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EFFICIENT, PURELY CHEMICAL HCl LASER

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Centre de Recherches pour la Défense

Defence Research Establishment

Valcartier, Québec

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HCL

AN EFFICIENT, PURELY CHEMICAL HCl LASER

by

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RESUME

On a obtenu une émission laser purement chimique à 3.6-4.0 µm en utilisant le HCℓ dans un appareil à écoulement transversal. La réaction bien connue Cℓ + HI → HCℓ$^+$ + I a été utilisée pour le pompage. Le chlore atomique a été produit chimiquement par l'interaction de NO et CℓO_2. Le système laser a donné une puissance maximale de 4 W, ce qui correspond à une efficacité de 9% basée sur la fraction d'énergie de la réaction de pompage transformée en énergie de vibration. Le rendement laser multiligne fut observé sur 8 bandes P provenant des bandes de vibration v=3 → 2, v=2 → 1 et v=1 → 0. En outre, le laser fonctionna efficacement lorsque le Cℓ de la réaction de pompage était produit 'in situ', une caractéristique qui peut être importante dans la recherche de plus grandes puissances. (NC)

ABSTRACT

Purely chem.cal laser emission at 3.6 to 4 µm from HCℓ has been achieved in a transverse flow device. The pumping reaction was the well known Cℓ + HI → HCℓ$^+$ + I reaction. Atomic chlorine was produced chemically from the reaction of NO with CℓO_2. The maximum power obtained from this system was 4 W, which corresponded to a chemical efficiency of 9% based upon the fraction of pumping reaction energy that goes into vibration. Multiline laser output was observed for eight P-branch lines emanating from the v=3 → 2, v=2 → 1 and v=1 → 0 vibrational bands. The laser also operated successfully under conditions where the Cℓ for the pumping reaction was produced in situ, a feature which may be important in scaling to higher powers. (U)

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TABLE OF CONTENTS

1.0 INTRODUCTION

The advantages of directly converting the energy stored in
chemical bonds into laser radiation has been recognized for some time.
Such purely chemical lasers could be portable and could operate in
environments where electrical power is unavailable. However, since
atomic species are usually required to initiate chemical laser action,
many chemical lasers need electrical energy to initiate the reaction.
This electrical energy can be used directly, in the form of transverse
or longitudinal electrical discharges, or indirectly by using flash
lamps to photolytically initiate laser chemistry.

However, atomic species have been produced thermally by
burning suitable gas mixtures in high-temperature plenums (Refs. 1,2).
This method has proved to be suitable for dissociating fluorine,
which is a weakly bound molecule (bond energy = 35 kcal/mol). For
chlorine, however, the bond energy is much larger (57 kcal/mol),
and prohibitively high temperatures are required to produce significant
amounts of chlorine atoms. Because this method of atom production is
accomplished at high pressures and temperatures, an environment not
suited to lasing action, the hot gas must be cooled before it is
introduced into the laser. This is commonly accomplished by rapid
supersonic expansion of the high-pressure, high-temperature plenum
gases. This rapid expansion, which reduces both the temperature
and the pressure of the gas, is accomplished so rapidly that the atomic
species do not have time to decay (recombine). This type of laser
can be regarded as purely chemical since no electrical excitation
is required, but it is perhaps better classified as a thermally
assisted chemical laser.

In some purely chemical lasers it has proved possible to
chemically produce atomic species at more modest temperatures and
pressures where direct utilization of the atoms is possible. Three
such systems discovered previously are described below:

(1) **HF, DF, HF-CO_2 and DF-CO_2 lasers (Ref. 3)**

Laser action was achieved by producing F atoms from
the reaction F_2 + NO → NOF + F followed by the reaction of
these atoms with either H_2 or D_2. The product $HF^\dagger$ or $DF^\dagger$
could be made to undergo laser action directly (at 2.8 μm and
3.8 μm, respectively) or the energy could be transferred to
CO_2 with subsequent lasing of the excited CO_2 at 10.6 μm.

(2) **The $CS_2/O_2/N_2O$ Free-Burning-Flame Laser (Ref. 4)**

Laser power at 5.0 to 5.5 μm due to $CO^\dagger$ may be extracted
from this system. The requisite O atoms and CS radicals for
the laser pumping reaction O + CS → $CO^\dagger$ + S are produced by
the flame. The region of positive gain lies immediately
upstream of the flame front in lean $CS_2/O_2/N_2O$ flames.

(3) **The N_2O Chemical-Flame Laser**

This system relies upon the catalytic effect of atomic
sodium as a chain carrier in the reaction sequence:

$$Na + N_2O \rightarrow NaO + N_2$$

$$NaO + CO \rightarrow CO_2^\dagger + Na$$
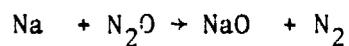
The atomic sodium was provided by passing helium over sodium
azide (NaN_3) which was fed in with a 'hopper'. Although the
excited CO_2 did not lase directly, laser action was observed
from N_2O (Ref. 5). This presumably resulted from energy
transfer from the CO_2 molecule to the N_2O.

