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Submitted on 1 Jan 1980

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GASDYNAMIC LASERS: SPECTRAL REGION EXTENDING AND EFFICIENCY INCREASING

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Abstract.- It is reviewed the suggested and realized heat pumped molecular GDL's that are lasing in different spectral regions from visible to submillimeter parts using different active molecules and transitions. These systems differ also by their efficiency that is increased the more the lower laser levels were used.

INTRODUCTION

Presently a CO₂-Gas Dynamic Laser (CO₂-GDL) with a lasing wavelength of \( \lambda_{\text{las}} \sim 10.6 \) mkm is mostly known /1-3/. Just this GDL was first realized /4-7/; the investigators have payed most attention to this laser because of its very cheap and common active mixture components (CO₂-N₂-H₂O) which are automatically produced (heated up to required temperatures) in the air-flame of usual carbon-hydrogen fuels /8/. Another a well-known laser is CO-GDL with \( \lambda_{\text{las}} \sim 4.6 \pm 5.4 \) mkm /9,10,2,3/.

From the first works on heat pumped GDL (the only type we shall discuss in this brief review) the possibilities of lasing with the help of another molecules were studied. The nitrogen mixtures with addition of CO₂, N₂O and CS₂ were suggested in the theoretical work /II/. Authors of /III/ obtained lasing on CO₂-N₂-He and N₂O-N₂-He mixtures. The pointed tendency was developed later. It was the goal of such a research to use the main GDL advantages: (1) significant power generation in CW; (2) heat pumping that permit very different methods of preheating of the working gas mixture including methods which provide the system's autonomy, independence of power supply. However, it is advisable to hold the mentioned advantages at the same time with broad range \( \lambda_{\text{las}} \) varying according to the problems of selective light-matter interaction (laser isotope separation; laser chemistry and so on); to the problems of the atmosphere energy transmission improvements, etc. As soon as we know there is no any appropriate methods of \( \lambda_{\text{las}} \) changing for CO₂-GDL at the realized power of MW with sufficient efficiency and in spectral region beyond vibrational-rotational structure of CO₂. CO-GDL has relatively broader spectral tuning region within CO-vibrational bands (4.6±5.4 mkm). Theoretically it is possible to obtain overtone lasing, as example for CO-GDL /IIV/, it will shift \( \lambda_{\text{las}} \) to 2.3-2.7 mkm region. But this method is very specific, it gives only a blue shift and has very low efficiency.

At present time the only method of GDL significant \( \lambda_{\text{las}} \) variation is a change of the lasing molecule (N₂O, CS₂, SO₂ etc.) or lasing transitions (as for 18mkm CO₂-GDL /IV/).

It is very important that a change of lasing molecule and working mixture leads to efficiency changing of GDL known as a low efficiency laser. Having the cha-
nged lasing molecules with lower levels one can get, generally speaking, GDL efficiency increasing, because of higher level populations at the same stagnation temperatures. It is reasonably to develop this method of GDL efficiency increasing /15/ together with a selective level pumping method /16/ realized in mixing GDL's scheme (see /12/, /17/, /18/ and review /19/).

Thus, the GDL spectral region extending is applied so that the laser system efficiency could be increased.

The problem of the efficiency increasing by correct using of nonresonance energy exchange was also formulated along with discussion of the adventures appearing for different GDL molecule operation. The point is that for GDL conditions the smaller quanta oscillator is excited more effectively at two different quanta oscillator collisions for GDL conditions because of higher probability of an extra vibrational energy transfer to translational degree of freedom than for the backward process of translational energy transfer to vibrations required for the excitation of greater quanta oscillator. This effect is a main reason of inversion populations between the upper CO-levels with decreasing quanta because of unharmonicity /20, 9, 2,3/. The nonresonance exchange affects negatively in the case of CO$_2$-N$_2$-He(H$_2$O) -GDL energy transfer from N$_2^*$ to CO$_2$ because (CO$^0$)CO$_2$ level is higher then (v'=1)N$_2$. But this effect is positive as in the case of N$_2$O-N$_2$-GDL /22/ as for CS$_2$-CO-GDL (see the following part) and the authors /22/ suggested to use the same effects for partial population inversion heat-pumped GDL on different molecules.

