

GAS
FLOW
AND
CHEMICAL
LASERS

GAS
FLOW
AND
CHEMICAL
LASERS

**GAS
FLOW
AND
CHEMICAL
LASERS**

Edited by
Michele Onorato

GAS FLOW AND CHEMICAL LASERS

Edited by

Michele Onorato

*Polytechnic Institute of Turin
Turin, Italy*

PLENUM PRESS • NEW YORK AND LONDON

Library of Congress Cataloging in Publication Data

International Symposium on Gas Flow and Chemical Lasers (4th: 1982: Stresa, Italy)

Gas flow and chemical lasers.

"Proceedings of the Fourth International Symposium on Gas Flow and Chemical Lasers, held September 13-17, 1982, in Stresa, Italy"—Verso of t.p.

Includes bibliographical references and index.

1. Gasdynamic lasers—Congresses. 2. Chemical lasers—Congresses. 3. Laser beams—Congresses. 4. Optics—Congresses. I. Onorato, Michele. II. Title.

TA1695.I54 1982

621.36'6

83-27016

ISBN 0-306-41478-3

Proceedings of the Fourth International Symposium on Gas Flow and Chemical Lasers, held September 13-17, 1982, in Stresa, Italy

©1984 Plenum Press, New York

A Division of Plenum Publishing Corporation

233 Spring Street, New York, N.Y. 10013

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, microfilming, recording, or otherwise, without written permission from the Publisher

Printed in the United States of America

GAS FLOW AND CHEMICAL LASERS

SCIENTIFIC ADVISORY COMMITTEE

H.G.Ahlstrom, USA; J.R.Airey, USA; V.Y.Baranov, USSR; N.G.Basov, USSR; L.R.Bissonnette, Canada; W.L.Bohn, West Germany; G.Born, West Germany; H.Brunet, France; H.P.Brunne, Poland; J.P.Caressa, France; J.Daugherty, USA; C.Fenstermacher, USA; M.Fiebig, West Germany; M.H.Flaum, Sweden; B.Forestier, France; G.Fournier, France; A.Hertzberg, USA; H.E.Hügel, West Germany; G.Inglesakis, France; R.Jalin, France; A.F.Kaye, U.K.; K.Kasuya, Japan; E.M.Kudriavtsev, USSR; A.V.La Rocca, Italy; M.M.Mann, USA; R.A.Meinzer, USA; H.Oguchi, Japan; F.Pandarese, Italy; P.E.Philippe, France; A.N.Pirri, USA; N.L.Rapagnani, USA; J.P.Reilly, USA; P.Rigny, France; J.Rom, Israel; D.C.Smith, USA; S.Solimeno, Italy; R.I.Soloukhin, USSR; J.Spalding, U.K.; Y.M.Timnat, Israel; C.Verdier, France; W.R.Warren, USA; W.S.Watt, USA; J.F.Wendt, Belgium; L.E.Wilson, USA; W.J.Witteman, Holland; J.D.L.H.Wood, U.K.

SYMPOSIUM SPONSORS

Consiglio Nazionale delle Ricerche (CNR); European Office of Aerospace Research and Development (EOARD); European Research Office (ERO); Office of Naval Research - London Branch (ONRL); Politecnico di Torino

EXECUTIVE COMMITTEE

M.S.Oggiano, M.Onorato, B.Piombo

SESSION CHAIRMEN

C.M.Bowden, USA; J.D.Daugherty, USA; B.Forestier, France; R.W.Gross, USA; A.Hertzberg, USA; H.E.Hügel, West Germany; A.V.La Rocca, Italy; O.A.Volkovitsky, USSR; J.F.Wendt, Belgium

SYMPOSIUM CHAIRMAN

M.Onorato, Italy

PREFACE

This volume contains eight invited papers and seventy-three contributed papers presented at the Fourth International Symposium on Gas Flow and Chemical Lasers, which was held in Stresa, Italy, from September 13 to 17, 1984.

