Springer Theses

Recognizing Outstanding Ph.D. Research

Aims and Scope

The series "Springer Theses" brings together a selection of the very best Ph.D. theses from around the world and across the physical sciences. Nominated and endorsed by two recognized specialists, each published volume has been selected for its scientific excellence and the high impact of its contents for the pertinent field of research. For greater accessibility to non-specialists, the published versions include an extended introduction, as well as a foreword by the student's supervisor explaining the special relevance of the work for the field. As a whole, the series will provide a valuable resource both for newcomers to the research fields described, and for other scientists seeking detailed background information on special questions. Finally, it provides an accredited documentation of the valuable contributions made by today's younger generation of scientists.

Theses are accepted into the series by invited nomination only and must fulfill all of the following criteria

- They must be written in good English.
- The topic should fall within the confines of Chemistry, Physics, Earth Sciences, Engineering and related interdisciplinary fields such as Materials, Nanoscience, Chemical Engineering, Complex Systems and Biophysics.
- The work reported in the thesis must represent a significant scientific advance.
- If the thesis includes previously published material, permission to reproduce this must be gained from the respective copyright holder.
- They must have been examined and passed during the 12 months prior to nomination.
- Each thesis should include a foreword by the supervisor outlining the significance of its content.
- The theses should have a clearly defined structure including an introduction accessible to scientists not expert in that particular field.

More information about this series at http://www.springer.com/series/8790

Chao Feng

Theoretical and Experimental Studies on Novel High-Gain Seeded Free-Electron Laser Schemes

Doctoral Thesis accepted by
University of Chinese Academy of Sciences, China

Springer

Author
Dr. Chao Feng
Shanghai Institute of Applied Physics
Chinese Academy of Sciences
Shanghai
People's Republic of China

Supervisor
Prof. Zhentang Zhao
Shanghai Institute of Applied Physics
Chinese Academy of Sciences
Shanghai
People's Republic of China

ISSN 2190-5053 ISSN 2190-5061 (electronic)
Springer Theses
ISBN 978-3-662-49064-8 ISBN 978-3-662-49066-2 (eBook)
DOI 10.1007/978-3-662-49066-2

Library of Congress Control Number: 2015957787

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer-Verlag GmbH Berlin Heidelberg

Parts of this thesis have been published in the following journal articles:

C. Feng, H.X. Deng, D. Wang, Z.T. Zhao, New J. Phys. 16 (2014) 043021.
C. Feng, T. Zhang, H.X. Deng, Z.T. Zhao, Phys. Rev. ST Accel. Beams 17 (2014) 070701.
C. Feng, L. Shen, M. Zhang, D. Wang, Z.T. Zhao, D. Xiang, Nucl. Instrum. Methods A 712 (2013) 113.
C. Feng, H.X. Deng, G.L. Wang, D. Wang, Z.T. Zhao, Phys. Rev. ST Accel. Beams 16 (2013) 060705.
C. Feng, J.H. Chen, Z.T. Zhao, Phys. Rev. ST Accel. Beams 15 (2012) 080703.
C. Feng, M. Zhang, G.Q. Lin, *et al.*, Chin. Sci. Bull. 57 (2012) 3423.
C. Feng, T. Zhang, J.H. Chen, *et al.*, Phys. Rev. ST Accel. Beams 14 (2011) 090701.
C. Feng, Z.T. Zhao, Chin. Sci. Bull. 55 (2010) 221.
B. Liu, W.B. Li, J.H. Chen, *et al.,* Phys. Rev. ST Accel. Beams, 16 (2013) 020704.
Z.T. Zhao, D. Wang, J.H. Chen, *et al.*, Nature Photon. 6 (2012) 360.

Supervisor's Foreword

High-gain free-electron lasers (FELs), serving as high-intensity, ultra-short coherent light sources, are being actively developed around the world in the past decades. Applications for FELs in the EUV and X-ray regimes are practically unlimited: they can be used within a wide range of femtochemistry, for ultra-high resolution imaging, the investigation of the dynamics in atomic and biological systems and for many more experiments in leading edge sciences.

Study of the operation scheme is one of the core issuses of modern FEL physics research and is always an important topic for the design of high-gain FEL facilities. Till date, self-amplified spontaneous emission (SASE) and high-gain harmonic generation (HGHG) are the two leading candidates for approaching EUV to x-ray region. Most of the existing high-gian FEL facilities are based on the SASE principle, which can provide extremely high-intensity, ultra-short light pulses with good spatial coherence but poor temporal coherence and relatively large shot-to-shot fluctuations. HGHG holds the ability for significantly improving the FEL temporal coherence and stability, which has been experimentally demonstrated. However, the high harmonic up-conversion efficiency limited the wavelength cover range of a single stage HGHG. To overcome these problems and meet the new requirements of FEL users, novel high-gain FEL schemes have been proposed in recent years.

This Ph.D. thesis of Dr. Chao Feng mainly focuses on the study of novel high-gain FEL schemes with external seed lasers. The technique of manipulating the phase space of electron beam, which is widely used in novel seeded FEL schemes, has been systematically studied. Several novel FEL schemes have been proposed for the generation of intense coherent FEL pulse with short wavelength, sub-femtosecond pulse length or multiple carrier frequency properties, which meet the requirements of FEL users. Experiments have been carried out for the recently proposed FEL schemes such as echo-enabled harmonic generation and cascaded high-gain harmonic generation. New photon/electron beam diagnostic methods have been developed for these experiments based on the Shanghai deep ultraviolet FEL facility.

Researches on high-gain FELs have been just started in China. However, we already have three high-gain seeded FEL facilities under construction or operation. Investigations on novel seeded FEL schemes will help us to further understand the theoretical basis and functioning of the existing FEL schemes and provide us more options for the operation of these FEL facilities. We also hope that the new methods and techniques drawn from this study will be beneficial to other presently existing or planned high-gain FEL facilities.

Shanghai
September 2015

Prof. Zhentang Zhao

Acknowledgments

This thesis was guided by Prof. Zhentang Zhao. I was extremely fortunate to have Prof. Zhentang Zhao as my advisor and mentor at the Shanghai Institute of Applied Physics, Chinese Academy of Science. I would like to express my sincere gratitude to Prof. Zhentang Zhao for his continual support and encouragement during the course of my Ph.D. He has given me every opportunity I could have wished for, and I am always inspired by his motivation, enthusiasm and immense knowledge.

I am heartily thankful to Prof. Dong Wang for his help and guidance during the entire research period. Professor Dong Wang was very helpful and patient as I grew accustomed to being part of a large team for FEL experiment collaboration and learned accelerator commissioning in the process.

I am grateful to Bo Liu, Haixiao Deng, Jianhui Chen, Qiang Gu, Meng Zhang, Wencheng Fang, Xingtao Wang and Tong Zhang for their selfless support and helpful discussions in FEL theory and experimental research. I would also like to thank Prof. Chuangxiang Tang, Prof. Qika Jia, Prof. Zhirong Huang, Dr. Yuantao Ding, Prof. Alex Chao and Prof. Dao Xiang for their encouragement, insightful comments and kindly help in my research.

Finally, I would like to thank my parents for their love, patience, caring support and perspective.

Contents