CW OPTICAL RESONANCE TRANSFER LASERS (ORTL)

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CW OPTICAL RESONANCE TRANSFER LASERS (ORTL)*


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Abstract.—Wavelength-agile, single and multiline laser radiation has been obtained from a subsonic gas flow system which is optically pumped with a multiline chemical laser. This optical resonance transfer laser (ORTL) concept was first demonstrated on the 10.6μm DF/CO₂ system in 1976. Since then, several IR laser pumped molecular lasers have been demonstrated. The pump laser is either a cw HF or DF chemical laser. Two classes of ORTL have been developed: inter- and intramolecular ORTLs. The demonstrated intermolecular systems include: 10.6 μm DF/CO₂, 10.8 μm DF/N₂O, 4.1 μm DF/HBr, 3.8μm HF/DF and 3.85μm HF/HCN. The intramolecular ORTLs include 2.9μm HF/HF and 3.9μm DF/DF. Demonstration experiments and the kinetics of ORTL systems will be described.

1.0 Introduction

CW HF/DF chemical lasers are efficient but they are multi-band, multi-line lasers with large density and J-dependent gain variations in the active medium. This is due to the supersonic mixing of fuels, the heat generated during the chemical excitation reaction processes and the rapid deactivation processes associated with hydrogen fluorides. Elaborate engineering efforts are required to efficiently extract the available power to produce an output beam with good optical quality for specific applications. Recently, an Optical Resonance Transfer Laser (ORTL) concept has been developed in which the chemical laser is used strictly as an optical pump source where good beam quality is not required. On the other hand, an output with good beam quality is easily achievable from an ORTL medium because it is a subsonic flow system with minimum external disturbance and no chemical reaction and mixing in the active medium. Several ORTL systems have been demonstrated and they can be classified into two categories: the intermolecular ORTL including 10.6μm DF/CO₂, 10.8μm DF/N₂O, 4.1μm DF/HBr, 3.8μm HF/DF⁴, and 3.9μm HF/HCN⁴; and the intramolecular ORTL including 2.9μm HF/HF⁵ and 3.9μm DF/DF⁶. These demonstrations have illustrated several advantageous ORTL characteristics including large vibrational excitation, high small signal gain, nondissociative excitation and wavelength agility. In this paper, the recent developments on the ORTL technology will presented.

2.0 ORTL Kinetic Considerations

In an intermolecular ORTL, there are three components in the flowing ORTL medium: the donor, the acceptor and the helium diluent. A DF or HF chemical laser serves as the resonant pump source to excite the donor molecules (DF or HF) in the ORTL cell. The vibrational excitation energy in the donor is transferred via rapid near resonance V-V collisions to the acceptor molecule which then becomes the active laser molecule. Lasing in CO₂, N₂O and HCN has been achieved with total inversion in a three-level scheme while the lasing in HBr and DF has been demonstrated with partial inversion in a two-level scheme. Typical energy level diagrams for a three-level system in DF/CO₂ and for a two-level system in DF/HBr are illustrated in Figures 1 and 2, respectively. In the latter approach, a larger upper level population density is required because the lower laser level is the ground state; this high upper level density causes intramolecular V-V exchange in the acceptor to become a dominant process.
Figure 1. DF/CO$_2$ ORTL Level Diagram

Figure 2. Energy Level Diagram for DF/HBr
Two Level ORTL System
In an intramolecular ORTL, the HF or DF molecule in the ORTL medium serves as both the donor and the acceptor. The absorbed energy during the vibrational excitations is redistributed among all rotational levels and a partial inversion is produced on some vibrational-rotation levels with higher rotational quantum numbers than those of the pump laser. A level diagram and the principle kinetic processes for an intramolecular HF/HF ORTL are shown in Figure 3. The efficiency is governed primarily by the rotational energy transfer rates between the pumped levels and the ORTL lasing lines. Since rotational transfer rates are usually orders of magnitude higher than both the V-V exchange rate and the V-RT quenching rate, high overall efficiency in the intramolecular ORTL is expected.

3.0 Experimental Apparatus

In most demonstration experiments, the outcoupled beam from a chemical laser was focused at the optical interaction zone and an ORTL gas mixture was introduced into the interaction zone through a rectangular subsonic nozzle. The gas flow, the pump laser excitation and the ORTL lasing axis were mutually orthogonal. In some cases, the ORTL lasing axis was rotated to a 20° angle relative to the pump laser optical axis so that the 2.3 cm pump beam could excite a 6 cm gain length in the ORTL flow. A schematic diagram of the experimental apparatus with this rotated ORTL cell is shown in Figure 4. For each system, the ORTL flow velocity and pressure were chosen to allow the optical interaction time to be several times longer than the time needed for the donor-acceptor transfer collisions. Prior to the lasing demonstration, chemiluminescence measurements were made to determine the vibrationally excited number densities of both donor and acceptor as a function of ORTL parameters. In the lasing demonstrations, stimulated emission was observed first in a closed cavity resonator. Where appropriate, outcoupled power was measured and efficiency established.