The development of idea to use the nonresonance effect in the case of GDL lasing CO$_2$ molecule results in suggestion and realization of 18.4mkm GDL /14/ on $\nu_2-\nu_1$ transition instead of usual CO$_2$-GDL $\nu_3-\nu_3\nu_2$ transitions. The mentioned effect helps in high speed relaxation to Boltzman population distribution with very low nozzle translational temperature on the Fermi-resonating CO$_2$ levels forming a "multiplet" population inversion appears between different "multiplet" levels. This method of population inversion formation was theoretically investigated for a number of other three atomic molecule transitions /23/. For convenience we shall turn in this review to Fiq.1 which presents all published, suggested (top lines) and realized (bottom lines) heat pumped GDL. The $\lambda_{las}$ value, transition, GDL active media and reference are listed in Table I.

The $\lambda_{las}$ increasing for molecular lasers under consideration means physically a frequency decreasing in the line of laser transitions between electronic states (spectral region up to $\sim$ 2 mkm, the recombination GDL); vibrational levels of two-atomics (spectral region $\sim$ 3+7mkm); different mode vibrational levels of three-atomics ($\sim$ 7+750mkm); molecular rotational levels ($\sim$ 20+100 mkm); dimers and trimers inter- and intra-molecular mode vibrational levels ($\sim$ 30+100mkm)

**GAS DYNAMIC LASERS WITH $\lambda_{las}<$ 10 mkm**

The possibility of heat-pumped recombination electron transition GDL was dis-
cussed and experimentally proved by different investigation groups (see review in /3/) for some two-atomic VI and VII Mendeleev's Periodic Table column molecule (O₂, S₂; Cl₂, Br₂ and others, see Fig.1) and also for some three-atomic molecules as NO₂, SO₂, CO₂. The advantages of such lasers should be high specific powers (on one order higher than for IR CO₂ GDL /24/) mainly because of one order increasing of quanta energy, and also of high efficiency, as example, about 20% for Br₂-GDL /24/. The 1las decreasing leads to quicker laser beam cross-section decreasing having importance for energy transfer problems. It is important also that 1las of some recombination laser is in visible "window" of the atmosphere.

The essential disadvantage of the heat-pumped recombination GDL is its small gain value, < 10⁻⁴ cm⁻¹ /25-29,3/ at least for the first realization experiments. It could be the reason that such a laser is not realized yet but one should take into account that calculations could not be finished without some assumptions because of lack of experimental data. The realization experiments were performed with the help of shock tubes having optical length 9 cm /25,26/ and 50 cm /3/ - for single nozzle, and 13 cm - for nozzle grid /27,29/.

It was discussed /30/ the possibility to use the high population inversion values calculated for recombination lasers with the help of energy transfer to some atomic system that provides laser emission.

It was suggested theoretically /22/ to use HF, DF, HCl, HI, DCl, DBr, DI as lasing molecules of the heat-pumped partial inversion GDL's. It is possible to get lasing in seven areas of the spectrum between 2.5 and 6.2 mkm (see Fig.1) at the appropriate choice of the energy reservoir molecule for GDL working mixture (see Table I). The comprehensive calculation was made in /22/ (see also /31/) for the case of HCl-D₂-He-GDL. It was shown that the efficiency of such a laser could reach I-1.5% at the value of specific power 100-150 W/kg/sec. The 1las of HCl-GDL is about 3.5 mkm and gets into the atmosphere "window". The calculation of the same GDL
but for the mixing scheme was made in /32/ and it was found that the gain value is not less than $3 \times 10^{-3}\text{cm}^{-1}$ (see also /33, 34/). Theoretical and experimental investigations of HCl-D$_2$-laser were performed in /35/.

The $\lambda_{\text{las}}$ of HBr-GDL suggested in /36/ also gets to the same spectral region. The calculated gain value for pure HBr is two orders higher than CO-N$_2$-GDL gain value. The calculation /36/ gives also pure NO-GDL ($\lambda_{\text{las}} \approx 5.26\mu\text{m}$) gain value comparable with that for pure CO-GDL.

The 2.35-2.7\mu m part of Fig. I presents the overtone CO-GDL spectral region calculated in /13/. The gain value $\lambda \sim 10^{-2}\text{cm}^{-1}$ sufficient for the experimental approval was calculated in /13/ for stagnation parameters $T_0=1800\text{K}$, $P_0=100$ at of CO-Ar (1:4)-mixture escaping from the single profiled nozzle with $h^* = 0.04\text{cm}$ at 58 cm distance from the throat.

