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# INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

## LAMP SERIES REPORT
(Laser, Atomic and Molecular Physics)

# ANALYSIS OF NEW ACTIVE MEDIA FOR HIGH POWER GAS FLOW LASERS IN VISIBLE AND NEAR IR SPECTRUM


V.V. Naumov

V.A. Kochelap

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I.A. Izmailov



INTERNATIONAL ATOMIC ENERGY AGENCY

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# ANALYSIS OF NEW ACTIVE MEDIA FOR HIGH POWER GAS FLOW LASERS IN VISIBLE AND NEAR IR SPECTRUM

V.V. Naumov,* V.A. Kochelap *
International Centre for Theoretical Physics, Trieste, Italy

and

I.A. Izmailov
Institute of Semiconductor Physics, Ukranian Academy of Sciences,
Kiev 252650, Ukraine.

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* Permanent address: Department of Theoretical Physics, Institute of Semiconductor Physics, Ukrainian Academy of Sciences, Kiev 252650, Ukraine.

# Preface

The ICTP-LAMP reports consist of manuscripts relevant to seminars and discussions held at ICTP in the field of Laser, Atomic and Molecular Physics (LAMP).

These reports aim at informing LAMP researchers on the activity carried out at ICTP in their field of interest, with the specific purpose of stimulating scientific contacts and collaboration of physicists from Third World Countries.

If you are interested in receiving additional information on the Laser and Optical Fibre activities at ICTP, kindly contact Professor Gallieno Denardo, ICTP.

## Abstract

To look forward to the new trends of high power gas lasers and their future applications, current theoretical and experimental studies of S+S, Cl+Cl, Br+Br and other halogens radiative recombination in the supersonic flow conditions being carried out with the aim to develop a new class of molecular thermally and chemically driven continuous wave lasers on electronic transitions are reviewed.

The general problems (optics and gasdynamics) of the ET laser operation are discussed. The key spectral and kinetic characteristics (recombination efficiency, it branching ratio, quantum yields, rates of E-V-T energy relaxation processes, radiative lifetimes, etc.) important for pumping the B-X band system of $S_2$, $Cl_2$, $Br_2$ and other halogen molecules are analyzed. The initial thermodynamic parameters, gas mixture composition, flow pressure and temperature regimes, and other conditions favourable for a population inversion formation and a light gain sufficient to excite the laser oscillation are searched and optimized. The special strategy of research including a gasdynamic modeling by means of shock-tube driven supersonic flow technique and an optical modeling by flash photolytic technique to understand the behavior of such laser generator/amplifier systems are suggested and tested.

The results of pre-laser studies presented indicate principal possibilities to work out a new GDL of visible and near IR diapasons for industrial applications in progress.


## 1. Introduction

Since the discovery of the first laser by Basov, Prokhorov and Maiman, there has been considerable progress in the development of industrial lasers and their applications. Due to unique physical properties of the laser beam (high coherence, monochromatic radiation and high power density), modern laser technologies offer such important advantages as high productivity, precision accuracy, high quality, economy of material and energy resources, possibility of full-automatic processing and clean environment.

Now there are hundreds firms in the world that produce about 1 million of commercial laser products with total sales up to $ 10 billion, and the laser market growth rate of 10-20% annually is predicted through 2000 (good analogy as for computers' market).

Further progress of laser technology depends on improvement of existing industrial lasers (in order to increase output stability, efficiency, reliability, simplicity in use and service, etc.) on the one hand, and on research and development of perspective industrial lasers of new capabilities (in terms of energy and spectral ranges) on the other hand.