The purpose of the Symposium was to record and discuss current research developments and applications related to high power lasers. Papers were solicited from the entire spectrum of activities, including basic physics, aerothermodynamics, new laser media, laser design, diagnostic techniques, laser propagation, interaction phenomena, applications.

The Symposium was an opportunity for scientists and engineers representing all these disciplines to come together to report their recent work, to exchange ideas and to provide an up-to-date account of international progress in these fields.

The contributed papers were reviewed by the members of the Scientific Advisory Committee, who also took responsibility for formulating the program of invited lectures.

As editor I wish to express my appreciation and my gratitude to people and organizations that made this Symposium a success: the Members of the Scientific Advisory Committee, the Members of the Local Organizing Committee, the Sponsors and the Symposium Secretary. A grateful acknowledgement is expressed to Dr. M. Sandra Oggiano for assistance in the organization of the Symposium and publication of these proceedings.

Michele Onorato

CONTENTS

INVITED LECTURES

Chemically Pumped Electronic Transition Lasers P.V.Avizonis	1
Optical Resonance Transfer Lasers for Mode Control P.K.Baily, J.H.S.Wang, J.Finzi, and R.C.Smith	19
Optical Phase Conjugation in Laser Resonators C.R.Giuliano, R.C.Lind, T.R.O'Meara, and G.C.Valley	35
Laser Material Processing G.Herziger	55
The Oxygen-Iodine Chemical Laser W.E.McDermott	69
Air Force Laser Research M.Salkind	73
Flow Laser Diagnostic Techniques R.I.Soloukhin	83
Pulsed-Laser/Material Interaction J.Woodroffe	97

CHEMICAL LASERS

Numerical Solutions of Complete and Reduced Navier-Stokes Equations for Supersonic Chemical Laser Flow Modeling V.K.Baev and V.I.Golovichev	111
A Pulsed, Multi-Kilohertz-Repetition-Rate, Supersonic HF Chemical Laser D.Chuchem and S.Rosenwaks	121
Saturation Processes in Doppler-Broadened HF Vibrational Transition R.W.F.Gross and J.G.Coffer	127
Enhanced Mixing in CO-Flowing Laminar Streams L.Manfriani, J.Sandford, and M.Carbonaro	141
Experimental Study of the Spectral Output of a DF-Laser J.H.Massig	149
Operation of Small Scale, Efficient Chemical Oxygen-Iodine Laser and Study of the Reaction of $O_2(^1\Delta)$ with Pb Atoms S.Rosenwaks and J.Bachar	157
A New Numerical Method for Turbulent Mixing of Supersonic Reacting Flows in Chemical Laser Cavities R.Schmitt	165
Theoretical and Experimental Study of cw HF Chemical Laser Performance L.H.Sentman, M.H.Nayfeh, W.O.Mosebach, P.Renzoni, K.Herrick, K.King, P.Schmidt, and S.Townsend	173
Propagation Velocity of the Ionization Front Driven by a High-Current Relativistic E-Beam Through the Active Laser Media of Increased Pressure G.V.Sholin, A.V.Demura, J.V.Karasev, G.P.Maksimov, G.L.Nedoseev, V.D.Rusanov, A.M.Spector, and V.L.Shiryaevsky	183

Time Resolved Spectra and Small Signal Gain in HF: An Experimental and Theoretical Investigation P.E.Sojka, W.K.Jaul, and R.L.Kerber	193
Quasi One-Dimensional Model of a Ring Diffusion cw Chemical Laser and some of its Applications A.A.Stepanov and V.A.Scheglov	203
Flowfield Diagnostic of Supersonic cw HF Chemical Laser by Using Improved LIF and Chemiluminescence Methods Z.Qi, X.Xingbin, S.Fengting, H.Ruiping, S.Siyuan, and Z.Cunhao	211

