EMISSION SPECTRUM OF A CHEMICAL LASER USING AN $H_2 + F_2$ MIXTURE

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This paper is devoted to an investigation of the rotational-vibrational spectrum of induced transitions of excited HF molecules. The vibrational-rotational HF molecules were obtained by the reaction of hydrogen with fluorine in an $H_2 + F_2$ mixture. This reaction is one of the energetically-branched chains [1] predicted in [2]. In [3] they obtained a high efficiency (relative to the energy of the triggering pulse) in an $H_2 + F_2$ laser. This confirms the branched character of the reaction, for it is precisely in lasers based on self-maintaining reactions that the output energy depends little on the triggering energy [4].

In our experiments the chemical reaction was excited in a quartz tube 110 cm long with inside diameter 10 or 17 mm. The self-maintaining reaction was initiated by entering into the ignition region through the lower limit. Lasing was attained at the vibrational-rotational transitions of the HF molecule and could be triggered either optically or electrically. The uv light pulse from the quartz lamp had an approximate duration 100 μsec and a rise time 15 μsec. Electric pulses of 1 μsec duration were applied to the tube with the gas mixture through molybdenum electrodes. The shape of the generation signal obtained by the two triggering methods is shown in Fig. 1. Figure 2 shows a plot of the amplitude of the output signal (3572 cm^{-1} line) against the power of the electric exciting pulse. At a slight excess above the threshold pump energy, the generation signal amplitude reaches a limiting value and remains practically unchanged with further increase of the triggering pulse energy. This proves that the reaction enters into the ignition region.

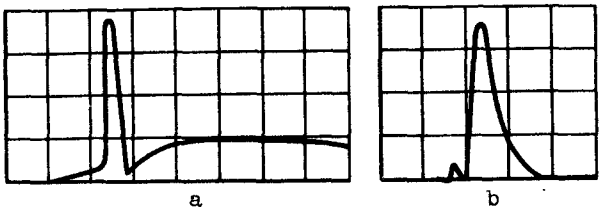

Fig. 1. Generation pulse of HF chemical laser: a) reaction initiated by uv light, b) reaction initiated by electric pulse (frequency 3572 cm^{-1}). Time sweep rate 5 μsec/div.

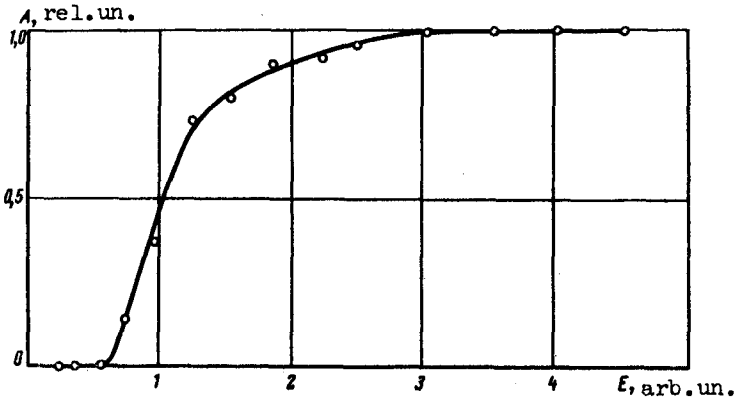

Fig. 2. Generation amplitude (at frequency 3572 cm^{-1}) vs. power of triggering pulse.

The laser emission spectrum was investigated with a monochromator with an LiF prism. The frequency was determined accurate to ±2 cm^{-1}. The spectrum was plotted while the gas mixture flowed continuously through the tube; the pump pulses followed one another at intervals of 10 sec. This ensured a complete change of the gas in the tube between two successive pulses. Lasing was observed also at a higher repetition frequency (up to 1 Hz).

Working with external gold mirrors and extracting the power through an aperture of 1.5 mm diameter, 10 most intense generation lines were registered in the range from 3230 to 3620 cm^{-1}. Dielectric-coated mirrors with a reflectance of about 99.8% in the interval 2900 - 3160 cm^{-1} made it possible to observe eight additional transitions.

To identify the observed lines we calculated the rotational-vibrational spectrum of the HF molecules in the range 2800 - 3800 cm^{-1} on the basis of [5, 6]. The frequencies of the observed lines and the calculated values of the frequencies of the closest lines are listed in the table.

The experiments have shown that the largest number of transitions occurs in the (2 - 1) and (5 - 4) bands, the most intense lines lie in the (2 - 1) band, and the spectrum contains no transitions of the (1 - 0) band.

Lasing on HF was obtained in a large number of mixtures of fluorine compounds with hydrogen or with hydrocarbons [7 - 8]. Unlike the reaction of H_2 with F_2, none of these mixtures yield branched chains, and produce only simple reactions or simple chain reactions.