Near IR and visible high power gas lasers on electronic transitions (ET) might be extremely attractive for many scientific and industrial applications. Unfortunately, all existing now ET lasers operate in pulsed regime (rare gas-halide excimers, halogen dimers, et al.) commonly initiated by electron impact or optical pumping [Ref.1]. As is known, the convective-flow techniques can be used both to improve performance of pulsed lasers and to provide more efficient methods for achieving a continuous wave (CW) laser action. However, there is only one CW chemically pumped oxygen-iodine laser (COIL) operating on atomic ET of iodine in near IR spectrum at 1.315 μm [Ref.2] and it is a most promising type of industrial lasers nowadays [Ref.3]. CW lasers on molecular ET in visible spectrum have not been demonstrated yet [Refs.4,5]. In the case of success, we expect the discovery of a new generation of powerful and efficient short wavelength gas flow lasers (ET GFL) [Refs.6,7].

## 2. General Conception. Background.

In principle, from an operational viewpoint, the ET GFL is analogous to well-developed chemical HF/DF, CO - or $CO_2$ - GDLs operating on vibration-rotation transitions (VRT) in the mid IR spectrum because the key laser elements are similar: gaseous gain medium, thermogasdynamic pumping technique and optical resonator (see a typical GFL arrangement in Fig. 1). But to extend the idea of GDL from IR to visible spectral region (from VRT to ET), some complex physical and technical nontrivial problems should be overcome.

The *general conception* about the specificity of ET GFL can be given without going into particulars of the laser action [Ref.7]. One of the main difficulties is to produce a good

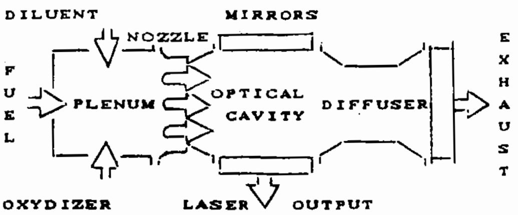


Fig. 1 Scheme of the GFL.

intensive excitation of electronically excited states (EES), another is to provide the conditions for a population inversion during the EES relaxation in a gas flow. The integration of these hard-combined requirements imposes strong limitations on the properties and parameters of active medium and dictates a choice of methods for laser pumping and operational regimes. For illustration, in Table 1 the comparative characteristics for different types of CW laser transitions are presented: pumping rate $R^*$ required for achieving the threshold small signal gain coefficient $\alpha \sim 10^{-3}$/cm, specific spontaneous emission power $W_{sp}$ and stimulated emission cross-section $\sigma_e$. As is seen, for a change-over from IR to visible region, the rate of laser pumping should be increased by a factor of $10^3$ or more. On the other hand, molecular ETs, due to a close spaced manifold of the vibrational and rotational energy levels, have a broad bandwidth that leads to a low gain cross-section (in comparision with atomic ETs), thus a large value of EES population necessitates for a reasonable light amplification. In practice, these conclusions result in a high density of active particles and low temperatures of the medium necessary to use. Therefore, the commonly used reactive flow mixing technique could not be useful for ET GFL pumping so must bring some new problems. In addition, quite a number of further important points should be borne in mind (reaction stability, inversion range, optical homogeneity of the gain medium as well as the design of the gasdynamic tract) for reaching a laser effect. That is why more easily to initiate the molecular ET lasing in pulsed regime as far as its operational time is much shorter that associated with the flow mixing and relaxation in the CW mode. Still one difficulty is the lack of reliable kinetical and spectral data (EES excitation and deactivation rates, radiative lifetimes, absorption cross-sections, etc.), crucial to the selection of suitable laser molecules and chemical reactions. All this gains the impression that the visible ET GFL development would require much more efforts than for conventional IR GDLs.

Table 1 General characteristics of CW laser operation.

| Value | Molecular VRT | Atomic ET (line) | Molecular ET (bound) | Molecular ET (continuum) |
|---|---|---|---|---|
| $\lambda$, $\mu m$ | 2.7...2.9 | 0.5 | 0.5 | 0.5±0.05 |
| $\tau_R$, s | $10^{-2}$ | $10^{-7}$ | $10^{-5}$ | $10^{-5}...10^{-7}$ |
| $R^*$, $/cm^3s$ | $10^{16}$ | $10^{17}$ | $10^{21}$ | $\geq 10^{22}$ |
| $W_{sp}$, $W/cm^3$ | $10^{-5}$ | $10^{-3}$ | 5 | $\geq 50$ |
| $\sigma_e$, $cm^2$ | $10^{-15}$ | $\geq 10^{-14}$ | $\geq 10^{-17}$ | $\sim 10^{-18}$ |

