 

***CHRONICLE***

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# IX all-Russian seminar on chemical and electric-discharge CO lasers (KhL/COL'99, Smolyachkovo)

V I Mashendzhinov, M A Rotinyan

**Abstract. A review of reports made at the IX seminar, which was held at the 'Applied Chemistry' Russian Research Centre (Smolyachkovo, Leningradskaya province), is presented.**

For about the past 20 years, a seminar mainly devoted to the development of high-power chemical lasers has been held once every two years at the 'Applied Chemistry' Russian Research Centre (ACRRC). Beginning in 1995, reports on the development of high-power technological electric-discharge CO lasers have been included in the program of the seminar on the initiative of I B Kovsh, President of the Laser Association. Sixty participants took part in the work of the IX seminar. Four meetings were held at the seminar, and 22 reports were made.

The seminar was opened by M A Rotinyan who spoke on the 30-year history of the laser program at the 'Applied Chemistry' Russian Research Centre (ACRRC) and who presented a well-illustrated chronicle of the seminars in Smolyachkovo.

Several reports were devoted to the application of chemical lasers. V I Barinov (VIMI State Enterprise, Moscow) reviewed in detail all areas of application of chemical lasers (CLs) mentioned in the literature, paying special attention to civil applications. A high absorption coefficient of water at wavelengths greater than 3 μm and the availability of optical fibres make an HF laser a promising source for medicine, in particular, for ophthalmology, angioplastics, and cosmetology. A DF chemical laser was used in lidars for ecological monitoring of the atmosphere and detecting leakage of natural gas in main pipelines. An HF chemical laser was pro-posed for monitoring the environment of electrochemical aluminium plants. In the opinion of Japanese scientists, an oxy-gen-iodine chemical laser can compete with conventional technological lasers. The high optical quality of its medium, the availability of fibre optics with the required radiation resistance, and a lower reflectivity of the oxygen-iodine laser radiation by the surface of materials being processed in comparison with $CO_2$ lasers are substantial advantages of oxy-gen-iodine lasers, especially in the case where one needs a high average power (greater than 10 kW ) and autonomous laser operating conditions.

**V I Mashendzhinov, M A Rotinyan** 'Applied Chemistry' Russian Research Centre, prosp. Dobrolyubova 14, 197198 St.Petersburg, Russia

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In addition to this report, G K Vasil'ev from the Institute of Chemical Physics in Chernogolovka (ICPCh) told about the work presented at the XXI International Laser Conference LASERS'98 (7 – 11 December 1998, Tucson, Arizona, USA), where technology for drilling rocks with radiation of a DF chemical laser was proposed.

In the report of E F Sobotkovskaya (ACRRC), which was based on information published in the literature, some trends in the development of cw CLs for military purposes were considered. She briefly analysed the stages of the development of high-power CLs abroad and commented on advertising material of TRW Corporation (USA), which is the global leader in this field. Data on the current situation in the execution of programs of the development of spaceborne, airborne, and land-based lasers were presented.

V G Karel'skii ('Energomash' Research and Production Association, Khimki, Moscow oblast) analysed different areas of application of a spaceborne laser technological system (SLTS) based on a cw CL with the output beam power of up to 30 kW, including space technologies for processing and growing materials, power supply of space vehicles by transferring radiant energy, atmospheric monitoring, space debris removal, etc. It was noted that an advantage of a cw CL, in spite of a large consumption of the laser working material, is the possibility of using a turbogenerator at its exhaust, which, according to the estimates made at M V Keldysh Research Centre (Moscow), is able to produce electric power as high as 50 kW. Preliminary analysis of the design of the SLTS showed the feasibility of its arrangement on 'Progress' and 'Resurs' type space vehicles.

B G Bravyi (ICPCh) considered the specific features of applying of a lidar using a pulsed HF(DF) CL with the pulse energy of 100 J for remote monitoring toxic aerosols. Its principle of operation is based on backward aerosol scattering, and only an HF(DF) CL, with its high output energy and a wide spectral range, is able to solve this problem for a wide class of toxic substances at distances up to 10 km. It was shown by the example of tributylamine, which is a spectral analogue of modern toxins, that the region of anomalous dispersion depends on the droplet size (the smaller their size, the narrower the region). Minimum detectable concentrations (MDCs) were presented. For a gaseous impurity with the absorption cross section of $10^{-17}$ cm$^2$, the volume MDC is $4 \times 10^{-9}$; for the cross section of $10^{-21}$ cm$^2$, it is $4 \times 10^{-5}$; for an aerosol, the MDC is about 2 mg m$^{-3}$.

