

Spectral and energy parameters of a pulsed $F_2 - (H_2 + D_2) - He$ -mixture HF/DF laser

M.A. Azarov, B.S. Aleksandrov, A.V. Arsen'ev, V.A. Drozdov, G.A. Troshchinenko

Abstract. Theoretical and experimental studies of spectral and energy characteristics of radiation of a photoinitiated HF/DF laser working on the chain reaction in the $F_2 : (H_2 + D_2) : O_2 : He = 3 : 1 : 0.3 : 6.7$ mixture are performed under atmospheric pressure as functions of the ratio of the initial concentrations of H_2 and D_2 and the resonator losses. Optimal conditions are determined for simultaneous lasing in HF and DF molecules in the spectral range 2.7–4.8 μm .

Keywords: pulsed chemical HF/DF laser, chain reaction, emission spectrum.

1. Introduction

Broadband lasers are required for a number of practical applications (e.g., in spectroscopy and for monitoring gaseous and aerosol mixtures in the atmosphere). The laser emission spectrum in this case should provide

- (i) a wide range of wavelengths,
- (ii) a large number of lasing lines in this range,
- (iii) a uniform spectral distribution of lines, and
- (iv) a uniform energy distribution between the lines.

Pulsed chemical lasers emitting simultaneously at several vibrational transitions of different excited molecules can be used as such sources. Hydrogen fluoride lasers are among the most technologically developed and high-power sources [1–3].

The possibility of simultaneous lasing in the spectral ranges 2.6–3.0 μm and 3.7–4.1 μm by using electric-discharge lasers operating on the $SF_6 - HD$, $SF_6 - HD - D_2$, and $SF_6 - H_2 - D_2$ mixtures was demonstrated in Refs [4, 5]. The energy parameters of an electric-discharge $SF_6 - H_2 - D_2$ laser and a photoinitiated $F_2 - (H_2 + D_2) - SF_6 - O_2 - He$ laser were studied in detail in Ref. [6]. However, the spectral parameters of broadband lasers have not been studied in detail.

In this paper, we studied the kinetics of simultaneous lasing at the transitions of vibrationally excited molecules HF(ν) and DF(ν) and determined the dependence of the

spectral and energy parameters of a broadband laser on the mixture composition and on the ratio of the initial concentrations of H_2 and D_2 . Experiments were performed using a photoinitiated pulsed HF/DF laser [7], whose pulse energy achieved several kilojoules, depending on the experimental conditions. The final aim of our study was to determine the optimal conditions of laser operation under which the laser pulse energy was distributed most uniformly in the spectral range 2.7–4.8 μm .

2. Numerical simulation

We simulated numerically a pulsed chemical laser to determine its optimal lasing regime providing the output radiation satisfying the above requirements. The computational model was similar to models developed in Refs [8–10]. We solved a system of ordinary differential equations containing the equations describing the initiation of a chemical chain reaction, chemical and relaxation processes in a gaseous medium, and the formation of spontaneous and induced radiation in an optical cavity, as well as the equation for the gas temperature in a closed volume varying as a result of chemical and relaxation processes. It was assumed that the active medium and the parameters of initiation of a chemical chain reaction are uniform over the entire volume. It was also assumed that a plane-parallel cavity was uniformly filled by radiation. In this case, the process time is the only independent variable in these equations.

The energy and the emission spectrum of a pulsed chemical HF/DF laser depend substantially on the lasing threshold determined by the optical cavity parameters [11]:

$$K_{th} = -\frac{\ln(R_1 R_2)}{2L},$$

where R_1 and R_2 are the reflectivities of the resonator mirrors, and L is the length of the active medium. Figures 1a, 2 and 3 show the results of calculations of the energy and the emission spectrum of a pulsed chemical laser based on the $F_2 : (H_2 + D_2) : O_2 : He = 3 : 1 : 0.3 : 6.7$ mixture at an initial pressure of 0.112 MPa. The parameters of the active medium and the cavity used in our calculations correspond to the experimental conditions described below. Calculations were carried out taking into account the fact that the initial gaseous mixture contains a small admixture of HF and DF molecules (0.01 of the volume density of the $H_2 + D_2$ mixture) appearing under real experimental conditions during the preparation of this mixture. It was