The chemical lasers which are most likely to have military
applications are HCℓ and DF since these lasers exhibit multiline
output in a wavelength region (3.5 to 4.0 μm) that is readily trans-
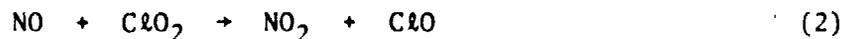mitted through the atmosphere. The DF laser has so far attracted

the most interest since atomic fluorine is readily formed thermally
as described above. Although $C\ell$ atoms are difficult to produce
thermally, the reaction of $C\ell$ atoms with HI is suitable for converting
chemical energy into laser energy.

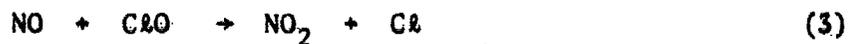$$C\ell + HI \rightarrow HC\ell^{\dagger} + I \tag{1}$$

This reaction, which produces vibrationally excited $HC\ell^{\dagger}$, proceeds at
almost every bimolecular collision. More than 70% of the energy
released in this reaction appears in the newly formed $HC\ell$ bond, and
the energy is so distributed between the various vibrational states
of $HC\ell$ that a population inversion is attained on the first three
fundamental vibrational transitions (Ref. 6).

HCℓ chemical lasers have been built using the $C\ell$ + HI reaction
to provide the pumping mechanisms. Atomic chlorine was produced by
electrical discharges in $C\ell_2$ using a transverse flow-configuration
(i.e., flow transverse to the optical axis (Ref. 7, 8)). In these
experiments powers of less than 100 mW were obtained, but recently
Linevsky and Carabetta (Ref. 9) substantially improved the performance
of this laser, achieving output powers of 5 W.

The achievement of an efficient purely chemical HCℓ laser
employing transverse flow and operating at 3.8 μm is reported herein.
The pumping reaction for the present system is the well known $C\ell$ + HI
reaction. Atomic chlorine is provided by the reaction of chlorine
dioxide ($C\ell O_2$) with nitric oxide (NO). This reaction was used to
achieve laser action in a longitudinal $HC\ell/CO_2$ transfer laser
(Refs. 10, 11). The reaction steps leading to the formation of atomic
$C\ell$ are the following:

$$NO + C\ell O_2 \rightarrow NO_2 + C\ell O \tag{2}$$

$$k_1 = 3.4 \times 10^{-13} \text{ cm}^3 \text{ s}^{-1}$$

$$NO + C\ell O \rightarrow NO_2 + C\ell \qquad (3)$$

$$k_2 = 1.7 \times 10^{-11} \text{ cm}^3 \text{ s}^{-1}$$

$$C\ell + C\ell O_2 \rightarrow 2C\ell O \qquad (4)$$

$$k_3 = 5.9 \times 10^{-11} \text{ cm}^3 \text{ s}^{-1}$$

The rate coefficients for these processes have been measured by Clyne (Ref. 12).

The above sequence constitutes a branched chain mechanism whereby NO is converted to NO_2, and $C\ell O_2$ is converted to $C\ell O$ (if the initial NO concentration is equal to that of $C\ell O_2$) or $C\ell$ atoms (if the initial NO concentration is twice that of $C\ell O_2$). The chain-branching step is reaction (4). As long as starting material ($C\ell O_2$) is present, reaction (4) keeps the ambient $C\ell$ concentration low and stores the chlorine in the form of $C\ell O$. Reaction (4) decreases in importance as the $C\ell O_2$ concentration diminishes. Provided enough NO remains, this accumulated $C\ell O$ is then converted to $C\ell$ via reaction (3). Because of the chain-branching step in this reaction sequence, the overall reaction may be rapid even though the initial reaction (2) is quite slow.

This paper represents a continuation of work on purely chemical lasers based upon the $NO/C\ell O_2$ reaction chemistry. The work described herein was conducted in mid-1975 under PCN 34B01 (formerly PCN 07C01, Project No. 97-01-39) "Research on Chemically Excited Lasers".

2.0 EXPERIMENTAL

2.1 ClO_2 Generator

The ClO_2 generator used has already been described (Ref. 13); hence only a brief summary will be included here. A schematic diagram of the apparatus is shown in Fig. 1. The conversion of molecular chlorine to chlorine dioxide was accomplished by passing Cl_2 through a column which was packed with $NaClO_2$ (Ref. 14). The following heterogeneous reaction then occurred:

$$Cl_2 + 2NaClO_2 \rightarrow 2NaCl + 2ClO_2 \qquad (5)$$

Complete conversion yielded a flow rate of ClO_2 that was twice that of the input Cl_2.

