Short Wavelength Chemical Lasers

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Experimental results on the operation of HF chemical lasers on the $v = 2$ to $v = 0$ overtone transitions are presented. Two separate cw laser devices with gain lengths of 15 and 30 cm produced 21 and 56 W of overtone power. The comparable power on fundamental transitions of the same lasers was 97 and 180 W. Thus, these overtone HF lasers produce 22% and 31% of the available fundamental power, much higher percentages than previous overtone chemical lasers. The implications of this new short wavelength chemical laser for highpower lasers are discussed briefly.

Introduction

THIS paper is the first publication of experimental results on a new short wavelength chemical laser concept that is potentially scalable to very high-output power. The concept is to operate an HF chemical laser on the first overtone transitions, thus shifting the output wavelengths from the usual 2.8-μ band to a narrow region centered at 1.33 μ. The basic requirement for an overtone HF laser is that the optical resonator stay below threshold for the fundamental transitions while lasing on the overtone transitions. Results to be presented here were obtained following the first demonstration of an efficient, overtone HF laser in late 1984.[1]

There have been earlier examples of overtone chemical lasers dating back to 1971; DF,[2,5,6] CO,[3] and HF[4,5] overtone lasing had been observed in various pulsed and cw laser experiments. In all cases, overtone power or pulse energy was small (10% or less) or not measured compared to fundamental output of the same laser. The most comprehensive and serious overtone laser work was done by Holleman and Injeyan using a combustion-driven cw chemical laser.[6] This device produced 7 W on the overtone DF transitions compared to 700 W on the fundamental DF transitions. Thus, there was little interest in overtone chemical lasers as potential high-power systems.

Laser Experiments

A priori, several considerations were apparent before the first experiment in late 1984.

1) Molecular overtone gain coefficients usually will be much smaller than corresponding fundamental gain coefficients. The primary difference for the first overtone is the reduced vibrational matrix element for the $\Delta v = 2$ as compared to the $\Delta v = 1$.[7] Therefore, the best candidate overtone laser will be the one having highest fundamental gain, namely HF.[8]

2) For high-power laser applications, current interest is in shorter wavelengths. Again, HF is the best choice, since the first overtone falls approximately at 1.3 μ. There is no other chemically pumped molecular laser with shorter wavelengths. The chemically pumped atomic Iodine laser at 1.315 μ also falls in the same wavelength region.

3) Consideration of the $F + H_2$ pumping reaction vibrational product distribution,[9] illustrated in Fig. 1, shows a very favorable situation for pumping the $v = 2$ to $v = 0$ overtone transitions. Direct pumping into $v = 2$ occurs with 69% probability for each reaction. Assuming $v = 3$ can be transferred into $v = 2$ via fast collisional de-excitation, approximately 85% of the pumping reaction energy can be coupled into the $v = 2$ upper level of the overtone transition.

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Although these considerations were known before the experiment, the questions of optical discrimination to avoid fundamental lasing and of proper output coupling for the overtone transitions were not well understood. Nevertheless, the first experiment succeeded very well compared to earlier overtone lasers.

Two separate laser devices will be described, and results for overtone HF lasing and comparative fundamental HF lasing will be presented. The first laser is a 15-cm gain-length device identical to that used in the 1984 experiments. A 30-cm laser will be presented as a second case to illustrate overtone lasing at longer gain length and higher power. Both lasers are standard commercial Helios hardware that has evolved from earlier designs by Spencer et al.[10] The F-atoms are produced by electrical dissociation of SF_6 in a dc discharge; the $F + H_2$ pumping reaction is initiated by H_2 injection through an array of small sonic orifices. Reaction and lasing occur within a few millimeters of the H_2 injection station of a subsonic flow channel. These laser devices have been extensively characterized and modeled by Sentman.[11,12]

Table 1 lists most of the relevant operational parameters for the 15-cm and 30-cm laser devices, including optics and resonator parameters; in all cases the resonators are stable, producing multiline and multimode output beams.

Also listed in Table 1 are the overtone and fundamental output powers for both lasers. We emphasize that the overtone HF laser produces up to 31% of fundamental HF power, completely distinguishing it from all previous overtone chemical lasers. With 31% overtone efficiency, this concept immediately qualifies as a potential short wavelength high-energy laser.

Laser spectra for both gain lengths are shown in Fig. 2. Overtone lasing occurs on the $v = 2$ to $v = 0$ P-branch transitions, typically P4, P5, and P6. The vacuum wavelengths for $v = 2$ to $v = 0$ overtone transitions are tabulated in Table 2. The HF fundamental lasing occurs as usual on the $v = 2$ to

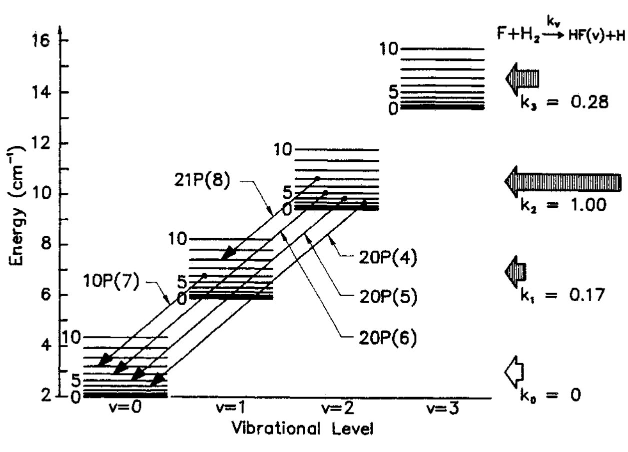

Fig. 1 Fundamental and overtone transitions of HF chemical lasers.