An alternate cell configuration was designed to achieve higher ORTL efficiency. In contrast to the previous double pass geometry (Figure 4), this cell employed a multipass design where the pump radiation underwent multiple reflections between two flat parallel reflectors as it traversed the ORTL medium. A schematic is shown in Figure 5. The cell parameters were: 8.8 cm gain length, 12.4 cm absorption length, and 15 cm³ excitation volume. Lasing performance with HF/He in this configuration will be described later.

4.0 Results and Discussion

CW lasing was achieved in CO₂ and N₂O on the (001 -+ 100) transition oscillations indicated that total inversions were achieved. Results in the DF/CO₂ system include an outcoupled power of 14 watts with three percent overall efficiency, a quantum conversion efficiency of the absorbed DF photons to the coherent CO₂ photons of 78 percent and a small signal gain of 0.083/cm on the P(20) line. Under similar experimental conditions, the observed output in the DF/N₂O system was one-third of that in the DF/CO₂ system. A comparison of the output performance in these two ORTL systems under the same experimental conditions is shown in Figure 6. In the HF/CO₂ system the output power was one-tenth of that in the DF/CO₂ system. These results can be correlated with the kinetic transfer and quenching rates.

Chemiluminescence measurements in HF/HCN showed a population density of 1 x 10¹⁶ molecules/cm³ (30 percent of the total population) in the excited
1. OPTICAL PUMPING
2. STIMULATED EMISSION
3. ROTATIONAL ENERGY TRANSFER
4. V-V EXCHANGE
5. DEACTIVATION

Figure 3. Level Diagram and Principle
Kinetic Processes in HF/HF Intramolecular ORTL

Figure 4. Schematic Diagram for the Rotated ORTL Experiments

Figure 5. Multiple Pass Cell Schematic
HCN (001) state. By comparing fluorescence signals from the (001 - 000) transition of 3.0μm and the (001 - 010) transition of 3.8μm, one obtained a value of $6 \times 10^{-40}$ erg·cm$^3$ for the square of the transition moment and a small signal gain of 0.001/cm on the (001 - 010) transition. ORTL oscillation was achieved at 3.85μm on the (001 → 010) transition and at 3.90μm on the (01 → 02) transition. This is the first reported CW lasing on these HCN transitions.

Two-level lasing was observed on the HBr $P_1$ (8 to 12) and $P_2$ (9 to 12) transitions in the DF/HBr system and the DF $P_{1}$ (11 to 13) and $P_2$ (11 to 12) lines in the HF/DF system. Partial inversions were achieved and oscillations occurred only when more donor than acceptor was present in the ORTL medium. The relation between the donor-to-acceptor transfer rate and the acceptor V-V exchange rate is illustrated by the experimental results.

Intramolecular ORTL operation has been observed under a wide range of conditions with energy conversion efficiency reaching 30 percent. The HF/He system was operated with approximately one percent HF at a total pressure between 20 and 110 torr. Both pumping and lasing transitions were in the $V = 2 \rightarrow 1$ and $V = 1 \rightarrow 0$ bands. The rotational shift between the pumping and lasing transitions ranged from $P_1$ (7) to $P_1$ (10) and $P_2$ (6) to $P_2$ (11). The measured spectral distributions of the ORTL output and the pump beam as a function of the HF mole fraction are shown in Figure 7. The ORTL spectrum shifts to longer wavelengths with increasing HF mole fraction because the average medium temperature increases. The maximum power output was 135 watts and small signal gain in excess of three percent per centimeter was observed. The maximum observed quantum conversion efficiency of absorbed power to output power in this system was 83 percent.

Similar experiments were performed in DF/He systems with the pressure range extended to 460 torr. In this case, pumping occurred on three vibrational bands: $V = 3 \rightarrow 2$, $V = 2 \rightarrow 1$, and $V = 1 \rightarrow 0$. Similar shifts in rotational quantum number were observed with transitions extending up to $P_3$ (21), $P_2$ (24), and $P_1$ (23). The importance of V-V processes in this system was underscored by the observation of $V = 4 \rightarrow 3$ lasing transitions in the absence of pump radiation in that band.

A comprehensive computer simulation code has been developed to describe ORTL systems. The principle processes included in the code are: optical pumping, V-V transfer, R-R transfer, V-R, T deactivation and ORTL lasing. Results are in reasonable agreement with the experimental observations. Based on this code, extremely high overall efficiency (over 50 percent) can be realized in some optimized experimental configurations. Detailed comparison of experimental results with theoretical predictions will be discussed for each ORTL system.

References

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Figure 6. DF/CO₂ and DF/N₂O ORTL Output Power vs. Acceptor Concentration. Acceptor Molecules are CO₂ and N₂O, respectively. Outcoupling mirror reflectivity is R.

Figure 7. Multiple Pass Cell Output Spectra (76 torr, 3.8 x 10⁻³ cm/sec)


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