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IV International Conference on Atomic and Molecular Pulsed Gas Lasers (AMPL'99)

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Abstract. A brief review of the most interesting papers presented at the IV International Conference on Atomic and Molecular Pulsed Gas Lasers (AMPL'99), which was held in Tomsk, September 13 – 17, 1999, is provided.

The IV International Conference on Atomic and Molecular Pulsed Gas Lasers (AMPL'99) was held in Tomsk, September 13 – 17, 1999. This conference was organised by the Institute of Atmosphere Optics (IAO), Siberian Division (SD), Russian Academy of Sciences (RAS), Institute of High-Current Electronics (IHCE), Siberian Division, Russian Academy of Sciences, Tomsk State University (TSU), and Siberian Physics and Technology Institute (SPTI).

Scientists from Russia, France, the USA, Germany, Australia, Belarus, Japan, and Ukraine took part in the conference. Prilezhaev Readings on optics and spectroscopy for students and young scientists were held as a part of the conference. The program of these readings included invited lectures delivered by the leading scientists attending the AMPL conference.

The scientific program of the AMPL conference continued traditions of this conference series and consisted of the following six sections: gas and plasma lasers, metal-vapour lasers, dye lasers and photoprocesses in complex organic molecules, physical processes in gas lasers, laser systems and their applications, incoherent sources of UV and VUV radiation, and conversion of laser radiation. The program of the conference comprised 223 papers, including 112 oral papers and 111 posters. Fifteen papers of major interest were presented at plenary and round-table sessions devoted to new laser applications.

Below, we provide an overview of the most interesting papers grouped in accordance with their topics.

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1. Metal-vapour lasers

The opening paper of the conference was presented by G A Petrash (Lebedev Physics Institute, Russian Academy of Sciences, Moscow). This paper was devoted to the history and modern trends of the development of metal-vapour lasers. In particular, the problems of increasing the pulse repetition rate and improving the kinetics due to molecular additions have been considered in this paper. These issues will be also discussed below.

G S Evtushenko et al. (IAO SD RAS, Tomsk) pointed out that the maximum pulse repetition rates attainable with lasers using copper compounds (CuBr) exceed maximum pulse repetition rates characteristic of metal-vapour lasers due to the lower energy deposition in the discharge. The authors of this paper believe that the achieved pulse repetition rate of 300 kHz is still far from the physical limit, as it is determined by the frequency parameters of a TGU1-5/12 tasitrone switch employed in experiments.

The results presented by N A Yudin (ISP SD RAS, Novosibirsk) indicate that the presence of an inductance in a discharge circuit may prevent electrons from gaining a sufficient heating velocity. The author of this paper has determined conditions when the influence of the prepulse electron concentration is reduced to a minimum and the pulse repetition rate can be further increased through the increase in the relaxation rate of lower working levels.

S I Yakovlenko (General Physics Institute (GPI), RAS, Moscow) presented the results of numerical simulations of the kinetic mechanism limiting the pulse repetition rate in a copper-vapour laser due to the residual electron density. The results of this analysis demonstrate that, with some critical electron density and a fixed current, the electron temperature does not exceed the value of 1.7 eV, which is necessary for population inversion. A simple estimate of this limiting density is provided.

The experimental data presented by V M Klimkin (IAO SD RAS) indicate that step processes resulting in the decay of the upper working levels of copper atoms may have a considerable influence on the pulse repetition rate. The author of this paper argued that discharge discontraction caused by the delivery of a metal vapour to the active medium may be of fundamental importance for the physics of repetitively pulsed regimes of lasing. G G Petrash was the first to employ this effect in metal-vapour lasers to generate high-power laser radiation.

The paper by G G Petrash et al. (Lebedev Physics Institute, Russian Academy of Sciences, Moscow) demonstrated that, under certain conditions, the presence of electric-negative molecules (HBr, HCl) may improve the efficiency and power of lasing in metal-vapour lasers.

