ss} F_{in} \quad F_{in} \rightarrow 0$$

$$F_{out} = F_{in} + F_s \ln G^{ss} = F_{in} + h\nu \frac{nL}{b} \quad F_{in} \rightarrow \infty$$

In the second place, one can derive a simple expression for the incident flux required to extract a fraction θ of the extractable stored energy:

$$F_{\theta} = F_s \ln \left[\frac{G^{ss} - 1}{G^{ss} - (G^{ss})\theta} \right] .$$

If $G^{ss} \gg 1$, which is almost always the case, the flux required to extract one-half the maximum possible amount is given by

$$F_{1/2} = F_s / \sqrt{G^{ss}} . \quad (4)$$

If the laser beam is not diverging strongly, and by this is meant that the beam diameter is not changing by more than a few percent within a given amplifier, the previous eqs. (1) - (4) apply to a given radius within the transverse span of the beam. Thus, all fluxes depend on radius r and the pulse energy is obtained by integration:

$$E = 2\pi \int_0^{\infty} r dr F(r) .$$

The radial integral over flux cannot be performed analytically, even in the case of an r -independent inversion and an incident Gaussian beam. Thus the energy is evaluated numerically before and after each amplifier pass. The fluxes are evaluated on a radial grid consisting of more than 100 points within the radial span of the pulse.

B. Atomic Iodine Transition Parameters

There are six hyperfine transitions in atomic iodine,⁶ each of which is pressure broadened by Ar at the rate of ~ 6 MHz/Torr.^{7,8} The oscillator

typically runs only on the $^2P_{1/2}(F = 3) \rightarrow ^2P_{3/2}(F = 4)$ line. The small signal gain cross section is evaluated at the oscillator frequency by considering all six transitions and their appropriate overlap (although small at Ar pressures ≤ 1250 Torr) with the oscillator frequency. The appropriate upper state populations are likewise included. There are two upper state levels, $^2P_{1/2}(F = 3)$ and $^2P_{1/2}(F = 2)$. Only the former contributes significantly to the energy extraction at the $F = 3$ to $F = 4$ wavelength at amplifier pressures ≤ 1250 Torr, so the effective inversion number density is only $(g_F = 3)n/(g_F = 3 + g_F = 2) = \frac{7}{12} n$. Recall that n is the total inversion number density in the $^2P_{1/2}$ manifold. The degeneracy of the $^2P_{1/2}(F = 3)$ level is 7, and this is taken to be g_U . The effect of a two-line oscillator is discussed further in Section V, but briefly it would be to increase the effective inversion number density to n with degeneracy 12.

The lower $^2P_{3/2}$ hyperfine levels are strongly coupled by collisions with Ar, which also create the line broadening. At a pressure of 600 Torr, the characteristic time for mixing the lower hyperfine levels is 0.04 nsec.⁹ Thus it is assumed that the lower state degeneracy $g_L = g(^2P_{3/2}) = 24$, i.e. the entire lower $^2P_{3/2}$ manifold is coupled into a single state. These choices for g_U and g_L and the exact evaluation of G^{ss} allow the inclusion of all the important properties of the six-level system into the two-level analytic solution given in the previous sub-section.

No kinetic pumping or deactivation terms are included in eq. (1). These are not important in the iodine system for the present pumping and extraction time scales.

C. Beam Propagation

The oscillator in SAIL-1 in its current form emits a beam very similar to a TEM₀₀ Gaussian with a Rayleigh range ($z_0 = \pi w_0^2/\lambda$) of 4.09 m, a waist

(w_0) of 1.31 mm, and a divergence ($\theta_d = \lambda/\pi w_0$) of 320 μ rad. The oscillator beam diameter varies with distance z from the oscillator as¹⁰

$$w(z) = w_0(1 + (z/z_0)^2)^{1/2} . \quad (5)$$

In addition to any beam expansion produced by a telescope, the natural beam expansion is accounted for by evaluating $w(z)$ at the midpoint of each amplifier (preamplifier) and correcting the radial flux distribution by the appropriate expansion factor. For example, referring to Fig. 1, the diameter at the preamplifier (PA1) is 2.3 mm, and the beam expands a factor of 1.42 upon reaching the beam expander (BE) position. There the beam expander introduces an additional expansion of 7.5X and is assumed to collimate the beam through the main amplifier. All of the distances used in this study are given in Figs. 1-3 and may be used in conjunction with eq. (5) to evaluate the oscillator beam radius at the various elements in the system.

