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LASERS FOR THERMONUCLEAR FUSION AND THEIR PROPERTIES*

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ABSTRACT

A discussion of the laser system requirements for fusion applications is presented. A comparison between the photolytic atomic iodine and electron beam pumped rare gas oxide laser systems are made in the context of a fusion laser system. The use of spontaneous and super-fluorescent emission from selected rare gas halogen exciplex systems to pump high average power atomic iodine lasers is explored with emphasis on the pump source kinetics in relation to amplifier design.

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INTRODUCTION

The objectives of the U.S.E.R.D.A. Laser Fusion Program are to 1) demonstrate the scientific feasibility of initiating thermonuclear burns in a fuel pellet by irradiation with a high power pulse of laser radiation, and 2) to develop applications of this energy source in the national interest [1]. The achievement of the early scientific milestones of the ERDA program (significant TN-burn, light-breakeven, and net energy yield) is anticipated on a single pulse basis using laser systems and facilities presently under construction (the 10 kJ Nd:glass laser (SHIVA) at LLL) and planned (SHIVA-NOVA at LLL and/or the 100 kJ CO₂ laser system at LASL). In looking beyond the scientific milestones it must be recognized that laser induced fusion can be approached using many different target concepts, which in terms of projected applications, dictate a range of laser systems performance requirements. As these various pellet concepts become more refined through extensive experimental and computational development in the next few years, we expect to harden optimized laser systems performance requirements for various laser fusion power applications (engineering test reactors, hybrid and pure fusion prototype reactors, production reactors). Preliminary analyses to establish nominal ranges of laser systems performance requirements for these various reactor applications have been made [1], based on the current body of knowledge concerning pellet implosion processes [2]. A summary of the range of nominal laser performance requirements spanning fusion applications are presented in Table I.

Table 1
Advanced Laser Requirements for Fusion Applications

Characteristic	Value Range
Wavelength ($\text{\AA}$)	3000 - 15000
Energy Storage Density (J/l)	10 - 100
Pulse Length (nsec)	1 - 5
Pulse Energies (kJ)	100 - 1000
Pulse Repetition Rate (Hz)	10 - 110
Average Power (Mw)	0.1 - 10
Efficiency (%)	≥ 1
Inversion Storage Time (μsec)	≥ 0.5
Beam Quality	High, Target Dependent

Inspection of the laser performance characteristics cited in Table 1 leads to the conclusion that Nd:glass and CO_2 lasers, presently used for scientific research, will not be useful for the implementation of fusion applications. The Nd:glass laser fails primarily because of its relatively low operating efficiency and low average power capability; the CO_2 laser fails primarily because of its relatively long operating wavelength. In principle, this situation could change through a radical improvement in laser performance (Nd:glass) or development of more viable targets operating at long wavelengths; however, the main thrust toward development of power applications is centered on the identification and development of new laser media satisfying the requirements outlined in Table 1. Given these requirements, an analysis [2] has been performed to determine the physical, spectral, and collisional properties of atoms and/or molecules which are consistent with these requirements. A summary of these microscopic properties of potentially

viable laser media are presented in Table II together with an indication of the principal constraining phenomena in laser scaling. The wavelength, energy storage density and storage duration requirements, when combined, dictate the use of atoms or molecules exhibiting laser transitions forbidden in the electric-dipole approximation. While this requirement greatly limits the number of potentially viable atomic and/or molecular media, several generic microscopic systems have been identified. Table III lists five generic gas phase systems which are under current evaluation and/or development, together with a specific example of each species, operating wavelengths, and laser transition character. Rapid evaluation of these systems, and the identification of other metastable electronic transition laser media, has been hampered by a paucity of basic structural, kinetic, and collisional data in this literature. At the present time, only the atomic iodine and the rare gas oxide lasers have been sufficiently characterized to begin an assessment of scalability and systems performance.