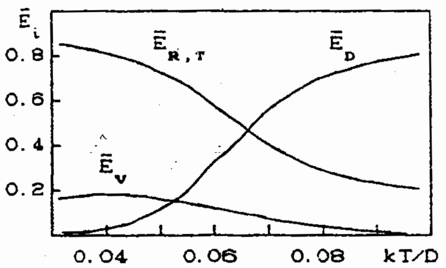


Fig. 2 AB total energy fractions stored in internal degrees of freedom.

*Radiative recombination* of atoms and free radicals in gases presents an important class of rapid and highly excenergic chemiluminescent reactions [Ref.8]. It attracts our attention potentially as a most perspective way to create a thermally pumped (chemically driven) ET GFL - the so-called recombination GDL (RGDL). Unlike usual IR GDLs on VRT, RGDLs can use EES with the excitation energy up to 4 eV. An exemplary distribution of the diatomic AB gas energy for different degrees of freedom versus temperature are shown in Fig. 2. As it seen, in contrast with a relatively small fraction of the vibrational energy, the heat energy that can be stored in breaking chemical bonds under molecular dissociation and partitioned into EES under atomic recombination amounts to 60%. The typical potential energy diagram for the diatomic AB lasant with possible transitions are shown in Fig. 3. If to produce the net ET inversion with a quantum efficiency of, say, 50%, one could create a chemical laser with an efficiency of conversion up to 30%. Hence, the RGDL may be regarded as a powerful and efficient laser energy sourse.

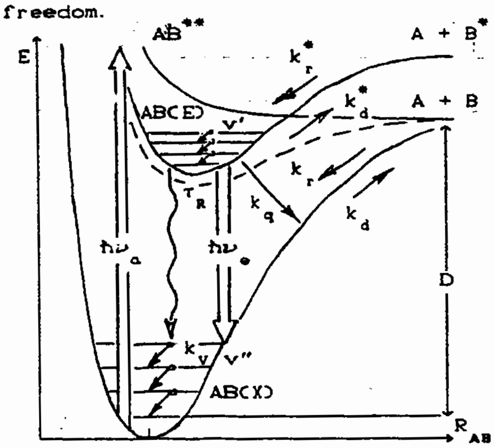


Fig. 3 AB potential energy curves and possible transitions.

The simple scheme of the recombination *pumping mechanisms* is following:

$$A + B + (M) \rightarrow AB(X) + (M) \qquad (1)$$
$$A + B + (M) \rightarrow AB(E) + (M) \qquad (2)$$
$$AB(E) + (M) \rightarrow AB(X) + (M) \qquad (3)$$
$$AB(v) + (M) \rightarrow AB(v \pm \Delta v) + (M) \qquad (4)$$
$$AB(E) \rightarrow AB(X) + h\nu \qquad (5)$$

Here, A and B are recombining atoms, process (1) is a recombination into the ground ES of product molecules AB, (2) - recombination into EES, (3) - collisional quenching of EES, (4) - vibrational relaxation of ES, (5) - radiative ET generating a laser output; (1)-(3) compose a "dark" channel of recombination, (2)-(5) determine a "light" channel.

This kinetic mechanism can provide a high rate of EES production and a large enough quantum yield. In quasistationary conditions, $[AB(E)] = k_r^*[A][B][M]/(k_d^*[M] + k_q[M] + 1/\tau_R)$. A usual order of magnitude of the atomic recombination rate constant is $k_r = 1 \times 10^{-33}\ cm^6/s$ (at room temperatures) and its branching ratio into EES is 0.2...0.7, therefore, to reach a required value of EES pumping rate $R^* = 10^{21}/cm^3 s$, the concentration of atoms should be as high as $[A]=[B] = 1 \times 10^{18}/cm^3$ (at dilution [AB]:[M] = 1:5). It means, the process should be proceed at strong chemically nonequilibrium condiditions to shift one toward to EES production. To do it, the characteristic gasdynamic time, $\tau_{gas} = 1/(d\ln T/dt)$, should be much less than the recombination time, $\tau_{rec} = 1/k_r[A][B]$, which in its turn, should be much less than the times of EES radiative decay $\tau_R$ and collisional quenching $\tau_q = 1/k_q[M]$.

