Joint Scientific Session of the Division of General Physics and Astronomy with the Nuclear Physics Division, USSR Academy of Sciences (27-28 December 1972)

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A joint scientific Session of the Division of General Physics and Astronomy with the Division of Nuclear Physics of the USSR Academy of Sciences was held on December 27 and 28, 1972 at the conference hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. N. G. Basov, É. M. Belenov, V. A. Danilychev, and A. F. Suchkov. Compressed-Gas Lasers.

2. Yu. V. Afanas'ev, N. G. Basov, O. N. Krokhin, V. B. Rozanov, G. V. Sklizkov, and S. I. Fedotov. Theoretical and Experimental Investigations of Laser-Plasma Dynamics.

3. V. I. Gol'danskiĭ and Yu. M. Kagan. Feasibility of the Nuclear-Transition γ Laser (Gaser).

4. Yu. A. Il'inskiĭ and R. V. Khokhlov. The Possibility of Observing Stimulated γ Radiation.

5. V. S. Letokhov. Use of Lasers in Nuclear Spectroscopy.

We publish below the contents of some of the papers.

N. S. Basov, É. M. Belenov, V. A. Danilychev, and A. F. Suchkov. Compressed-Gas Lasers

Interest in compressed gases as laser active media arises out of their high optical homogeneity, the possibility of attaining high active-particle densities, and the existence of gas-laser designs with efficiencies up to 50%. In addition, it is possible at high pressure to obtain smooth frequency tuning, to generate ultrashort pulses, and obtain high power and coherence in the radiation. These properties of compressed gases have attracted attention to them as possible active media for powerful lasers, which are needed particularly urgently at the present time in connection with the development of research on controlled thermonuclear fusion, guided stimulation of chemical reactions, and other applications of lasers.

The following difficulties arise in the design of compressed-gas lasers. Firstly, because of the instability of the discharge at high pressures, the traditional electric-discharge method of exciting gas lasers cannot be used for volume excitation of compressed gases. Secondly, the collision broadening of the laser levels, which is proportional to the gas pressure, requires a substantial *increase* in the pumping rate as the pressure rises. Finally, it has been hypothesized that it may not be possible to obtain lasing at all at high pressures because of the increased importance of triple quenching collisions.

An electroionization method for volume excitation of compressed gases has been developed during the last few years as a result of research done in the Quantum Radiophysics Laboratory of the Institute of Physics, USSR Academy of Sciences[1]. This method has made it possible to obtain generation with a number of compressed gases, e.g., carbon dioxide compressed to 60 atm. The electroionization CO_2 laser demonstrated the advantages of compressed gases as laser active media. High efficiency (~30%) and a high active-particle density of $\sim 10^{18}$ cm^{-3}/atm were obtained, the possibility of continuous tuning of the generating frequency was demonstrated, and ultrashort pulses lasting $\sim 10^{-9}$ sec and high powers ($>10^7$ W/cm^3) and energies ($>10^{-1}$ J/cm^3) were obtained in the radiation; diffractively divergent radiation was produced[1,2]. At the present time, the electroionization excitation method is the only known method for pumping high-power lasers with high efficiencies.

In the electroionization excitation method, the pumping energy is taken from the energy of an electric field. In contrast to the gas-discharge method, however, the conductivity that the working medium must have to transmit an electric current is created by irradiating the medium from an external source of ionizing radiation (fast electrons[1,2], light[3,4], or nuclear fission products[5]). This makes it possible to place the value of the electric field in the range of most efficient excitation of rotational-vibrational levels—a field that is, as we know, weaker than the discharge-initiating field. Here the energy expended on ionization does not exceed 1% of the electrical energy. Elimination of the independent discharge makes it possible to excite compressed gases with no restrictions in principle on pressure and volume. If the ionizing radiation and the independent discharge were to act simultaneously on the active medium, the deficiencies of the gas-discharge method would remain and excitation of the compressed gases would be impossible[6]. The influence of a space charge on the current through an ionized working medium may render electroionization excitation practically unworkable[3,7]. Under the conditions of strong ionization of the gas, however, the space-charge effect is found to be insignificant and, as has been shown by experiments[1,8], the electrical energy W to be invested in the gas is determined by Ohm's law

$$W = \sigma E^2,$$

where σ is the conductivity of the medium, as determined by the external ionization, and E is the electrical field.

A property of electron-impact excitation of rotational-vibrational levels—the proportionality of the excitation rate to the product of the electron and molecule concentrations—has as a consequence that the power radiated per unit volume of active medium in electroionization excitation increases as the square of the pressure. Thus, an increase in the working-gas pressure from the tens of Torr encountered in ordinary gas-discharge lasers to the tens of atmospheres will increase the power radiated per unit volume of active medium by a million times[1].

The use of high pressures will substantially broaden the lasing line and make it possible to generate powerful ultrashort pulses with durations down to 10^{-11}–10^{-12} sec[1,2]. The high efficiencies of electroionization lasers in the ultrashort-pulse mode (10%) is encouraging for the use of these lasers to obtain a controlled thermonuclear reaction efficient enough for power generation.

[1] Yu. V. Afanas'ev, É. M. Belenov, O. V. Bogdankevich, V. A. Danilychev, S. G. Darznek, and A. F. Suchkov, Kr. soobshch. fiz. (FIAN SSSR), No. 11, 23 (1970); N. G. Basov, É. M. Belenov, V. A. Danilychev, and A. F Suchkov, Kvantovaya élektronika, No. 3, 121 (1971); Vestn. Akad. Nauk SSSR, No. 3, 12 (1972); N. G. Basov, É. M. Belenov, V. A. Danilychev, O. M. Kerimov, I. B. Kovsh, and A. F. Suchkov. ZhETF Pis. Red. 14, 421 (1971) (JETP Lett. 14, 285 (1971)); N. G. Basov, V. A. Danilychev, O. M. Kerimov, and A. S. Podsosonnyĭ, ibid., 17, 147 (1973) [17, 102 (1973)].

