Radiation-chemical laser using $SF_6 + H_2$ and $CCl_2F_2 + H_2$ mixtures at pressures up to 3 atm

L. E. Dovbysh, N. I. Zavada, A. T. Kazakevich, A. A. Karpikov, S. P. Mel'nikov, I. V. Podmoshenskiĭ, and A. A. Sinyanskiĭ

(Submitted July 29, 1974)
ZhETF Pis. Red. **20**, No. 6, 407–410 (September 20, 1974)

Generation was produced in the gas mixtures SF_6+H_2 and $CCl_2F_2+H_2$ excited by an electron beam from an accelerator. The laser-radiation energy increases linearly with pressure up to 3 atm. For the optimal SF_6+H_2 mixture (6:1), the efficiency of the system was not less than 5%. Addition of He to the mixture does not affect the energy of the laser radiation.

The use of high-energy particles to excite a chemically-active gas medium offers many conveniences. The radiation action can be produced with any gas, regardless of its chemical, optical, and gas-discharge properties. In comparison with other types of excitation, the obtained primary radicals have the largest potential, ensuring the occurrence of the required exothermal reactions. In the primary stage of the radiolysis, the energy contribution to the gas heating and to vibrational excitation is small, and this provides good kinetic conditions for attaining inversion in the active medium. At the present time, lasing initiated by an electron beam was obtained in the following mixtures with chain reactions $N_2F_4 + H_2$, $N_2F_4 + B_2H_6$, $NF_3 + H_2$[1]; $IF_7 + H_2$[2], and $H_2 + F_2$.[3] The use of high-power ionizing-radiation sources makes it possible to pump the system also with nonchain chemical reactions.

We report here attainment of lasing induced by an electron beam from an accelerator in $SF_6 + H_2$ and $CCl_2F_2 + H_2$ mixtures at pressures up to 3 atm, and present the results of an investigation of the lasing characteristics. The choice of the $SF_6 + H_2$ mixture was dictated by the fact that when fast particles interact with SF_6 molecules one expects an effective buildup of atomic fluorine as a result of three fundamental processes. For electrons with energies more than several dozen eV, atomic fluorine is produced in the dissociative ionization reactions[4]

$$SF_6 + e \to SF_5^+ + F + 2e\,,$$
$$SF_6 + e \to SF_4^+ + 2F + 2e\,,$$
$$SF_6 + e \to SF_3^+ + 3F + 2e \quad \text{etc.}$$

Practically each ionization act leads to the formation

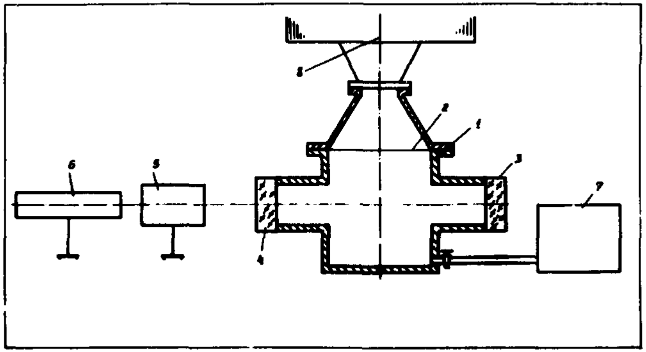

FIG. 1. Diagram of setup: 1—laser cell, 2—aluminum foil, 3—total-reflection spherical mirror, 4—flat mirror with opening, 5—IÉK-1 calorimeter, 6—adjusting laser, 7—filling and evacuation system, 8—RIUS-5 accelerator.

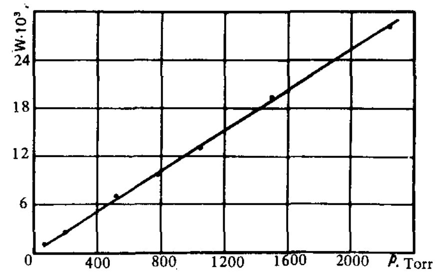

FIG. 2. Dependence of the generation energy on the pressure of the $SF_6 + H_2$ (6 : 1) mixture.

of atomic fluorine, since no stable SF_6^+ ion has been observed.

At low electron energies, the predominant process is that of dissociative trapping:

$$SF_6 + e \to (SF_6^-)^* \to SF_6^-$$
$$\to SF_5^- + F$$

It is known[5] that this reaction has a resonant character at electron ~0.4 eV, and a high cross section $\sigma \approx 1.2 \times 10^{-14}$ cm².