M.A. Azarov, B.S. Aleksandrov, A.V. Arsen'ev, V.A. Drozdov, G.A. Troshchinenko Federal State Unitary Enterprise, Russian Research Centre 'Applied Chemistry', prosp. Dobrolyubova 14, 197198 St. Petersburg, Russia; e-mail: gtrosh@GT4631.spb.edu

Received 26 February 2003

Kvantovaya Elektronika 33 (11) 949–952 (2003)

Translated by Ram Wadhwa

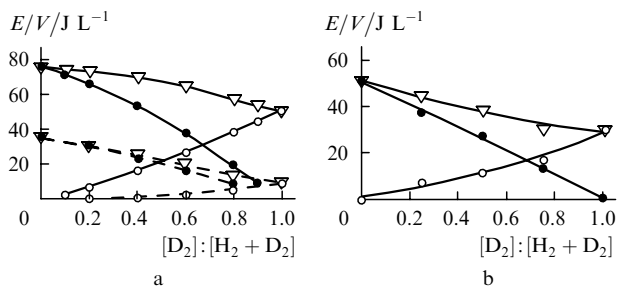
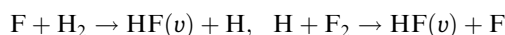


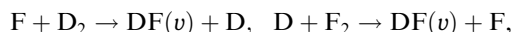
Figure 1. Dependences of the specific emission energy on HF (dark circles) and DF (open circles) molecular transitions, as well as the total specific emission energy (∇) on the ratio of H_2 and D_2 concentrations in the initial gas mixture, obtained (a) by numerical simulation and (b) in experiments for $K_{th} = 0.354$ (a) and 0.341 m^{-1} (b) (solid curves), and 2.83 m^{-1} (dashed curves).

assumed that the output CaF_2 mirror has a reflectivity $R_1 = 0.06$ and the highly reflecting mirror has a reflectivity $R_2 = 0.98$. Two series of calculations were made, one for $K_{th} = 2.83 \text{ m}^{-1}$ ($L = 0.5 \text{ m}$) and the other for $K_{th} = 0.354 \text{ m}^{-1}$ ($L = 4.0 \text{ m}$).

Figure 1a shows the variation in the specific output energy E/V (lasing at the transitions of HF and DF molecules and the total emission) as a function of the ratio of concentrations of H_2 and D_2 molecules in the initial gaseous mixture. The calculated output emission spectra are presented in Fig. 2 ($K_{th} = 0.354 \text{ m}^{-1}$) and Fig. 3 ($K_{th} = 2.83 \text{ m}^{-1}$). A decrease in the lasing threshold leads to an increase in the number of vibrational–rotational transitions involved in lasing. The emission spectrum for a cavity with $K_{th} = 2.83 \text{ m}^{-1}$ contains a small number of lines, especially for the DF molecules whose gain is much lower than for HF molecules. The difference in the gains is due to the fact that if nearly the same amounts of energy are released in the chain reactions



and



this energy is distributed in DF molecules over a larger number of vibrational–rotational levels than in the case of HF molecules, and also due to the fact that the Einstein coefficient for transitions in the P -branch of DF molecules is smaller and the chain reaction involving deuterium develops more slowly. For this reason, the output energy decreases with increasing K_{th} , especially in the case of DF molecules. A decrease in K_{th} makes it possible to solve the above-mentioned problems, i.e., to obtain output radiation whose distribution is quite uniform over a broad spectral range.

3. Experimental results

We performed experiments with a modular cylindrical laser with a centrally located flashlamps for a total volume 50 L of the active medium and a beam aperture 130 mm . The active medium of the laser consisted of an $F_2 : (H_2 + D_2) : O_2 : He = 3 : 1 : 0.3 : 6.7$ mixture at an overall pressure of 0.112 MPa . The energy stored in the capacitors of the discharge circuit was 6 kJ [7].