The paper by R Mildren et al. (Macquare University, Sidney, Australia) summarised the results of studies devoted to metal-vapour lasers with an improved kinetics and efficient harmonic generation in nonlinear crystals for producing high-power ultraviolet radiation.

Much attention was focused on the applications of metal-vapour lasers. In particular, the problems of the creation of new laser systems for medicine, laser isotope separation, and remote sensing of the atmosphere, as well as laser navigation and laser television systems were discussed.

A N Soldatov (TSU) provided a review of the methods and devices allowing the optimisation of lasing characteristics and permitting a high-speed control of the main output laser parameters, including the laser energy and power, pulse repetition rate, and frequency of radiation. Record characteristics of metal-vapour lasers obtained experimentally were also presented in this paper: an output radiation power per unit volume equal to 2 W cm^{-3} for a tube with a diameter of 4 – 6 mm and 0.2 – 0.3 W cm^{-3} for a tube with a diameter of 25 – 35 mm, the pulse repetition rate of 150 – 270 kHz, and the efficiency of a copper-vapour laser (with respect to the energy deposited in the active medium) equal to 9%. The author of this paper also reported on the development of new metal-vapour and dye lasers for medicine, laser light graphing, and other applications.

The high potential of the Russian industry for the creation of sealed-off copper- and gold-vapour lasers with an output power from 1 to 100 W were impressively demonstrated in the paper presented by A D Chursin (Istok State Research and Production Enterprise, Fryazino, Moscow Region). Istok is currently the best company producing metal-vapour lasers.

The paper by G S Evtushenko and V M Klimkin (IAO SD RAS) provided examples of using metal-vapour lasers in devices for single- and multifrequency probing of the atmosphere and ultraviolet spectroscopy of atmospheric gases, as well as in navigation instruments and systems of atmosphere adaptive optics. The capabilities of metal-vapour lasers for the location of metal-vapour layers in the atmosphere and for the remote sensing of iodine radio nuclides in waste gases of radio chemical plants have been also demonstrated. V D Burlakov (IAO SD RAS) presented new results of studies on the remote sensing of clouds with the use of a Cu laser.

I I Klimovskiĭ (Institute of High Temperatures, Russian Academy of Sciences, Moscow), who presented a paper on behalf of the research group from Vladimir State University, demonstrated that a monitor based on a copper-vapour laser allows the real-time observation of processes on the surfaces of substances irradiated with a high-power laser light during the period of laser action.

This section of the conference has shown that the modern trends in the development of highly efficient metal-vapour lasers are associated with lasers using mixtures of metal vapours. The kinetics of physical processes in such lasers is still to be adequately understood. However, the results obtained by now indicate that the kinetics of physical processes in such lasers differs from the kinetics of physical processes in conventional lasers. Lasers using mixtures of metal vapours allow higher pulse repetition rates, higher mean powers of radiation, and higher lasing efficiencies to be achieved. In particular, the use of small additions of special impurities (e.g., hydrogen) seems to hold much promise for the improvement of parameters of metal-vapour lasers.

2. Gas and plasma lasers

Much attention was also focused on gas and plasma lasers, including lasers pumped with electron beams and fragments of nuclear reactions.

The paper by S I Yakovlenko and A M Boĭchenko (GPI RAS) provided a review of studies devoted to the kinetics of active media of plasma lasers using exciplex molecules excited with an electron beam.

The paper by A Ulrich and his colleagues from Munich Technical University (Germany) and Rutgers University (Newark, USA) reported on the creation of a compact 1.73-μm Ar – Xe laser pumped with a low-energy (10 – 15 keV) electron beam injected into a laser chamber through a ceramic foil. Lasing was observed in the quasi-continuous-wave mode. The duration of radiation pulses was equal to 45 μs, and the pulse repetition rate was 150 Hz. This system is a prototype of small-scale lasers pumped with an electron beam that do not require any biological protection.

