NOVEL APPROACHES TO SHORT-WAVELENGTH CHEMICAL LASERS

S. Rosenwaks

To cite this version:
S. Rosenwaks. NOVEL APPROACHES TO SHORT-WAVELENGTH CHEMICAL LASERS. Journal de Physique Colloques, 1987, 48 (C7), pp.C7-339-C7-342. <10.1051/jphyscol:1987781>. <jpa-00227085>

HAL Id: jpa-00227085
https://hal.archives-ouvertes.fr/jpa-00227085
Submitted on 1 Jan 1987

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
NOVEL APPROACHES TO SHORT-WAVELENGTH CHEMICAL LASERS

S. ROSENWAKS

Department of Physics, Ben Gurion University of the Negev, Beer-Sheva, IL-84105, Israel

Abstract - Short-wavelength chemical lasers (SWCL's) have been pursued in many laboratories, following the great success achieved with infrared chemical lasers utilizing simple atom molecule exchange reaction. However, all efforts to obtain SWCL's (<1um) have failed to date. The reasons for failure and possible ways to overcome the difficulties are discussed. In particular, a novel approach to obtaining SWCL's based on a premixed fuel-lasant capable of producing high energy pulses, is described. Electronically-excited nitrogen molecules are produced by detonation of metal azides. Lasing is expected via energy transfer from the nitrogen molecules to metal atoms or within the nitrogen molecules. Preliminary results obtained by detonation of metal azides are presented.

The search for short-wavelength chemical lasers (SWCL's) began in the early sixties.1 It has been pursued in many laboratories, encouraged by the great success achieved with infrared chemical lasers utilizing simple atom-molecule exchange reactions (for a summary on infrared chemicals lasers prior to 1976 see reference 2; for later developments see the proceedings of the Gas Flow and Chemical Laser Symposia, references 3a-f).

Until the mid-seventies, most attempts to obtain SWCL's utilized reactions of metal atoms with oxidants, although reaction paths not involving metal atoms were suggested as well.5 A well-known example of this "direct" approach to the SWCL is the reaction

\[ \text{Ba} + \text{N}_2\text{O} \rightarrow \text{BaO}^* + \text{N}_2, \]

which was studied in a number of laboratories.6 Extensive efforts to obtain a threshold population inversion via reaction (1) and many other, analogous, "direct" reactions 5 have failed to date. This approach has been largely abandoned.

A more recent approach to the SWCL has been based on the "indirect", transfer chemical laser approach. This approach was utilized to obtain infrared chemical lasers, e.g. via energy transfer from chemically-produced, vibrationally-excited HF to CO₂, which, in turn, lased at 10.6 microns.2 A High-efficiency electronic-transition infrared transfer chemical laser has in fact been developed. This laser is the chemical iodine laser, in which electronically excited O₂ is chemically produced and transfers its ~1 eV energy to iodine atoms, which lase at 1.315 microns.7

The last few years have seen extensive efforts to achieve transfer chemical lasers at short wavelengths (<1 micron).3d-f One example is the reaction

\[ \text{NF(b)} + \text{IF(X)} \rightarrow \text{NF(X)} + \text{IF(B)}, \]
ing of both lasing and reservoir species in potential SWCL mixtures is often significantly faster than mixing rates that can be achieved using current nozzle technology at pressures needed for high inversion densities. The quenching can be homogeneous (radiative or collisional - including chemical reactions) or heterogeneous (on the walls). Even if lasing is observed, the primary bottleneck to efficient CW SWCL lasing will in most cases be collisional quenching by the many species present in suggested reaction mixtures. It should be noted that operation of CW chemical mixing lasers is limited to low pressures (usually up to a few tens of torr) by the fact that the lower limit of the permissible mixing time is determined by the diffusion rate. High power operation of these lasers therefore requires the use of large vacuum pumps.

Species with long effective lifetimes are the obvious candidates for CW mixing lasers. The only reported, established example of a chemically-produced, electronically-excited reservoir molecule which is quenching resistant is \( O_2(1\Delta) \). Its ease of chemical production, long radiative lifetime, and low probability for quenching by collisions with many species and with various wall materials make it an ideal energy reservoir for CW transfer lasers. However, its energy content (1 eV) limits its use to infrared lasers unless excitation of high-lying metastable electronic states via multiple collisions with \( O_2(1\Delta) \) molecules can be contrived. This possibility has been explored recently in our laboratory. For \( Pb, \) \( S_p \) and \( P_2 \) states have been observed as well as highly electronically excited \( PbO \) species. For \( Bi, \) the \( 5D_{3/2} \) state as well as excited \( Bi_2 \) and \( BiO \) have been observed.