The first CO-GDL publications were discussed in monographs /2,3/. Between new reports we should like to point out two series of experiments conducted with a shock tube /37-39/ and adiabatic tube /40, 41/. The 200 Wt power and specific energy 5.9 J/g at 0.5% efficiency were achieved for CO-Ar-mixture in /37/.

The experimental approval of N$_2$O as a lasing molecule in GDL with N$_2$ electrical discharge excitation /12/ was likely to be the first. This molecule was first used for the heat-pumped GDL in /53/ where lasing was registered and in /54/ where the gain was measured with the help of probe laser (see also /55/). The experimental approval of N$_2$O as a lasing molecule in GDL with N$_2$ electrical discharge excitation /12/ was likely to be the first. This molecule was first used for the heat-pumped GDL in /53/ where lasing was registered and in /54/ where the gain was measured with the help of probe laser (see also /55/). The first theoretical and comprehensive experimental investigations made in /21,56-58/ helped to obtain some unknown vibrational relaxation constants and to precise another constants important for N$_2$O-GDL. There were established the technologically important facts:

(I) N$_2$O-N$_2$ and N$_2$O-He two component mix-
ture possibility of GDL operation and (2) low H$_2$O-vapour influence on the gain value (see also /59/).

![Graph showing N$_2$O-N$_2$ and CO$_2$-N$_2$ gain vs temperature](image)

Fig. 2

The gain versus temperature investigation results /21,57/ presented in Fig. 2 show N$_2$O-GDL advantages at low stagnation temperature as compared to CO$_2$-GDL as a result of nonresonance exchange effect influence. The energy exchange N$_2$O-N$_2$ measurements /60/ were important for N$_2$O-GDL model refinement.

The essential advantage of N$_2$O-laser is the possibility of more effective energy transfer in the atmosphere comparing to CO$_2$-laser /61/. The value smaller than for CO$_2$ of N$_2$O dissociation energy is the inadequateness of N$_2$O-GDL limiting the stagnation temperature by 1800 K. This disadvantage could be avoided in case of using of N$_2$O-GDL operation mixing scheme as it was suggested in /61/. The CW heat-pumped N$_2$O-GDL has been just first realized using this method of operation /62/. The N$_2$O- and CO$_2$-GDL power comparison made on the same installation /17/ for different stagnation temperatures and other parameters gave the region where N$_2$O-GDL is the competitive with CO$_2$-GDL; it was also established the operation possibility for cheap N$_2$O-air working mixture /63,64/. The gain $\gamma = 1.1 \times 10^{-2}$ cm$^{-1}$ and the saturation parameter $I_s \approx 3.0$ kWt/cm$^2$ were measured by the method of calibrated losses and appears to be only $\sim 10\%$ less then for CO$_2$-GDL at the same conditions /65/. Qualitatively comparable results were found for quasistational mixing N$_2$O- and CO$_2$-GDL's where cold lasing gases were provided closed to the nozzle crytic section /66/. The mixing was produced at the nozzle final part in /62-65/. Promising N$_2$O-GDL was realized in /50/ using CO which was produced by the fuel burning and mixed with cold N$_2$O in the nozzle. Since (00^2)N$_2$O level is lower then (v=0)CO level, then the effect of nonresonance exchange is positive for N$_2$O-CO instead of CO$_2$-CO mixture for which (00^1)CO$_2$ level is higher then (v=0)CO one. Authors /50/ are successed to obtain CW power 0.8 kWt which is a record now for N$_2$O-GDL.

CS$_2$-GDL (II,4 mkm) is going to the next in Fig.1. This (000$^1$-000$^0$) transition lasing for the heat-pumped CS$_2$-CO-He-GDL was first and independently obtained by two groups /67,15/ using a shock tube /13,45,6 and II7 mkm $\nu_9-\nu_7,\nu_2$ transitions (see Table I) were suggested for CS$_2$-GDL on the basis of experiment /15/. CS$_2$ molecule has essentially lower level position in comparison with CO$_2$ that is the reason to expect the higher GDL efficiency /15/.

The three-level nonresonance exchange was discussed in /68/, it is important especially for CS$_2$-CO-GDL. At the same work /68/ one can find vibration relaxation and exchange constants required for CS$_2$-GDL calculation and more detail description of
II. 4mkm CS₂ lasing experiment /15/. CS₂-GDL calculation and parameter's optimization were made in /69/ where the constants values were taken from /70/.