Table II

Physical and Dynamical Constraints on Fusion Laser Media

Metastable Electronic Transitions	(Storage Time)
Inversion Density $n = 10^{16}$ - 10^{17} cm ⁻³	(Energy Density)
Gain Cross Section $\sigma = 10^{-19}$ - 10^{-20} cm ²	(Parasitics; Saturation)
Spherical or Shielded Electronic State	(Collisional Stability)
Minimum Medium Density	(Nonlinear Effects; Beam Quality)
Sparse Level Structure	(No Excited State Absorption)
Gas Medium	(High Average Power; Flow)

Table III

References	Generic Species	Specific Example	Wavelength	Transition Character
5	Halogen Atom	Iodine ($2p_{1/2} \rightarrow 2p_{3/2}$)	1.315	Magnetic Dipole
6	Group VI Atom	Oxygen ($1s_0 \rightarrow 1p_2$)	0.588	Electric Quadrupole
7	Rare Gas Group VI Excimer	KrO ($1s \rightarrow 1s, 1s$)	~ 0.558	Forced Electric Dipole
8	Metal Excimers	Hg ₂	0.35	Spin Forbidden EV
9		HgCd	0.48	
10,11	Rare Earth Molecular Vapors	NdCl ₃ A.C. ($4f_{3/2} \rightarrow 4f_{11/2}$)	1.06	Parity Electric Dipole

A laser system delivering pulses in excess of 100kJ and an average power in excess of 100 kW is envisioned to be a multi-chain MOPA, consisting of a well-controlled master oscillator which drives *n* equivalent power amplifier chains. The number of chains *N* appropriate for the laser depends on a large number of issues including the required symmetry and uniformity of illumination of the pellet [2], laser constraints in scaling the transverse dimension of the largest power amplifiers, limits set by damage of optical components, unit cost of large optical elements, and unit cost of alignment and control instrumentation for each laser chain. A detailed systems optimization of this sort has been reported [2] for the SHIVA Neodymium Glass Laser currently under construction at the Lawrence Livermore Laboratory. For a system delivering 100-200 kilojoules, a reasonable working number for *N* is 32, requiring each MOPA chain to deliver ~ 3-6 kilojoules of energy. The optimum

sizing of the chain power amplifiers will not be considered here, nor the design characteristics of the master oscillator. We consider below the general characteristics of the larger power amplifier modules capable of delivering 3-6 kilojoules at the output aperture. Postulating optical components which can withstand a peak energy density of say, 10 J/cm^2 for 1 nsec pulses, typical output aperture sizes must range from 30 to 40 cm in diameter.

In the following sections, we present a status report of the iodine and rare gas oxygen laser media to give some feeling for the characteristic sizes of power amplifiers and for the kinds of technologies involved in their implementation. It should also be pointed out that these two laser media utilize radically different pumping techniques (and technologies), thus providing a diversity of systems options.

ATOMIC IODINE LASER SYSTEMS

The atomic iodine photodissociation laser, discovered by Kasper and Pimentel [3] in 1964, has recently been the object of intensive development in Germany [4, 5] and the Soviet Union [6, 7] as a single-pulse, high energy, high peak power laser source for scientific fusion research. The best performance for a single master oscillator power amplifier (MOPA) iodine laser chain was recently reported [8] as 260 joules in a 0.7 nsec pulse (0.4 terawatt) with an overall system efficiency of 0.1 percent. Output beam quality with respect to focusability on small targets has not yet been discussed in the literature. In assessing the atomic iodine laser medium for use in high average power laser fusion applications, there are a large number of basic, technological, engineering,

and economic issues which must be evaluated in a system context. A very simple analysis of these issues indicates that the presently utilized flashlamp pumping techniques and technologies comprise one of the least viable subsystems for average power scaling. We have recently proposed and demonstrated [9] alternative pumping sources which provide additional scaling options for relatively efficient, high average power iodine and other [10] optically pumped laser media for fusion applications. Recent experiments have shown that the rare gas-halogen exciplexes [11] and the diatomic halogen molecules [12] are efficient, relatively narrowband [13] radiators in the spectral region between 1900-4000 Å. These molecular vapors are readily pumped using relativistic electron beams of moderate current densities ($\sim 100 \text{ amp/cm}^2$) and several of these molecular systems have been utilized to produce coherent emission [] in the ultraviolet spectral region. While these molecular laser systems are non-energy storing (due to the short radiative lifetimes of the exciplex or diatomic molecules) they can be used to efficiently pump an energy integrating laser medium such as atomic iodine. In this respect, we have concentrated our experimental and computational efforts on three specific molecular systems whose emission spectra correlate with the photodissociation spectrum of the fluoroalkyl iodides shown in Figure 1. The molecular systems of immediate interest are XeBr, KrF, and Br₂ all of which are relatively efficient fluorosceners and which have been operated as lasers [11, 12]. Thus, in applying these emitting gases to the iodine laser pump problem, we have two generic options [10] to consider: 1) "incoherent pumping" using spontaneous emission of the fluorescing gas, much like a low density

flashlamp, and 2) "coherent pumping" using stimulated emission from the excited gas, permitting iodine pumping through a small solid angle because of the brightness of the pump source. These generic pumping techniques offer a wide range of options in the design of large power amplifiers consistent with volumetric flow of the iodine laser medium and the achievement of acceptable output beam quality. The choice between incoherent and coherent pumping with a specific pump gas, is dictated in part by the microscopic kinetic and collisional processes which dominate each molecular system.