The paper by H Tomizawa and his colleagues from Munich Technical University, Rutgers University, and Tokyo Technological Institute was devoted to the observation of an additional lasing pulse arising in the afterglow of a Xe laser (1.73 μm) in response to the heating of the working mixture of this laser.

A M Yancharina (SPTI, Tomsk University) presented papers devoted to the analysis of unique properties of a recombination-nonequilibrium plasma excited with a low-energy (2 – 10 keV) electron beam produced in a discharge. Characteristics of active media consisting of mixtures of rare and molecular gases and parameters of Penning plasma lasers using transitions of helium and neon atoms were considered. The possibilities of using such a plasma for industrial technologies were also discussed. V P Demkin (SPTI), A V Karelin, and S I Yakovlenko (GPI RAS) proposed and developed a high-efficiency plasma-chemical reactor for precision plasma technologies, in particular, for ion nitration of materials.

The paper by A A Sinyavskiĭ and V N Krivonosov (ARIEP, Sarov, Nizhnii Novgorod Region) was devoted to the project aimed at the development of reactors-lasers, i.e., systems converting the energy of nuclear fission into the energy of laser radiation bypassing the thermal stage.

A V Karelin (GPI RAS) analysed kinetic mechanisms in new nuclear-pumped lasers using transitions of carbon, oxygen, nitrogen, and chlorine atoms.

V F Tarasenko (IHCE SD RAS, Tomsk) provided a review of the progress achieved by the Laboratory of Optical Radiation within the last seven years in creating pulsed dense-gas lasers and high-power sources of spontaneous ultraviolet radiation. In particular, coaxial XeCl ($\lambda \sim 0.308$ μm) and KrCl ($\lambda \sim 0.222$ μm) excilamps with a mean radiation power of 200 W have been developed. In cooperation with other laboratories of the IHCE SD RAS, this research group has created high-power lasers generating radiation at $\lambda = 0.249$, 0.308, 1.73, 2.03, and 2.8 μm with pulse energies of 100, 200, 100, 50, and 200 J, respectively.

N G Ivanov et al. (IHCE SD RAS) analysed the divergence of radiation produced by a two-cascade laser system ($\lambda = 0.308$ μm) with an output aperture of 25×25 cm. Optimisation of this system allowed the authors of this paper to generate radiation with a divergence of the order of 10^{-5} rad. The paper by E L Latush (Rostov State University) was devoted to the development of efficient compact recombination lasers using strontium and calcium vapours.

The paper by A N Panchenko et al. (IHCE SD RAS) demonstrated that the use of inductive energy accumulators with semiconductor current switches allows the pumping conditions to be optimised for pulsed dense-gas lasers. High efficiencies of lasing were achieved for a nonchain HF laser, a TEA CO_2 laser, an excimer XeCl laser, and a laser using self-terminating transitions of molecular nitrogen.

A A Chernenko (ISP SD RAS, Novosibirsk) reported the observation of population inversion for transitions coupling energy levels of He I and He II in a buffer zone of a high-power capillary discharge. This effect can be employed for the creation of active media for vacuum-ultraviolet lasers.

V Hasson (Textron Systems Corporation, USA) attracted a considerable attention of the participants of the conference by presenting the results of development of miniature molecular lasers pumped with a self-sustained discharge with ultraviolet preionization and high-power lasers pumped with a discharge stabilised by an electron beam.

A Ionin presented interesting results obtained by a group of researchers from the USA and Russia, who achieved a high lasing efficiency and a high radiation energy by using the first overtone of CO molecules pumped with a discharge controlled by an electron beam. The results of simulations of a CO laser confirm that high lasing efficiencies can be achieved under these conditions. These simulations also make it possible to determine the conditions necessary to achieve a high lasing efficiency.