Considering terms in the [AB(E)] equation, it is useful to draw the *limit regions* of pressure and temperature parameters to classify the different cases of EES recombinative population (Fig. 4). In 𝒜 region, only equilibrium radiative recombination/dissociation process is realized. The nonequilibrium one occurs in ℬ, 𝒞 and 𝒟 regions. In ℬ region, the quenching predominates of emission, so the EES population and radiation have an "apparent" two-body character. In 𝒞 region, the emission dominates, so the chemiluminescence has a three-body character. 𝒟 region corresponds to low temperatures when VT-relaxation in excess of EES decay. Maximum of AB(E) population is achieved in ℬ region with increasing of [M] and decreasing of T. Lines 1-5 in Fig. 4 determined by relationships: $[M] = f_1(T) = 1/\tau_R k_d^*$; $T_2$ is found from $k_d^*(T_2) = k_q$;
$[M] = f_4(T) = 1/\tau_R k_q$; $T_4$ is found from $k_{VT}(T_4) = k_q$;
$[M] = f_5(T) = 1/\tau_R k_{VT}$.

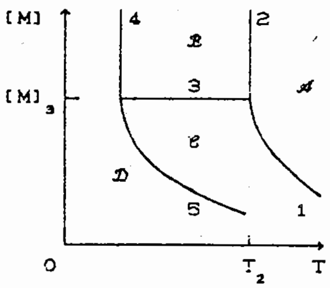


Fig. 4 Status diagram for EES population.

The case of achieving the *population inversion* and *light amplification* requirements, $\alpha^{(+)} = \sigma_e[AB(E)] > \alpha^{(-)} = \sigma_a[AB(X)]$, varies with a spectral structure of working molecules (Fig. 3) and presents a complex trade-off between gain and loss mechanisms. For most appropriate lasants due to a shift of the EES potential energy curves relative to the ground ES and because of favourable Frank-Condon factors, a partial population inversion should be created between low v'-levels of the lasing EES and high v"-levels of the ground ES essentially unpopulated at low operational temperatures. This occurs necessarily when VT-relaxation is more rapid than EES-deactivation (due to the presence of chemically active atoms and relatively small vibrational quants). The condition $(k_{VT}[M])^{-1} < \tau_R$ determines a bottom limit of mixture densities [M]. A simple criterion for the inversion to form during CW recombination pumping is $[A][B] \geq [AB] \times K_p(T) \exp(hc/\lambda kT)$, where $K_p(T)$ is the $A+B \Leftrightarrow AB$ equilibrium constant. Putting $[A]=[B] = [AB]$, one can define a top limit of temperatures $T^* = (D-hc/\lambda)/k \ln(K_o/[AB])$, in which the inversion and light gain occurs.

The bandwidth of radiative ETs also depends on the parameters of the emitting EES and ground ES as well as on the distribution among vibrational and rotational levels.

Most molecular species have the metastable EES that lie close and sometimes below the upper laser level. These EES act as the energy storage reservoirs for excitation that can channel through the radiative EES. The role of such metastables should not be ignored.