In a recent SPIE Symposium [10], we provided nominal scaling estimates of atomic iodine power amplifiers using both coherent (KrF) and incoherent (XeBr) rare gas halogen pump sources. These estimates were based on present (and incomplete) knowledge of kinetic processes relevant to the rare gas halogen pump sources and on projections of pulse power and electron gun diode technologies. This analysis indicates that "coherent pumping" is the more viable approach to scaling iodine amplifiers.

The basic scheme for an iodine amplifier providing high average power capability is illustrated in Figures 2 and 3. Each amplifier module consists of a pump laser cavity and an iodine amplifier cavity, both with nominally the same volume and aspect ratio. The iodine amplifier mixture consists of several atmospheres of argon buffer gas and several tens of Torr of C_3F_7I vapor. The working medium is flowed transverse to the optical axis at a subsonic velocity, consistent with pulse repetition rates of less than 100 Hz. Provision is made for quasi-closed cycle

operation in which Ar and C_3F_7I fuel is recirculated and undesirable photolytic products ($C_6F_{14}I_2$, etc.) and any other impurities are abstracted from the flow to acceptable levels. Photolytic products must be recycled off-line to provide for fuel make-up.

The KrF pump source consists of a radiating gas channel pumped by opposing electron beam guns. The working medium, consisting typically of several atm of argon, 100-200 Torr Kr, and several Torr F_2 , is flowed in a closed loop. Aside from production of contaminants, the Ar, Kr, F_2 gas mixture should be relatively stable because of the inert nature of the rare gas and the dissociative nature of the ground state of the KrF molecule. As indicated schematically in Figure 4, superfluorescent radiation is extracted from the KrF channel transverse to the flow and is directed by a pair of reflecting mirrors R_1 and R_2 and a pair of dichroic mirrors D_1 and D_2 into the two ends of the iodine amplifier cavity.

The use of axial pumping of the iodine amplifier cavity has both significant advantages and some notable disadvantages. By shaping the spatial distribution of the pump beam and taking into account effects due to beaching of the alkyl iodide fuel, a wide variation in spatial distribution of iodine gain can be produced and used as a design tool to optimize the output beam quality of the iodine amplifier. The high spatial brightness of the KrF pump source allows for high transport efficiency to the iodine amplifier. One of the major drawbacks of this configuration is that the area of irradiation of the iodine amplifier is limited to the aperture area of the amplifier. This implies large

UV optical fluences on the transport and window optics. Transverse pumping of the iodine amplifier cavity over a much larger area alleviates this problem but greatly complicates beam generation and handling of the KrF pump radiation.

The overall efficiency of such a power amplifier is an important quantity. In most general terms, the efficiency η_T can be expressed as

$$\eta_T = E_{out} / (E_{elec} + E_{chem} + E_{mech}) \quad (1)$$

where E_{out} is the photon energy extracted from the stored inversion in the amplifier, E_{elec} is the total input electrical energy to produce the amplifier inversion, E_{chem} is the effective input energy required to chemically recondition the laser fuel from one pulse to the next, and E_{mech} is the input energy to transport and mechanically (density uniformity, temperature uniformity, and flow) recondition the laser working medium. In the limit where $E_{elec} \gg E_{chem}, E_{mech}$, Eq. (1) reduces to $\eta_T = E_{out} / E_{elec} < 1$, a quantity commonly represented as "the laser efficiency". In this approximation we can write η_T as

$$\eta_T = \eta_{ph} \eta_{ext} \eta_{p} \eta_{t} \eta_{ph} \eta_{ext} \quad (2)$$

where

- η_c = power conditioning efficiency to generate the e-beam,
- η_{eb} = e-beam transport and deposition efficiency,
- η_p = ratio of pump-laser energy to e-beam deposited energy,
- η_t = efficiency of pump-laser energy transport and deposition
- η_{ph} = ratio of iodine and rare-gas-halogen photon energies,
- η_{ext} = energy extraction efficiency from I*.

