

BEAMED ENERGY PROPULSION

Seventh International Symposium

Ludwigsburg, Germany 10 – 14 April 2011

EDITORS

Hans-Albert Eckel
Stefan Scharring

*DLR – German Aerospace Center, Institute of Technical Physics,
Stuttgart, Germany*

AIP
American Institute
of Physics

Melville, New York, 2011
AIP I CONFERENCE PROCEEDINGS ■ 1402

Editors

Hans-Albert Eckel
Stefan Scharring

DLR – German Aerospace Center
Pfaffenwaldring 38 – 40
70569 Stuttgart
Germany

E-mail: Hans-Albert.Eckel@dlr.de
Stefan.Scharring@dlr.de

Authorization to photocopy items for internal or personal use, beyond the free copying permitted under the 1978 U.S. Copyright Law (see statement below), is granted by the American Institute of Physics for users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the base fee of \$30.00 per copy is paid directly to CCC, 222 Rosewood Drive, Danvers, MA 01923, USA: <http://www.copyright.com>. For those organizations that have been granted a photocopy license by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Services is: 978-0-7354-0974-3/11/\$30.00

© 2011 American Institute of Physics

No claim is made to original U.S. Government works.

Permission is granted to quote from the AIP Conference Proceedings with the customary acknowledgment of the source. Republication of an article or portions thereof (e.g., extensive excerpts, figures, tables, etc.) in original form or in translation, as well as other types of reuse (e.g., in course packs) require formal permission from AIP and may be subject to fees. As a courtesy, the author of the original proceedings article should be informed of any request for republication/reuse. Permission may be obtained online using RightsLink. Locate the article online at <http://proceedings.aip.org>, then simply click on the RightsLink icon/“Permissions/Reprints” link found in the article abstract. You may also address requests to: AIP Office of Rights and Permissions, Suite 1N01, 2 Huntington Quadrangle, Melville, NY 11747-4502, USA; Fax: 516-576-2450; Tel.: 516-576-2268; E-mail: rights@aip.org.

L.C. Catalog Card No. 2011939513
ISBN 978-0-7354-0974-3
DVD ISBN 978-0-7354-0982-8
ISSN 0094-243X
Printed in the United States of America

AIP Conference Proceedings, Volume 1402
Beamed Energy Propulsion
Seventh International Symposium

Table of Contents

Preface: Beamed Energy Propulsion Hans-Albert Eckel	1
Program Committee	3
PLENARY	
The Thin Disk laser—A versatile laser source for beamed energy propulsion Jochen Speiser	7
Update on modular laser launch system and heat exchanger thruster Jordin T. Kare	19
Laboratory facilities and measurement techniques for beamed-energy-propulsion experiments in Brazil Antonio Carlos de Oliveira, José Brosler Chanes Júnior, Thiago Victor Cordeiro Marcos, David Romanelli Pinto, Renan Guilherme Santos Vilela, Victor Alves Barros Galvão, Arthur Freire Mantovani, Felipe Jean da Costa, José Adeildo dos Santos Assenção, Alberto Monteiro dos Santos, Paulo Gilberto de Paula Toro, Marco Antonio Sala Minucci, Israel da Silveira Rêgo, Israel Irone Salvador, and Leik N. Myrabo	31
Review on Japanese-German-U.S. cooperation on laser-ablation propulsion Stefan Scharring, John E. Sinko, Stephanie Karg, Hans-Albert Eckel, Hans-Peter Röser, Akihiro Sasoh, Naoya Ogita, Noritsugu Umehara, and Yosuke Tsukiyama	47

SESSION 2
LASER LIGHTCRAFT I

Experimental study on pulsed laser propulsion performance of parabolic thrusters	
Rongqing Tan, Jing Chen, and Yijun Zheng	65
Investigation on multiple-pulse propulsion performance for a parabolic nozzle with inlet slit	
Ming Wen, Yanji Hong, and Junling Song	74
Axial impulse generation of lightcraft engines with ~ 1 μs pulsed TEA CO₂ laser	
D. A. Kenoyer, I. I. Salvador, and L. N. Myrabo	82
Beam-Riding behavior of lightcraft engines with ~ 1 μs pulsed TEA CO₂ laser	
D. A. Kenoyer, I. I. Salvador, and L. N. Myrabo	93
Flow visualization of thrust-vectoring lightcraft engines with ~1μs pulsed TEA CO₂ laser	
D. A. Kenoyer, I. I. Salvador, S. N. Notaro, and L. N. Myrabo	106
Beam-riding analysis of a parabolic laser-thermal thruster	
Stefan Scharring, Hans-Albert Eckel, and Hans-Peter Röser	115
Three-dimensional numerical analysis for posture stability of laser propulsion vehicle	
Masayuki Takahashi and Naofumi Ohnishi	132

SESSION 3
LASER LIGHTCRAFT II

Hypersonic inlet for a laser powered propulsion system	
Alan Harrland, Con Doolan, Vincent Wheatley, and Dave Froning	145
2-D airbreathing lightcraft engine experiments in quiescent conditions	
Israel I. Salvador, Leik N. Myrabo, Marco A. S. Minucci, Antonio C. de Oliveira, Paulo G. P. Toro, José B. Chanes Jr., and Israel S. Rego	158

2-D Air-breathing lightcraft engine experiments in hypersonic conditions Israel I. Salvador, Leik N. Myrabo, Marco A. S. Minucci, Antonio C. de Oliveira, Paulo G. P. Toro, José B. Chanes Jr., and Israel S. Rego	174
Airbreathing laser propulsion experiments with 1 μm terawatt <i>Pharos III</i> laser: Part 1 L. N. Myrabo, P. W. Lyons, R. A. Jones, S. Liu, and C. Manka	187
Airbreathing laser propulsion experiments with 1 μm terawatt <i>Pharos III</i> laser: Part 2 L. N. Myrabo, P. W. Lyons, R. A. Jones, S. Liu, and C. Manka	207