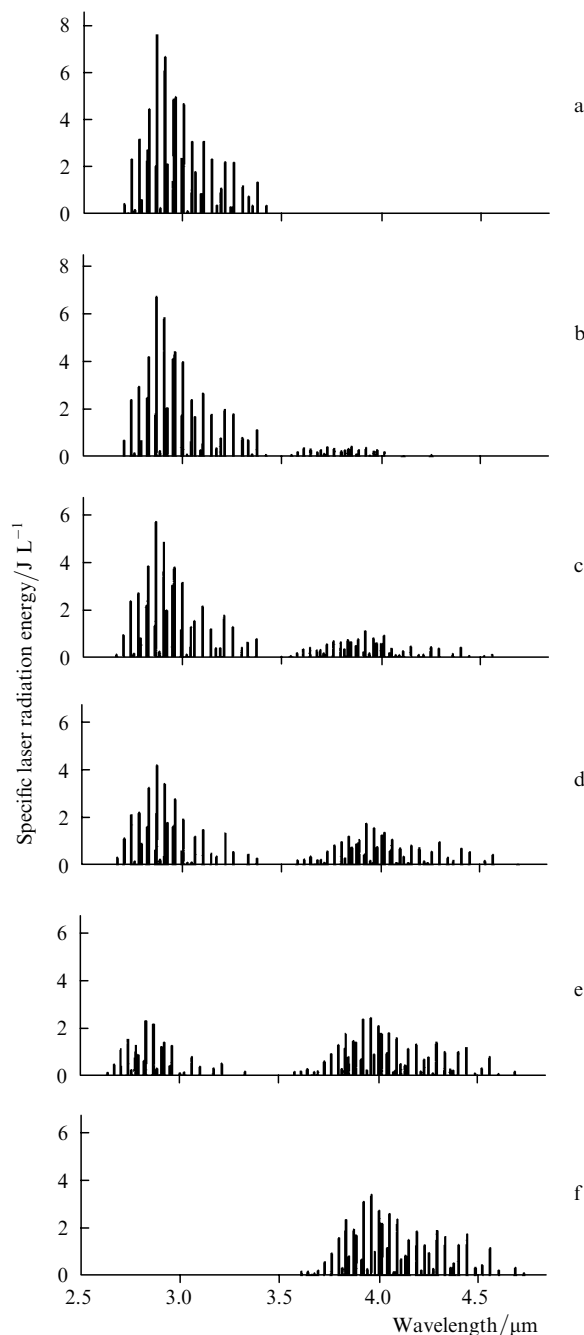


Figure 2. Results of numerical simulation of the emission spectrum of an HF/DF laser for the $[H_2] : [D_2]$ concentration ratio (a) $1 : 0$, (b) $0.8 : 0.2$, (c) $0.6 : 0.4$, (d) $0.4 : 0.6$, (e) $0.2 : 0.8$, and (f) $0 : 1$, and for $K_{th} = 0.354 \text{ m}^{-1}$.

Figures 1b and 4 show the experimental dependences of the specific output energy and the lasing spectrum on HF and DF molecules on the ratio of the initial concentrations of H_2 and D_2 molecules. One can see that the addition of deuterium causes an almost linear increase in the specific output energy emitted by DF molecules, which achieves a maximum value of 29 J L^{-1} upon a total substitution of hydrogen. The specific energy of radiation by HF molecules decreases in this case from 50 J L^{-1} to zero.

The most uniform distribution of laser energy in the spectrum was observed for a ratio $H_2 : D_2 = 1 : 3$. In this case, the main fraction of energy is concentrated in the

