Annual Report

Funding Programme:	Helmholtz Young Investigators Groups
Project ID No.:	VH-NG-804
Project Title:	Towards Laboratory-Based Ultrafast Bright EUV and X-ray Sources: High-Power Fiber Laser Frequency combs and Cavity Enhanced Ultrafast Optics
Group Leader:	Guoqing Chang
Helmholtz Centre:	DESY
Participating University:	University of Hamburg
Report Period (=Calendar Year):	01/2014-12/2014

1) Group Structure

Please report briefly on the structure and personnel development of your group.

Current group includes the group leader and 4 PhD students. Prof. Shanhui Xu from South China University of Technology (China) visited my group for 1 month. Now we also have one visiting PhD student from Beijing University who will stay for 1 year and is working on low-noise microwave extraction from 1-GHz Yb-fiber lasers.

2) Network

Please describe how you / your research group are integrated within the Helmholtz Centre and the partner university (e.g. as member of committees).

My group closely collaborates with Professor Franz Kärtner's group at DESY and HI-Jena on enhancement-cavity based terahertz sources.

In a collaboration with Professor Henry Chapman at DESY and Professor Christian Betzel from University of Hamburg, our group is developing a novel microscope method to analyze protein nanocrystals. This project is funded by the Hamburg Centre for Ultrafast Imaging (CUI) within the German excellence initiative.

In a collaboration with Dr. Markus Perbandt and Dr. Alke Meents both at DESY, we launched a new project – on-chip room-temperature time-resolved protein micro-crystallography based on UV-induced structural changes.

3) Satisfaction

How satisfied are you with the general working conditions provided by the Helmholtz Centre / partner university? Is there anything that meets your criticism?

The working conditions are excellent. As shown by my recent collaborations, I was able to establish quickly several new research projects with substantial funding and collaborations at DESY, UHH, CUI, HI-Jena and with CAS through the Helmholtz-CAS joint research program.

4) Scientific Progress / Milestones

How has your work plan progressed? Which important milestones could be achieved during the report period? Is the progress of your work in accordance with original planning or has the work plan been changed?

In the summer of 2013, we finally finished setting up the lab starting from an empty room in the brandnew building of the Center for Free-Electron Laser Science (CFEL). As for the research projects, we have achieved following milestones in 2014:

1. We demonstrated a pre-chirp managed Yb-doped fiber laser system that outputs 75 MHz, 130 W spectrally broadened pulses, which are compressed by a diffraction-grating pair to 60 fs with average powers as high as 100 W. Fine tuning the pulse chirp prior to amplification leads to high-quality compressed pulses. Detailed experiments and numerical simulation reveal that the optimum pre-chirp group-delay dispersion increases from negative to positive with increasing output power for rod-type high-power fiber amplifiers. The resulting laser parameters are suitable for extreme nonlinear optics application such as frequency conversion in femtosecond enhancement cavities. Now we are using this powerful laser source to drive an enhancement cavity for high power THz-wave generation.

2. We have both numerically and experimentally investigated the dependence of the relative intensity noise (RIN) and timing jitter of Raman soliton sources on optical fiber parameters. We show that soliton fission converts the pumping pulse's RIN into the RIN of resulting Raman solitons, which is converted into timing jitter during the process of Raman self-frequency shifting. A combination of shorter fiber length and optimized excitation pulse parameters can significantly reduce both the RIN and timing jitter of a Raman soliton. This finding is of particular importance for our project of implementing a high-power Mid-IR ultrafast laser source using difference frequency generation in the Helmholtz-CAS program.

3. We have come up with a new method of generating wavelength-tunable femtosecond pulses based on a home-built high-power Yb-fiber laser system. Such a tunable ultrafast source is of particular importance for nonlinear microscopy. More specific, we demonstrated a 60-fs source centered at 920 nm to match the 2-photon excitation wavelength of green fluorescence protein (GFP) and imaged GFP-labeled cancer cells.

