Theoretical comparison of electron beam initiated HF/DF laser output characteristics

Young-Woo Lee, *Member, KIMICS*

Abstract—The output characteristics of HF and DF lasers were compared theoretically. The simulation code shows the good agreement with the experimental results well. As results, the effect of chain termination reaction in F_2 rich mixture is larger than that of SF_6 rich mixture in HF and DF lasers.

Index Terms— HF laser, DF laser, Chemical laser, e-beam pumping

I. INTRODUCTION

Recently, electron beam initiated HF and DF chemical laser has been made rapid progress with advanced pulse power technology. For the case of HF laser, it has advantageous output characteristics of high efficiency and high power, for that reason, this system arise the promising candidate which apply to laser fusion driver or energy device of various kinds.

The first lasing of HF molecules produced by chain reaction was operated by Batovskii in 1969[1]. Subsequently, the first report of chain HF laser using electron beam system was performed by Zharov in 1972[2]. From 1974, an intense and relativistic electron beam system(MeV level) initiated HF laser has been mainly developed by Gerber and co-workers at Sandia National laboratory in U.S.A., they achieved the output energy over 4 kJ[3]. Since then, this laser system has been chiefly advanced on making a high power and high electrical efficiency in priority. Until now, e-Beam initiated HF laser obtained the characteristics of maximum output energy(4.4 kJ) and electrical efficiency (2%) as a single pulse operation[4].

On the other hand, DF chemical laser also has been developed actively[5,6]. As its priority of atmospheric transmission, it employed various initiation ways. Recent research has shown the possibility that DF chemical laser can be made to lase with the potential for high power(kJ level) and efficiency.

As mentioned above, there have been significant advances in development of HF/DF chemical laser using intense e-Beam system as a natural consequence it follows that these system brought up the need to develop accurate numerical model for further optimization of various parameters.

Numerical models for HF and DF laser has been developed in many points of views. The previous research in numerical analysis was mainly performed in long initiation pulse and low initiation level regimes. (as optical pumping electrical discharge)

However, short pulse and intense electron beam system makes it possible to get high initiation level at initial state of chain reaction. Until now there's no presentation of a theoretical comparison with different characteristics between HF and DF chemical lasers in this initiation regime concretely. Especially, in those previous theoretical works, two fluorine donors containing mixtures were not studied, and comparison of two lasers (HF/DF) was not investigated quantitatively.

II. SIMULATION CONDITION

Constant gain method was used in this study. The empirical output energy of HF and DF lasers, which is initiated by short pulse, intense e-Beam device

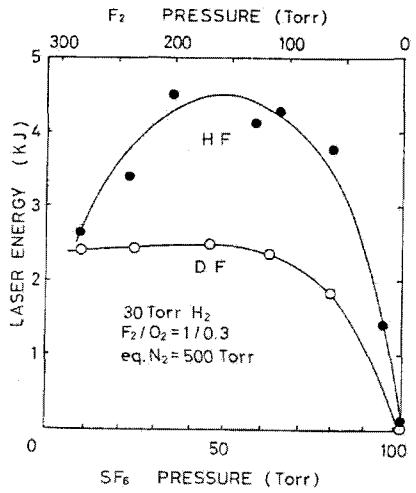


Fig. 1 Laser energy output as functions of F_2/SF_6 pressures. (● HF laser ○ DF laser)

(2MeV, 65 kA, 65 ns), as a function of gas mixture is given in Fig. 1. This figure shows optimizing gas pressures of two components as fluorine donor under the conditions where the e-Beam stopping power by the laser gas media is equivalent to 500 Torr of N_2gas. The partial pressure of Hydrogen gas was 30 Torr constant and the ratio of F_2 and O_2 is equal to 1/0.3 which were determined by previous experiment. The maximum regime of HF and DF laser using this initiation record

Manuscript received November 27, 2007

Lee, Young Woo is a professor of electronic engineering department in Mokwon University, Daejeon, Korea (Tel: +82-42-829-7654, Fax: +82-42-823-8506, E-mail: ywlee@mokwon.ac.kr)

about 4.5 kJ and 2.5 kJ respectively. In this point-source model, the reflectivity of optics were 100% and 7% respectively, and active volume is 2.7*l* (Φ 12cm, 240cm long).

