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Review Article

HF (DF) Ecologically Safe High-Energy/Power Lasers

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ABSTRACT

The following review is focused on two fundamental problems investigated by our teamThe formation of a scalable self-sustained volume discharge in strongly electronegative gases and the creation of wide-aperture high-energy non-chain HF (DF) chemical lasers; The generation spectrum of a non-chain HF (DF) chemical lasers expanding and creating lasers with high energy per pulse, pulsed and average power in the spectral range>4.1 μm.

Keywords: High energy/power lasers; Non-chain chemical lasers; Wide-aperture laser system; Electronegative gas

DESCRIPTION

Chemical HF (DF) lasers. The principle of operation and general characteristics, with the discovery of chemical lasers (CL) high hopes was pinned on them.

They were connected with the possibilities of their use in various fields, mainly in the field of military applications, in power engineering, in the creation of laser engines, etc., i.e. in those areas where laser beams with low divergence and extremely high energy characteristics are necessary.

A distinctive feature of the CL is the possibility of obtaining laser energy with efficiency higher than 100%, i.e. the emitted energy may be several times higher than the energy expended to initiate a chemical reaction.

A classic example of such a laser is a chain HF (DF) laser, in which lasing in the mid-IR range occurs on the vibrational-rotational transitions of the HF (DF) molecule, which is formed when fluorine gas interacts with hydrogen (deuterium).

The energy characteristics of the CL are record-breaking among the whole class of gas lasers. An additional factor that stimulated the development of HF (DF) laser research was that the DF laser radiation is little absorbed by atmospheric gases (falls into the atmospheric transparency window).

It shows the dependence of the atmospheric transmission on the radiation wavelength (Figure 1) [1].

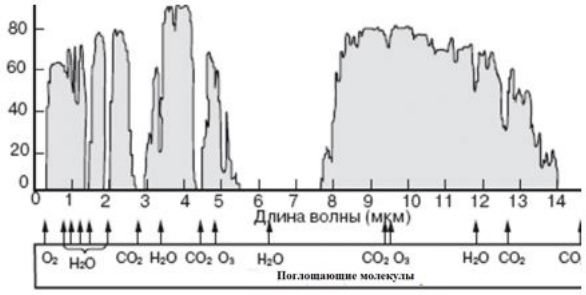

Figure 1: Transmission of the atmospheric surface layer (15°C, humidity 40%). Shaded areas are atmospheric transparency windows.

Due to the high interest in the DF laser from the military-industrial complex by the beginning of this century, laser systems of the megawatt level had already been created, including in the mobile version. The main drawback of the chain CL, greatly limiting their field of application, is the high toxicity and explosiveness of the starting components. It is because of this that it is possible to work with chain HF (DF) lasers only on specially equipped sites. Another significant drawback of the chain CL is the difficulty of implementing the IP mode, especially when a number of applications require work with a high pulse repetition rate (~100 Hz and more). At the same time, lasers on non-chain reactions lack the disadvantages listed above. The efficiency and energy parameters of non- chain HF (DF) lasers are not as high as those of chain analogy, but the lasing spectrum also lies in the average IR range (λ=2.6 ÷ 3 μm

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for the HF laser and λ=3.6 ÷ 4.1 μm for the DF laser), while they are safer and more convenient to use. The first papers describing the generation of non-chain lasers based on vibrational-rotational transitions of HF and DF molecules appeared in 1967, i.e. long before the CL were created on chain reactions. Over the next 50 years, interest in the non-chain HF (DF) CLs was unstable. Periods of a sharp increase in the number of publications devoted to HF (DF) laser studies (or their applications) alternated with periods of decline, when the activity of research groups in this area decreased markedly. The uneven activity of scientific groups working in the field of the non-chain HF (DF) CL is due to several reasons. First, the progress in the development of such lasers required for their decision a deeper understanding of the physical processes occurring in the gas-discharge plasma, the application of new approaches, the development of technologies or the development of a new elemental base. The second reason is associated with progress in the field of creating solid-state lasers, which gave hope for obtaining comparable energy characteristics, including in the spectral region of 2.7–4.5 μm. This is the reason for the decrease in the level of funding for other areas of research. However, even today, in the spectral region of 2.6–4.2 μm, the energy characteristics pulse energy, pulsed and average power, of the non-chain HF (DF) CLs are still significantly superior to solid-state lasers [2].

