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Abstract

We discuss the results of and future plans for experiments to study the possibility of producing an x-ray laser. The schemes we have investigated are all pumped by the Novette Laser, operated at short pulse ($\tau_L \sim 100$ psec) and an incident wavelength of $\lambda_L \sim 0.53 \mu\text{m}$. We have studied the possibility of lasing at 53.6, 68.0-72.0, 119.0, and 153.0 eV, using the inversion methods of resonant photo-excitation, collisional excitation, and three-body recombination.

The quest for producing an XUV wavelength laser has greatly escalated in recent years. Present researchers still strive for a high gain scheme since resonant cavities,^{1,2} such as those used in optical lasers, are presently not demonstrated. Rapid progress is being made, though, on normal-incidence multilayer mirror assemblies^{3,4} which should soon enable the possibility of multipassing through a gain medium.

There are numerous approaches to achieving a population inversion.⁵⁻⁹ These include 1) photo- or collisional ionization of ions or atoms,¹⁰⁻¹⁵ 2) photo- or collisional excitation,¹⁶⁻²⁵ 3) atom-ion resonance charge exchange,²⁶⁻²⁹ and 4) collisional recombination of ions.³⁰⁻⁵² To date there have been few tests of these schemes.^{25,43,49,50,53} As to the establishment of lasing, none of the

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results have completely satisfied either the investigators or critics.

The purpose of this report is to discuss the results of a series of experiments that were attempted at the Novette Laser Facility. The schemes tested were of the type 2) and 4) as listed above. We chose them because they are best suited to the pump power characteristics supplied by a large optical laser. These schemes could have led to lasing on XUV wavelength atomic transitions in the interval from 230 to 80 Å.

The Resonant Photoexcitation Laser

The resonant photoexcitation scheme received the primary emphasis in these experiments. Gains predicted for the scheme are extremely high,⁵⁴ The design, however, is fairly complicated. The basic method for obtaining the population inversion is shown in Fig. 1. A

1. A simplified cross-sectional view of the resonant photoexcitation x-ray laser target.

rectangular cross section gas cell is bounded on two sides by x-ray flashlamp foils which are irradiated by the high power, $0.53\mu\text{m}$ wavelength Novette Laser. The plasma produced by the laser interaction (laser intensity $\sim 1 \times 10^{14} \text{ W/cm}^2$) produces copious amounts of continuum and discrete x rays, which, in turn, ionize the lasing gas and resonantly-pump excited states of the ions. Electron-ion collisions then transfer the population to higher angular momentum states which cannot decay to the ground state from which the ion was photoexcited. A specific case for this scheme is shown in Fig. 2. Here we illustrate a level diagram for the He-like neon ion system. In one of the schemes attempted, we chose a flashlamp material which emitted 11.000 Å x rays which are necessary to resonantly photoexcite the $1s4p$ level of helium-like neon. We then depend on collisions in the plasma to populate the $1s4f$ level. This can lead to a population inversion of that level over the $1s3d$, thus leading to a laser transition at 231 Å . Obviously this same idea can be used to pump the $1s3p$ level, with collisions again leading to a population inversion of the $1s3d$ over the $1s2p$. This resonant pumping concept was also used to pump He-like fluorine to produce a possible laser transition at 104.2 Å . Finally, we also applied the technique to the H-like sequence of fluorine in order to pump the $3p$ level, again

2. A simplified level scheme for the He-like neon laser, lines which should not be present in the pump, are shown dashed with an x.

with collisional transfer leading to an inversion of the 3d level over the 2p. Table I summarizes all the schemes attempted as well as the flashlamp material used to provide the resonant transition for pumping the lasant. This is a reduced list of the number of potential pump candidates that had been tabulated by Hagelstein.^{54,55} This reduction comes as a result of some eliminations due to the high precision spectroscopy performed by P. Burkhalter et al.⁵⁶ in support of these experiments.

There are some serious physics and technical phenomena which can affect the outcome of a test of this laser scheme. Principally, the degree of resonance between the pump and lasant transition, the presence of lines that can pump the ground state (destroys the inversion), the brightness of the pump lines, integrity of the gas cavity during the course of the laser pulse, the lasant ion temperature, and the time of occurrence of the relevant ion charge state (ground state of photoexcitation). Out of this long list, only the degree of resonance of the Na-Ne scheme was known with sufficient accuracy prior to our experiments. In addition, we were only able to certify the brightness of the pump for one of the schemes, namely, the Cr-F at 14.458 Å. As for the plasma conditions inside the possible lasing channel, nothing was done to determine this before or during the measurements.