Table 1 HF laser parameters and performance

	15-cm gain length	30-cm gain length
Reactant flow rates: $He/O_2/SF_6/H_2$, g/s	0.20/0.02/0.23/0.06	0.4/0.04/0.46/0.12
Cavity pressure, Torr	4.9	5.7
Discharge current/ voltage, mA/kV	390/7.45	750/7.82
Resonator length	57 cm	57 cm
Fundamental optics M1/M2		
Curvatures	3mCC/plano	3mCC/plano
2.8-μ reflectances	99%/91%	99%/65%
Overtone optics M1/M2		
Curvatures	3mCC/3mCC	3mCC/plano
1.3-μ reflectances	99.1%/94.5%	99.4%/95.1%
2.8-μ reflectances	1.4%/2.3%	0.4%/3.7%
2.8-μ output power, W	97	180
1.3-μ output power, W	91	56
Overtone efficiency[a]	22%	31%

[a] Overtone efficiency is the ratio of overtone to fundamental laser power for identical laser operating conditions, except using different optics for overtone vs fundamental lasing.

Table 2 Vacuum wavelengths[a] for the first overtone transitions of HF

	$v = 2$ to $v = 0$	$v = 3$ to $v = 1$
P1	1.29707 μ	1.35652 μ
P2	1.30453	1.36438
P3	1.31258	1.37288
P4	1.32125[b]	1.37202
P5	1.33053[b]	1.39182
P6	1.34043[b]	1.40229
P7	1.35099	1.41344
P8	1.36219	1.42530
P9	1.37406	1.43787
P10	1.38662	1.45118
P11	1.39988	1.46524
P12	1.41385	1.48007

[a]Calculated using the molecular coefficients given in Ref. 17.
[b]Laser lines observed in these experiments.

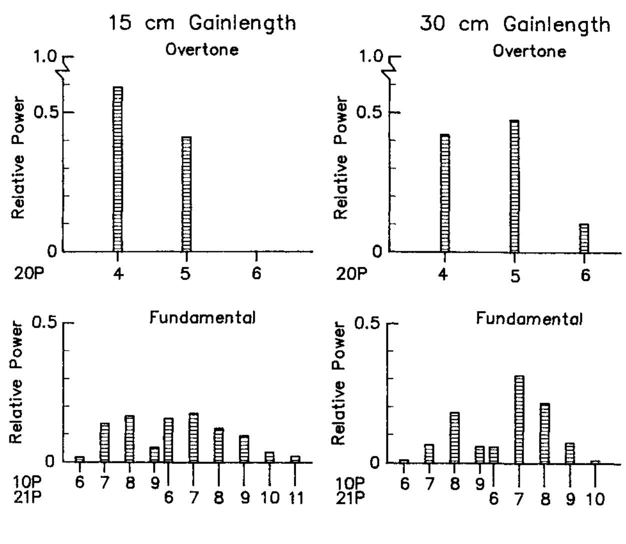

Fig. 2 Overtone and fundamental HF laser spectra.

$v = 1$ and $v = 1$ to $v = 0$ P-branch transitions. The fundamental spectra of Fig. 2 are typical of most cw HF lasers.

Discussion

The data presented here suggest that the overtone mode of operation will be possible with very high-power combustion-driven lasers. In the context of high-power HF lasers, it is appropriate to briefly consider the implications of overtone HF.

1) Shorter wavelength, 2.8 μ to 1.3 μ: Equal power and optics sizes produce increased far-field brightness,[13] varying approximately as λ^{-2}, a factor of $\times 4$ in this case.

2) Atmospheric transmission: The 2.8-μ fundamental HF lines are all highly absorbed by atmospheric water. The overtone HF transitions, particularly P5 and shorter wavelengths, have relatively good atmospheric transmission.[14] These facts raise the new possibility of transmitting overtone HF laser beams through the atmosphere.

3) Target lethality: Coupling to most targets increases with decreasing wavelength, particularly for metals.[15] If targets have been hardened against a given wavelength, e.g., 2.8 μ, they may be much more vulnerable to another wavelength such as 1.3 μ.

At this time, overtone HF operation of combustion-driven lasers has not been conclusively explored. Some remaining issues for extending this concept to high power are the following:

1) Maximum available overtone efficiency: Very recent experiments with electrically driven lasers have demonstrated 50%,[16] significantly higher efficiency than available from the laser design reported here. The experimental limit has yet to be determined, both for electrically driven and combustion driven HF lasers.

2) Discrimination techniques: Discrimination to suppress 2.8-μ lasing and allow 1.3-μ lasing has been demonstrated for electrically driven lasers up to 75-cm gain length. Maximum gain-length limits will be set by 2.8-μ amplified spontaneous emission due to residual 2.8-μ gain.

3) Optics: Overtone HF operation requires optics with minimum reflectance for the 2.8-μ band and with high reflectance in the 1.3-μ region. In addition, efficient overtone power

extraction requires that residual optical losses such as scattering and absorption be small compared to useful outcoupling.

To summarize, overtone HF is an experimentally demonstrated short wavelength chemical laser concept that has good prospects for scaling to very high power. Extension of the concept to combustion-driven lasers will be done in the near future. Issues on the ultimate scalability of overtone HF are presently under investigation.

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