The papers by K N Firsov et al. (GPI RAS) aroused a particular interest of conference attendees. The authors of these papers pointed out that the conditions of the formation of a volume discharge in mixtures with a high concentration of SF_6 considerably differ from the conditions typical of conventional working mixtures of exciplex and CO_2 lasers and a volume discharge can be produced at high pressures without preliminary ionisation (due to the special treatment of electrodes). These researchers were able to produce radiation with an energy of ~ 400 J with a nonchain HF laser pumped with a self-sustained discharge, which is the highest radiation energy for lasers of this type so far.

B Lacour (Cilas, Marcousis, France) presented new results of the studies of nonchain HF and DF lasers pumped with a self-sustained discharge in the pulse–periodic regime. These investigations have demonstrated that the use of SF_6-rich mixtures allows the creation of compact laser chambers with low inductivities of discharge circuits and the excitation of volume discharges with a highly uniform distribution of radiation power in the discharge volume.

The paper by V M Orlovskiĭ et al. (IHCE SD RAS) was devoted to the investigation of the influence of various factors on the efficiency of a nonchain HF laser. Analysis of spectral and amplitude–time characteristics of radiation confirmed the hypothesis that the formation of excited HF molecules involves not only atomic, but also molecular fluorine.

The papers by Yu I Bychkov, S L Gorchakov, and A Ya Yastremskiĭ (IHCE SD RAS) were devoted to the theory of a volume electric discharge in gas mixtures containing SF_6. The authors of these papers proposed a model describing the evolution of a plasma channel, performed numerical simulations, and discussed the physical processes influencing the evolution of plasma channels.

One of the general conclusions of this section is that the main direction of the development of plasma–recombination lasers is associated with the creation of both small-size systems convenient in operation and large-size systems. In certain cases, helium and calcium ion lasers can compete with copper-vapour lasers. This is the case, for example, in laser isotope separation, when shorter wavelengths of pump radiation are necessary. Currently, the work is in progress on the creation of nuclear power systems (reactors-lasers) developed on the basis of nuclear-pumped lasers.

Participants of the conference expressed growing interest in 4-μm infrared lasers. High-power efficient nonchain HF and DF lasers pumped with a self-sustained discharge and an electron beam have been created for the generation of radiation within this range. Such systems may gain a wide acceptance. Lasers pumped with a self-sustained discharge are especially convenient for practical use, as it is comparatively easy to excite a volume discharge in this case. Highest lasing efficiencies can be achieved at high pressures with electron-beam pumping. Additional chemical reactions giving rise to population inversion can be initiated in a working mixture under these conditions. Another promising way of generating radiation within this wavelength range is to create lasers using the first overtone of a CO molecule.

3. Incoherent sources of ultraviolet and vacuum-ultraviolet radiation

Participants of the conference paid much attention to the problem of third continua in rare gases. The results obtained by the researchers of five groups from Germany, France, and Russia involved in the INTAS-96-351 project were discussed. According to one of the hypotheses, these continua arise due to electronic molecular transitions in doubly charged ions. Another hypothesis is that these continua are associated with transitions in singly charged ions.

The paper by E Robert and his colleagues from France, Russia, and Germany demonstrated that the third continua consist of a large number of separate bands. Conditions when these bands appear in the third continua depend on the gas pressure and are independent of the regime of pumping with a hard ioniser.

A M Boĭchenko, V F Tarasenko, and S I Yakovlenko (GPI RAS, IHCE SD RAS) provided a detailed analysis of the main processes influencing the formation and emission of singly and doubly charged molecular ions. It was shown that, for high pressures (~ 1 atm and higher), the hypothesis that singly charged molecular ions provide a dominant contribution to the emission of third continua, which was proposed earlier by these authors, is valid for the UV spectral range.

The paper by J Wieser and his colleagues from Munich Technical University and IHCE SD RAS presented the emission dynamics of separate bands in the third continua within different time intervals upon pumping by a nanosecond pulsed ion beam. Positions of separate overlapping bands were also determined. J Wieser agreed that singly charged molecular ions provide the main contribution to emission at high pressures, but his opinion was that these ions are mainly generated through processes involving doubly charged rare-gas ions.