GASDYNAMIC LASERS

Rapid Expansion Nozzles for Gasdynamic Lasers D.Chuchem	219
Turbulence Measurement in the Flow of a CO ₂ LEDA type Laser M.Duchet, J.P.Crançon, and J.Solmon	227
Subsonic TE N ₂ -CO Mixing Laser M.Iyoda, K.Sugino, K.Komatsu, and T.Fujioka	235
Numerical Estimations of 16 μ m CO ₂ Gasdynamic Lasers with Various Contours of 2-Dimensional Nozzles K.Kasuya and K.Horioka	243
On Simple Estimation of Characteristics for CO ₂ /N ₂ Mixing Gasdynamic Laser K.Maeno	257
Aerodynamic Disturbances from Supersonic Nozzle Arrays D.A.Russell and Yung K.Chu	267
Modeling of 16 μ m CO ₂ Gasdynamic Laser in Intracavity Cascading Mode S.Saito, M.Obara, and T.Fujioka	277

Development of a Closed-Cycle CW TE CO Laser Operating in the Temperature Region 100-300 K S.Sato, M.Iyoda, and T.Fujioka	289
Microwave Excited Gasdynamic CO ₂ -Laser W.Schall, P.Hoffmann, H.Hügel, and W.Schock	301
Screen Nozzle Mixing Laser Calculations W.Schall and H.Hügel	309
Theoretical Design of Mixing Gasdynamic Lasers H.-X.Yan and J.-H.Xu	319
Two Simplified Models and their Application to Performance Study of Mixing Gasdynamic Lasers H.-X.Yan and J.-H.Xu	329

HIGH AVERAGED POWER SYSTEMS

Photoionization of CO ₂ and CO Laser Media Containing Low-Ionization-Potential NO-NO ₂ Admixtures G.V.Abrosimov, S.A.Akhmanov, K.S.Klopovsky, E.A.Muratov, T.S.Pulinets, A.T.Rakhimov, and V.B.Saenko	341
High Power Blackbody Pumped CO ₂ Lasers W.H.Christiansen and R.J.Insuik	349
A Novel Command Charging System for High Repetition-Rate Pulsed Discharge Lasers D.Chuchem and E.Margalith	359
Flow Effects on the Laser Power of Transverse Flow TE Lasers V.Fantini, V.Donati, L.Garifo, G.Incerti, and A.Borghese	367
Flow Characteristics of Closed Loop High PRF E-Beams or X-Ray Assisted Discharge Exciplex Laser S.M.Fournier, M.L.Sentis, B.M.Forestier, and B.L.Fontaine	375
A New 10 kW Industrial Carbon Dioxide Laser A.S.Kaye, A.Delph, E.Hanley, and C.Nicholson	383

Further Development of the Non-Stationary Stochastic Model of Diffuse Electric Discharges in Turbulent Gas Flows Y.Khait	393
The Effect of Chemical Processes on the Stratification of Volume-Dominated Gas Discharges K.S.Klopovsky, A.P.Osipov, I.G.Persiantsev, A.T.Rakhimov, T.V.Rakhimova, N.V.Suetin, and M.A.Timofeev	403
A Study of Propagation of a Conducting Channel in the Plasma of a Non-self-Sustained Discharge A.S.Kovalev, A.M.Popov, and A.T.Rakhimov	411
Suppressing Attachment-Induced Instabilities by Operating Gas Discharges in an HF Mode A.S.Kovalev, A.T.Rakhimov, N.V.Suetin, and V.A.Feoktistov	417
Limiting Energy Inputs in the Non-Self-Sustained Discharge of a CO ₂ -Flow Laser G.B.Lopantseva, A.P.Napartovich, A.F.Pal', A.F.Perevoznov, I.G.Persiantsev, and A.N.Starostin	427
Subsonic Flow CO ₂ Laser With Transverse RF Excitation W.Schock and H.Hügel	435
High-Repetition-Rate Long-Pulse-Discharge XeCl Laser Preionized by a Low-Density Electron or X-Rays Beam M.L.Sentis, B.L.Fontaine, and B.M.Forestier	443
A Compact 75 Watts CO ₂ Laser at 750 Hertz R.C.Sze	453