The column was constructed of Corning 'Double-Tough' pyrex tubing and tees. Teflon gaskets were employed in all Double-Tough connections. Two columns were in fact fabricated. The first column, 3-in diameter tubing, was packed with 17 lb of $NaClO_2$ whereas the second column, 4-in diameter, was packed with 25 lb of $NaClO_2$. Each column was also equipped at the downstream end with a 2-lb charge of Drierite. This removed water vapor from the effluent gas. Water has an adverse effect on laser performance. With the exception of the spectroscopy experiments, in which both columns were employed, all other experiments were done using the 3-in column only.

In view of the potentially explosive nature of ClO_2, certain precautions were taken:

    (a)   Installing a rupture disc, held in place with teflon putty, in the column;

    (b)   Installing the column in a metal enclosure;

(c) Blackening the surface of the ClO_2 column and
associated tubing to reduce the possibility of
photo-initiated chain reactions;

(d) Maintaining the partial pressure of ClO_2 below
30 torr. Diluent helium was added such that the
total column pressure was slightly more than
1 atmosphere;

(e) Maintaining a constant flow of NO sufficient
to react with the ClO_2, thus avoiding con-
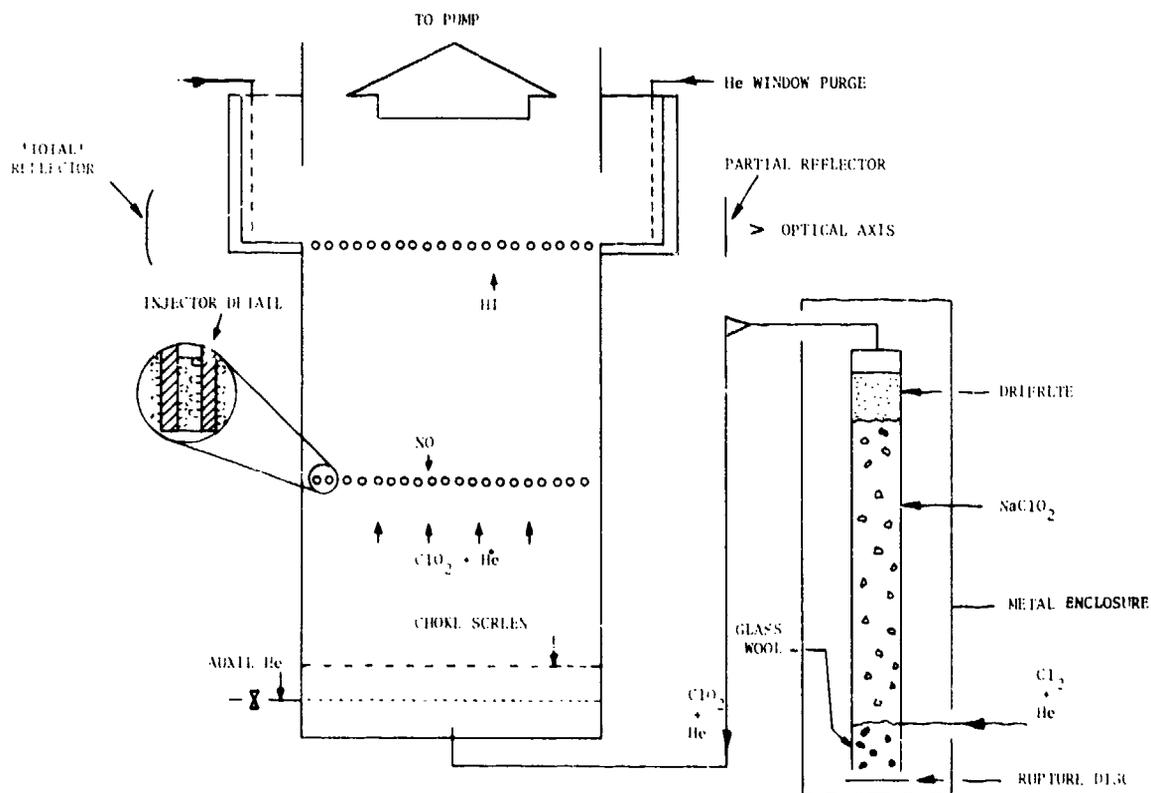densation of ClO_2 in the cold trap.

Figure 1 - Diagram of the Apparatus

2.2 Transverse Flow HCℓ Laser

The transverse flow laser apparatus used was very similar to that employed for the CS_2/O_2 system by Foster and Kimbell (Ref. 15), except for some modifications. These modifications included: lengthening of the flow channel in the flow direction by adding a duplicate housing in series; mounting HI injectors in a teflon rather than an aluminum block; installing a liquid-nitrogen cooled trap in the exhaust line.

The modified transverse-flow laser (Fig. 1) consists of a rectangular 1.5-cm by 14-cm flow channel having two injector rows separated by 12 cm. Each row consisted of twenty injector 'needles' containing eight 0.3-mm-diameter holes. Situated upstream of both injector rows was a teflon choke screen, which served to make the flow of $CℓO_2$/He uniform across the full channel width. This screen was simply a teflon gasket through which about 80 holes were drilled over the 1.5-cm by 14-cm cross section.