The principle of the non-chain HF (DF) CL is based on the fact that in a laser working medium, which is a stable mixture of fluorine and hydrogen-containing (deuterium-containing) gases, a non-chain reaction is initiated by the input of energy from an external source. Molecules of the starting materials dissociate to form chemically active centres (fluorine atoms), the reactivity of which is many times greater than the reactivity of the starting materials. As a result of the production of fluorine atoms in the working volume, it becomes possible for a chemical reaction to form HF (DF) molecules in a vibration ally excited state. In a non-chain laser, the hydrogen (deuterium) is mainly used. SF is a non-toxic, chemically stable compound that is used in fire fighting as a gas flame arrester, and in high-voltage technology as a gas electrical insulation [3,4].

SF molecules dissociate with the formation of fluorine atoms due to an external energy source. A schematic diagram of the IP of a non-chain HF (DF) CLs. The flow of non-reacting gases is pumped through laser zone 2, where a non-chain chemical reaction is initiated from an external energy source. The reaction in this mixture is possible only while the fluorine atoms are being generated. After the laser zone, the mixture is pumped through filter 3, on which HF (DF) molecules and dissociation products are deposited, and the mixture again. Active centres form only as a result of the external energy source, and after the cessation of energy supply, the chemical reaction quickly fades. The degree of dissociation in the laser zone, as a rule, does not exceed 5%; therefore, the gas consumption for one cycle is insignificant (in real lasers, usually the volume of the laser chamber significantly exceeds the volume of the laser zone). During long-term operation with a high pulse repetition rate in a non-chain HF (DF) CL, a continuous supply of a fresh mixture is carried out to compensate for the reacted components (Figure 2) [5].

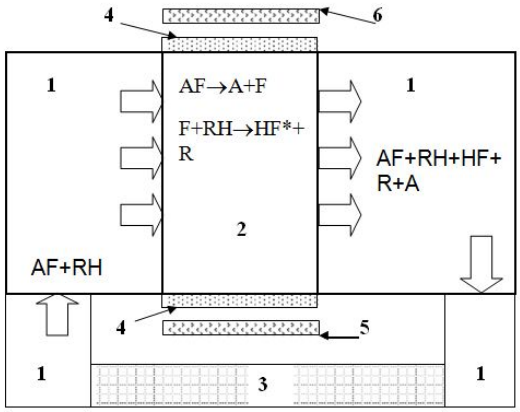

Figure 2: I–P scheme of non-chain HF(DF) laser: 1) chamber; 2) laser zone, where using an external energy source cause the dissociation of the fluorine-containing component; 3) filter for binding HF (DF); 4) windows for outputting radiation to the resonator; (5,6) resonator mirrors.

The non-chain HF (DF) CLs are characterized by large values of the gain, while lasing occurs according to a cascade mechanism, i.e. the lower laser level of the previous transition is the upper for the next. For example, transitions in the vibrational bands n=3 → n=2, n=2→n=1, n=1→n=0 are observed in an electric-discharge HF laser based on SF :H mixtures. In this regard, the laser has a rather complex spectrum of output radiation, which is a large number of closely spaced lines corresponding to different rotational numbers of vibrational transitions. Figure 3 shows a typical lasing spectrum of a chemical DF laser. (The spectrum of a non-chain laser is usually poorer, but depending on the particular implementation in the spectral region up to 4.1 μm, it is similar to the lasing spectrum shown in Figure 3. When using a selective cavity mirror or introducing a selective absorber inside the cavity, it is possible to control the spectral composition of non-chain CLs quite efficiently, highlighting certain vibrational- rotational lines [6-9].

F+RH(RD)=HF (DF)+R	Q, eV	Q, kcal/ mol	Chemical efficiency η ,
H	1.43	32.9	0.71
D	1.4	21.7	0.7
HI	1.95	44.8	0.95
HBr	2.11	48.5	0.24

Table 1: The energy effect of the chemical reaction of the interaction of fluorine atoms with various hydrogen donors RH (deuterium RD) and the fraction of this energy (η), which is used to excite vibrational levels of the HF (DF) molecule.