NEW LASER MEDIA

Scaling Relations for the Plasma Recombination Laser W.L.Bohn and W.Schall	459
Kinetic Study of the VUV Emissions of Ar-Kr Mixtures H.Brunet, A.Birot, S.Busquets, J.Galy, P.Millet, and Y.Salamero	467

CW Ion-Argon-Lasers with the Supersonic Transverse Gas Flow V.I.Donin and G.N.Alferov	475
Rovibrational State Population Distributions Calculated from Spontaneous Fluorescence Measurements for CO ($v \lesssim 4$, $J \lesssim 10$) in Highly Heated Supersonic Free Jets of CO in N ₂ and Ar M.A.Gaveau, J.Rousseau, A.Lebéhot, and R.Campargue	483
A XeF-Excimer Laser Excited in a Longitudinal Discharge T.Gerber, W.Lüthy, and R.Schmiele	491
Population Inversion Occuring in the Soft X-Rays Range in Lithium-Like Aluminium Ions G.Jamelot, P.Jaeglé, A.Carillon, H.Guennou, and A.Sureau	499
3-Photon Excitation of Xenon and Frequency Tripling by Non-Linear Effect Y.Salamero, A.Birot, H.Brunet, J.Galy, P.Millet, and J.Monso	507
A Compact Resistively Stabilized Excimer Laser for Injection- and Mode-Locking Applications R.C.Sze	519

HIGH ENERGY OPTICS. ADAPTIVE OPTICS

Atmospheric Turbulence Simulation Cell for Optical Propagation Experiment M.Billard, G.Fertin, and J.C.Fontanella	525
Analysis of Waveguide Systems for Transmitting and Shaping Infrared Radiation A.Cutolo, L.Palumbo, and S.Solimeno	533
Resonators for High Power Lasers J.Dembowski, R.Hauck, H.P.Kortz, and H.Weber	541
Aberrations in Laser Beam Expanders Due to Tilt of Input Beam R.W.Jones, C.Cason, and J.F.Perkins	549

Mirrors and Windows for High-Energy Lasers: the Wavefront Distortion Problem C.A.Klein	557
An Analysis of Optical Resonators with Tapered- Reflectivity Mirrors P.Luchini and S.Solimeno	567
Experimental and Theoretical Investigations of CO ₂ -GDL with a High Hydrogen Content S.S.Novikov, V.M.Doroshenko, and N.N.Kudryavtsev	577
Effects of Injection Hole in Concave Mirror of Unstable Resonator With Saturable Gain J.F.Perkins, C.Cason, and R.W.Jones	587
Analytical Model of Optical Cavity for a Gasdynamic Laser G.Rabczuk	595

MATERIAL PROCESSING AND APPLICATIONS

Production of Gram Quantities of Highly Enriched Carbon-12 by Selective Infrared Dissociation G.I.Abdushelishvili, O.N.Avatkov, A.B.Bakhtadze, V.Yu.Baranov, V.S.Doljnikov, S.A.Kazakov, A.G.Kudziev, V.S.Letokhov, S.V.Pigilski, G.I.Pismenni, E.A.Ryabov, G.I.Tkeshelashvili, and V.M.Vetsko	605
Application of Mathematical Heat Transfer Analysis to High Power CO ₂ Laser Material Processing G.Alessandretti, P.Gay, and G.Manassero	613
A Powerful cw CO ₂ -Oscillator-Amplifier System for Research and Material Processing C.Carlhoff, S.Müller, H.Odenthal, J.H.Schäfer, and J.Uhlenbusch	621
Inert-Gas-Assisted Cutting of Low-Carbon Steel Sheets Using a High Power-Laser System G.Dionoro, F.Memola Capece Minutolo, and V.Tagliaferri	629