Another topic that was widely discussed by the participants of this section was the investigation and creation of sources of spontaneous emission within various spectral ranges pumped with discharges of different types. R C Sze (Los Alamos National Laboratory, USA) presented interesting results on the observation of high-power spontaneous emission in high-pressure neon and in mixtures of rare gases with alkaline metals.

R P Mildren with his colleagues (Macquare University, Australia) experimentally demonstrated that the use of short pump pulses allows the emission efficiency of xenon dimers to be considerably increased.

The results of extensive studies devoted to the investigation of spontaneous emission sources have been presented by researchers from the IHCE SD RAS. The paper by P Schwarz and his colleagues (Polytechnical Institute, University of Karlsruhe, Germany) attracted a considerable interest of specialists who use a barrier discharge for pumping spontaneous emission sources. This paper provided a detailed discussion of the scheme and the parameters of a power converter created by the authors.

M Sentis with his colleagues (Institut de Recherche sur les Phenomenes Hors Equilibre, Marseilles, France) considered the problem of cleaning of surfaces with laser radiation and presented the results of experiments performed with the use of a XeCl laser. R C Sze (Los Alamos National Laboratory) presented a paper on the detection of oxygen using ArF lasers. This problem is important for the industrial production of glass. The solution of this problem requires the development of noncontact methods of monitoring.

N G Ivanov, V F Losev, and V F Prokop'ev (IHCE SD RAS) presented the results of studies devoted to the conversion of a highly coherent beam of a XeCl laser in hydrogen. Stokes beams with a limiting divergence (close to the diffraction limit) and a very narrow line (0.01 cm^{-1}) were generated. The photon efficiency of conversion of pump radiation into the first Stokes component was equal to 95%.

4. Dye lasers and photoprocesses in complex organic molecules

The use of complex organic molecules as laser-active media requires the investigation of photoprocesses initiated in such molecules by light absorption. The results of studies of the photonics of complex organic compounds were reported by G V Maier and T N Kopylova (TSU).

A vivid discussion was stimulated by the presentation of the results of fundamental and applied investigations of photoprocesses in laser-excited organic molecules and the development of modern laser systems based on such processes. Yu P Meshalkin and his colleagues from Technical University, State University, and Siberian Centre of Laser Medicine (Novosibirsk) demonstrated the possibility of efficient two-photon excitation of dyes using radiation with a wavelength shorter than the doubled wavelength of maximum absorption. This finding allows a single laser source to be employed for two-photon excitation of different classes of photochromic materials with different absorption and fluorescence spectra. This approach also makes it possible to increase the penetration depth of laser radiation in a biological tissue in photodynamic therapy with the use of photosensitisers.

R T Kuznetsova and V A Svetlichnyĭ and their colleagues (TSU) analysed substituted para-terphenyl and demonstrated that the qualitative composition of photoproducts emerging from a series of photoprocesses is independent of the excitation intensity and the mode of operation. The composition of photoproducts may change only on the quantitative level. In the opinion of the authors, one of the mechanisms responsible for such changes may be associated with the population of highly excited states and two-photon processes. V A Chernyavskii, L G Pikulik, and A F Grib (Institute of Atomic and Molecular Physics, Minsk, Belarus) proposed a method for the analysis of artificially induced optical anisotropy in solutions of organic compounds, which allows the orientation of oscillators in a molecule and, thus, the orientation of electronic transitions in a molecule to be determined in a reliable way. It was also demonstrated that the observed spectral dependences of the induced quasi-crystal parameters of dye solutions excited in the visible and ultraviolet ranges of the absorption spectrum can be interpreted in terms of an oscillator model of a molecule.