Some theoretical reports have been published on this problem; we shall not discuss very interesting results of an electric discharge excited laser (EDGDL) (see /71/ and its bibliography).

The modification of /71/ was calculated in /94/ on the basis of usual CO₂-N₂-H₂O (T₀=1200 K, P₀=15 at) with addition of short-pulse 9.4mkm pumping. It was suggested in /72/ to develop /71/ by producing 9.4mkm continuous pumping in usual GDL on the CO₂-N₂-H₂O (I:II:0.5) mixture with the help of additional selective resonator situated closer to nozzle entrance than basic selective 16mkm resonator. It was suggested in /73/ to get a 16mkm lasing from usual GDL but operating on the mixture of CO₂-Ar(I:9 or I:4) under conditions of T₀=2200 K, P₀~50 at, h'=0.2mm. An assumed possibility of producing 16mkm lasing with the help of usual GDL operating on the CO₂-Ar (I:II) mixture was also mentioned in /74/. But calculations /I4, 75/ show that such a laser is unreal because of the required essential flow density decreasing (~10⁻⁴), very low stagnation pressure P₀~2±5 at and CO₂ content (~2%) in the working mixture. These results for 16mkm(02O°-01'0) CO₂ transition population inversion are more reasonable because the theoretical relaxation model /I4, 75/ is in good agreement with 18mkm CO₂-Ar-GDL experimental results /I4, 75/, see next part.

The 16,7mkm (03'0-02°0) and 17,2mkm (04°0-03'0) CO₂ transitions are also inside-of-ν₂-mode transitions, for which the population inversion (~10⁻¹⁴cm⁻³) and gain (~0.02 cm⁻¹) were calculated /I4/ in the case of CO₂-Ar-GDL. But it was not proved in experiments /I4, 75/ where the lasing on these transitions and on 16mkm transition was not detected. The possible reasons of such a disagreement are discussed in /I4, 75/. The reasons of ~16.8mkm CO₂-GDL unreality will be discussed in next part of this work.

c). 18mkm CO₂-GDL and its analogues (transitions between ν₁ and ν₂ modes).

At present the 18mkm CO₂-Ar-GDL is the longest IR wave-length continuous gas dynamic laser /76/. Population inversion formation has been investigated in /I7/ theoretically for (03'0-01'0)CO₂ transition in the case of an electric discharge laser (see fig. 3). CO₂-Ar mixture gas dynamic laser was suggested independently in /I4/ and /74/ as a development of /77/ and was experimentally proved in /I4/ with the help of shock tube. The results of theoretical and experimental 18mkm CO₂-GDL investigations are presented in /75/. The lasing was recorded /I4/ in a broad region of stagnation temperature 1000-2800 K and measured λ₁₉ was as high as (18.4±0.2)mkm. Fig.4 presents the Ttrans measurements for the CO₂-Ar(I:9) supersonic plume. This experimental data gave the opportunity to develop the adequate CO₂-Ar-mixture vibrational relaxation model /75/ for the case of the strong unequilibrium conditions when they were combined with the probe laser 10.6 and 9.4mkm absorption measurements.
and with the measured laser power dependences on stagnation parameters, mixtures and so on. It's important to note that high quality experimental results /73,79/ were very helpful in the model development.

The specific energy estimations ( ≤ 60Wt/g/sec) were made for the new 18mkm CO$\text{2}$ GDL in /80/, and energy dependence on the CO$\text{2}$-content in CO$\text{2}$-Ar-mixture were calculated in /81/. The nozzle shape, stagnation parameters and H$_2$O-impurities effects were studied theoretically for 18mkm CO$\text{2}$ GDL parameters in /82 -84/. It was found there also that efficiency of this laser could be as high as ~2%. This value is much higher then efficiency of usual CO$\text{2}$-GDL (without "mixing"). This advantage is due to relatively low laser level position, degeneration of energy stored vibrational mode and low buffer rare gas heat capacity /15/.

This new GDL inversion generation

principle is rather universal and suitable for different molecules.

In the case of CO$\text{2}$-Ar-mixture it gives the population inversion not only for 18,4mkm (03'0-10'0) transition. There were calculated /14/ΔN and χ values also for 19,7mkm (04'0-II'0): 21,2mkm (04'0-II'0); 50,2mkm(04'0-00'1) so far without experimental approval.