A very attractive energy reservoir that has been explored for the past several years is the \( N_2 \) molecule in its lowest excited state, \( A^3\Delta^* \). This state has an energy content of 6.2 eV and a radiative lifetime of 2 seconds. Furthermore, in extensive investigations carried out in our laboratory it has been found that energy transfer from \( N_2(A) \) to a number of atomic species is both efficient and state-selective, i.e., there is a preferential population of electronic levels that fulfill certain propensity rules. The possibility of preferential energy transfer from \( N_2(A) \) to specific molecular states has also been explored recently. However, there is a very severe problem in using \( N_2(A) \) as an energy reservoir.

\[ N_2(A) + N_2(A) \rightarrow N_2^* + N_2, \quad (3) \]

which is very efficient, the rate constant being at least gas-kinetic. As a result, production of high concentrations of \( N_2(A) \) for high-power CW mixing lasers is impractical, even if a reaction scheme which produces "clean" \( N_2(A) \) is found. The limitations inherent in the schemes described above to obtain high power SWCL's have led us to a novel approach based on a "premixed" solid fuel-lasant. The core of our approach is to bypass the mixing and quenching problems so detrimental to operation of high-power SWCL's by using "premixed" fuel-lasant systems capable of producing high energy laser pulses. To illustrate our approach, the discussion will deal with a specific system; other examples have been considered but will not be discussed here. Our model fuel-lasant molecule is lead azide, \( Pb(N_3)_2 \). The lasant is the \( Pb \) atom and the fuel is the \( N_2 \) molecule, excited to the \( A \) state.

The chemical and lasing kinetics scheme in shorthand is the following:

\[ Pb(N_3)_2 \xrightarrow{\text{detonation}} Pb + N_3 + N_2 + N, \quad (4) \]

\[ N_3 + N_3 \rightarrow N_2^* + 2N_2, \quad (5) \]

\[ N + N_3 \rightarrow N_2^* + N_2, \quad (6) \]

\[ Pb + N_2^* \rightarrow Pb^* + N_2, \quad (7) \]

\[ Pb^* \xrightarrow{hv(laser)} Pb. \quad (8) \]

\( Pb(N_3)_2 \) is a well known explosive that can be handled safely with adequate precautions and can be detonated upon flash initiation. Reactions (5) and (6), where
N and N\textsubscript{2} are ground state species and N\textsuperscript{3} a triplet state, are energetically and spin allowed. Measurements in several laboratories indicate that triplet nitrogen is indeed a product of (5) and (6).\textsuperscript{17} Since all triplets end up as N\textsubscript{2}(A), decomposition of Pb(N\textsubscript{3})\textsubscript{2} produces N\textsubscript{2}(A).

Since the fuel and the lasant originate in the same molecule, there is no need for mixing. Furthermore, the reaction sequence (4) -> (7) favors fast energy transfer from N\textsubscript{2}(A) to Pb, thus preventing the buildup of high concentrations of N\textsubscript{2}(A) and largely eliminating the detrimental effect of the energy pooling reaction (3).

We have initiated lead azide by short (\~\textasciitilde{}10ns), laser pulses at wavelengths from 266 to 1064nm at energies from a few to several hundred millijoules. Preliminary results indicate that electronically excited N\textsubscript{2} is formed following the initiation and that nonstatistical excitation transfer to high lying states of Pb takes place. Moreover, calculations based on a coupled kinetic-hydrodynamic model point out that the initiation should result in population inversion between potential laser levels of Pb. A comprehensive description of the experiments and modeling will be the subject of future publications.

References

c. Journal de Physique 41, C-9 (1980).
6. For example: a) C.R. Jones and H.P. Broida, J. Chem. Phys. 60, 4369 (1974);
b. A.T. Pritt and D.J. Benard in reference 3e and references cited therein.
c. S.J. Davis in reference 3f and references cited therein.
b. S. Rosenwaks and J. Bachar in reference 3e.


and references therein.