In general the maximum efficiency of individual sub-systems will be moderated when a fully optimized amplifier system is designed. However, it is useful to estimate a nominal, high overall efficiency for an iodine amplifier by assuming fairly generous efficiencies to the major subsystems:

- $\eta_c = 0.95$
- $\eta_{eb} = 0.6$
- $\eta_p = 0.2$
- $\eta_t = 0.5$
- $\eta_{ph} = 0.75/1.32 = 0.18$
- $\eta_{ext} = 0.66$

Inserting these values into Eq. (4), we obtain $\eta_o = 8 \times 10^{-3}$, a rather unattractive efficiency for even optimistic performance of a fusion target. This low projected efficiency is dominated by the two low subsystem efficiencies: $\eta_p = 0.20$ and $\eta_{ph} = 0.18$. The energy efficiency of the

rare-gas-halogen pump source ($\eta_p = 0.2$) is the maximum value projected for this class of systems and is likely to be somewhat lower in practice. The low ratio of iodine to photolyzing photon energies is an intrinsic property of the photolytic iodine laser and arises because of the relatively strong bonding of the iodine atom to the C_3F_7 radical. This low intrinsic ratio is the basis of our continuing search for other, slightly bound molecules that can be photolyzed by radiation from relatively efficient rare-gas-halogen laser pump sources and yield energetic, metastable atoms or radicals.

In estimating η_i values, the maximum value of 0.66 has been assumed for the laser extraction efficiency η_{ext} . In a laser system meeting a specific application requirement, η_{ext} must be interpreted as the efficiency of extracting stored energy in a laser beam that has a spatial intensity and phase distribution that allows it to be properly focused on the fusion target. Meeting focusing requirements generally implies a beam/amplifier filling factor less than unity and imposes a limitation on the beam intensity to avoid optically induced phase and intensity variations on the laser beam and its reduction of focusability. In practice, these constraints can seriously reduce the useful extraction efficiency well below the maximum theoretical value.

In the case of the atomic iodine laser, in which the active laser specie is produced by molecular dissociation, the quantity E_{chem} in Eq. (1) may not be small compared to E_{elec} ; similarly, for a laser system operating at several atmospheres of pressure and requiring substantial cooling under closed cycle operation, E_{mech} may not be insignificant

compared to E_{elec} . Preliminary analysis indicates that, in fact, E_{chem} is comparable to E_{elect} , and may even be larger. This will reduce the overall amplifier efficiency to 0.4%, or less.

A more meaningful projection of iodine-laser systems efficiency can only be generated on the basis of a detailed design; however, these general considerations indicate that real iodine laser systems will operate at an overall efficiency below one percent.

RARE GAS OXIDE LASERS

Stimulated emission on the 5577 Å collision-induced molecular bands of the rare-gas oxide excimers was first demonstrated by Powell, Murray, and Rhodes [14] in 1974, using a relativistic electron-beam pump source. Since that time theoretical, computational, and experimental efforts have emphasized the structural and kinetic properties of the rare gas oxide excimers as energy storing laser media [15]. These studies have not yet progressed to the point where point designs of high performance power amplifiers can be established. However, there is now sufficient information available on the radiative and collisional properties of these systems to indicate the general features of rare gas oxide amplifiers and the types of e-beam technologies attendant to their future development.

Figure 4 illustrates the structural features of the rare-gas - group VI atom excimers. This figure shows specifically the molecular states of the XeO excimer, formed by the five p^4 electronic states of the ground electronic configuration of oxygen and the ground 1S_0 state of Xe. The observed rare gas oxide laser transitions correlate with the 5577 Å "auroral" electric quadrupole transition between the 1S_0 and