To our knowledge we have a sufficient *background* for the RGDL:

a) there are specific diatomic molecules as the potential lasants and radiative gas-phase recombination processes going by the scheme (1)-(5), for which the spectral, kinetical and other properties are favourable and well known (halogens, halkogens and other possible candidates from the elements of Group VI and VII);

b) high degree of dissociation of this molecules is reached at the practicable temperatures of plenum gas: for the $Br_2$ which have the dissociation energy $D \simeq 2$ eV the characteristic temperature is $T_d \simeq 2000$ K, $Cl_2$ - $D \simeq 2,5$ eV and $T_d \simeq 3000$ K, $S_2$ - $D \simeq 4$ eV and $T_d \simeq 4000$ K; this allows to produce the high densities of atoms in the plenum chamber under thermal heating by electrical arc, shock waves, explosion or combustion (there are some fuels can containe the necessary species and supply the necessary temperature and pressure regimes);

c) dissociated gas can be gasdynamically cooled ("chemically frozen") to temperatures below 1 kK fast enough under the supersonic expansion (Mach number $M \geq 3$) in small-scale Laval nozzles (throat height $h_* \leq 1$ mm) duiring the times $\tau_{VT} \ll \tau_{gas} \simeq 10^{-6}$ s $\sim \tau_{rec} < \tau_q$ to initiate EES recombinative pumping followed by the population inversion and gain media formation;

d) in addition to the translation temperature regulation, the supersonic flow provides also to rapid remove the waste species and heat release following the laser action;

e) the presence of the diluent in the gas composition promotes to extend the inversion zone along the cavity flow up to a few tens cm.

f) laser can operate at pressure levels which allow recovery to the atmospheric pressure by a simple supersonic diffuser, thus eliminating the need for mechanical pumps or ejectors.

Table 2 Typical conditions selected in view of theory predictions for the RGDL.

| Gas composition | To K | Po atm | h* mm | M – | T K | P atm | $\alpha^{(+)}$ /cm | λ µm | Molecular band electronic transition |
|---|---|---|---|---|---|---|---|---|---|
| $Br_2$:Ar = 1:5 | 2200 | 20 | 0.2 | 5 | 300 | 0.10 | 0.002 | 1.0...1.3 | $B^3\Pi_{1u}(v'=0) \rightarrow X^1\Sigma_g^+(v''=14-20)$ |
| $Cl_2$:Ar = 1:5 | 3000 | 25 | 0.2 | 4 | 500 | 0.15 | 0.003 | 0.9...1.2 | $B^3\Pi_{ou}^+(v'=0) \rightarrow X^1\Sigma_g^+(v''=12-18)$ |
| $S_2$:Ar = 1:5 | 4000 | 30 | 0.2 | 3.5 | 650 | 0.20 | 0.005 | 0.4...0.5 | $B^3\Sigma_u^-(v'=0) \rightarrow X^3\Sigma_g^-(v''=10-15)$ |

### 3. Results of Pre-Laser Studies. Critical Review.

Because of a complexity of the RGDL development, it takes the *special strategy of research*: first of all, to carry out the *pre-laser* gasdynamic and photochemical studies and only then to work out the RGDL-like machine. The elements of such strategy have been tested by our Advanced Laser Research Group in Kiev.