[2] C. A. Fenstermacher, M. J. Nutter, W. T. Leland, J. P. Rink, K. Boyer, Bull. Amer. Phys. Soc. 16, 42 (1971); C. A. Fenstermacher, M. J. Nutter, W. T. Leland, and K. Boyer, Appl. Phys. Lett. 20, 56 (1972). K. Boyer, Los Alamos Scientific Laboratory Presentation at Japan U. S. Seminar on Laser Interaction with Matter, Kyoto, Japan, September, 1972.

[3] A. V. Eletskiĭ and B. M. Smirnov, Dokl. Akad. Nauk SSSR 190, 809 (1970) [Sov. Phys.-Dokl. 15, 109 (1970)].

[4] J. S. Levin and A. Javan, Appl. Phys. Lett. 22, 55 (1973).

[5] V. M. Andriyakhin, E. P. Velikhov, V. V. Vasil'tsev, S. S. Krasil'nikov, V. D. Pis'mennyĭ, I. V. Novobrantsev, A. T. Rakhimov, A. I. Starostin, and V. E. Khvostionov, ZhETF Pis. Red. 15, 637 (1972) [JETP Lett. 15, 451 (1972)].

[6] V. M. Andriyakhin, E. P. Velikhov, S. A. Golubev, S. S. Krasil'nikov, A. M. Prokhorov, V. D. Pis'mennyĭ, A. T. Rakhimov. ibid. 8, 346 (1968) [8, 214 (1968)]; G. G. Dolgov-Savel'ev, V. V. Kuznetsov, Yu. L. Koz'minykh, and A. M. Orishich. Zh. Prikl. Spektrosk. 12, 737 (1970).

[7] J. J. Thomson, Conduction of Electricity through Gases, v. 1, Cambridge, Cambridge Univ. Press, 1928.

[8] B. M. Koval'chuk, V. V. Kremnev, and G. A. Mesyats. Dokl. Akad. Nauk SSSR 191, 76 (1970) [Sov. Phys.-Dokl. 15, 267 (1970)].

V. I. Gol'danskiĭ and Yu. M. Kagan. Feasibility of the Nuclear-Transition γ Laser (Gaser)

The few proposals that have appeared in the literature over the past ten years concerning ways to obtain stimulated γ emission have reduced to attempts to prepare large numbers of long-lived nuclear isomers in pure or strongly enriched form and to use the Mossbauer effect.

However, it is easily shown that this approach offers no promise of success. The excited-nucleus concentration needed to bring about stimulated γ emission is[1]

$$n^* = \left(\frac{E_0}{\pi\hbar c}\right)^2 \frac{\Gamma}{\Gamma_0} \frac{1+\alpha}{f\xi} \frac{1}{l(E_0)}, \tag{1}$$

where E_0 is the energy of the γ transition, Γ_0 is the natural and Γ the actual excited-level width, α is the internal conversion coefficient, $l(E_0)$ is the free path of the resonant photons, ξ is the probability of population of the upper level on pumping ($(1+\xi)/2$ of the nuclei are initially on the upper level and $(1-\xi)/2$ on the lower level), and f is the probability of the absence of recoil when the Mössbauer transitions are used.

Since $(E_0/\pi\hbar c)^2 \approx 10^{16}$–$10^{18}$, at $E_0 \approx 10$–100 keV and $l(E_0) \approx 10^{-3}$–10^{-2} cm for medium and heavy nuclei, we have $n^* \approx (10^{19}$–$10^{20})\Gamma/\Gamma_0$ even without consideration of the multiplier $(1+\alpha)/f\xi$. This means that when the resonance line is hundreds and thousands of times broader, the necessary values of n^* are in general already outside the range of matter densities N (further compression changes nothing, since then $n^* l(E_0) = \text{const}$).

Thus, in sharp contrast to the optical region, an extreme sensitivity to any broadening of resonance lines is brought about by the increase in the energies of the transitions.

It is precisely this that dictates the use of the Mössbauer effect, because the Doppler broadening of the resonance in the presence of a recoil energy R, $\Delta_D \approx 2\sqrt{RkT}$ (or $\Delta_D \approx 2\sqrt{Rk\Theta_D}$ at $T \ll \Theta_D$, where Θ_D is the Debye temperature) is many orders greater than Γ_0 for any γ-transition time that may be of interest. In turn, use of the Mössbauer effect imposes additional limitations on the temperature of the system and on the transition energies.

Decisive among the factors that impose an upper limit on the γ-transition times suitable for the production of stimulated emission are the various possible inhomogeneous broadenings of the Mössbauer resonance line. The sources of this broadening include: 1) isomeric shift, 2) quadrupole interaction, 3) magnetic hyperfine interaction, 4) magnetic dipole-dipole interaction between nuclei, 5) temperature red shift and broadening, and 6) gravitational level shift over the thickness of the sample.

We shall not concern ourselves with broadening due to magnetic interaction because, in principle, a diamagnetic substance could be chosen and an attempt made to reduce the dipole-dipole interaction between the nuclei by means of known NMR methods.

The purely electrical interactions 1) and 2) are the principal sources of inhomogeneous broadening. Prime importance attaches to the isomeric shift, which inevitably exists in the Mössbauer effect, since two nuclear levels with different charge radii R participate in the transition (in NMR, transitions occur between HFS sublevels of the same nuclear level, so that the relative shift of the center of the HFS "comb" on different nuclei is not a factor).

For a given nuclear transition, the isomeric shift