4. We constructed a second harmonic generation (SHG) microscope for screening protein nano-crystals for X-ray diffraction imaging to determine the three-dimensional structure of protein molecules. We have succeeded in imaging several protein nanocrystals provided by Professor Christian Betzel's group. Preliminary results have shown excellent performance. The SHG microscope has a lateral resolution of 500 nm, capable of providing video-rate image. We are planning to further improve this microscope (e.g., using light-sheet illumination) and make it suitable to image nanocrystals flowing in a capillary.

Besides the work at DESY, I have visited Massachusetts Institute of Technology (MIT) on a regular basis as a visiting scientist and supervised the development of high repetition rate Yb-fiber laser frequency combs. The technology is crucial for the ongoing projects we are pursuing at DESY. The work at MIT has led to 7 journal papers and 18 conference papers which I coauthor since I established my Helmholtz Young Investigator group at DESY starting from August, 2012.

In collaboration with Prof. Franz Kärtner, we have successfully constructed a high power Yb-

fiber laser system and employed it to drive a femtosecond enhancement cavity, which is the first part of the originally proposed project. According to the proposal, we will apply this laser-driven enhanced cavity to implementing an extreme ultra-violet (EUV) source via high harmonic generation or an X-ray source via inverse Compton scattering. After a careful analysis, Prof. Franz Kärtner and I agreed that current cavity-enhancement system has more impact in generating high-power terahertz pulses, and implementation of EUV source and X-ray source will be pursued separately by other means in Prof. Franz Kärtner's group.

In addition to the work on the enhancement cavity system, I expanded my research into two other areas: 1) high-power mid-infrared femtosecond sources for quantum material spectroscopy and 2) multi-photon microscopy. Working in these two research areas will help me acquire a more distinct profile separating my work from the work of Prof. Franz Kaertner—my DESY host, and therefore will serve better my career perspectives.

5) Financial Plan / Time Schedule
Can you comply with the financial plan and time schedule or do you see a need for adjustment?

At this stage, everything works out in terms of the financial plan and time schedule.

6) Status
Do you hold a joint Junior Professorship or a W2/W3 Professorship? Do you aim for such a position? What is the status of your negotiations in this respect?

No, I do not hold a joint Junior Professorship or a W2/W3 Professorship.
Yes, I aim pursuing such a position, i.e. an academic career path in general. The negotiations have not yet started.

7) Teaching Activities of the Group Leader

Co-teaching of a *Special Topics Seminar in Nonlinear Optics and Ultrafast Laser Physics* at in WiSe 2013/2014 and 2014/2015 jointly with Prof. Kärtner at University of Hamburg
Co-teaching of the Ultrafast Optical Physics Class in SoSe 2015 jointly with Prof. Kärtner at University of Hamburg

8) Publications of the Group

<u>4 Journal papers published since 2014</u>

A. G. Glenday, C. –H. Li, N. Langellier, **G. Q. Chang**, L.-J. Chen, G. Furesz, A. Zibrov, F. X. Kärtner, D. F. Phillips, D. Sasselov, A. Szentgyorgyi, and R. L. Walsworth, "Operation of a broadband visible-wavelength astro-comb with a high-resolution astrophysical spectrograph" Optica 2, 250 (2015)

W. Liu, D. N. Schimpf, T. Eidam, J. Limpert, A. Tuennermann, F. X. Kärtner, **G. Q. Chang**, "Pre-chirp managed nonlinear amplification in fibers delivering 100 W, 60 fs pulse" Opt. Lett. 40, 151 (2015)

J. K. Lim, H. -W. Chen, S. H. Xu, Z. M. Yang, **G. Q. Chang**, and F. X. Kärtner, "3 GHz, Watt-level femtosecond Raman soliton source," Opt. Lett. 39, 2060 (2014)

S. –H Chia, L. –J Chen, Q. Zhang, O. D. Mücke, **G. Q. Chang**, and F. X. Kärtner, "Broadband continuum generation in mode-locked lasers with phase-matched output couplers," Opt. Lett. 39, 1445 (2014)