Molar flow rates of the individual gases were measured with either Matheson or Hastings-Raydist mass flowmeters. These latter are directly calibrated in standard cm^3/min (SCCM) where the reference temperature is $295^{\circ}K$ and the pressure is 1 atm. The Hastings-Raydist flow meters were particularly convenient since they could be operated accurately over a wide pressure range. Back pressure in the individual flow lines was monitored with Leybold-Heraeus gauges (0 to 1500 torr precision manometers) for helium and with corrosion resistant gauges (Helicoid) for the more corrosive gases. The pressure in the main flow channel containing the laser region was measured with a 'quartz-spiral' type of gauge (Texas Instruments Model 145).

In a typical experiment, a flow of some 11 mmol s^{-1} of He was established through the $CℓO_2$ generator. The pressure in the column, set at 970 torr, was controlled by a teflon metering valve at the exit of the column. A flow of approximately 0.22 mmol s^{-1} of $Cℓ_2$ was then

added. After about 30 s the characteristic yellow-green color of ClO_2 was visible at the exit of the column. Subsequently, an additional 25 mmol s^{-1} of He was injected just upstream of the choke screen. The addition of He with the ClO_2 above ensured safe operation of the column. The second downstream addition of helium allowed an independent control over the optimum dilution for maximum laser output power. Typical pressures immediately upstream of the choke screen were 50 to 100 torr. In the low-pressure region (2.5 torr) 1.2 mmol s^{-1} of NO were added through the upstream injector row and 0.94 mmol s^{-1} of HI was added through the downstream injector row. An additional flow of 4 mmol s^{-1} of helium was added through each window support to prevent deposition on the window surface and to eliminate the build-up of ground state HCl. The average linear velocity of the gas was 160 m s^{-1} in the laser region.

The optical cavity consisted of a 'total' reflector of the 'protected metal' type having a radius of curvature of 10 m, and a partially reflecting (96% R) multilayer dielectric mirror on a CaF_2 flat. The distance between the optical axis and the HI injector row could be varied but was typically kept at 0.5 to 1 cm. For most experiments the mirrors were externally mounted. However, certain total power measurements were performed in which the CaF_2 windows were eliminated and the mirrors were mounted internally.

Total continuous-wave (CW) power measurements for the HCl chemical laser were conducted with a Coherent Radiation power meter.

The spectral content of the multiline laser output was chopped at 670 Hz and analyzed with a 0.3 m MacPherson Model 218 monochromator which employed a 150-l/mm grating, blazed for 3 μm. Detection was accomplished with a cooled photovoltaic InSb detector, and the signal was processed with a Princeton Applied Research (HR8) Lock-In amplifier.

The approximate small signal gain of the most intense lines was measured by a variable loss technique. This technique has been used elsewhere (Ref. 7); it has also been used in connection with the longitudinal HCl/CO_2 laser (Ref. 11). The laser power was measured as a function of the angular orientation of two CaF_2 flats introduced as intra-cavity loss elements.

3.0 RESULTS AND DISCUSSION

3.1 Preliminary Modeling of Pre-Pumping Chemistry

The rate equations corresponding to the NO/ClO_2 reactions (2), (3), and (4) were integrated numerically to follow the time evolution of ClO radicals and atomic Cl. The technique used is described more fully in another publication (Ref.16) and was employed in an earlier publication (Ref. 11).

Some of the results of these calculations appear in Fig. 2 and show the corresponding times for 90% completion of the conversion of ClO_2 to ClO (for equal initial NO and ClO_2 concentrations) and for conversion of ClO_2 to Cl atoms (for an initial NO concentration twice that of ClO_2). In this simple kinetic scheme, all Cl atom or ClO radical loss processes have been neglected.

Figure 2 clearly shows that there is a linear relationship between the initial ClO_2 concentration and the time required for 90% completion of the reaction. The results were used to estimate reaction times for various laser conditions. For example, the average linear flow velocity was 160 m/s. For this velocity, the time between the injection of NO and the subsequent injection of III was 750 μs. The estimated concentration of ClO_2 (assuming a ClO_2 flow rate twice that of Cl_2, i.e., complete conversion of Cl_2 to ClO_2 in the sodium chlorite