Target designs for this laser scheme placed some unusual constraints on both target fabrication and assembly. Most of the physics reasons for the critical dimensions have been recently reviewed by Hagelstein⁵⁵. Some of the actual laser cavity dimensions are summarized in Figs. 3 and 4. Embodied in this design is the structural requirement that we support over a narrow rectangular opening a very thin flashlamp with an even thinner coating of metal vapor. The flashlamp had to seal the cavity to maintain a gas pressure of

Table I
Resonant Photoexcitation X-ray Laser Schemes

	PUMP	LASANT
(1)	$\left\{ \begin{array}{l} \text{Na}(1s2p^1P_1 + 1s^2\ ^1S_0) \rightarrow \text{Ne}(1s^2\ ^1S_0 + 1s4p^1P_1)4d + 3p(53.6\text{ eV}) \\ \lambda = 11.003\text{ \AA} \end{array} \right.$	$\left\{ \begin{array}{l} \lambda = 11.000\text{ \AA} \\ \\ \text{Ni(N-like, } 3d + 2p) \rightarrow \text{Ne}(1s^2\ ^1S_0 + 1s4p^1P_1)4d + 3p(53.6\text{ eV}) \\ \lambda \stackrel{?}{=} 11.000\text{ \AA} \end{array} \right.$
(2)	$\left\{ \begin{array}{l} \text{Cr(B-like, } 3d + 2p) \rightarrow \text{F}(1s^2\ ^1S_0 + 1s3p^1P_1)3d + 2p(119.0\text{ eV}) \\ \lambda \stackrel{?}{=} 14.456\text{ \AA} \end{array} \right.$	$\left\{ \begin{array}{l} \lambda = 14.458\text{ \AA} \end{array} \right.$
(3)	$\left\{ \begin{array}{l} \text{Mn(Be-like, } 3d + 2p) \rightarrow \text{F}(1s^2S_{1/2} + 3p^2P_{1/2,3/2})3d + 2p(153.0\text{ eV}) \\ \lambda \stackrel{?}{=} 12.641\text{ \AA} \end{array} \right.$	$\left\{ \begin{array}{l} \lambda = 12.643\text{ \AA} \end{array} \right.$

3. Actual laser cavity cross section for $n = 4-3$ schemes.

4. Actual laser cavity cross section for $n = 3-2$ schemes.

roughly 20-50 Torr of gases like neon or CF_4 . The final target superstructure is shown in Fig. 5. This final design allowed us to accurately position the target, crudely verify the pressurization of the laser cavity, and discriminate against unwanted x-ray signals. A much improved version of the target is currently being tested. The mechanical design, fabrication, and assembly methods are radically changed. Basically, the micromachining methods previously employed are to be replaced with the microfabrication technologies of photolithography and anisotropic, chemical etching of single-crystal silicon wafers. This is the same precision technology that

5. Detail of an actual x-ray laser target for the 3+2 resonantly-pumped schemes. The gas channel lies between two knife edges which are held by a large aluminum super structure. The protrusion of the knife edges into the laser channel helps relieve radiation trapping on the $n = 2+1$ line (the laser transition ground state).

is employed in the electronics industry for the production of miniature circuits. The use of the silicon wafer technology permits the reliable mass production of quality target components that are easy to modify when necessary. During the early development phase of the project several process innovations have been achieved which are extremely important to the successful construction of a viable x-ray laser target. These innovations include:

The fabrication and assembly of ultra thin wafers ($40\text{ }\mu\text{m}$ thickness).

The generation of approximately 1500 Å-thick silicon nitride windows that have been able to withstand a differential pressure of one atmosphere with minimal distortion. (These can be used as substrates for the flashlamp metal).

The formation of a long, very straight knife edge by means of anisotropic etching.

The patterning of both sides of a thin silicon wafer with an alignment accuracy of better than $1\text{ }\mu\text{m}$ over the 1.2 cm length of the laser cavity.

This new target design is shown in Fig. 6.

The Collisional Excitation Laser

The collisional excitation laser design was initiated considerably later in the planning phase of this particular set of experiments. Considerable recent work has been done on the scheme,^{57,58} particularly for the Kr atom, but we elected to avoid the difficulties of working with a gas target and chose to use a nearby solid element in the periodic table, selenium.