All of the amplifiers are assumed to have operating characteristics and dimensions similar to those of the current system. One difference is that the 75 mm amplifier will have an active length of 3.52 m instead of the present 3.12 m when new flashlamps are installed. Table 1 gives the operating characteristics for the preamplifier stages, as well as the variation of small signal gain with Ar pressure. Table 2 presents the same data for the SAIL-1 75 mm main amplifier. The Faraday rotators do not enter into the calculations except that they are assumed to have a transmission of 0.75.

LAYOUT OF ONE PREAMP SYSTEM

Figure 1. Assumed configuration of system with one preamplifier in chain. PA, FR, and BE denote preamplifier, Faraday rotator and beam expander. Distances between elements are indicated.

LAYOUT OF TWO PREAMP SYSTEM

Figure 2. Assumed configuration of system with two stages of preamplification. PA, FR, and BE denote preamplifier, Faraday rotator, and beam expander.

LAYOUT OF THREE PREAMP SYSTEM

Figure 3. Assumed configuration of system with three stages of preamplification. PA, FR, and BE denote preamplifier, Faraday rotator, and beam expander.

Length, active	.88 m
Radius, active	.008 m
Inversion, total	$2.45 \times 10^{17}/\text{cm}^3$
Extractable energy	4.365 J
Extractable on 3-4	2.957 J

<u>P_{Ar} (Torr)</u>	<u>G^{ss}</u>	<u>F_s (J/cm²)</u>	<u>F_{1/2} (J/cm²)</u>
750	1275	.21	.006
1000	310	.26	.015
1250	134	.30	.026

Table 1. Specifications of the preamplifier stages used in the calculation. The small signal gain G^{ss} , the saturation flux F_s , and the flux to half saturate $F_{1/2}$, are all calculated for an oscillator operating on the $F = 3$ to $F = 4$ line.

Length, active	3.52 m
Radius, active	.03 m
Inversion, total	$0.5 \times 10^{17}/\text{cm}^3$
Extractable energy	50.11 J
Extractable on 3-4	33.94 J

P_{Ar} (Torr)	G^{ss}	F_s (J/cm ²)	$F_{1/2}$ (J/cm ²)
600	1113	.17	.005
800	256	.22	.014
1000	108	.26	.025

Table 2. Specifications of 75 mm ID main amplifier used in the calculation. The small signal gain G^{ss} , the saturation flux F_s , and the flux to half saturate $F_{1/2}$ are all calculated for an oscillator operating on the $F = 3$ to $F = 4$ line.

III. Parametric Study of Energy Extraction in Upgraded SAIL-1

In order to assess the potential of the SAIL-1 facility, the following survey of operating parameters has been performed. First, the oscillator output energy was varied from 1 to 3 to 5 mJ, with a beam as described in the previous section. Second, either one, two, or three preamplifiers were included in the optical chain. Third, the Ar pressure in the preamplifiers was varied over 750, 1000, and 1250 Torr, with the associated variation in the small signal gain as given in Table 1. Fourth, the Ar pressure in the main amplifier was varied over 600, 800, and 1000 Torr, with the associated small signal gain variation as given in Table 2. The magnification of the single beam-expander element in each layout (Figs. 1-3) was adjusted for rough maximization of the final output energy. The beams are strongly apertured at a few places, and always at the entrance to the main amplifier. Soft apertures will be necessary to retain good beam quality.

Tables 3-5 present the output energies expected from one, two, and three preamplifier systems, respectively, for various preamplifier and 75 mm amplifier pressures. The oscillator output energy affects the total output very little, except in the low gain (high pressure), single preamplifier case. This is because of the large amount of saturation in the system. In fact, in the three preamplifier system, the oscillator energy had almost no effect on the final output. Figure 4 summarizes most of this information and also plots the output energy vs input energy to the main amplifier alone. It is judged that two preamplifiers are required for moderately efficient extraction, and that a third preamplifier would add only ~ 5 J to the output.

Alternative schemes and upgrading modifications to achieve higher output energy are discussed in Section V.

Preamplifier Pressure → Main Amplifier Pressure ↓	750	1000	1250
600	17.9 17.3 15.8	16.8 15.9 13.5	15.7 14.5 11.6
800	12.9 12.2 10.5	11.6 10.7 8.3	10.5 9.3 6.5
1000	9.2 8.6 7.0	8.1 7.2 5.2	7.0 6.0 3.8

Table 3. Calculated energy output (J) for the one preamplifier system. The different energies in each box correspond to an oscillator output of 5, 3, and 1 mJ. All energies reflect single line $F = 3$ to $F = 4$ operation of system.