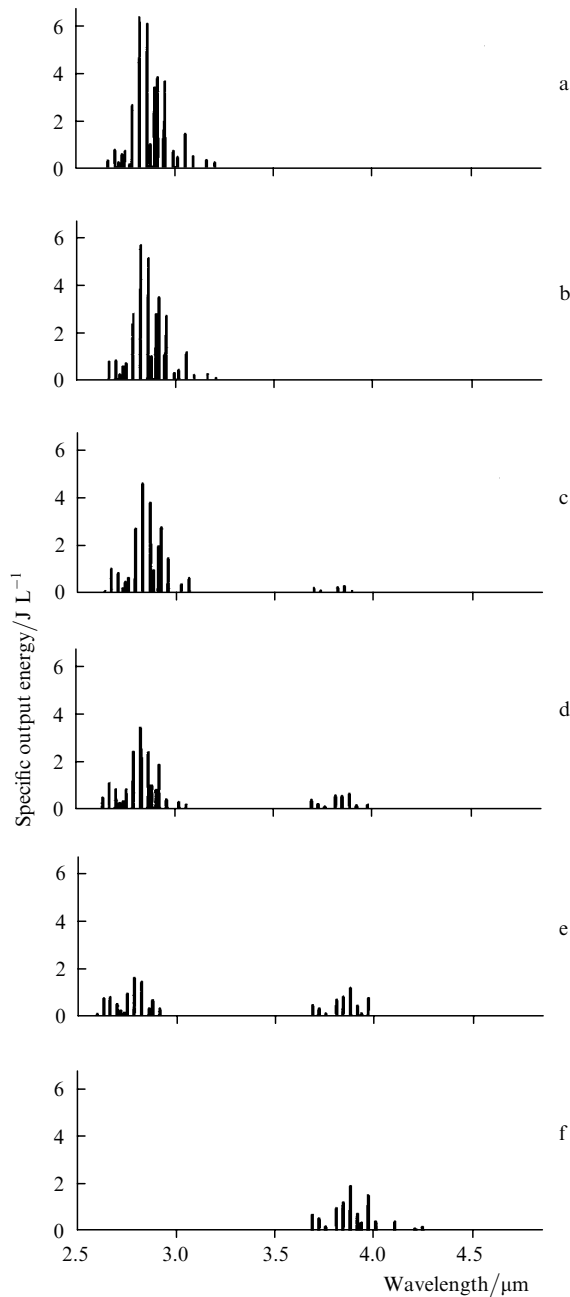


Figure 3. Results of numerical simulation of the emission spectrum of an HF/DF laser for the same $[H_2] : [D_2]$ concentration ratios as in Fig. 2, and for $K_{th} = 2.83 \text{ m}^{-1}$.

spectral ranges 2.7–3.25 μm (42 % in 30 spectral lines) and 3.7–4.2 μm (56.5 % in 41 lines). Only 12 spectral lines with less than 1.5 % total fraction of the radiation energy were observed in the spectral range 4.3–4.8 μm .

Figures 4e and f show the lasing spectra of the $F_2 - D_2 - O_2 - He$ mixture. The main difference in these experimental versions was that in the latter case the initial gas mixture was thoroughly cleaned to exclude the impurity of CO_2 molecules. Decontamination leads to a considerable increase in the energy efficiency (the specific energy increases from 29 to 43 J L^{-1}) and to a broadening of the long wavelength part of the spectrum. A detailed description of this effect is given in Ref. [12]. The effect of CO_2 molecules was not taken into account in the calculations, and this fact

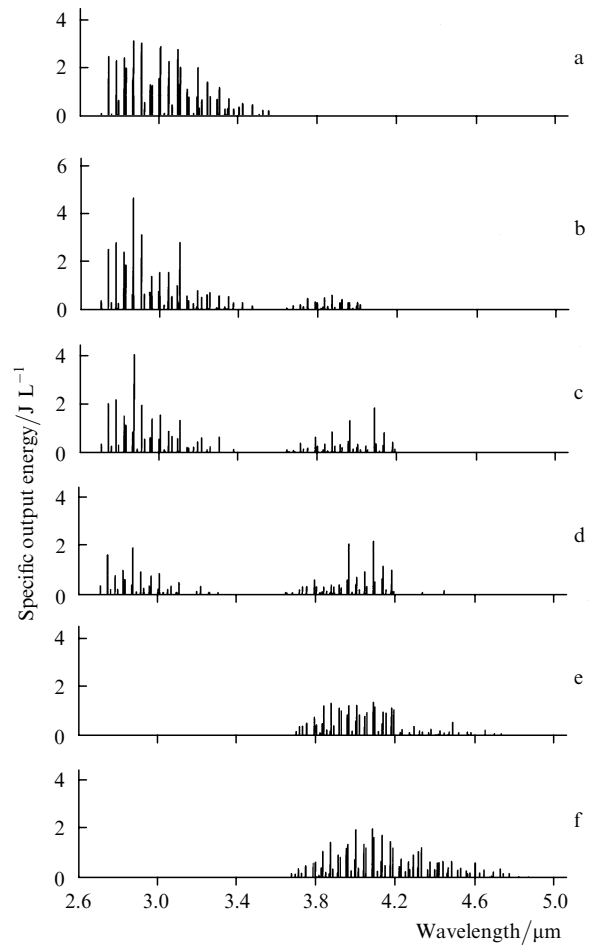


Figure 4. Spectral dependences of the specific energy of an HF/DF laser for the $[H_2] : [D_2]$ concentration ratio (a) 1 : 0, (b) 3 : 1, (c) 1 : 1, (d) 1 : 3, and (e, f) 0 : 1, for $K_{th} = 0.341 \text{ m}^{-1}$, $[CO_2] = 0.07 \%$ (a–e), and for $K_{th} = 0.161 \text{ m}^{-1}$, $[CO_2] = 0.01 \%$ (f).