In this study, theoretical analysis was performed under comparison of experimental results as a basis of pumping process. Main procedure of laser operation in HF and DF chemical lasers is as follows ; Collective electron group which has relativistic intensity and high energy (MeV level) collides with fluorine donor molecules, as results, coming into beings of F atoms as a seed react on H_2/D_2 molecules and then initiated a chain reaction which creates vibrationally excited HF and DF molecules. That is, exothermic energy which is produced by chain reaction distributes to each vibrational levels of these molecules, and forms population inversion among each levels which are states of nonequilibrium.

This initiation regime makes it possible to get a high concentration of F atoms at initial state as compared with other pumping device. In theoretical analysis of this chemical laser, it is the most important thing to determine the initiation level which is the equivalent of a excitation rate of other gas lasers.

In the case of a intense electron beam initiation, the production of F atoms and F^- ions occurs as follows[7,8];

$$F_2 + e_p \rightarrow F_2^+ + e_p + e_s$$
$$F_2 + e_p \rightarrow F_2 + F^-$$
$$F^- + F_2^+ \rightarrow 3F$$

Where e_p and e_s are the primary and secondary electrons at initial collision state.

Until now no reports explained how much e_s and F^- ions contribute t_Θ forming vibrationally excited HF and DF molecules. Accordingly, it may be thought discrepant that initiation level calculated from characteristic dissociation energy applies to variable two fluorine component system intactly.

Especially, it is certain that F_2 rich region, as shown in Fig. 1 have many formation channels of laser molecules, which is produced by reactions of ion –ion, ion-atom pairs under state of plasma. It was clarified that additives of SF_6 gas make it possible to obtain high initiation level according to increasing deposition energy.

However, in our calculation, partial pressures of two fluorine donors (F_2/SF_6) vary against to each gas mixtures. Therefore, it is doubt that SF_6 rich region has high initiation level simply. Consequently, in this study, it is assumed that F_2 rich reason has higher initiation level than SF_6 rich region. This assumption resulted in good agreement with experimental results.

III. RESULTS AND DISCUSSION

This paper presented further investigation of difference of output characteristics between H_2 gas pressure and chemical efficiency.

Fig. 2 shows the calculated HF and DF laser output energy as a function of gas mixture under same conditions described section II. This results shows that output energy depends on a balance of gas mixture rather than initiation level. According to this results the output energy of HF laser increased almost linearly with SF_6 pressure up to 70 Torr and decreased cliffly over 80 Torr because of decreasing F_2 gas pressure which contribute to chain reaction. On the other hand, that of DF laser was estimated higher than empirical results. However, the whole tendency of curve was well accorded to experimental results well.

The output energy ratio of calculated HF and DF laser is about 60 % at peak pint, which is in excellent agreement with the experimental value of 56%. The results of this calculations, we made a certain of the truth of importance in defining the balance of F_2 and SF_6 mole fractions.

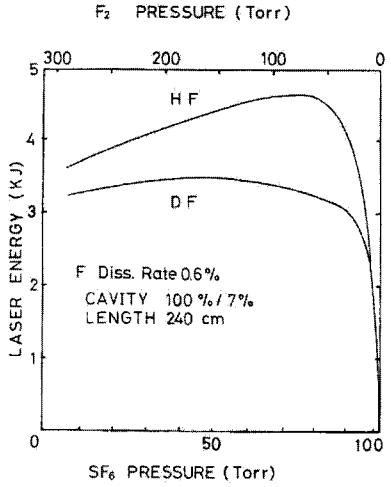


Fig. 2 Calculated laser energy output as functions of F_2/SF_6 pressures.

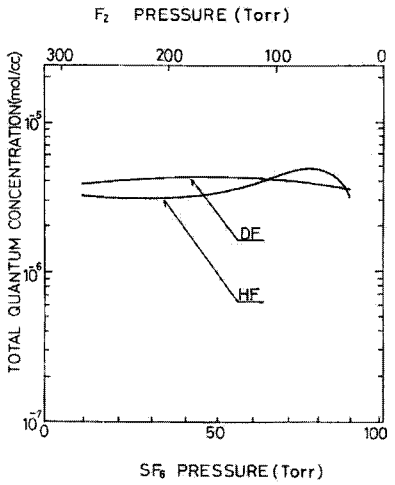


Fig. 3 Total concentration of quantum as functions of F_2/SF_6 pressures.