The method of thermal heating-fast cooling of the medium under the supersonic flow conditions was realized for the $Cl_2(B-X)$ recombination pumping and population inversion formation in the gasdynamic pre-laser experiments [Refs.9-12]. The plant of the "shock tube + Laval nozzle" type was used. The optical (shadow and interferometry) and spectroscopic (emissive and absorptive) flow visualization in complex with a 2-D flowfield numerical modeling were performed. The measurements were conducted in various diagnostic sections $h/h_*$ of tested micronozzles where the flow Mach number was ~ 3-5. Very high nonequilibrium concentrations of chlorine atoms $[Cl] \geq 10^{17}/cm^3$ in the supercooled flow were produced, and extremely intensive recombination emission of chlorine molecules, $I_\Sigma = \int I_\lambda d\lambda \simeq 10^{18}$ phot/cm$^3$s was achieved (equivalent specific power of radiation is evaluated to be up to 0.1 W/cm$^3$). The effects of "chemiluminescence ignition" in downstream, red shift and narrowing of the spectrum also was observed. Using the calibrated diagnostic channels of "interference filter + photoelectric multiplier" type ($\lambda_1$ = 325, $\lambda_2$ = 441.6,...,$\lambda_i$ = 1008±8 nm), the population of the ground ES $[Cl_2(X)]$ and vibrational temperature $T_v$ were restored from the measured values of the gas absorptivities $A_\lambda$, while the population of the EES $[Cl_2(B)]$ - from the measured gas emissivity $I_\lambda$ (necessary coefficients of absorption $\varepsilon_\lambda$ and radiative lifetime $\tau_R$ were determined previously on the basis of analogous measurements behind the shock wave in the test tube and respective spectroscopic calculations). By a computational experiment technique, based on the above nozzle flow diagnostics and comparative gasdynamic calculations, a set of quantitative characteristics of $Cl_2$ kinetics was determined: recombination reaction efficiency $k_r(M)$, excitation branching ratio $k_r^*/k_r$, rates of EES quenching $k_q(M)$, vibrational relaxation $k_{VT}(M)$, etc. (See for details [Ref.7]). Example of numerical simulation of the flow parameters is shown on Fig. 5. It was found, that in the nonequilibrium flow due to a high rate of recombination pumping into the radiative B-state ($R^* \geq 10^{20}/cm^3s$), slow quenching of $^3\Pi$- EES as a whole ($k_q \leq 10^{13} cm^3/s$) and rapid VT-relaxation in the absorbing X-state ($p\tau_{VT} \leq 5x10^{-8}$ atm s, so Tv not for much more than T), the partial population inversion with a density of $\Delta N \geq 10^{13} cm^3$ is formed on the $Cl_2(B, v'=0,1 \rightarrow X, v''=12-18)$ ET in near IR spectral diapasons ($\lambda$ = 0.9...1.2 $\mu$m).

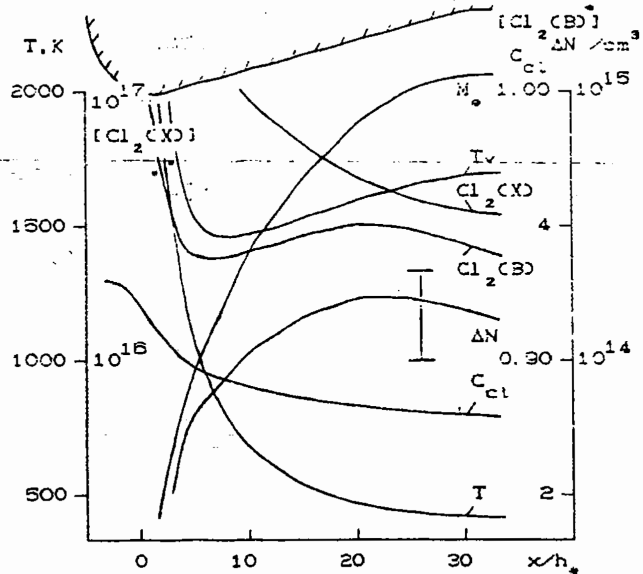


Fig. 5. Evolution of recombining gas flow parameters and population inversion formation versus distance $x/h_*$ in the nozzle $h_*$=0.18 mm, $\theta°$=30° for the plenum conditions To= 3530 K, Po=17 atm, pure chlorine. I - observation.

Experimental varying of the initial thermodynamic parameters over the range of To = 2000-4000 K, Po= 10-50 atm, gas composition $Cl_2$ : Ar = 1:0-1:8 as well as the nozzle flow regimes showed that the obtained value of light gain $\alpha \sim 10^{-3}$/cm is in a good agreement with the theoretical predictions and sufficient to excite a laser oscillation.

The gasdynamic quality of the supersonic flow of recombining gas in the designed part of tested micronozzles also was found to be a good enough.

The typical conditions and results of experiments are summarized in Table 3.