V Ya Artyukhov (SPTI) discussed the possibility of calculating the populations of excited electronic states in organic (dye) molecules with the use of calculated and measured rate constants of photoprocesses. It was shown that, in the regime of nonlinear absorption, when the integral Bouguer law fails (which is the case when high-power pulsed pump sources are used), the differential Bouguer law for thin optical layers should be employed.

An interesting result of the investigation of trans-stilbene is the observation of lasing with these molecules in ethanol and hexane solutions pumped by a $XeCl^*$ exciplex laser. This finding was reported by L G Samsonova, T N Kopylova, N N Svetlichnaya, and O S Andrienko (SPTI). The use of a nonpolar solvent and naphthyl substituents increases the quantum yield of fluorescence and the efficiency of lasing.

The investigation of spatial–angular characteristics of radiation generated by flashlamp-pumped dye lasers in different temperature regimes of laser active elements, carried out by M I Dzyubenko, V V Maslov, V P Pelipenko, and V V Shevchenko (IRE, Khar'kov, Ukraine), demonstrated that the divergence of radiation depends on the parameters of the active element and the conditions of cooling of this element. To ensure a low divergence of radiation produced by lasers of this type in the repetitively pulsed regime, one has to stabilise the temperature of the active element and the liquid cooling agent.

The paper presented by V V Shevchenko (IRE, Khar'kov) was devoted to the investigation of parameters and regimes of pulsed xenon lamps and the analysis of spectral–temporal characteristics of high-power microsecond discharges. These studies have shown that the parameters of an electric pulse, the thermal inertia of the discharge gap, and the spectral range where the lamp bulb is transparent play an especially important role in this case.

The paper by T N Kopylova and her colleagues from SPTI, IAO SD RAS, TSU, and the Alpha Akonis company (Dolgoprudnyĭ, Moscow Region) was focused on the prospects for creating solid-state laser-active media capable of generating radiation in the green–blue spectral range with $XeCl^*$-laser pumping and within the red spectral range with copper-vapour-laser pumping.

The papers devoted to the photophysics and photochemistry of phenols were a subject of active discussion. The complicated nature of light-induced transformations occurring under the action of ultraviolet radiation in aqueous media with pollutants necessitates the analysis and monitoring of such phenomena. The review paper 'Physicochemical Methods for the Solution of Ecological Problems of Hydrosphere', presented by I V Sokolova (SPTI), was devoted to a detailed discussion of photochemical methods of solution of ecological problems of hydrosphere. Much attention was focused on phenols, which often pollute the environment.

The paper by O K Bazyl' et al. (SPTI) reported the application of the methods of quantum chemistry to the

investigation of the influence of complex formation on the photolysis of phenol and its chlorine-substitution derivatives. It was demonstrated that the experimentally observed dependence of the fluorescence quantum yield for aqueous solutions of phenol is the result of the increase in the probability of the light-induced breaking of OH bonds with the growth in the excitation energy.

Several papers reported the results of quantum-chemical calculations of spectral luminescence properties of organic compounds. V Ya Artyukhov (SPTI) concluded that the experimental fluorescence characteristics of organic compounds containing a styryl group (C–C = C–C) reflect the scenario of the photoisomerisation reaction through the linear structure of this group (butadiene model). N Yu Vasil'eva et al. (SPTI) demonstrated the possibility of the formation of π-complexes through a phenyl ring in para-terphenyl in proton – donor solvents.

The papers presented at this conference are published in special issues of 'Proc. SPIE' and 'Optika Atmosfery i Okeana' (no. 11, 1999, and no. 3, 2000) and in this issue of 'Kvantovaya Elektronika'.

Summarising the results of this conference, we can conclude that the investigations of atoms and molecules oriented at the physics of laser-active media continue to attract a considerable interest of researchers. At the same time, major laser conferences do not pay an adequate attention to these problems. Therefore, we anticipate that the role of conferences on atomic and molecular pulsed gas lasers will keep growing.