Preamplifier Pressure → Main Amplifier Pressure ↓	750	1000	1250
600	27.5 27.4 27.1	26.9 26.7 26.1	26.2 25.8 24.7
800	24.6 24.4 24.0	23.8 23.5 22.8	22.9 22.5 21.1
1000	21.9 21.7 21.3	21.0 20.7 19.9	20.0 19.5 18.0

Table 4. Calculated energy output (J) for the two preamplifier system. The different energies in each box correspond to an oscillator output of 5, 3, and 1 mJ. All energies reflect single line $F = 3$ to $F = 4$ operation of system.

Preamplifier Pressure → Main Amplifier Pressure ↓	750	1000	1250
600	31.5	31.1	30.6
800	28.9	28.5	27.9
1000	26.5	26.0	25.4

Table 5. Calculated energy output (J) for the three preamplifier system. The oscillator output is 1 mJ. All energies reflect single line $F = 3$ to $F = 4$ operation of the system.

Figure 4. Performance curves of the main amplifier for three different Ar pressures. The ranges of input energy to the main amplifier that may be achieved with one, two, or three preamplifiers (PA) are indicated. Ar pressure in the pre-amplifier chain is denoted by: ● - 1250 Torr, ▲ - 1000 Torr, ■ - 750 Torr. The oscillator output energy is 1 mJ and single line F = 3 to F = 4 operation is assumed.

IV. Beam Quality Limitations

A. Prelase and Self-Oscillation

The Plasterix iodine laser¹¹ at Max-Planck-Institut für Plasmaphysik is an iodine laser system with two preamplifiers and one final amplifier. The output is 30 joules in 600 - 800 psec. Prelase, as distinguished from self-oscillation, is unimportant in this system. To estimate the amount of prelase in the SAIL-1 system, consider the power radiated into a solid angle $\Delta\Omega$ by a volume V of emitters of number density n :

$$P = nV A_{sp} \Delta\Omega h\nu / (4\pi) .$$

A_{sp} is the spontaneous decay rate. If the dimensions and inversion characteristics of a preamplifier (Table 1) are used and if $\Delta\Omega$ is assumed to be close to the solid angle characteristic of the oscillator beam divergence, one obtains

$$P \approx 10^{-7} \text{ W} .$$

If the total small signal gain is G^{tot} and the delay time from pumping to pulse extraction is on the order of 10 μsec as is currently the case, an energy of $< 10^{-12} G^{\text{tot}}$ J will be delivered to the target prior to the main pulse. Thus, the four-stage system (three preamplifiers and main amplifier) with a small signal gain of 100/stage would deliver $< 10^{-4}$ J prelase; if the gain is 1000/stage, there will be on the order of a joule of prelase. Target isolators would be necessary in the latter case.

The likelihood of self-oscillation is difficult to predict in the system. The principal allowance that has been made for it is to include a range of small signal gain for each amplifier stage in the survey reported in Section

III. A value of G^{ss} as low as 100/stage should not produce self-oscillation in the amplifiers. A value of G^{ss} as large as 1000/stage, however, will probably result in some self-oscillation of the amplifiers. The experience obtained by the German group on Plasterix indicates that the small signal gains may have to be kept as low as 100/stage to suppress self-oscillation. The SAIL-1 system has been run with a small signal gain of 100 in the preamplifier and 2700 in the 75 mm amplifier with no isolators; the amplifiers did not self-oscillate in this configuration. However, when the gain was increased slightly in either the preamplifier or the main amplifier, self-oscillation occurred. At these gains, prease due to amplified spontaneous emission was negligible. Hence, both in Plasterix and in SAIL-1, self-oscillation of the amplifiers is the limiting factor. That is why Faraday rotators are included in the upgrading study in Section III.

B. Target Feedback

Back-reflection from the target is not so severe a problem for the iodine laser system as for glass laser systems, because the medium is not subject to damage. Windows and other optical elements are, however, so the problem cannot be ignored. It is anticipated that the large amount of saturation present in the main amplifier will reduce the backward pass gain to a sufficiently low value that damage will not occur. From Fig. 4 one finds that the gain is on the order of 20 for two-preamplifier operation. This is low enough that the back-reflected radiation should not damage the entry windows of the main amplifier. The remaining part of the system is protected by the Faraday rotator after the final preamplifier. If the target is highly reflective in its initial state (i.e. a metallic target),

a Faraday rotator may be necessary after the 75 mm amplifier to prevent the main amplifier from self-oscillating. For the purpose of this report, it is assumed that a final Faraday rotator will not be necessary. Ensuing developments may change this viewpoint.