The total concentrations of quantum produced by chain reaction is shown in Fig. 3. These plots show that the one of DF laser is larger than that of HF in F_2 rich region. It is apparent, from this result, that the reaction rate of DF laser is better than that of HF laser, but reason of this appearance cannot be explained at present. Both

some parameter of time characteristics and peak intensity as a function of each gas mixtures are shown in Fig. 4.

The $t_{1/2}$ means time duration required to release on half the total pulse energy, and, t_f and t_c are FWHM and laser pulse duration till cutoff time respectively.

All pulse durations of these lasers, as shown in Fig. 4., increased with increasing SF_6 mole fraction while the peak intensity of F_2 rich region is higher than that of SF_6 rich region. This shows that the fast pumping rate can be obtained by higher initiation level of F_2 rich region, as a result, the shorter rising time of laser pulse can be shown because a peak intensity is proportion to the pumping rate. These numerical appearance is in accord with experimental results. On the other hand, it is thought that the effect of O_2 gas contained for stable-mixture is large on F_2 rich region because of their contribution to chain termination reaction.

In this study, we did not include the ionic reaction to our model. The rate coefficient for ionic pumping reaction was estimated to be approximately one order higher than that of neutral pumping reaction. We believe that it is possible to coincide with pulse duration of experiment, if the model includes these fast reactions.

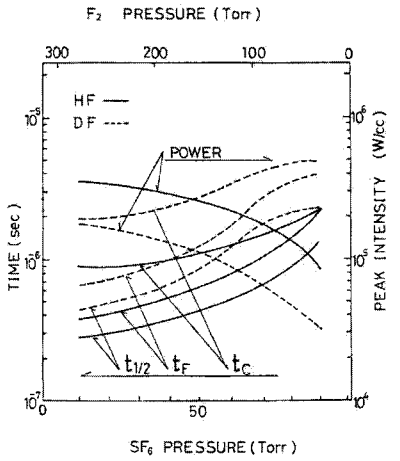


Fig. 4 Time duration and peak Intensity as functions of F_2/SF_6 pressures.

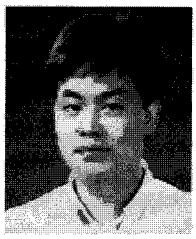
IV. CONCLUSIONS

The performance of HF and DF laser was compared quantitatively. Several conclusions can be made from this investigation;

1. We can conclude that H_2 rich mixture region has high initiation level.
2. The effect of chain termination reaction in H_2 rich mixture is larger than that of SF_6 rich region.
3. Simulation results of intense e-Beam excitation scheme in HF/DF lasers agree quantitatively with experimental results.

REFERENCES

[1] O.M. Batovskii, et. al. JETP Lett. 9, 341(1969)
[2] V.F.Zharov, et. al. JETP Lett. 16, 154(1972)
[3] R.A.Gerber, et. al. J. Appl. Phys., 47, 3524(1976)
[4] T. Fujioka, J . Appl. Phys., 58, 3975(1985)
[5] H. Inagaki, et. al., J. Appl. Phys., 59,324(1986)
[6] T.D.Dreiling, et. al., J.Appl. Phys., 61, 1688(1987)
[7] N.Cohen,"SPIE- A Review of rate constants in the D2-H2 chemical laser system" TR-0077(2603)-3 USA.
[8] J. J.T. Hough," SPIE-A Computer model for the H2(D2)+F2 Pulsed chemical laser system" TR-0078(3940)-4 USA.



Young Woo Lee
was born in Seoul, Korea, on April 29, 1959. He received Ph.D. degree in electrical engineering from Keio University, Yokohama, Japan, in 1990. In 1990-1992, he was a research associate at Laser Physics group in Max-Planck-Institute for Biophysical Chemistry at Goettingen in Germany. In 1992, he joined the department of electronic engineering, Mokwon University, where he is a professor. He is currently working on optoelectronics/Lasers and their applications, and bio/medical photonics, ultrafast optoelectronics. Dr. Lee is a Member of IEEE and KIMICS.