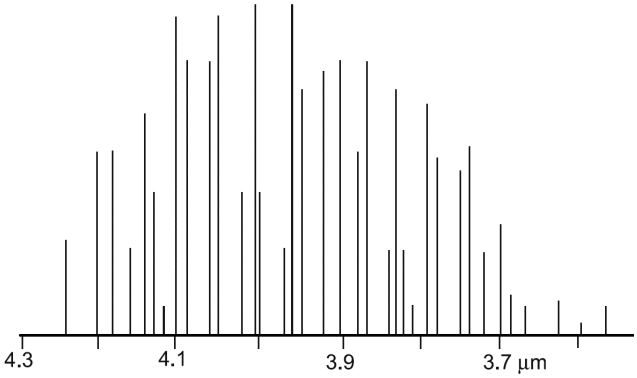

Figure 3: Relative intensity of lasing lines of a pulsed DF laser.

The amount of energy concentrated in the vibrational degrees of freedom of the HF (DF) molecules is largely determined by what substance was used as a hydrogen (deuterium) donor. The Table 1 presents data on the amount of energy released during the chemical exothermic reaction (Q), as well as its fraction (η), which is used for vibrational excitation of the HF (DF) molecule for various hydrogen donors (deuterium). The value of η is at the same time the limiting value of the chemical efficiency of an HF (DF) CL in mixtures containing the RH (RD) molecules. It should be noted that Q and η do not depend on the specific form of the fluorine-containing compound AF, since the AF compounds do not directly interact with RH, and a false assumption may arise that the lasing spectrum of the HF (DF) laser also does not depend on which fluorine-containing compound the substance is used. However, this is not the case. The fact is that AF dissociation products are formed not only in the ground state, but also in the excited state, and thus carry some excess energy, the magnitude of which, with the chosen initiation method, depends on AF. The choice of AF also has a direct effect on the overall efficiency of CL, since the main energy consumption in nonchain HF (DF) CLs is the dissociation of AF fluoride molecules to form F atoms. Most studies have been carried out on lasers in which fluoride dissociation occurred due to electron impact; in the literature this type of lasers is also called electrochemical. It should be noted that the difference in the energy consumption for the dissociation of AF molecules leads to different absolute values of the gain of the active medium of non-chain HF (DF) CLs, which also affects the lasing spectrum. It was shown that the problem of creating an effective non-chain HF (DF) CL reduces, firstly, to the choice of suitable fluorine and hydrogen-containing gases, in which, with minimal initiation energy, it is possible to obtain the maximum output energy of the laser W out, and second, to the choice of an effective method of initiating a non-chain chemical reaction. The method based on the dissociation of fluorine-containing molecules by electron impact, carried out in a SSVD, has the greatest advantages (low energy costs for the formation of fluorine atoms, the possibility of exciting large volumes of the medium, etc.) over all other methods of initiating non-chain chemical reactions. In contrast to photolysis, this method is also more versatile, since it allows the use of a much wider range of fluorine-containing compounds, and in contrast to the use of an electron beam, it does not require sophisticated protection from X-rays and has higher characteristics in terms of structural reliability [11-13].

At present, among various gas lasers, it is electric discharge systems that have found the greatest application. Electric-discharge non-chain HF (DF) CLs are used in medicine, for optical pumping of crystals, in laser chemistry, in military science, for recording holograms and in environmental monitoring. In this regard, we consider electric discharge HF (DF) CLs in more detail [14-16].

CONCLUSION

HF (DF) lasers with the initiation of non-chain chemical reaction by electric discharge. The first lasing on the HF in an electric discharge was obtained by Deutsch in 1967. After that, the main effort of researchers was focused on finding the most appropriate fluorine and hydrogen- containing compounds and improving the methods for obtaining the discharge .In the first works, schemes with a longitudinal electric discharge were used (the highest characteristics of the HF laser with this method of excitation were obtained in, but the possibility of increasing the working volume and laser energy was limited by the need to supply extremely high voltages to the electrodes. Therefore, almost immediately after the appearance of the first publications on the creation of a CO laser with pumped transverse SSVD, the methods developed for this purpose began to be used to initiate a chemical reaction in non-chain HF(DF) CLs. It is this type of electric discharge that allows more energy to be introduced into the gas and to excite large volumes of the active medium. Independently of one another by many experimental groups, it was found that the best parameters of a non-chain HF laser are realized when SSVD is ignited in the SF:H or SF:C H working mixtures. It should be clarified why the SSVD in gas mixtures containing fluorine atoms as SF as a donor turned out to be the most effective way to initiate a chemical reaction in the non-chain HF(DF) CLs. When an electric current flows in a gas, the main parameter that determines such parameters as the average electron energy, ionization constants, adherence, etc., is the parameter E/N, where E is the magnitude of the electric field strength and N is the number of gas particles per unit volume.

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