The problem of cw CLs was discussed in seven reports. S I Zhdanovich (ACRRC) presented experimental data supporting the possibility of additional chemical pumping in a gasdynamic laser operating on combustion products of an exotic fuel representing a mixture of dicyanacetylene, nitrous oxide, and nitrogen. Additional injection of $N_2O$ into the near-critical region of a nozzle causes an increase in the small-signal gain by a factor of 1.5. In this case, the gain reaches 1.9 $m^{-1}$, whereas the calculation neglecting the $N_2O \rightarrow N_2 + O$ and $CO + O \rightarrow CO_2$ reactions gives the gain as low as 1.2 $m^{-1}$. However, a final conclusion on the presence of additional chemical pumping can be made only after additional experiments and calculations based on a more detailed chemical kinetics.

Calculations of the optimal characteristics of cw DF CLs were presented in the report of K K Nekrasov ('Energomash' RPA). He considered a generator of an active medium, a diffuser, and an ejector. Specific output laser powers (related to the summary generator and ejector rate of flow) for two pressures of an active medium (4 and 10 Torr) were compared. The initial data for the calculation (the specific output power and the pressure at the diffuser input) were taken from the previous work of M L Shur (ACRRC). The closeness of the compared specific powers suggests that it is desirable to use low pressures in a laser cavity, which provide a high specific output power and a lower consumption of expensive deuterium) at least for the DF laser.

V K Rebone (ACRRC) reviewed all the experiments on the study of cw HF CLs with radially divergent nozzle blocks. Seven versions of devices with the consumption of the working material in a range of 27 – 700 g $s^{-1}$ were tested (the specific output energy for the model of maximum size was $\sim$ 260 J $g^{-1}$). Using the results obtained upon improving the design of small-size models and the optimisation of the chemical composition of their working material, potentialities of increasing specific output energy for this model were estimated. The feasibility of obtaining specific output energy as high as 560 J $g^{-1}$ was demonstrated.

Results of studies of cw HF CLs with three-jet nozzle blocks were generalised in the report of S V Konkin (ACRRC). Such nozzle blocks (in which oxidiser and fuel jets are separated by helium) allow us to increase the specific output energy and the length of an active medium along the flow (up to 15 cm) and to decrease the optical inhomogeneity of a medium in comparison with their two-jet analogues. Data on the influence of the angle of secondary-fuel injection and the pressure of an active medium on the specific output energy were also presented.

I A Fedorov (ACRRC) presented a review of experimental and theoretical works on the study of an overtone HF CL, which were made at the 'Applied Chemistry' Russian Research Centre in collaboration with 'Energomash' Research and Production Association and 'Vavilov State Optical Institute' All-Russia Research Centre. Data on the influence of gas-dynamic characteristics of a flow of a working mixture and specific features of the optical cavity on laser parameters were presented. For a laser with an active medium 70 cm long, the maximum output power was determined. It was obtained by varying the mass flow of components, the excess of oxidiser, the degree of dilution of a working mixture with helium, and the position of an optical cavity axis with respect to the output plane of the nozzle block.

In laser experiments, parameters of dichroic mirrors used in a cavity were also studied. The surface scattering factor ($\sim$ 0.001) and the radiation resistance (37 kW $cm^{-2}$) for 10-s exposure time were determined. The maximum output laser powers in the overtone region (7.8 kW) and the efficiency (43 %), which was measured with respect to the power in the fundamental mode under the same conditions, were reported.

Supersonic HF CLs, with $SF_6$ molecules used as donors of fluorine atoms, were studied in detail by many authors. In all cases, the pyrolysis of $SF_6$ took place in a plasmatron at a temperature of $\sim$ 2000 K. V E Revich (ACRRC) presented the results of thermal chemical calculations for the $SF_6 - O_2$ mixture. He showed that in the case of decomposition in air, one does not need a high temperature to obtain the same flow of atoms as in the case of fluorine, and the temperature as low as $\sim$ 1700 K is sufficient for this purpose. This allows us to analyse the feasibility of designing an autonomous cw CL using non-toxic components based, for example, on a gas-turbine source of hot air, a Cowper stove, or other devices of this kind. Mass flows required for obtaining in this laser an output power of 300 kW were calculated.