In the case of Ar-exchanging in the mixture for another rare gases one can get variations in GDL energy parameters for different transitions with the goal of optimization. 18,4mkm lasing was registered to be less intensive for CO$\text{2}$-Xe then for CO$\text{2}$-Ar mixture.

In the case of exchange of lasing CO$\text{2}$ molecule one can get GDL spectral region extending with the help of Ar-mixture with another linear three-atomic molecule with Fermi-resonance between symmetrical and bending modes. There were calculated GDL parameters /23/ for N$_2$O-Ar (λ$_{las}$=21.5mkm) COS-Ar (29.5 and 30.5mkm) and CS$_2$-Ar(38.3
and 39.3 mkm) mixtures. The method is described for the unknown spontaneous probability calculation of all mentioned transitions and the paper presents all known relaxation constant data. A part of the relaxation data were measured by ultrasonic absorption especially for H2O-Ar-GDL /35/ and CS2-Ar-GDL /86/ investigation program.

The highest values of \( \Delta N \sim 7 \times 10^{-4} \text{cm}^{-1} \) and \( \Delta N \sim 1 \times 10^{15} \text{cm}^{-3} \) were found /23/ for CS2-Ar-GDL. The population inversion is even higher than in case of CO2-Ar-GDL /75/ at lower temperature \( T_0 = 800 \text{ K} \) instead of \( 1200 \text{ K} \) that is likely to support a suggestion on higher efficiency. This result is in agreement with relatively lower CS2 level position /15/.

d). GDL on nonlinear molecule transitions.

One of the first attempts to study the possibility of nonlinear molecule application for a heat pumped GDL is the work /87/ where SO2-Ar-GDL parameters are calculated for \( \lambda_{\text{las}} = 11.8 \text{ mkm} \) (see Fig. 5). SO2 molecule is interesting because of two widely different vibration relaxation times of the upper and the lower laser levels (an extra component for lower level relaxation speeded like in the case of 10 mkm CO2-GDL is not required). At the same time the SO2 \( \nu_1 \) and \( \nu_2 \) relaxation times are long enough for nonequilibrium vibrational energy accumulation at supersonic expansion cooling. By the authors /87/ opinion from the known three-atomics SO2 molecule is most promising one for GDL application. It is thermally stable, not very toxic, low price and has rather good known spectroscopical constants. In /87/ one can see the list of important SO2 relaxation constants and the discussion of possibility of O2 addition into working mixture as a heat-source molecule. It could be pointed out that lower position of upper laser level \( \sim 1000 \text{cm}^{-1} \) less than for (00^01) CO2 will tend to efficiency increasing of the proposed SO2-GDL /15/. The calculated population inversion is \( \Delta N \sim 5 \times 10^{15} \text{cm}^{-3} \) for the temperature as low as \( T_0 = 1000 \text{ K} \) in case of SO2-Ar (2:3) mixture. But the value of \( \Delta N \sim 2 \times 10^{-4} \text{cm}^{-1} \) is relatively small because of much bigger number of nonlinear molecule rotational levels than in the case of CO2-molecule. The probability of spontaneous transition calculated in /87/ is ten times less than for 10mkm CO2-GDL. It follows from spectroscopic data that 16.8 mkm (100-010) SO2 transition probability is 50 times less than the corresponding value for 11.8 mkm transition (in spite of comparable population inversion) so we can conclude that 16.8 mkm SO2-GDL is unreal one.

Another example of nonlinear lasing molecule is also discussed theoretically in /88/ where heat pumped H2O-GDL is suggested for \( \lambda_{\text{las}} \equiv 28 \) and 33 mkm conform-
ing to (001-020) and (100-020) $H_2O$ transitions. The difference between $SO_2$ /87/ and $H_2O$ /88/ GDL calculations is that the gain values $\mathcal{A} = 0.9 \times 10^{-2} \text{cm}^{-1}$ and $0.8 \times 10^{-3} \text{cm}^{-1}$ are about 2 orders higher for 28mkm and 33mkm $H_2O$ transitions at the typical pure water vapour stagnation conditions $T_0 = 2500 \text{K}$, $P_0 = 1 \text{at}$. It should be possible very easy to check such a high gain experimentally. In accordance with calculations of /88/ the population inversion is as high as $10^{16} \text{cm}^{-3}$ and the specific energy could reach the value 40Wt/g/sec for 28 mkm lasing. The investigation of the possible $O_2$ and $H_2$ impurities effect on $H_2O$-GDL parameters have shown that $O_2$ role is negligible, but $H_2$ changes sufficiently the (001) and (100) levels population resulting in population inversion between them. In accordance with this conclusion the same authors calculated $H_2O-H_2$-GDL /89/. The gain value around $\sim 3 \times 10^{-2} \text{cm}^{-1}$ was found for five different submillimeter transitions $\sim 150$, $\sim 163$, $\sim 173$, $\sim 208$, and 733 mkm in the case of $T_0 = 2500 \text{K}$, $P_0 = 0.5 \text{at}$ for the $H_2O-H_2(4:1)$ mixture.