columns) was 10^{15} cm^{-3}. For this concentration of ClO_2 and an NO concentration of twice this value, the estimated time for 90% conversion of ClO_2 to Cl atoms was 470 µs (see Fig. 2). Thus, sufficient time was provided in the present apparatus to accomplish this conversion before the injection of III.
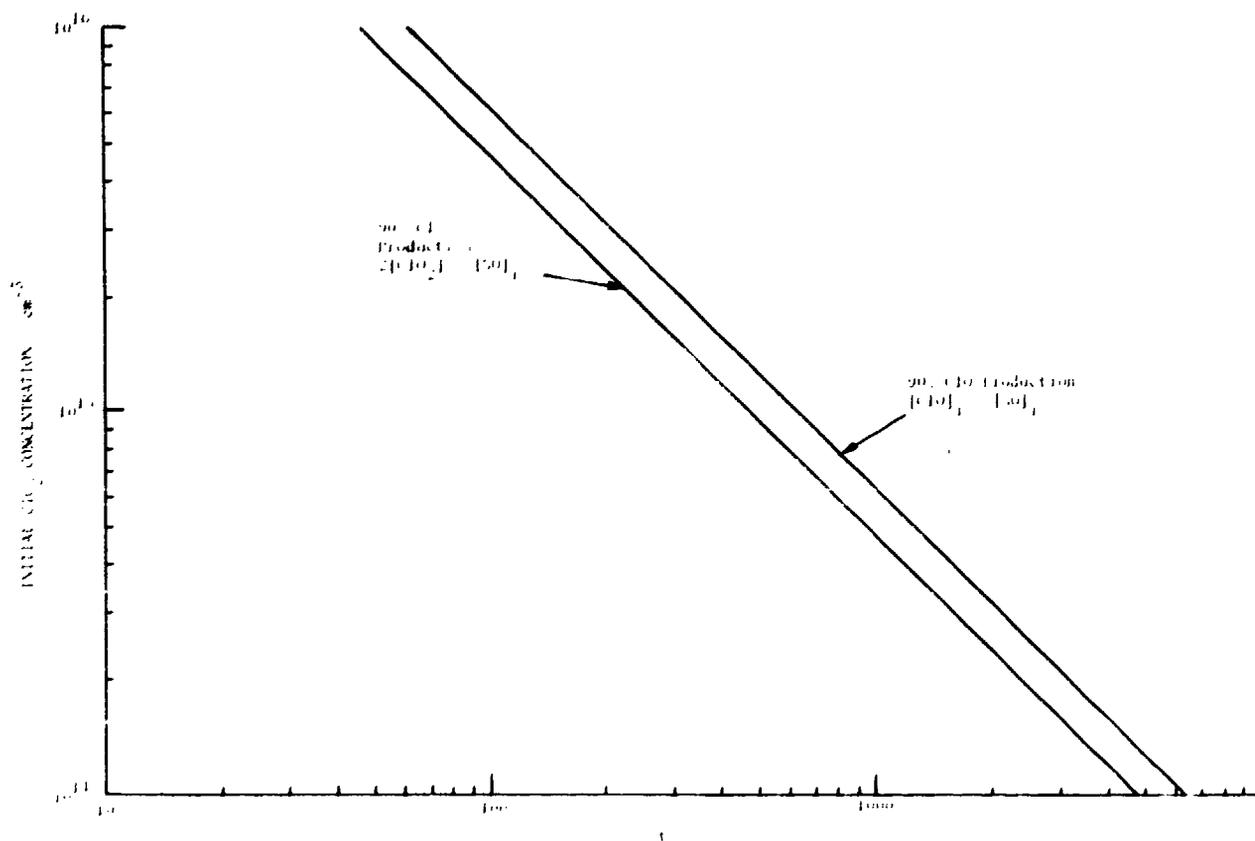

Figure 2 - Time for 90% Completion of the NO + ClO_2 Reaction to form ClO radicals (for $[NO]_i$ $[ClO_2]_i$) and to form atomic Cl (for $[NO]_i$ $2 [ClO_2]_i$) as a function of initial ClO_2 concentration

3.2 Power and Efficiency Measurements

The purely chemical HCl laser described herein gave a maximum
CW multiline power of 4 W. This occurred when the mirrors were
mounted internally. The flow conditions corresponding to the fore-
mentioned power were:

$$He: \qquad 10.8 \; mmol \; s^{-1}$$

$$Cl_2: \qquad 0.22 \; mmol \; s^{-1}$$

$$He: \qquad 25 \; mmol \; s^{-1} \quad (auxiliary)$$

$$NO: \qquad 1.2 \; mmol \; s^{-1}$$

$$HI: \qquad 0.94 \; mmol \; s^{-1}$$

$$He: \qquad 8.9 \; mmol \; s^{-1} \quad (total \; window \; purge)$$

Total cavity pressure: 2.43 torr

From these conditions, it is possible to compute an overall
chemical efficiency. On the basis of the total exothermicity of the
pumping reaction:

$$Cl \; + \; HI \; \rightarrow \; HCl \; + \; I \; + \; 32.8 \; kcal/mol \qquad\qquad (1)$$

the total energy input is 137.2 J/mmol. The limiting flow rate of
Cl will be twice the Cl_2 flow rate, i.e., 0.44 mmol s^{-1}.
The chemical power input $P_{in} = 137.2 \; F_{Cl}$, where F_{Cl} is the flow
rate of atomic Cl in mmol s^{-1}. The chemical laser efficiency is
then:

$$\eta \; = \; \frac{Laser \; Power \; Out}{Chemical \; Power \; In} \; = \; \frac{4}{137.2 \; x \; F_{Cl}}$$

$$= \quad 6.6\%$$

In the literature, the chemical efficiency is sometimes computed on
the basis of the fraction of the pumping reaction exothermicity that
goes into the vibration of the lasing molecule. For the $C\ell$ + HI
reaction, about 70% of the reaction exothermicity appears in $HC\ell$
vibration (Ref. 6). By this definition, then, the efficiency of the
present chemical $HC\ell$ laser would be 9.4%. To our knowledge, this
represents the most efficient purely chemical laser performance so
far reported.