B A Vaskubenko from the 'Research Institute of Experimental Physics' Russian Federal Centre, Sarov (RIEP) discussed the problems of pressure recovery in a supersonic oxygen-iodine laser. He noted that presently available jet generators of $O_2(^1\Delta)$ are able to form at the input of the nozzle array the summary static pressure as high as 100 Torr, and the use of the worm type generator developed in the RIEP promises even greater results. This generator is able to increase the power density by a factor of two with respect to the jet generator (up to 1700 W $cm^{-2}$), with the degree of $Cl_2$ utilisation above 90%, and provide the pressure of $O_2(^1\Delta)$ at the input of a nozzle above 70 Torr, which exceeds the value achieved nowadays by a factor of three.

Pulsed CLs were discussed in six reports. S D Velikanov (RIEP) reported the concept of designing repetitively pulsed non-chain CLs with a high pulse energy, which was developed in the RIEP. This concept uses identical modules, an oscillator-amplifier scheme, a closed cycle for a working medium, $H_2(D_2)$ as donors of H(D), blade electrodes without additional preionisation devices, and the voltage is applied to electrodes from pulse GIN type generators with different polarity. Results of the study of a system containing three identical modules were reported. The output energy from a single model in the case of lasing on DF was $\sim$ 10 J, and the laser efficiency was 2 – 2.5%. Operation at a 10-Hz repetition rate was demonstrated. A master oscillator with an unstable cavity provided diffraction divergence.

G M Mishchenko (RIEP) presented the calculations of a system consisting of many modules developed by S D Velikanov for obtaining a total energy of 1 kJ. He showed that his model well describes the experimental characteristics of the module and presented the calculated dependences of the module efficiency on the input power. He also calculated the effect of the magnification factor of an unstable cavity on the output laser energy, and the effect of the mismatch of triggering times of different modules and the time delay of amplifier triggering on the total energy of the system of modules (with the length of an active medium of up to 6 m). The results of detailed studies of the effect of small-scale optical inhomogeneities on the quality of a beam of an electric-discharge CL of this type were also presented.

The idea of thermal chain initiation of a pulsed HF CL was developed in the report of V I Igoshin (P N Lebedev Physics Institute, Samara Branch). Active centres in a working mixture of this laser ($F_2 - H_2 - HF - He$) are produced through the decay of compounds with a low decomposition activation energy. It was proposed to use $F_2O_2$ and $N_2F_2$ as such compounds. Energy is introduced into the system by optical pumping HF using an external source. Possible characteristics of the laser were calculated.

At present there is only little experience in designing repetitively pulsed $F_2 - H_2(D_2)$ CLs, so that any paper in this field attracts great interest. K A Kutuzov (ACRRC) reported some methods providing stable operation of the chain reaction HF laser with an active volume of 50 $cm^3$ and a pulse repetition rate of 50 Hz. In the case of reaction initiated by a barrier discharge (semiconductor ferroelectric ceramics), the technical efficiency reached 10%.

In the reports of M A Azarov and A V Arsen'ev (ACRRC), working processes determining the limiting energy characteristics of pulsed photoinitiated HF/DF CLs were analysed. The results of the calculated optimisation and of the experiments made by the authors using a model of this laser, with an active volume varied in the range from 50 to 100 litre, were presented. It was shown that

(1) the achievement of limiting energy characteristics requires a 100-fold excess of unsaturated gain over the threshold value;

(2) one can vary the laser pulse duration from fractions of microsecond to $\sim$ 100 μs by changing the degree of fluorine dissociation and the total pressure of a working mixture; in the experiments, this range extended from 1 to 50 μs;

(3) 'the master oscillator – amplifier' scheme provides the best solution of the problem of obtaining high-energy extraction from a medium and good optical quality of output radiation;

(4) a substantial effect on the operation of a pulsed DF CL is produced by $CO_2$ contained in a laser medium and air filling a part of a complex laser cavity.

Both combined and independent effects of absorption and relaxation involving $CO_2$ impurity on energy and spectral characteristics of pulsed DF CLs were experimentally studied. In particular, the requirements for the content of $CO_2$ in fluorine were determined. In the authors's opinion, for fluorine used in a working mixture of a pulsed DF CL, this content should not exceed 0.005%.

Three reports were devoted to CO lasers. V F Sharkov from the Troitsk Institute for Innovation and Thermonuclear Research, Troitsk, Moscow oblast (TIITR), presented a review of works on subsonic CO lasers and the development of an experimental base for their testing performed in the ACRRC, its Perm Branch, and the Troitsk Branch of Kurchatov Institute of Atomic Energy (nowadays TIITR). He emphasised that the experience accumulated in the 1960s – 70s was successfully applied to in the development of large-scale facilities in the TIITR.