$^1\text{O}_2$ energy levels of the oxygen atom. In the mixed rare gas-oxygen system, the proximity of the rare gas atom induces the $\text{O}(^1\text{S}_0)$ atom to radiate enormously faster (e.g. $\sim 10^6 \text{sec}^{-1}$) than the isolated atom ($\sim 1 \text{sec}^{-1}$), giving rise to one of the unique aspects of the rare gas oxides as laser media. The stimulated emission cross-section is proportional to the rare gas pressure and the saturation flux is inversely proportional to this pressure, a behavior exactly opposite that of a molecular medium with a nominally fixed transition moment, such as the Ar-iodine medium described above. (Strictly speaking, the argon buffer in the atomic iodine system will modify the magnetic dipole moment of the atom, but the effective cross-section and saturation energy will be largely determined by the free-atom transition moment because it is relatively large.) Figure 5 shows the spontaneous and stimulated emission spectra [] of the ArO , KrO and XeO excimers. The pronounced difference in the character of these spectra reflect the differences in binding of the molecular states for the different rare gases. Typical laser medium parameters obtainable in a rare gas oxide amplifier are indicated in Table IV. In this experiment [15] an electron beam delivering 1 MeV electrons in a pulse 100 nsec long, at a current density of $\approx 50 \text{ A/cm}^2$ was used to excite a mixture of 25 atm Kr and 10 Torr molecular oxygen. Under these pumped conditions, a small signal gain coefficient of 0.005 cm^{-1} was measured, indicating a stored energy density of 5 J/liter . The lifetime of the population inversion was found to be $\sim 0.5 \text{ usec}$. Based on the collisional induced cross-sections inferred for the KrO excimers, the saturation energy flux is estimated to be $h\nu_0 = 1.7 \text{ J/cm}^2$. All of these

laser parameters are quite apropos for a high energy fusion laser. However, the medium efficiency (η_{med}) defined as the ratio of energy stored in the population inversion to e-beam energy deposited in the laser gas, is found to be typically one percent. This efficiency can be increased under conditions of lower pump current density and at the expense of a lower stored energy density and small signal gain coefficient. The medium efficiency is intimately connected with the production mechanism of $O(^1S)$ in the e-beam excited rare-gas oxygen mixture, a process not yet firmly established. It has been suggested by Lorents and Huestis [16] that a two-step mechanism can be used to explain the Xe_2^* kinetic decay dependence on O_2 as well as the similar yields of $O(^1S)$ from various oxygen donors (O_2 , CO_2). Ground state oxygen atoms are first produced by a dissociation step and are then excited to the $O(^1S)$ state by collision with a rare gas excimer (Xe_2^*). Huestis has modeled XeO kinetics using the oxygen reactions

and

The first step is experimentally observed in the time-decay of Xe_2^* excimer radiation at O_2 pressures greater than several Torr. The second step is

suggested to proceed via an ionic intermediate state $\text{Xe}_2^+0^-$ which predissociates to the outgoing channel. A bound ionic state, Xe^+0^- has been observed in emission near 230 nm from the reaction of Xe metastables with N_2O .

TABLE IV

Wavelength	557.8 nm
Medium	25 atm Kr, 10 Torr O_2
Pump	Electron Beam: 1 MeV, 50 A/cm ² , 100 ns
Storage Time	0.5 μs
Gain Coefficient	0.5%/cm
Energy Storage	5J/liter
Saturation Flux	1.7 J/cm ²
Medium Efficiency	1%

For the mechanism given by Eq. (3) and (4), three xenon excimers are used to produce two excited oxygen atoms. If the xenon excimer efficiency is 25-50% as measured for low current density conditions, an upper limit on the oxygen laser efficiency is 5-10%. This assumes that the deactivation caused by electrons is negligible.

The effect of electron deactivation has been investigated by modifying the Xe_2^* excimer code of Werner, George, Hoff, and Rhodes [17] to include reactions (3) and (4) as well as electron processes with atomic oxygen:

The deactivation of $O(^1S)$ to $O(^1D)$ is the dominant electron process having a rate of $1.1 \times 10^{-9} \text{ cm}^3 \text{ s}^{-1}$ at 1 eV found by integrating over calculated cross sections. Results of the computer model are shown in Fig. 6 assuming that the rate of reaction (3) is $1 \times 10^{-10} \text{ cm}^3 \text{ s}^{-1}$ and the rate of (4) is $3 \times 10^{-10} \text{ cm}^3 \text{ s}^{-1}$. A saturation of the $O(^1S)$ production with input current is clearly observed. The peak $O(^1S)$ density at 150 A/cm^2 corresponds to a maximum extractable energy of 6.3 J liter^{-1} with a medium efficiency of 1.3. These predictions can be expected to have an accuracy no better than a factor of two. However, the general trend with electron current is clearly seen.