Atomic fluorine can also be produced as a result of dissociative recombination with participation of the ions SF_5^+, SF_4^+, F^-, SF_6^-, and others.

Figure 1 shows a diagram of the experimental setup. The fast-electron source was the RIUS-5 high-power pulsed accelerator.[6] The beam current was $\sim 6 \times 10^3$ A, the pulse duration $\sim 5 \times 10^{-8}$ sec, and the electron energy 2–4 MeV. The electron beam entered the laser cell (1) perpendicular to its axis through an aluminum foil 50 μ thick. A special focusing device made it possible to shape the beam in such a way that the length of the active part of the laser cell was 10 cm at a volume 20 cm³. The optical resonator was made up of two mirrors: a silver-coated total-reflection spherical mirror (3) with $R = 2$ m, and a gold-coated flat barium-fluoride mirror (4). The laser radiation was extracted through a two-mm diameter hole in the flat mirror and was registered with an IÉK-1 calorimeter (5). The distance between the mirrors was 30 cm. The adjustment of the optical system was effected with the aid of an He-Ne laser (6).

The experiments have shown the optimal component ratio to be 6 : 1 for the $SF_6 + H_2$ mixture and 10 : 1 for the $CCl_2F_2 + H_2$ mixture. An interesting feature is a possibility of repeated use of the mixture (without refilling the cell) with the energy output of the laser preserved. The dependence of the laser-radiation energy on the pressure of the $SF_6 + H_2$ (6 : 1) mixture is shown in Fig. 2. The lower pressure limit is imposed by the sensitivity of the calorimeter, and the upper by the strength of the foil. The linear character of the dependence shows that quenching processes have little effect up to 3 atm pressure. The energy of the optical radiation obtained with the $CCl_2F_2 + H_2$ (10 : 1) mixture was lower by one order of magnitude than that from the $SF_6 + H_2$ (6 : 1) mixture. Experiments aimed at determing the influence of He on the energy characteristics of the $SF_6 + H_2$ mixture have shown that addition of He does not influence the energy W of the laser radiation (see the table).

SF_6, Torr	H_2, Torr	He, Torr	W, mJ
180	30	290	3.1
180	30	–	2.9
675	112	750	9.2
675	112	–	9.6

The energy absorbed in the active medium was calculated from the known energy and from the stopping ability of the electrons. The efficiency of the $SF_6 + H_2$ laser, calculated as the ratio of the laser-radiation energy to the energy of the electrons absorbed in a gas, was not less than 5%. The results are probably not maximal, since no optimization of the resonator was carried out.

The results show that on the basis of high-power pulsed radiolysis it is possible to construct a chemical laser that operates without chain reactions only on the radiolysis products. Hopefully, other laser media operating on this basis can also be found.

In conclusion, the authors thank V.I. Lyamin, A.N. Nastagunin, and A.V. Pilipenko for help with the experiments.

Note. After this article was written, communications were published reporting the development of chemical lasers initiated by an electron beam, using radiation of 100 MW[7] and 4 GW.[8]

[1] D.W. Gregg, B. Kravetz, R.K. Pearson, B.R. Schleicher, S.J. Thomas, E.B. Huss, K.J. Pettipiece, J.R. Creighton, R.E. Niver, and Y.L. Pan, Chem. Phys. Lett. **8**, 609 (1971).

[2] Y.-L. Pan, C.E. Turner, and K.J. Pettipiece, Chem. Phys. Lett. **10**, 577 (1971).

[3] V.F. Zharov, V.K. Malinovskiĭ, V.S. Neganov, and G.M. Chumak, ZhETF Pis. Red. **16**, 219 (1972) [JETP Lett. **16**, 154 (1972)].

[4] I.D. Craggs and H.S.W. Massey, Handbuch der Physik **37**, No. 1, 314 (1959).

[5] P.W. Harland and J.C.I. Thynne, J. Phys. Chem. **75**, 3517 (1971).

[6] E.A. Abramyan, S.B. Vasserman, V.M. Dolgushin, L.A. Morkin, O.P. Pecherskiĭ, and V.A. Tsukerman, Dokl. Akad. Nauk SSSR **192**, No. 1 (1970) [Sov. Phys.-Dokl. **15**, No. 5 (1970)].

[7] C.P. Robinson, R.J. Jensen, and A. Kolb, IEEE J. Quantum Electronics **QE-9**, 963 (1973).

[8] Laser Focus **9**, 24 (1973).