In his report, V A Gurashvili (TIITR) presented a summary of basic achievements of the institute in the development of high-power CO lasers, including a large-scale subsonic CO laser with an efficiency of up to 30%, a repetitively pulsed CO laser with a pulse repetition rate of 100 Hz, a multikilowatt supersonic CO laser, and an overtone CO laser emitting in the 2.5 – 4-μm range with an efficiency (measured relative to the fundamental mode) of 10%. Phase conjugation in the active medium itself on the basis of four-photon mixing, with the reference wave intensity of $\sim$ 1 kW $cm^{-2}$, was also studied.

The speaker also discussed possible areas of application of high-power CO lasers, such as the separation of oxygen isotopes by multiphoton ionisation of $COCl_2$. In his opinion, the application of technological lasers in conventional fields (cutting, welding, etc.) would be cost-effective only if their application permits an increase into the productivity by a factor of 20.

The results of calculations of a supersonic repetitively *Q*-switched CO laser were reported by B S Aleksandrov (ACRRC). The author showed that this operating mode is able to increase the peak power of a CO laser by two-three orders of magnitude, with FWHM pulse duration being equal to 35 – 60 ns, to extend the spectral range of laser emission to the long-wavelength region, and to obtain in a laser operating with a repetition rate of $\sim$ 10 kHz the average radiation power at a level of 90% with respect to the value in the cw operating mode. A *Q*-switched CO laser offers promise for inducing selective chemical reactions, which are used particularly, in isotope separation.

A general report, which relates to all types of high-power lasers, was made by N E Sarkisov (TIITR). Using results of experimental studies of high-power cw electric-discharge CO lasers as an example, he showed that diffraction effects and weak inhomogeneities in a medium or in optical elements cause spatial disintegration of laser radiation and the formation of a stripe structure or of high-intensity spots. This effect was observed at radiation intensity as low as 10 kW $cm^{-2}$, and it is unlikely that one will be able to avoid it when increasing a single laser element in size for obtaining high output powers. In the author's opinion, high-power beams should be formed by coherent summation of beams produced in separate modules.

Unfortunately, not all lines of investigation of chemical and CO lasers in Russia were presented in the program of the IX seminar. For example, in spite of a tradition, only one report was devoted to oxygen-iodine lasers, problems of optics of high-power lasers were discussed only in one report, and excimer systems were not discussed at all. However, like at any other conference, this situation is determined by the membership of the seminar and does not characterise development trends. Nevertheless, some conclusions can be drawn from the analysis of an incomplete picture.

Leaving aside military applications of cw CLs, whose ideology is developed in much detail in the USA ('ABL', 'Alpha', 'Thel' and other programs), potentialities of their peaceful use are rather hazy. This conclusion relates in the same measure to CO lasers. The fulfilment of programs of the development of technological CO lasers with a medium output power in Japan and Europe did not supersede conventional $CO_2$ and solid-state lasers from industry in spite of the fact that the use of CO lasers offers lower expenditure per unit product. As noted at the seminar, it is reasonable to expect that CO lasers will be beyond compare in technological processes where wavelength is of substantial importance, specifically, in isotope separation.

In our country, much scientific and engineering experience in the development of different types of CO lasers (subsonic, supersonic, repetitively pulsed) with different output powers has been accumulated (TIITR, Lebedev Physics Institute, ACRRC), and Russia occupies a prominent place in this field. As for CLs, their advantages become evident when autonomous systems with a low consumption of working components are required. For example, for the problems of space engineering.

For more than 30 years cw HF(DF) CLs have been studied, the basic scientific problems of kinetics and gas dynamics have been solved, and, therefore, one can hardly expect radically new results in this field. All studies represent an improvement of certain elements or generalise previously obtained results. Such problems as scaling of a cw CL operating on overtone transitions, coherent summation of radiation emitted by separate modules, and phase conjugation of multiline lasers are of principal importance, but they were not discussed at the seminar.

As for pulsed CLs, we note considerable progress in the development of multijoule non-chain reaction HF(DF) lasers. Now one can speak about a repetitively pulsed HF (DF) laser operating on an $SF_6 - H_2(D_2)$ mixture as a technical device with the pulse energy of 100 J.

We also note repeated attempts of modelling a chemical system with photon or thermal chain branching, which, if realised, will produced an ideal cascade CL with initiation energy almost equal to zero. The importance of this work is as great as the problems encountered in the realisation of these ideas in a real laser system.