6. Schematic of the new target design which utilizes etched silicon wafer technology.

Figure 7 illustrates the principal physics mechanisms responsible for producing an inversion with this scheme. Laser light is used to produce a freely expanding coronal plasma having a specific density and temperature variation in the dimension parallel to the incident laser beam. Irradiation conditions are chosen to maximize the abundance of the neon-like ion species in the density regime around $1 \times 10^{21} \text{ cm}^{-3}$. Collisional population of the 3s, 3d, and 3p levels leads ultimately to an inversion between the 3p and the 3s because the upper level (3p) cannot dipole decay back to the neon-like ground state configuration, whereas the 3s has a strong radiative decay to the 2p level. Actually the strongest candidates for lasing are those states having a $j=0$ initial and $j=1$ final state. A full level diagram showing some of the transitions emitted by the neon-like Se M-shell is shown in Fig. 8.

Unfortunately, the collisional population of the $n=3$ levels is non-trivial. Whereas producing neon-like ground state configurations is simple (it only requires the removal of weakly bound M-shell electrons), exciting one of the L-shell electrons to the $n=3p$ state requires approximately 30% more plasma temperature (800 instead of 600 eV). This requires that a laser design incorporate plasma heating conditions which produce significant plasma temperature and density. Table II actually illustrates the sensitivity of the calculated gain to the plasma electron temperature for a Kr plasma (from the calculations of Feldman, Bhatia, and Suckewer).⁵⁸ Figure 9 shows the gain for our scheme as calculated by Hagelstein.⁵⁵ Note the region of plasma at a density of $1 \times 10^{21} \text{ cm}^{-3}$, where the gain is of order 10 cm^{-1} .

The principal physics issues which can effect the collisional laser scheme are: a) the refraction of x rays due to the steep density gradient along the dimension parallel to the incident laser beam, b) the optimum plasma conditions necessary for producing the

7. An illustration of the neon-like selenium collisional excitation laser scheme. Lasing can possibly occur between the 3p and 3s levels because of preferential radiative decay out of the 3s.

TABLE II

Calculated Gain Coefficients for the Neon-like Kr $2p^5 3p (^1S_0) \rightarrow 2p^5 3s (^3P_1)$
Transition as a Function of Two Electron Temperatures and Four Electron Densities.

	$\alpha(\text{cm}^{-1})$			
$T_e(^{\circ}\text{K})$	$N_e = 10^{19}\text{cm}^{-3}$	$N_e = 10^{20}\text{cm}^{-3}$	$N_e = 10^{21}\text{cm}^{-3}$	$N_e = 10^{22}\text{cm}^{-3}$
1×10^7	0.045	0.92	8.8	35
3×10^7	0.067	1.7	16.5	66

8. A simplified level scheme illustrating the wavelengths, radiative rates, and $g-f$ values for Se.

maximum population of $j=0$ neon-like states, and c) significance of absorption from the copious number of transitions present from other ionic species.

The Collisional Recombination Laser

The final scheme we studied, with only a few experiments, involves preferential recombination of electrons into high n -states of hydrogen-like oxygen ions. The original idea for this scheme comes from Gudzenko and Shelepin²⁷ with numerous later extrapolations to laser-pumped plasmas (Irons and Peacock³⁸, Pert³⁹, Korukhov et al.⁵³). The basic recipe to produce the inversion is as follows: a) rapidly fully-ionize a plasma using a short pulselength high intensity optical laser, b) rapidly cool the plasma by adiabatic expansion, electron conduction, radiative power loss, or, preferably, some combination of the three.

Some of the physics questions that affect the performance of this laser scheme include: a) is population inversion maintained for this density and temperature plasma, i.e., can collisional recombination into the $n=2$ level dominate the collisional excitation into the $n=2$ level, and can the plasma be limited in size so that the trapping of the ground state for the laser (i.e., the $n=2$ to 1 Lyman alpha line) remains negligible, at least during the times of peak upper state population, b) can we truly model the atomic physics of this problem, i.e., the ionization kinetics, level populations, line widths, and radiation transport?