Rare gas oxide fluorescence intensities as a function of input current have been measured. Relative deposition was measured from the pressure rise in the gas. Peak fluorescence intensity as a function of deposition is shown in Fig. 7. The Xe and Kr curves are normalized to lie on the Ar curve at low current. The maximum deposition point corresponds to the efficiencies given previously. Optimized efficiency clearly occurs for much smaller current densities, that is, less than 100 A cm^{-2} .

The characteristic current saturation for other oxygen donors was found to differ from O_2 . At the smallest current densities ($\sim 25 \text{ A/cm}^2$), the $O(^1S)$ fluorescence using N_2O exceeded the O_2 value by a factor of two.

Detail experimental and computational studies are continuing to elucidate the relevant kinetic channels for the formation of $O(^1S)$ and to identify alternative oxygen fuels, in order to increase the medium efficiency in an e-beam pumped rare gas oxide laser.

In order to confirm the stimulated emission model developed for these collision type lasers, the first saturated MOPA experiment on a rare gas oxide amplifier has been implemented at LLL. For this experiment we are using the MEG II electron beam facility which provides a 50 cm long sheet beam of 1 MeV electrons with a current density of $\sim 100 \text{ A/cm}^2$. A sketch of the experimental arrangements is shown in Fig. 8. The amplifier cell consists of a $3 \times 10 \text{ cm}^2$ clear aperture and 50 cm length. A flashlamp pumped dye laser, tunable across the spectral gain region of the rare gas oxide amplifier, will be used as the master oscillator. Using an appropriate pair of folding mirrors, the input beam will be passed through the cell up to nine times in order to achieve several meters of optical path gain. Preliminary small signal gain measurements in mixtures of KrO indicate that some 2000 joules of energy can be deposited in the cell (compared to an energy of 10 kJ stored in the Marx, yielding an e-beam transport efficiency $\eta_{eb} \sim 0.2$). These deposition studies carried out by Schlitt [18], also indicate with advanced designs η_{eb} can be increased to approximately $\eta_{eb} \sim 0.4$.

In comparing the e-beam rare gas oxide laser amplifier with the atomic iodine system described above, several basic points can be made at this time. The electrical efficiency of the rare gas oxide amplifier can be simply expressed as

$$\eta_T^e = \eta_{pc} \eta_{eb} \eta_{med} \eta_{ext} \quad (7)$$

where η_{pc} is the efficiency of converting "wall plug" energy into energy stored in the Marx (or in a PFN for advanced power systems), η_{eb} is the efficiency of transfer of Marx energy into energy deposited in the gas, η_{med} is the medium conversion efficiency defined previously, and η_{ext} is the extraction efficiency of stored energy in the laser medium. Taking fairly optimistic efficiency values, in the spirit embraced in analyzing the iodine laser, we have $\eta_{pc} \sim 0.9$, $\eta_{eb} \sim 0.4$, $\eta_{med} \sim 0.01$, $\eta_{ext} \sim 1$, for a total electrical efficiency $\eta_T^e \sim 3.6 \times 10^{-3}$. This value is quite comparable to the estimated electrical efficiency for the atomic iodine amplifier. The principle advantage of the rare gas oxide laser appears therefore to reside in the fact that the only fuels employed are Kr and O_2 which are restored after each laser pulse (e.g., much like the recycle of Kr and F_2 fuels in the pump laser for the iodine system). From the analysis presented here, it is clear that substantial increase in performance will come from the development of techniques to improve the efficiency of medium conversion and operation at lower current density.

CONCLUSIONS

The laser system requirements for fusion applications have been presented. A brief status report of the atomic iodine and rare gas oxide laser media was discussed in the context of a fusion laser system. At the present time the overall system efficiencies appear to be less than one percent and thus

marginal in the context of the applications requirements as presently defined. Nevertheless they do serve as generally different, concrete laser systems which can be quantitatively modeled with relatively modest effort. Such modeling can stimulate the definition of major subsystems involved in any photolytic or electron beam pumped fusion laser and provide an expanded kinetics and technological data base from which either these lasers or other newly discovered laser media can be more accurately assessed as fusion applications requirements become better defined.

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FIG. 1

COHERENTLY PUMPED ATOMIC IODINE LASER — OPTICAL SCHEMATIC

FIG. 2

COHERENTLY PUMPED IODINE LASER-GAS FLOW SCHEMATIC

FIG. 3

FIG. 4

RARE GAS OXIDE SPECTRA

FIG. 5

FIG. 6

FIG. 7

FIG. 8