C. Aperturing

The beam will be hard-apertured at several points in the system. This would introduce distortions in the phasefront due to diffraction. While it is true that catastrophic self-focussing due to nonlinear effects would most likely not be a problem, the focussability of the beam at the target would definitely be affected.

One method to eliminate the hard aperturing is to use apodized or "soft" apertures. The soft apertures produced at Sandia Laboratories¹² would probably not be capable of withstanding the high power and energy densities of a large iodine laser, especially in the later stages. Soft apertures capable of withstanding high power and energy densities can probably be supplied by commercial vendors.¹³ Of course, soft apertures are an additional source of loss in the system, and if the requirement for extremely tight focussing necessitates the use of soft apertures, the expected output energies tabulated in Section III might be lowered slightly. However, the calculations have used an effective radius smaller than the inner diameter of the amplifiers in all cases.

V. Additional Possibilities for Increasing the Output Energy From SAIL-1

A. Two-Line Oscillator

In the preceding calculations it was assumed that the oscillator output was purely the $F = 3$ to $F = 4$ hyperfine transition. This input will extract energy from only the $F = 3$ upper level. At the pressures considered in this report, there is little overlap of the three hyperfine transitions starting from the $F = 2$ upper level with the $F = 3$ to $F = 4$ transition. However, $5/12$ of the inversion density is stored in the $F = 2$ upper level. Extracting this energy would increase the extraction efficiency by 30-50%.

One means of extracting this energy is to make the oscillator output spectrum have a component at the $F = 2$ to $F = 2$ transition wavelength. This could be accomplished by running two oscillators simultaneously, one at the $F = 3$ to $F = 4$ transition and the other at the $F = 2$ to $F = 2$ transition. The wavelength of each oscillator can be controlled with a Fabry-Perot etalon placed in the cavity.¹⁴ The $F = 3$ to $F = 4$ oscillator could be run slightly off line center, so that the two components have equal gain in the amplifiers. The gain would still be comparable to the range of gains studied in this report.

The main difficulty in using two separate oscillators is to reduce the relative time jitter between the two. The jitter in the present oscillator in SAIL-1 has been measured to be ± 30 nsec. Part of this is jitter in the breakdown of the spark gap and of the flashlamps, and part is in the statistical nature of the build-up of the laser radiation from noise. The first source of jitter can be eliminated by pumping both oscillators by the same flashlamps, i.e. by placing both laser tubes in the same head. The second source of jitter can be eliminated by chopping out the 1-10 nsec output pulse from both oscillators with the same optical

gate. Pulses with 50 nsec duration can be produced routinely by gain-switching the oscillators with high cavity loss (this can be accomplished by the mode-selecting aperture alone). Hence the degree of pulse overlap should be high, and the optical gate can select 1-10 nsec simultaneous slices from both oscillator outputs.

One question that remains to be answered by experiment is the relative amplitude stability of the two oscillators. The amplitude stability of the present oscillator is better than $\pm 10\%$, but slight thermally-induced shifts in the etalon frequencies may degrade the amplitude stability somewhat. Since the final amplifier will be heavily saturated, the final output energy should be relatively insensitive to the oscillator output energy, as is shown in tables 3-5.

B. Improved Pumping and Energy Storage in 75 mm Amplifier

The survey study reported in Section III assumed that the pumping of the main amplifier produced an inversion density of $0.5 \times 10^{17}/\text{cm}^3$, the current experimentally confirmed value. This corresponds to an extractable energy density of about $5\text{J}/\ell$ or $3.4\text{J}/\ell$ on the 3-4 transition. The inversion density of the main amplifier was originally $0.7 \times 10^{17}/\text{cm}^3$. The decrease in inversion density is probably due to degradation of the flashlamps or flashlamp reflectors, or to contamination of the mix tank due to reaction of $\text{C}_3\text{F}_7\text{I}$ with the nickel-plated walls. The latter has been confirmed for the case of stainless steel mix tank walls.

The energy storage may, in fact, be doubled if the $\text{C}_3\text{F}_7\text{I}$ pressure is increased. However, this produces a very strong gain-vs-radius profile and would require a careful study of radial beam tailoring to allow for large-radius, high-intensity radial intensity gradients and strong aper-

turing near the amplifier outer radius. In practice, it is doubtful that more than a 50% overall increase in main amplifier energy storage can be obtained at this time.