This scheme was not optimized before the experiments and our post-experiment modeling has definitely shown some flaws in our

9. The small signal gain for the neon-like Se scheme as a function of distance off the surface of the Se-coated foil . The calculations were done by P. Hagelstein using code XRASER. The curves illustrate the gains associated with different transitions. The highest gain is expected for the $1s^2 2s^2 2p^5 3p(1S_0) + 1s^2 2s^2 2p^5 3s(3P_1)$ transition.

design. We overstripped the plasma, i.e., the electron temperature was too high for optimum production of H-like ion species during the lifetime of the plasma. Moreover, we did not attempt to cool the plasma by any exotic means other than that which comes naturally, i.e., due to adiabatic expansion (a cooling rate which scales as the expansion velocity of the plasma density distribution).

The Measurements

The attitude was adopted early in the planning for these experiments to perform integrated tests of the targets. Our strategy was to a) insure that the new Novette laser could produce 5 TW of green light per beam with a pulselength of 100 psec FWHM, b) verify that the new cylindrical lenses were functional, which means they produced a fairly uniform 1.2 by 0.01 cm focal spot, c) check flashlamp line brightness at green wavelengths (our previous studies⁵⁹ had been done at Shiva at 1.0 μm), d) validate proper operation and spectral

10. A schematic illustration of the placement of the principal x-ray laser diagnostics on the Novette target chamber.

line coverage for the principal x-ray laser diagnostics, e) perform approximately 20 integral (complete) x-ray laser target tests, and f) perform null or other verification tests to certify success (in case positive results were obtained on any of our experiments). A complete table of criteria for verification of the achievement of lasing is shown in Table III.

The primary set of diagnostics used for these experiments is shown in Fig. 10. The streaked transmission grating (described by R. L. Kauffman, et al, in these Proceedings) provided a time-resolved measurement of the brightness of a prospective laser line and also provided the alignment method via an autocollimation technique. The streaked crystal spectrograph provided the time history of the pump lines for the Resonant Photoexcitation scheme. The Fail-Safe was a reflection grating instrument utilizing a micro-channel plate intensifier and so-named because of its tolerance to target misalignment (namely, a large acceptance angle).

These three main diagnostics were complemented by the following diagnostic array: x-ray microscopes and pinhole camera to measure the beam size from x-ray images; time-integrated x-ray crystal spectrographs to determine the absolute intensity of the flashlamp lines; optical diodes to determine laser absorption; and several other of our normal diagnostics for studying laser plasma conditions. The optical axes of the principal diagnostics (fail-safe and streaked transmission grating), together with the target chamber center, defined the line-of-sight along which we pointed the longitudinal axis of the laser focus, as well as the axis to which we aligned our x-ray laser target to high precision (± 0.5 mrad). The alignment scheme for the whole system is shown in Fig. 11.

Our experiments were divided into two parts: a) flashlamp shots to determine brightness and b) actual x-ray laser target shots. The results of a limited number of flashlamp shots are shown in Table III for Cr (14.458 Å He-like F scheme), Ni and Na (He-like neon scheme at 11.000 Å) and Mn (H-like F at 12.643 Å). The tables include the time-integrated intensity and x-ray pulselength data (when

TABLE III

Shot No. + Element	Pulsewidths, psec(FWHM)		Peak Line Intensity		Line Width (eV)	Emission Area (cm ²)	Brightness (Photons/Mode)	
	Laser	Line	(keV/keV-Sphere)					
<hr/>								
<u>NaCl</u>			Front	Back			Front	Back
93012706	96	165	7x10 ¹⁶	3.3x10 ¹⁶	~2.5	7.85x10 ⁻³	8x10 ⁻⁴	3.4x10 ⁻⁴
93012804	98	150	8.3x10 ¹⁶	4.3x10 ¹⁶	~2.5	7.85x10 ⁻³	1.04x10 ⁻³	4.9x10 ⁻⁴
93020107	230	190	9.5x10 ¹⁶	-----	~2.5	7.85x10 ⁻³	9.43x10 ⁻⁴	-----
93020204	102	60	1.4x10 ¹⁷	9.0x10 ¹⁶	~2.5	7.85x10 ⁻³	4.4x10 ⁻³	2.6x10 ⁻³
93020206	100	170	4.7x10 ¹⁶	-----	~2.5	7.85x10 ⁻³	5.2x10 ⁻⁴	-----
<u>Ni</u>								
93013110	116	190	2.7x10 ¹⁶	-----	2.5	7.85x10 ⁻³	2.7x10 ⁻⁴	-----
<u>Cr</u>								
93011906	94	100	4.0x10 ¹⁷	-----	2.0	7.85x10 ⁻³	1.1x10 ⁻²	-----
93012506	90	110	4.2x10 ¹⁷	-----	2.0	2.01x10 ⁻²	4.1x10 ⁻³	-----
93012509	100	100	2.3x10 ¹⁷	-----	2.0	7.85x10 ⁻³	6.3x10 ⁻³	-----
93012512	100	120	1.1x10 ¹⁷	-----	2.0	2.01x10 ⁻²	9.8x10 ⁻⁴	-----
<u>Mn</u>								
93013119	105	140	2.6x10 ¹⁷	-----	2.3	7.85x10 ⁻³	5x10 ⁻³	-----
93020104	101	160	2.3x10 ¹⁷	-----	2.3	7.85x10 ⁻³	4.9x10 ⁻³	-----