Table 3 Results of gasdynamic pre-laser $Cl_2(B-X)$ studies.

| $h_*$ mm | $T_o$ kK | $P_o$ atm | $Cl_2$ : Ar | $I_\lambda$ /cm$^4$s | $A_1$ % | $A_2$ % | T K | $T_v$ K | $[Cl_2(X)]$ /cm$^3$ | $\Delta N$ /cm$^3$ | $\alpha$ /cm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.11 | 3.3 | 20 | 1:0 | $1x10^{23}$ | - | - | 365 | 1230 | $6x10^{16}$ | $2x10^{14}$ | .003 |
| 0.11 | 2.6 | 19 | 1:2 | $2x10^{22}$ | - | - | 252 | 1120 | $8x10^{16}$ | $4x10^{14}$ | .002 |
| 0.18 | 3.4 | 41 | 1:0 | $8x10^{22}$ | - | - | 620 | 980 | $2x10^{17}$ | $8x10^{13}$ | .001 |
| 0.60 | 2.4 | 18 | 1:4 | $2x10^{22}$ | 38 | 7.9 | 430 | 850 | $5x10^{17}$ | $2x10^{13}$ | .0005 |

The recombination scheme (1)-(5) for the $Br_2(B-X)$ laser pumping under the flash photodissociation conditions was realized in the photochemical pre-laser experiments [Ref.13]. In the $Br_2$ : Ar = 1:8 mixture under the pressure ~ 1 atm, the light gain up to $5x10^{-4}$ /cm at 1.06 $\mu$m wavelength and specific laser energy up to 7 J/l in the pulse duration ~ 100 $\mu$s was achieved without any optimization. We estimated potentially, the specific laser energy can be increased by order of magnitude, and high efficiency up to 10% can be obtained.

It should be mentioned two unsuccessful attempts to realize a RGDL when the preliminary phase of laser studies was ignored [Refs.14-15].

In experiments [Ref.14] the $O_2$(B-X) system was wrongly selected as a laser candidate, and direct measurements in the recombining gas flow in the supersonic nozzle with the high quality resonator mirrors has not resulted into the laser effect. According with the our numerical estimating, under these conditions the light gain was not more than of $10^{-6}$/cm. The point is that the EES of $O_2$, populating by the O+O atomic recombination, have a strongly forbidden ET, thus laser action could not be possible.

Other researchers [Ref.15] failed to demonstrate a RGDL directly with the help of set-up from the trivial heat pumped $CO_2$-GDL. They run experiments simply using various dissociated molecular gases ($SO_2$, $NO_2$ and others) but did not have any laser effect. Moreover, they have not been able to do any conclusions since they did not try to measure any characteristics of active medium in the recombining gas flow. Such a way without pre-laser studies could not have been promising.

Recently the gasdynamic recombination studies for $Cl_2$(B-X) and $S_2$(B-X) systems have been started by LASERDOT (France) with the aim to obtain a chemically driven near IR or visible RGDL [Ref.16]. Unfortunately, the conditions of these experiments are unsufficient for the laser action, but they are promising in progress.

Besides the direct recombination laser pumping scheme, it is known the alternative way to create a powerful visible GDL on ET using a *donor-accepter scheme* based on the resonant molecular E-E energy transfer. There are quite a number of fast chemical reactions (atomic recombination reactions are among these) which have a high yield into metastable EES. In this way, one can obtain a high density of product metastables (up to $10^{16}$/$cm^3$), carrying a great excitation energy (from 1 to 5 eV).* Unfortunately, direct conversion of the metastables' energy into the laser radiation is difficult because such ETs into ground ES are forbidden by Vigner-Witmer rules on spin and orbital symmetry correlations and have a very small cross-section $\sigma \lesssim 10^{-20} cm^2$. Such a situation may be a case with products of recombination for the oxygen* - $O_2(a^1\Delta)$, nitrogen - $N_2(A)$, etc. But using these metastables as the EES energy donors, one can find the suitable near resonant EES energy accepters. The criteria for choice of donor-accepter pares are the ES excitation efficiency and radiative property of lasants. Here halogens and halkogens also are appropriate candidates due to a good combination of spectral and kinetical characteristics, so the partial population inversion arises between low v-levels of the radiative EES and high v-levels of the ground ES. To contrast with the above mentioned COIL on the atomic ET, the molecular one have not been demonstrated yet, although some efforts to develop such CW ET lasers attemped too [Ref.17].