Laser Parameters for Surface Treatments of Metals E.Ramous and L.Giordano	639
Laser Cutting of Bulk Steel (40 mm) Due to Guided Flow of Radiation and Reactive Gas in the Workpiece D.Schuöcker	647
Oxygen Assisted Laser Cutting of Low Carbon Steel Sheets V.Sergi, V.Tagliaferri, and R.Teti	655
LASER PROPAGATION AND LASER MATTER INTERACTION	
Broadening of CO ₂ -Laser Beam During its Propagation in Aerosol With Absorbing Solid Particles R.Kh.Almaev, L.P.Semenov, A.M.Skripkin, and P.N.Svirkunov	665
The Role of CO ₂ -Laser Beam Divergence in Cloud Clearing R.Kh.Almaev, L.P.Semenov, A.G.Slesarev, and O.A.Volkovitsky	673
On the Interaction of High-Power Laser Beam With Metal Targets M.Cantello, V.Donati, L.Garifo, R.Menin, F.Pandarese, A.V.La Rocca, M.Onorato, and P.Savorelli	681
Experimental Investigation of the Thermomechanical Effects Induced by a CO ₂ Laser on Various Materials in Rarefied Atmosphere C.Créput, D.Dufresne, G.Avakian, and F.Puech	693
Laser-Metal Interaction: The Gasdynamic of Emitted Vapours M.Germano and M.S.Oggiano	703
Advanced Lightweight Nuclear Power Sources for Laser Beam Power Applications A.Hertzberg	713
Hydrodynamic Perturbations in Radiation-Induced Vaporization of Metals A.I.Korotchenko, N.I.Popov, A.A.Samokhin, and B.M.Zhirjakov	725

Laser-Induced Flows in Aerosol	731
V.Ya.Korovin, S.D.Pinchuk, L.P.Semenov, P.N.Svirkunov and O.A.Volkovitsky	
Coherent Pump Dynamics and Pulse Evolution in Three- Level Superfluorescence and Control of Light by Light	739
F.P.Mattar and C.M.Bowden	
Evaluation of Laser Beam Profile Uniformity by Means of a Computerized Thermographic Method	749
R.Monti and C.Mamone Capria	
Hydrodynamical Models of Aerosol Induced Breakdown	761
P.Vigliano, M.Autric, J.P.Caressa, V.Chhim, and G.Inglésakis	
Index	771

CHEMICALLY PUMPED ELECTRONIC TRANSITION LASERS

Petras V. Avizonis

Air Force Weapons Laboratory

Kirtland Air Force Base, New Mexico

For a number of years we have been examining the ability to partition the chemical reaction energy directly into electronic transitions. The obvious advantage with this approach is that energy, which comes basically from chemistry, is partitioned directly into electronically excited states rather than going through an electrical power generation step with its associated inefficiencies. The disadvantage of such pumping schemes is that the excitation energy is limited to that of the chemical bond, 3 to 4 eV. Thus, unless multiple collisions are invoked, only electronic states below 4 eV could be pumped by such energy partitioning.

A successful demonstration of such an approach has been the oxygen/iodine transfer laser. Oxygen molecules are produced from a chemical reaction directly in the $a^1\Delta$ state with 100% quantum efficiency. This is a highly forbidden state (60 minutes radiative lifetime), and the only way that lasing can occur from such electronic energy reservoir is to transfer such energy to a radiating state. This occurs in the resonant transfer of energy to iodine atoms (the $^2P_{1/2}$ state) which has a weak magnetic moment and radiates 1.315μ photons (to the $^2P_{3/2}$ state).

The success of the O_2/I laser has an indicated "roadmap" for direct partitioning of chemical energy into electronic states. What has become evident both experimentally and from quantum mechanics is that for such partitioning to be successful, the desired electronic state in the product molecule has to be forbidden and the reaction pathway to such a product molecule/state has to be spin allowed. Under these conditions, and only