C. Cassegrainian Optics

Cassegrainian optics or other schemes to multiple-pass the 75 mm amplifier can, in principle, increase the energy extraction of the amplifier. Unfortunately, they suffer from two disadvantages. First, efficient overlap of the multiple passes is difficult. If the beams are comparable in size to the amplifier bore, the reflecting elements severely aperture the beam. Second, and most serious, due to its high aspect ratio, placing elements with high feedback at the output end of the 75 mm amplifier cause it to self-oscillate at quite low gains. In the case that only the target plasma is highly reflective, the feedback occurs only after the main pulse has saturated the amplifier, thus lowering the gain. It is not expected that multiple-pass schemes (for which the feedback is always high) will be a practical method for efficient energy extraction from the 75 mm amplifier.

Appendix: Correction to SLA-73-0976

In Sandia Internal Report SLA-73-0976,¹⁵ an error was made in eq. 6a. Because of the rapid equilibration of the lower state manifold n_ℓ , the change in the population of upper level n_2 is equal to the change in n_ℓ , not in the individual level n_1 . Hence eq. 6a should read

$$\begin{aligned}\frac{dn_\ell}{dt} &= W_{21} \left(n_2 - \frac{g_2}{g_1} n_1 \right) \\ &= W_{21} \left(n_2 - \frac{g_2}{g_\ell} n_\ell \right)\end{aligned}\tag{1a}$$

Adding this equation to eq. 6b yields

$$\frac{d}{dt} \left(n_2 - \frac{g_2}{g_\ell} n_\ell \right) = -W_{21} \left(1 + \frac{g_2}{g_\ell} \right) \left(n_2 - \frac{g_2}{g_\ell} n_\ell \right) .\tag{2a}$$

Following through the remaining equations yields a b-factor of

$$b = 1 + \frac{g_2}{g_\ell} ,\tag{3a}$$

not $b = 1 + \frac{g_2}{g_1}$ as given in the report. The inversion is still given by

$$\Delta N = n_2 - \frac{g_2}{g_1} n_1\tag{4a}$$

$$= n_2 - \frac{g_2}{g_\ell} n_\ell\tag{5a}$$

Hence, the effect of the rapid equilibration of the lower state manifold is that the effective lower laser level is the entire manifold n_ℓ with degeneracy g_ℓ , instead of the real lower laser level n_1 with degeneracy g_1 . The b-factor and inversion given above in eqs. 3a and 5a are the ones to be used in eqs. 1, 2, and 3 in Section II.

REFERENCES

1. K. J. Witte, G. Brederlow, E. Fill, K. Hohla, and R. Volk, presented at 4th Int. Workshop on Laser Interaction and Related Phenomena, RPI, Troy, NY, Nov., 1976.
2. V. A. Katulin, V. Yu. Nosach, and A. L. Petrov, Sov. J. Quantum Electron. 6, 998 (1976).
3. J. N. Olsen, J. Appl. Phys. 47, 5360 (1976).
4. E. O. Schulz-DuBois, Bell System Technical Journal 43, 625 (1964).
5. R. Bellman, G. Birnbaum, and W. G. Wagner, J. Appl. Phys. 34, 780 (1963).
6. V. S. Zuev, V. A. Katulin, V. Yu. Nosach, and O. Yu. Nosach, Sov. Phys. JETP 35, 870 (1972).
7. W. Fuss and K. Hohla, "Pressure Broadening of the 1.3 μ m Iodine Laser Line," Max-Planck-Institut für Plasmaphysik Report IPP IV/67, 1974.
8. T. D. Padrick and R. E. Palmer, J. Chem. Phys. 62, 3350 (1975).
9. E. A. Yukov, Sov. J. Quantum Electron. 3, 117 (1973).
10. A. Yariv, "Quantum Electronics," 2nd ed. (John Wiley & Sons, New York, 1975), p. 111.
11. K. Eidmann, Ch. Dorn, and R. Sigel, "Initial Target Experiments with the Iodine Laser," presented at the 10th European Conference on Laser Interaction with Matter, Palaiseau, Oct., 1976; Max-Planck-Institut für Plasmaphysik Report IPP IV/95, 1976.
12. J. P. Anthes, J. W. Lavasek, and M. A. Palmer, "A Picosecond and Nanosecond Nd:Glass High Power Laser Amplifier System," SAND-76-0432, 1976.

13. CVI Laser Corporation, Albuquerque, N. M., advertises high power apodized apertures.
14. E. S. Mukhtar, H. J. Baker, and T. A. King, Opt. Commun. 19, 193 (1976).
15. R. E. Palmer, "Degeneracy Factor in Laser Transitions with Non-degenerate Hyperfine Splitting," SLA-73-0976, 1973.

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