11. A schematic of the alignment scheme for the x-ray laser targets and the x-ray laser diagnostics: the transmission grating streak camera and the Fail-Safe.

available), in addition to an estimate of the brightness in photons/mode. In most cases, the brightness is less than optimum for achieving gain. For all cases, except Cr, the amount of data is too limited to conclusively state that sufficient brightness cannot be achieved. More experiments to determine the optimum laser irradiance and target thickness parameters for these flashlamps are planned in the near future.

Results

The results of the x-ray laser target experiments can best be discussed by the type of scheme. For the resonant photoexcitation scheme three potential laser scenarios were tested and are tabulated in Table I. Out of ~ 22 target tests, the basic result: no lasing transitions were observed to within the sensitivity limits of our diagnostics (require achievement of gain lengths greater than 5-6). Although there was an enormous number of ways to fail in the proper execution of the experiments, we believe that a proper test of the schemes took place. Some possible reasons for the lack of positive results are 1) we did not properly certify a resonance between lasant and pump lines (a $\pm 0.0015 \text{ \AA}$ overlap is required), 2) the brightness of our pump lines may have been too small to provide enough gain to observe with the sensitivity of our instruments, 3) the calculated laser kinetics may be slightly inaccurate or perhaps the lasant cavity ion temperature too high (neither was measured in the experiments), or 4) the laser cavity may have collapsed before the inversion was initiated.

The collisional excitation laser scheme with simple selenium coated on Formvar targets was also tested (See Fig. 12). No evidence of lasing lines was observed for this scheme either. Prior to finishing the experiments we already knew where one fault resided in

12. Schematic of Se x-ray laser target.

our design. Figure 13 illustrates the effects of a steep density gradient (which is produced with this type of target) on the trajectory of our potential x-ray laser beam. In short, our scheme would have been compromised by the effect of refraction bending the x-ray laser beam out of the maximum gain region, as well as out of the viewing area of our x-ray laser diagnostics. We have planned some major improvements to this scheme for our next series of experiments. These improvements should preclude the effects of x-ray refraction.

We believe x-ray refraction effects are large

$$d\vec{r}/ds = (1/\tilde{n})\nabla\tilde{n} \cdot \vec{n},$$

$$\tilde{n} = \text{index of refraction} = (1 - cn_e\lambda^2)^{1/2}$$

$$n_e \equiv n_e(\vec{r}), \text{ the density profile}$$

13. An illustration of the effects of a steep density gradient on the trajectory of a beam of x rays.

The final scheme tested was the recombination laser. Here we irradiated a simple Formvar foil (15% oxygen) with two of the Novette beams operated at relatively low intensity. Figure 14 shows our experimental setup and some of the actual results.

14. The experimental setup for the recombination laser experiment. Actual film illustrations of the data obtained for two different length plasmas are also shown.

We measured the time-dependent emission from the balmer α ($n=3$ to 2) transition of hydrogen-like O for both long and short foils. This determines if the signal is exponentiating in intensity with the length of the plasma, as would be the case if it were being amplified. An analysis of our data and comparison with theory indicates that a small amount of gain was achieved ($\alpha = 0.5 \text{ cm}^{-1}$). Since this scheme was not optimized prior to the experiments, we are encouraged by these results and hope to further test this scheme in a future experiment. Further details of these results are presented in a report.⁶⁰

The results of all these experiments led us to conclude that another more rigorous series of measurements is warranted. Our latest effort incorporates improved physics understanding, target design and diagnostics instrumentation.