e). GDL on rotational transitions and "condens laser".

A gasdynamic method of population inversion production on rotational states of molecules was suggested in /90/ and again in /91/. Authors of /90/ proceed from the assumptions that singlequantum processes start to be most important colliding rotational transitions with the temperature decreasing, when exchange processes and transition probabilities start to be significantly decreased; transition probabilities are strongly decreased also with increasing rotational quantum number. The calculations of $HCl-He$-GDL /90/ gave population inversion for the group of rotational levels ($J = 13\pm 20$), $\lambda_{\text{las}} \sim 40\mu$ 20mkm with $\mathcal{A} \sim 10^{-2} - 10^{-3} \text{cm}^{-1}$ and efficiency $\sim 0.1\%$.

The author /91/ who wrote the population inversion condition based on some simplifications made nearly the same assumptions. GDL with conversation of a solid state-liquid phase transition energy into laser radiation was suggested by authors of /92/; they called it as gasdynamic "condens laser". There were discussed two ways of population inversion productions on vibrational levels of intermolecular and intramolecular modes at such condensation conditions when there exist very excited products of condensation (dimers and trimers, in particular). The grade of excitation depends on complex association energy that is highest ($5\text{-}10\text{kkal/mol}$) for hydrogen-bond molecules $H_2O$, $HCl$, $HF$.

It was theoretically shown in /92/ that the gain and lasing are possible in the region of $\lambda_{\text{las}} \sim 30\pm 100\text{mkm}$ for $H_2O$-GDL "condens laser". Strongly unequilibrium spontaneous IR emission was registered experimentally from supersonic wet air jet ($T_0 = 300 \text{K}$, $P_0 = 1 \text{at}$). It was established in the following more careful experimental investigation /93/ that the rotational distribution of $H_2$ $16O$ molecules is unequilibrium and it's impossible to discribe it by Boltzman distribution with any rotational temperature $T_{\text{rot}}$. The integral absorption coefficients for four rotational submillimeter transitions were measured with...
the help of a flat supersonic rare water vapor jet ($T_0 = 320-450K$, $P_0 = 4$ Torr) for very different conditions of condensation development.

Authors of /93/ could not register the population inversion so far in spite of the fact that rotational distribution inequilibrium increased when homogeneous condensation develops in flow.

CONCLUSION

Summing up, one can note that there are many theoretical suggestions on developing of heat pumped GDL over different spectrum region from visible to submillimeter one and in the same time some of them should have the increased efficiency values. However, there are only five operating gasdynamic systems. While performing the program on extending of a spectral region and on increasing of GDL efficiency which was started in the laboratory of Lowtemperature plasma optics of the Lebedev Institute (Moscow) about five years ago, one has layed stress on experimental investigations /14,15,21,25,48,56-59,66, 69,75,85,86/, though a theoretical search was also made /21,23,26,30,61,75,87/.

The regular author's colleagues: head of the laboratory Prof. N. N. Sobolev, scientific workers A. I. Demin, A. Yu. Volkov and later A. A. Vedeneev, post-graduates Yu. A. Kulagin, V. N. Epikhin took part in performing this program. A number of works were succeeded only due to collaboration with Institute of Fluid Flow Machines of the Polish Academy of Sciences (division of Dr. E. Milevski) /62-65,76,80-84/.

Further progress on realization of theoretical works will depend, of course, on appearing of important applications for GDL on either wavelengths; one of the purpose of such a review is to give to the specialists the nowday information on possibilities to develop powerful continuous coherent radiation sources in different parts of the spectrum.
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BIBLIOGRAPHY