In conclusion, it should be stressed that all dimer candidates selected for RGDLs has been approbated in ET (B→X) and/or (D'→A') lasers with direct optical pumping [Refs.18,19]. If to consider the laser operation process as complex of three sequential stages: 1) high laser levels pumping, 2) broadband stimulated radiative ET and 3) low laser levels depopulation, experimentally two last ones have been successfully demonstrated, and V-T relaxation proved to be able "over-work" the molecular flow rate in quasi-CW lasing that comparable to analogous conditions of recombination pumping. This fact inspires our optimism.

## 4. General Features and Perspective

### 4.1. Expected RGDL performance.

RGDLs on ET will be different from usual GDLs on VRT by following advantages:

- more short wavelength of radiation ($\lambda$ = 0.4 - 1.2 $\mu$m);
- very wide tuning range of laser spectrum ($\Delta\lambda/\lambda \simeq \pm 15\%$);
- high stored energy (up to 500 J per 1 gramm of mass flow rate and
- up to 10 kW per 1 $cm^2$ of cross-section of flow input to the cavity);
- high laser efficiency (up to 30%).

The RGDL intracavity active media parameters will differ from GDLs also:

- more high pressure (0.1...1.0 atm);
- more high temperature (500...800 K);
- length of the inversion zone ~ 10...50 cm (laser pulse duration ~ 10...100 $\mu$s).

### 4.2. Supposed RGDL applications.

Because of its unique properties, the RGDL will have potential for all known high power laser applications in industry and science.

As the RGDL has no theoretical limitation in output power and the beam quality can be good enough, an efficient application for *material processing* should be expected. In fact, for powerful laser technology applications, the gas flow $CO_2$ and solid state Nd:YAG lasers are most widely used now: the users of $CO_2$ lasers take advantage of its high power output capability, and the users of Nd:YAG lasers focus on its high fiber transmission capability. The RGDL will possess both important advantages simultaneously with being able to operate in CW and multi-pulsed regimes. While a power level of the RGDL (scaling up to 10...100 kW) is superior to that of $CO_2$ lasers at the same conditions, the operating wavelength lies near the minimum optical less range of silica fibers as for Nd:YAG lasers. Therefore, it is feasible to produce and deliver high power laser output through a multi-users fiber network system with the RGDL as a central power station combined it with a robot and X-Y processing table for precision *microtechnology*.

Decrease in the RGDL beam divergence (up to 2-3 diffraction limits), associated with the shorter wavelength, results in the better focusibility ($\sim \lambda^2$) which allows to increase the energy concentration on the target as high as 100 times more than the $CO_2$ laser of the same power. Combining this effect with the lesser reflectivity and greater absorptivity of metals ($\sim \lambda^{-3/2}$), the RGDL may be expected to give more high quality of processing.

The wide-range tunability of RGDL (like to a dye laser system) will open new possibilities for *photochemistry* (laser-induced catalysis, isotope separation, etc.) and *biotechnology*. For special laser *energy production* and direct (wireless) long-distance *transmission* applications, the RGDL would operate in an autonomous regime as it will not use an electric input energy sources. The RGDL can be ground-based, transport-mounted or space-based system. The powerful lidar (laser radar) applications for *environment pollution control* and *atmospheric monitoring* will be possible as well. At last, due to favourable wavelength operation and high energy storage characteristics, the efficient repetitively-pulsed (up to $10^4$ Hz) laser generator-amplifier system can be expected to construct as an alternative laser driver for *fusion research*.

Despite these fascinating possibilities nobody has tried really to develop the RGDL probably because of some difficulties mentioned above. It motives us to take part in this challenge because it will be a discovery of new generation of high power short wavelength GDLs and will have a significant impact in the laser technologies of the next century.

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