Emission at the P(4) - P(8) transitions of the (2 - 1) band was observed in [7, 8] and was attributed by the authors of [8] to the atomic-fluorine reaction

$$F + H_2 = HF + H \qquad \Delta H = -32 \text{ kcal/mole}. \tag{1}$$

In our case, besides the lines of the (2 - 1) transition, there were observed lines of the bands (3 - 2), (4 - 3), (5 - 4), and (6 - 5). This circumstance is connected with the fact that in addition to the process (1), the reaction

$$H + F_2 = HF + F \qquad \Delta H = -98 \text{ kcal/mole}, \tag{2}$$

also takes place in a laser using the $H_2 + F_2$ mixture, and as a result much higher vibrational levels can become populated.

The large number of transitions terminating at the level v = 4 may be the result of the depletion of this level because of the process $HF_{(v=4)} + F_2 \rightarrow HF_{(v=0)} + 2F$. No direct proof of the branching of the reaction just as a result of the direct energy transfer from HF to F_2 can be found in the literature. However, if direct collisions between HF and F_2 do play an important role in the branching of the reaction, then the main role in this process should be played just by the $HF_{(v=4)}$ molecules, since the dissociation energy of F_2 lies between the vibrational levels v = 4 and v = 3 of the HF molecule. The presence of intense transitions in the (2 - 1) band is abetted by two circumstances: the possible population of the level with v = 2 both as a result of the reaction (1) and as a result of reaction (2), and the depletion of the level v = 1 by resonant energy transfer from the HF to the hydrogen by collisions of the second kind, $HF_{(v=1)} + H_{2(v=0)} \rightarrow HF_{(v=0)} + H_{2(v=1)}$, in

Lines observed in $H_2 + F_2$ laser emission

ν_{exp}, cm^{-1}	Possible transitions		
	Band	Transition	ν_{calc}, cm^{-1}
2960	6 – 5	*P*(5)	2961,14
2999	6 – 5	*P*(4)	2999,94
3025	5 – 4	*P*(7)	3026,29
3070	5 – 4	*P*(6)	3068,71
3111	5 – 4	*P*(5)	3110,42
	6 – 5	*P*(1)	3108,99
3149	5 – 4	*P*(4)	3150,75
3084	4 – 3	*P*(9)	3083,83
	3 – 2	*P*(12)	3082,53
3130	4 – 3	*P*(8)	3130,09
3416	3 – 2	*P*(5)	3417,99
3230	2 – 1	*P*(12)	3229,97
	3 – 2	*P*(9)	3232,51
	5 – 4	*P*(2)	3227,72
3284	2 – 1	*P*(11)	3282,76
3334	2 – 1	*P*(10)	3334,48
	5 – 4	*R* (0)	3333,15
3386	2 – 1	*P*(9)	3385,23
	4 – 3	*P*(2)	3384,27
3434	2 – 1	*P*(8)	3435,10
3482	2 – 1	*P*(7)	3483,71
3529	2 – 1	*P*(6)	3531,20
	4 – 3	*R* (1)	3527,67
3572	2 – 1	*P*(5)	3577,52
3620	2 – 1	*P*(4)	3622,58
	4 – 3	*R* (4)	3619,42

view of the small difference between the vibrational frequencies of HF (ν = 3961.6 cm^{-1}) and $H_{2(v=1)}$ (ν = 4161.2 cm^{-1}) [11]. The latter circumstance, together with the possible presence in the original mixture of HF in the ground state, hinders lasing at the (1 - 0) transition, which was not observed in our experiments.

The presence of only one generation line of low intensity in the 3 - 2 band probably indicates a preferred population of the v = 2 level in the process of reaction (1).

Account must be taken of the fact that the ignition region does not coincide, generally speaking, with the region in which states with inverted population are obtained, and depends on the reaction between the rate of the reactions and the relaxation time of the

working levels [4]. Inasmuch as the reaction rate (the rate of population of the levels during the course of the reaction) and the relaxation times depend on the temperature and on the other parameters of the mixture, and are different for different levels, the generation spectrum can vary with these parameters. It is therefore of great interest to study the distribution of the generation energy over the spectrum and the time evolution of the dynamics of the spectrum as functions of the mixture parameters.

If the rate of relaxation from the lower working level exceeds its population from the higher level as a result of relaxation processes, then the reaction should be accompanied by inversion in the entire ignition region. It is possible that this is precisely the situation in the $H_2 + F_2$ mixture with respect to the (2 - 1) transition in HF, owing to the depletion of level 1 in collisions between HF and H_2. This gives grounds for hoping to obtain a lasing regime without external triggering of the reaction and in the continuous regime.

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PASSAGE OF ELECTROMAGNETIC WAVE THROUGH A FERROMAGNETIC METAL IN THE ANTIRESONANCE REGION

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It is known that the propagation of an electromagnetic wave inside a metal is determined principally by the presence of the conduction electrons. The magnetic system acts on the conduction electrons via the Lorentz force $\vec{F} = (e/c)\vec{v} \times \vec{H}$, whence it follows that the singularities of the high-frequency magnetic susceptibility should affect the propagation of an electromagnetic wave inside a ferromagnetic metal. The reciprocal of the depth of penetration in a ferromagnetic metal is

$$\mathrm{Re}(k) \sim [(\mu'^2 + \mu''^2)^{1/2} + \mu'']^{1/2},$$

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