A set of experiments is underway to study underlying physical processes which could have compromised the demonstration of these lasers or the measurement of their performance. The work is being done using a relatively small laser at KMS Fusion, Inc., Ann Arbor, Michigan. In these experiments we are concentrating on the measurement of most of the major plasma physics issues which could have jeopardized the schemes. As an example, in the resonant photoexcitation scheme we must verify that a pump line overlaps the energy of an absorbing laser state to within a part in 10^4 . This is currently being accomplished with some extremely accurate spectroscopic measurements.

Our strategy to achieve success includes more than a certification of the relevant plasma conditions. We also are constructing more sensitive diagnostics to permit detection of the laser lines, even if they are much weaker than predicted. In addition, we are improving our x-ray laser target construction techniques in order to make the critical components of a target more closely resemble the complex geometries that have been generated during redesign of the laser scheme. Improved target design also enables better execution of the experiment, since often we must certify alignment to our diagnostics to extremely close tolerances.

In the next Novette experiments we will test only one or two schemes. In these tests we will concentrate on iterating target design and optical laser pump parameters around the values predicted by our simulation codes. Hopefully, this method will reduce the possibility that a small uncertainty in the calculation might prevent a successful demonstration.

We envision our program expanding in the near future both due to an increased understanding of the relevant physics issues as well as the emergence in October of this year of an even bigger optical pump laser, Nova. This will enable us to study even more exotic laser design, as well as extend our measurements to shorter x-ray laser wavelengths.

References:

1. R. W. Waynant and R. C. Elton, Proceedings of IEEE 64, 1059(1976).
2. G. Chapline and L. Wood, Phys Today 28, 40(1975).
3. E. Spiller, AIP Conference Proceedings #75, Low-Energy X-ray Diagnostics-1981, edited by D. Attwood and B. Henke (Monterey, CA 1981) p.124.
4. T. Barbee, Jr., AIP Conference Proceedings #75, Low-Energy X-ray Diagnostics-1981, edited by D. Attwood and B. Henke (Monterey, CA 1981) p.131.
5. A. G. Molchanov, Sov Phys. - Usp. 15, 124(1972).
6. V. A. Bushuev and R. N. Kuzmin, Sov. Phys. - Usp. 17, 942(1975).
7. M. A. Duquay and P. M. Reutzepis, Appl. Phys. Lett. 10, 350(1967).
8. Y. L. Stankevich, Sov. Phys. - Dokl. 15, 356(1970).
9. R. McCorkle, Phys. Rev. Lett. 29, 982(1972).
10. W. W. Jones and A. W. Ali, Phys. Lett. 50A, 010(1974).
11. E. J. McGuire, Phys. Rev. Lett. 35, 844(1975).
12. R. C. Elton, Appl. Opt. 14, 2243(1975).

13. T. S. Axelrod, Phys. Rev. A13, 376(1976); A15, 1132(1977).
14. B. A. Norton and N. J. Peacock, J. Phys. B8, 989(1975).
15. A. V. Vinogradov, I. I. Sobelman, and E. A. Yukov, Sov. J. Quantum Electron. 5, 50(1975).
16. R. A. Andrews, Progress in Lasers and Laser Fusion, edited by A. Perlmutter and S. Widmayer (Plenum, New York, 1975), p.235.
17. R. W. Waynant, Appl. Phys. Lett. 22, 419(1973).
18. K. G. Whitney and J. Davis, J. Appl. Phys. 46, 4103(1975).
19. J. Davis and K. G. Whitney, Appl. Phys. Lett. 29, 419(1976).
20. I. Knyazev and V. Letokhov, Opt. Comm. 3, 332(1971).
21. T. Bristow, M. Lubin, J. Forsyth, E. Goldman, and J. Soures, Opt. Comm. 5, 315(1972).
22. B. Lax and A. Guenther, Appl. Phys. Lett. 21, 361(1972).
23. A. Vinogradov and I. Sobelman, Zh. Eksp. Teor. Fiz. 63, 2113(1973); Sov. Phys. JETP 36, 115(1973).
24. A. Zherikhin, K. Koshelev, and V. Letokhov, Sov. J. Quant. Mech. 6, 82(1976).
25. A. Illyukhin, G. Peregudov, E. Ragozin, I. Sobelman, and V. Chirkov, JETP Letters 25, 536(1977).
26. H. Zwally and D. Koopman, Phys. Rev. A2, 1850(1970).
27. R. M. Dixon and R. C. Elton, Phys. Rev. Lett. 38, 1072(1972).
28. R. Dixon, J. Seely, and R. Elton, Phys. Rev. Lett. 40, 122(1978).
29. L. I. Gudzenko and L. A. Shelepin, Sov. Phys. JETP 18, 998(1964); Sov. Phys. - DOKI 10, 147(1965).
30. L. I. Gudzenko, Y. K. Zentsov, and S. I. Yekovlenko, Sov. Phys. - JETP Lett. 12, 167(1970).
31. L. I. Gudzenko, L. A. Shelepin, and S. I. Yakovlenko, Sov. Phys. - Usp. 17, 848(1975).
32. B. F. Gordiets, L. I. Gudzenko, and L. A. Shelepin, Sov. Phys. - JETP 28, 489(1969).
33. E. Y. Konov and K. N. Koshelev, Sov. J. Quant. Electron. 4, 1340(1975).
34. J. Green and W. Silfvast, Appl. Phys. Lett. 28, 253(1976).