The dependence of the laser power near the HI injectors on the
HI flow rate can, in fact, be used to 'titrate' for atomic $C\ell$, as shown
in Fig. 3. The laser power increases monotonically with HI flow
until the atomic $C\ell$ has been exhausted. The power then remains re-
latively independent of the HI flow rate. It will be noted that the
'end-point' of the titration corresponds to an HI flow rate that is
slightly greater than twice the $C\ell_2$ input flow. This may be attribu-
table to incomplete mixing near the HI injectors. The conversion of
$C\ell_2$ to $C\ell O_2$ and the subsequent reaction with NO to produce $C\ell$ appear
to be quantitative. That the portion of the curve above 0.6 mmol s^{-1}
of HI flow does not decline sharply indicates that the depletion of
$HC\ell^{\ast}$ by energy transfer processes with HI is not important.

3.3 Spectral Output Characteristics

The laser output spectra were taken with the optical axis
1 cm from the HI injectors. Eight P-branch lines were found to lase.
The relative contributions of the various lines and their identity
are shown in Table I. These results may be directly compared with
the spectra obtained in the electrically assisted $HC\ell$ laser of
Linevsky and Carabetta (Ref. 9). These authors observed nine P-branch
lines emanating from $HC\ell^{35}$ and four weak lines from $HC\ell^{37}$. No $HC\ell^{37}$
lines were observed in the present system, an indication that the

gain in this chemical HCl laser was lower than that in its electrically
assisted counterpart. Some 60% of the total power originates from
$v = 2 \to 1$ transitions while the $P_{2-1}(6)$ line is responsible for about
30% of the total power.

An estimation of the highest small signal gains which prevail
in the present system was made using the Fresnel loss technique. This
involved measuring the effect of the cavity loss, introduced by two
CaF_2 flats of varying orientation, on the total laser power. The
small signal gain coefficients of the most intense lines were found
to exceed 1.1%/cm by this method.
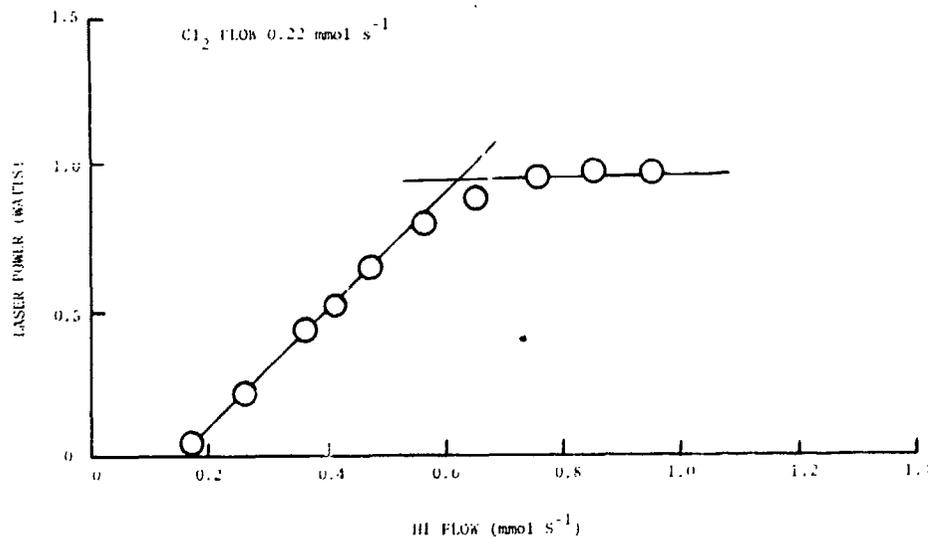
Figure 3 - Dependence of Laser Power (W) on HI Input Flow Rate (mmol s^{-1})

TABLE I

LASER OUTPUT SPECTRUM

HCl^{35} Line	Approx % Total Power
P_{1-0} (5)	6.5
P_{1-0} (6)	8.1
P_{1-0} (7)	0.8
P_{2-1} (5)	4.9
P_{2-1} (6)	29.3
P_{2-1} (7)	26.0
P_{3-2} (6)	9.7
P_{3-2} (7)	14.6

3.4 Scaling Considerations

In a subsonic laser such as that described here, the power
cannot be increased indefinitely by increasing the ClO_2 concentration
since HCl^+ self-deactivation eventually limits the power extraction
because collisions between excited HCl molecules lead to vibrational-
vibrational (v-v) energy transfer and to a consequent decay of the
initially inverted population. As the ClO_2 (and hence HCl^+
concentration) is increased a point will be reached where this
process occurs in a time that is comparable to the flow time between
the HI injection needles and the laser axis. At this point power loss
will occur because of the reduced gain of the HCl vibration-rotation
transitions.