SESSION 4

LASER ABLATION PROPULSION

Numerical study of thrust generation in the process of laser ablated doped polymer Nanlei Li, Yanji Hong, and Xiuqian Li	227
Time-resolved force and Schlieren visualization study of TEA CO₂ laser ablation of water droplets Xiuqian Li, Yanji Hong, Ming Wen, Jifei Ye, and Cunyan Cui	235
Effects of propellant surface morphology on laser ablative propulsion performance Naoya Ogita, Mitsuhiro Shikida, and Akihiro Sasoh	241
The Bouguer-Lambert-Beer absorption law and non-planar geometries John E. Sinko and Benjamin I. Oh	245
Experimental study on the effect of structural geometry of "ablation mode" thruster on propulsion performance Long Li, Zhiping Tang, Xiaojun Hu, and Jie Peng	258

SESSION 5

DYNAMICS OF LASER-SUPPORTED DETONATION AND COMBUSTION

Numerical study on propulsion performance of the parabolic laser thruster with elongate cylinder nozzle Fuqiang Cheng, Yanji Hong, Qian Li, and Ming Wen	271
--	-----

Thrust measurement of laser detonation thruster with a pulsed glass laser	
Bin Wang, Taro Han, Keisuke Michigami, Kimiya Komurasaki, and Yoshihiro Arakawa	282
Pressure distribution on inner wall of parabolic nozzle in laser propulsion with single pulse	
Cunyan Cui, Yanji Hong, Ming Wen, Junling Song, and Juan Fang	290
Numerical analysis of laser repetition rate and pulse numbers in multi-pulsed laser propulsion	
Junling Song, Yanji Hong, Ming Wen, and Qian Li	296
Numerical models analysis of energy conversion process in air-breathing laser propulsion	
Yanji Hong, Junling Song, Cunyan Cui, and Qian Li	306
Laser wavelength dependency of laser supported detonation	
Kohei Shimamura, Keisuke Michigami, Bin Wang, Toshikazu Yamaguchi, Kimiya Komurasaki, and Yoshihiro Arakawa	314
Photoionization in the precursor of laser supported detonation by ultraviolet radiation	
Kohei Shimamura, Keisuke Michigami, Bin Wang, Kimiya Komurasaki, and Yoshihiro Arakawa	326

SESSION 6

LASER ORBITAL DEBRIS REMOVAL

What's new for laser orbital debris removal	
Claude Phipps and Mike Lander	339
CLEANSPACE “small debris removal by laser illumination and complementary technologies”	
Bruno Esmiller and Christophe Jacquard	347
Laser-based space debris monitoring	
Uwe Voelker, Ivo Buske, Thomas Hall, Bernd Hüttner, and Wolfgang Riede	354

SESSION 7
MICROPROPULSION

Applications of microthrusters for satellite missions and formation flights scenarios	
H. Dittus and T. van Zoest	367
Microthruster research activities at DLR Stuttgart—Status and perspective	
Stephanie Karg, Stefan Scharring, and Hans-Albert Eckel	374
Experimental investigation of the reflection mode micro laser propulsion under highly frequent and multi pulse laser	
Xinghua Zhang, Jian Cai, and Long Li	383
Acceleration mechanism of pulsed laser-electromagnetic hybrid thruster	
Hideyuki Horisawa, Yuki Mashima, and Osamu Yamada	391

SESSION 8
FLOW CONTROL AND DIRECTED ENERGY AIRSPIKES

Experimental investigation of laser-sustained plasma in supersonic argon flow	
David Sperber, Hans-Albert Eckel, Peter Moessinger, and Stefanos Fasoulas	405
Experiment of flow control using laser energy deposition around high speed propulsion system	
HyoungJin Lee, InSeuck Jeung, SangHun Lee, and Seihwan Kim	416
Efficient supersonic drag reduction using repetitive laser pulses of up to 80 kHz	
Akihiro Sasoh, Jae-Hyung Kim, Kiyokazu Yamashita, Takeharu Sakai, and Atsushi Matsuda	424
The influence of flight altitude on supersonic drag reduction with laser energy depositions	
Juan Fang, Yanji Hong, Qian Li, Ming Wen, and Zhun Liu	430
Conductive channel for energy transmission	
Victor V. Apollonov	437

SESSION 9
MICROWAVE PROPULSION

Engine cycle analysis of air breathing Microwave Rocket with reed valves	
Masafumi Fukunari, Reiji Komatsu, Toshikazu Yamaguchi, Kimiya Komurasaki, Yoshihiro Arakawa, and Hiroshi Katsurayama	447
Unsteady numerical analysis of microwave/laser-supported plasma	
Hiroyuki Shiraishi	457
Millimeter-wave beam conversion with quasi-optical mirrors for Microwave Rocket launch demonstration	
Toshikazu Yamaguchi, Kimiya Komurasaki, Yasuhisa Oda, Ken Kajiwara, Koji Takahashi, and Keishi Sakamoto	467
Millimeter-wave driven shock wave for a pulsed detonation Microwave Rocket	
Toshikazu Yamaguchi, Reiji Komatsu, Masafumi Fukunari, Kimiya Komurasaki, Yasuhisa Oda, Ken Kajiwara, Koji Takahashi, and Keishi Sakamoto	478

SESSION 10
ADVANCED BEP CONCEPTS

Remote electric power transfer between spacecrafts by infrared beamed energy	
Boris E. Chertok, Roman A. Evdokimov, Victor P. Legostaev, Vitaliy A. Lopota, Boris A. Sokolov, and Vjacheslav Yu. Tugaenko	489
Author Index	497