35. W. Jones and A. Ali, Appl. Phys. Lett. 26, 450(1975).
36. J. Peyraud and N. Pegraud, J. Appl. Phys. 43, 2993(1972).
37. W. Bohn, Appl. Phys. Lett. 24, 15(1974).
38. E. Y. Konov and K. Koshelov, Sov. J. Quantum Electron. 4, 1340(1975).
39. E. Y. Konov, K. Koshelov, Y. A. Levykin, Y. V. Sidelnikov, and E. S. Churilov, Sov. J. Quant. Electron. 6, 308(1976).
40. F. Irons and N. Peacock, J. Phys. B7, 1109(1974).
41. G. Pert, J. Phys. B9, 330(1976).
42. G. J. Tallents, J. Phys. B10, 1769(1977).
43. R. Dewhurst, D. Jacoby, G. Pert, and S. Ramsden, Phys. Rev. Lett. 37, 1265(1976).
44. K. Sato, M. Shiko, M. Hosokawa, H. Sugawara, T. Oda, and T. Sasaki, Phys. Rev. Lett 39, 1074(1977).
45. A. Skorupski and S. Suckewer, Phys. Lett. 46A, 473(1974).
46. S. Suckewer, R. Hawryluk, M. Okabayashi, and J. Schmidt, Appl. Phys. Lett. 29, 537(1976).
47. S. Suckewer and H. Fishman, J. Appl. Phys. 51, 1931(1980).
48. D. Jacoby, G. Pert, S. Ramsden, L. Shorrock, and G. Tallents 37, 193(1981).
49. J. G. Kepros, Appl. Opt. 13, 695(1974).
50. P. Jaegle, G. Jamelot, A. Carillon, A. Sureau, and D. Dhaz, Phys. Rev. Lett. 33, 1070(1974); P. Haegle, A. Carillon, D. Dhaz, G. Jamelot, A. Sureau, and M. Cukier, Phys. Lett 36A, 167(1971).
51. S. Slutz, G. Zimmerman, W. Lokke, C. Chapline, and L. Wood, Univ. of Calif., Lawrence Livermore National Laboratory Report UCID-16290 (1973).
52. W. Silfvast, J. Green, and O. R. Wood II, Phys. Rev. Lett. 35, 435(1975).
53. V. V. Korukhov, N. G. Nilulin, and B. I. Troshin, Sov. J. Quant. Elect. 12, 1099(1982).
54. P. Hagelstein, Ph.D. Dissertation, UCRL-53100, Jan. 1981, available from Lawrence Livermore National Laboratory Technical Information Department.

55. P. L. Hagelstein, Plasma Physics 25, 1345(1983).
56. P. Burkhalter, G. Charatis, and P. Rockett, Naval Research Laboratory Report #5022, June 31, 1983, and to be published.
57. R. Stewart (LLNL) private communication.
58. M. Feldman, A. K. Bhatia, and S. Suckewer, J. Appl. Phys., 54, 2188(1983).
59. D. L. Matthews, P. Hagelstein, E. M. Campbell, A. Toor, R. L. Kauffman, L. Koppel, W. Halsey, D. Phillion, and R. Price, IEEE J. Quant. Elec., Vol QE-19, 1786(1983).
60. D. L. Matthews, E. M. Campbell, K. Estabrook, W. Hatcher, R. L. Kauffman, R. W. Lee, and C. Wang, UCRL-90279 and submitted for publication (Appl. Phys. Lett.).