must be borne in mind when comparing the data in Figs 2 and 4.

The calculated energy parameters are much higher than the experimental values. One of the main reasons behind such a discrepancy is that the theoretical model neglects the spatial inhomogeneity of the active medium [11], which causes intracavity losses. Another reason behind the difference in the experimental and theoretical results on the energy distribution between individual spectral lines and on the total emission energy is the insufficient accuracy in the rate constants for chemical and relaxation processes in the active medium of the laser cited in the literature and used in our calculations. Taking these arguments into account, the agreement between the experimental and theoretical results can be treated as satisfactory.

4. Conclusions

We have determined the conditions for obtaining the most uniform energy distribution in the emission spectrum of a multifrequency laser. By using a cavity with low losses (0.34 m^{-1}), we have obtained lasing in broad spectral ranges (2.7–3.3 μm and 3.6–4.8 μm). The optimal ratio of the initial concentrations of H_2 and D_2 is from 1 : 2 to 1 : 4 (this result was obtained both in experiment and from a

numerical simulation of the process). If required, the number of spectral lines and the output energy in the spectral range 4.3–4.9 μm can be increased by lowering the concentration of CO_2 in the active volume of the cavity, increasing its Q -factor and the initial concentration of D_2 in the initial laser mixture.

Acknowledgements. This work was supported by the ISTC (Grant No. 1113-2).

References

1. Batovskii O.M., Vasil'ev G.K., Makarov E.F., Tal'roze V.L. *Pis'ma Zh. Eksp. Teor. Fiz.*, **9**, 341 (1969).
2. Basov N.G., Kulakov L.V., Markin E.P., Nikitin A.I., Oraevsky A.N. *Pis'ma Zh. Eksp. Teor. Fiz.*, **9**, 613 (1969).
3. Bashkin A.S., Igoshin V.I., Oraevskii A.N., Shcheglov V.A., in *Khimicheskie lazery (Chemical Lasers)* Ed. by N.G. Basov (Moscow: Nauka, 1982).
4. Kompa K.L., Pimental G.C. *J. Chem. Phys.*, **47**, 857 (1967).
5. [doi>](#) Rudko R.I., Drozdowicz Z., Linhares S. *Rev. Sci. Instr.*, **53**, 452 (1982).
6. Velikanov S.D., Elutin A.S., Zapol'skii A.F., Konkin D.V., Kulikov S.M., Novikov V.N., Sinityn M.V., Sukharev S.A. *Kvantovaya Elektron.*, **18**, 186 (1991) [*Sov. J. Quantum Electron.*, **21**, 165 (1991)].
7. [doi>](#) Azarov M.A., Aleksandrov B.S., Drozdov V.A., Troshchenko G.A. *Proc. SPIE Int. Soc. Opt. Eng.*, **3092**, 606 (1997).
8. Bulanin M.O., Malykh V.B., Mashendzhinov V.I., Filippovich B.S. *Opt. Spektrosk.*, **48**, 94 (1980).
9. Sojka P.E., Kerber R.L. *Appl. Opt.*, **25**, 76 (1986).
10. Kondrashenko A.V., Mishchenko G.M., Sevast'yanova T.G., Urlin V.D. *Vopr. Atom. Nauk. Tekhn.*, (3), 64 (1988).
11. [doi>](#) Azarov M.A., Aleksandrov B.S., Drozdov V.A., Troshchenko G.A. *Kvantovaya Elektron.*, **30**, 30 (2000) [*Quantum Electron.*, **30**, 30 (2000)].
12. Azarov M.A., Drozdov V.A., Troshchenko G.A. *Proc. SPIE Int. Soc. Opt. Eng.*, **3574**, 606 (1998).