To reduce this flow time, it would be advantageous to accomplish the HI injection and lasing in a supersonic flow regime. In such a device the $C\ell$ atom production could be accomplished in a high-pressure plenum; the consequent flow of $C\ell$ atoms could be expanded to obtain a low-pressure supersonic flow in which HI injection and lasing occurs. In the supersonic flow, much higher $HC\ell^+$ concentration can be tolerated (provided mixing is sufficiently fast) before power degradation occurs.

3.4.1   The Effect of NO_2

Certain questions immediately arise if the scaling possibilities of a purely chemical $HC\ell$ laser are considered. The fact that scaling to supersonic velocities requires a high pressure plenum suggests that recombination of atomic chlorine may be a limiting factor in such a laser.

A review of the relevant kinetic rate data indicates that in this laser the predominant loss process for $C\ell$ atoms will be the NO_2 catalyzed recombination of atomic chlorine.

A chemical laser based on the chemical formation of atomic $C\ell$ by the reaction of NO with $C\ell O_2$ has, out of necessity, ambient flows of NO_2 which are approximately twice the $C\ell$ atom flows. In order to ascertain if this NO_2 has an undesired effect on the $HC\ell$ laser operation of the present subsonic device, an additional flow of NO_2 was added immediately upstream of the HI injector row. This was accomplished by inserting a third injector row between the NO and the HI injectors. The laser output power was virtually independent of the additional NO_2 input for NO_2 concentrations ranging from 1.0 to 1.3 times the NO_2 level. This indicates that, at least for the conditions of these experiments, the ambient NO_2 does not severely limit the performance of the laser.

Although NO_2 did not greatly affect the laser performance under the present conditions, it is possible that the operation at high pressures would be limited by this NO_2 catalyzed recombination of $C\ell$ atoms as noted previously:

$$C\ell \; + \; NO_2 \; + \; M \; \rightarrow \; C\ell NO_2 \; + \; M \tag{6}$$
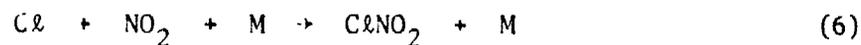
$$k \; = \; 7.2 \times 10^{-31} \; cm^6 \; s^{-1} \quad (Ref. \; 17)$$

followed by $C\ell NO_2 + C\ell \rightarrow C\ell_2 + NO_2$. If the second process is sufficiently rapid, then the apparent third-order rate constant for $C\ell$ atom loss would be $k_{app} \sim 14.4 \times 10^{-31} \; cm^6 \; s^{-1}$. The rate constant for the reaction $C\ell O + C\ell O + M \rightarrow$ products has been estimated to be only $6.6 \times 10^{-32} \; cm^6 \; s^{-1}$ (Ref. 18).

3.4.2 Split NO Addition

From the above considerations it is evident that in a high-pressure regime $C\ell O$ radicals decay much more slowly than $C\ell$ atoms: this suggests that the $C\ell$ atoms could then be released in a two step process with two separate additions of NO:

$$\text{Step 1} \qquad NO \; + \; C\ell O_2 \; \rightarrow \; NO_2 \; + \; C\ell O \tag{2}$$

$$NO \; + \; C\ell O \; \rightarrow \; NO_2 \; + \; C\ell \tag{3}$$

$$C\ell \; + \; C\ell O_2 \; \rightarrow \; 2C\ell O. \tag{4}$$
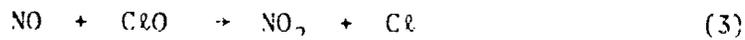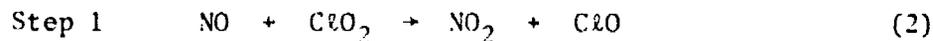
In the first step, a flow of NO equal to that of $C\ell O_2$ is established. Atomic chlorine produced in the second reaction is rapidly consumed in the branching step (4) until all the $C\ell O_2$ and NO is consumed. This first reaction sequence (Step 1) therefore converts all the $C\ell O_2$ to $C\ell O$ radicals.

$$\text{Step 2} \qquad NO \; + \; C\ell O \; \rightarrow \; NO_2 \; + \; C\ell \tag{3}$$

$$C\ell \; + \; HI \; \rightarrow \; HC\ell^\dagger \; + \; I. \tag{1}$$
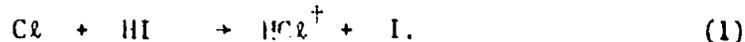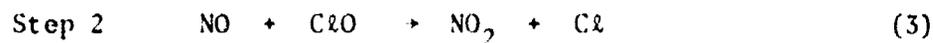
The requisite $C\ell$ atoms for the laser pumping reaction are then formed *in situ* in Step 2 by the second addition of NO. This NO can be added with the HI or just upstream of the HI injection. The rate of $HC\ell^+$ formation, therefore, is determined by the rate of the NO + $C\ell O$ reaction.