11 conference papers published since 2014

D. Schimpf, W. Liu, T. Eidam, J. Limpert, A. Tuennermann, F. X. Kärtner, and **G. Q. Chang**, "CPA-free ultrafast fiber laser source based on pre-chirp managed nonlinear amplification," paper Stu1O.4, CLEO/QELS, San Jose (2015)

G. J. Zhou, M. Xin, F. X. Kärtner, and **G. Q. Chang**, "Relative timing jitter and its effect on nonlinear wavelength conversion," paper SF2D.4, CLEO/QELS, San Jose (2015)

G. Q. Chang and F. X. Kärtner, "Ultrafast fiber laser technologies for multiphoton microscopy," paper TU-AF2-PAR-E-1, Focus on Microscopy, Gottingen, Germany (2015)

G. Q. Chang, C.-H Li, A. G. Glenday, G. Furesz, N. Langellier, J. K. Lim, H. –W. Chen, D. F. Phillips, D. Sasselov, A. Szentgyorgy, R. Walsworth, and F. X. Kärtner, "femtosecond laser frequency comb for precision calibration of HARPS-N," paper ATh3A.2, Advanced Solid-State Lasers, Shanghai (2014)

G. J. Zhou, M. Xin, W. Liu, F. X. Kärtner, and **G. Q. Chang**, "Relative intensity noise and timing jitter of Raman solitons," paper AM5A. 36, Advanced Solid-State Lasers, Shanghai (2014)

W. Liu, D. Schimpf, T. Eidam, J. Limpert, A. Tuennermann, F. X. Kärtner, and **G. Q. Chang**, "Pre-chirp managed amplification (PCMA) in fibers to 100 W with 60-fs output pulse duration," paper AW4A.2, Advanced Solid-State Lasers, Shanghai (2014)

G. J. Zhou, W. Liu, J. K. Lim, H. –W Liu, F. X. Kärtner, and **G. Q. Chang**, "Relative intensity noise of Raman solitons," paper ThC-T2-O-03, Europhoton, Switzerland (2014)

D. F. Phillips, C.-H Li, A. G. Glenday, N. Langellier, G. Furesz, **G. Q. Chang**, H. –W. Chen, J. K. Lim, F. X. Kärtner, A. Szentgyorgy, and R. Walsworth, "Silica nanowire growth on photonic crystal fiber by pulsed femtosecond laser deposition," paper H6.00010, 45th Annual meeting of the APS (DAMOP), Madison (2014)

N. Langellier, N. Tanjeem, A. G. Glenday, C.-H Li, G. Furesz, **G. Q. Chang**, H. –W. Chen, J. K. Lim, F. X. Kaertner, A. Szentgyorgy, R. Walsworth, "Green astro-comb for exoplanet searches: improved hardware and operation," paper D1.00080, 45th Annual meeting of the APS (DAMOP), Madison (2014)

H. –W. Chen, J. K. Lim, S. H. Xu, Z. M. Yang, F. X. Kärtner, and **G. Q. Chang**, "3 GHz, ultrafast Yb-fiber laser sources: filling the spectral gap," SPIE Optics&Photonics 2014 (2014) (invited paper)

W. Liu, G. J. Zhou, J. K. Lim, H. –W. Chen, F. X. Kärtner, and **G. Q. Chang**, "Relative intensity noise of Raman solitons: which one is more noisy," paper SM4N.7, CLEO/QELS, San Jose (2014)

9) External Funding

We submitted a joint proposal with our collaborators from Chinese Academy of Science and were awarded 360,000 Euros for three years to develop advanced ultrafast lasers for quantum materials spectroscopy (HCJRG-201). The project started from January 1 of 2014.

Within the Hamburg Center for Ultrafast Imaging, I have launched a new project to develop a new type of nanocrystal analyzer, which is funded by about 100k Euro in equipment and one PhD student.

10) Patent Applications
No. of pending/granted patents

None.

11) Awards received by Group Members / Professorship Appointments offered to Group Leader

None.