It should be empnasized that chain reactions are involved in Step 1 but not in Step 2. If appreciable concentrations of HI are present during the branched chain reaction then $C\ell$ atoms can react with HI rather than $C\ell O_2$, thus interfering with the chain branching reaction. However, in Step 2 there is no $C\ell O_2$ present and the $C\ell$ release reaction is a simple molecular reaction which is not affected by the HI.

Although the ambient pressures in the present device were too low for the potential advantage of this 'Split NO Addition' technique to be fully exploited, evidence was found that the *in situ* formation of atomic $C\ell$ is possible. In these experiments employing internal mirrors, 950 SCCM of NO was added through the upstream injector row, an amount which was insufficient for conversion of the $C\ell O_2$ to atomic chlorine. An additional 850 SCCM of NO was admitted through the downstream injector row by mixing NO and 1000 SCCM of HI before injection into the main flow channel. Laser action was indeed found and the output power was about 2 W. This may be compared to a laser power of 2.6 W which was observed in the same experiment when all the NO was directed through the upstream injector row. It should be noted that although a maximum laser power of 4 W was observed, typical power levels were about 2 to 2.5 W. The experiment giving 4 W output power was performed with a reduced cavity loss since the mirrors were mounted internally.

4.0 CONCLUSIONS

Multiline laser output powers of up to 4 W have been achieved in a purely chemical HCℓ laser based upon the reaction of NO with $C\ell O_2$ and subsequent pumping by $C\ell$ + HI. The chemical efficiency of the present device, corresponding to the forementioned maximum power and based on the fraction of the reaction exothermicity going in to HCℓ vibration, was about 9%.

The laser output consisted of eight P-branch lines of HCℓ[35] emanating from the 3→2, 2→1, 1→0, vibrational bands with the 2→1 band providing about 60% of the output power.

The ambient flow of NO_2, an unavoidable product of the Cℓ forming reaction and therefore present in the lasing region, does not appear to adversely affect the laser performance under the present experimental conditions.

Laser power of some 2 W has been observed under conditions where the requisite atomic chlorine was formed *in situ* with HI by a 'Split NO Addition' technique. This involved the initial conversion of $C\ell O_2$ to $C\ell O$ radicals by an upstream injection of NO, with an additional downstream injection of NO along with HI. This possibility of 'storing' atomic Cℓ in the form of a $C\ell O$ radical may have important consequences in the scaling of the chemical HCℓ laser to higher powers.

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DREV REPORT 4059/76 (UNCLASSIFIED)

Bureau - Recherche et Développement, Ministère de la Défense nationale, Canada. CRDV, C.P. 880, Courcelette, Qué. G0A 1R0.

"An Efficient, Purely Chemical HCl Laser"
by K.D. Foster, R.D. Suart and D.R. Snelling

On a obtenu une émission laser purement chimique à 3.6-4.0 µm en utilisant le HCl dans un appareil à écoulement transversal. La réaction bien connue $Cl + HI \rightarrow HCl^* + I$ a été utilisée pour le pompage. Le chlore atomique a été produit chimiquement par l'interaction de NO et ClO_2. Le système laser a donné une puissance maximale de 4 W, ce qui correspond à une efficacité de 9% basée sur la fraction d'énergie de la réaction de pompage transformée en énergie de vibration. Le rendement laser multiligne fut observé sur 8 bandes P provenant des bandes de vibration $v=3 \rightarrow 2$, $v=2 \rightarrow 1$ et $v=1 \rightarrow 0$. En outre, le laser fonctionna efficacement lorsque le Cl de la réaction de pompage était produit 'in situ', une caractéristique qui peut être importante dans la recherche de plus grandes puissances. (NC)

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Research and Development Branch, Department of National Defence, Canada.
DREV, P.O. Box 880, Courcelette, Que. G0A 1R0.

"An Efficient, Purely Chemical HCl Laser"
by K.D. Foster, R.D. Suart and D.R. Snelling

Purely chemical laser emission at 3.6 to 4 μm from HCl has been achieved in a transverse flow device. The pumping reaction was the well known $Cl + HI \rightarrow HCl^* + I$ reaction. Atomic chlorine was produced chemically from the reaction of NO with ClO_2. The maximum power obtained from this system was 4 W, which corresponded to a chemical efficiency of 9% based upon the fraction of pumping reaction energy that goes into vibration. Multiline laser output was observed for eight P-branch lines emanating from the v=3 → 2, v=2 → 1 and v=1 → 0 vibrational bands. The laser also operated successfully under conditions where the Cl_2 for the pumping reaction was produced ..., a feature which may be important in scaling to higher powers. (U)