21st June 2010

Scientific Report

concerning the exchange mobility supported by the ESF Research Networking Program entitled Super-Intense Laser-Matter Interactions (SILMI)

Applicant:
Kovács Katalin
NIRDIMT Cluj-Napoca
Romania

Host:
Dr. Varjú Katalin
TeWaTi Laser Group
Dept. Optics & Quantum Electronics
University of Szeged, Hungary

Period of visit: 31st May 2010 – 20th June 2010.
Project title: Attosecond pulse formation through high-order harmonic generation (HHG) in gases: modeling and theoretical pulse characterization

Purpose of the visit

Throughout this project we intended to model and reproduce the microscopic and macroscopic aspects of the physical processes that lead to attosecond pulse (AP) formation, both isolated pulses (SAP) and trains of pulses (APT). Especially we investigated the possibilities of obtaining SAP in a configuration where HHG in rare gas is realized using the superposition of an intense IR few-cycle laser pulse and a weak THz radiation [1].

Both the research team at the TeWaTi Laser Group and the grantee use the strong-field approximation (SFA) to describe the HHG process. The group in Szeged implemented the saddle-point approximation (SPA) [2] in order to calculate the single-atom response in the ultrashort laser pulse – atom interaction, while the grantee works with a 3D non-adiabatic model [3] which offers the possibility to include the effects of propagation in ionizing and dispersive media of both the fundamental and harmonic radiation [4]. Thus, using this latter model one can account for the macroscopic aspects of HHG and AP formation, such as dispersion effects during propagation, phase-matching and divergence of harmonic radiation.
One purpose of the present collaboration was to compare the two approaches and if possible to combine the results obtained using the facilities of both models.

Description of the work carried out during the visit

1. First of all we tried to find at least one configuration for the THz-assisted HHG which would be feasible experimentally, and which induces measurable modifications of the harmonic spectra in the presence of the additional THz field.
In order to investigate the macroscopic aspects of HHG we implemented rather loose focusing conditions for the initial beams and a short gas cell (< 2 mm long) filled with low pressure noble gases (He, Ne, max. 15 Torr).

2. We compared the results obtained for the single-atom response using the two approaches: SPA and the numerical integration of the Lewenstein formula [5]. The goal of the comparison was to obtain good agreement of the single-dipole spectra obtained with the two methods if there was no THz field present, and this way to set a common basis for further investigations.

3. We have then implemented propagation in the 3d non-adiabatic model and investigated the effects of focusing and different dispersion effects (dispersion on neutrals, plasma dispersion, Kerr-effect) on the combined IR+THz pulse shape.

4. We have also investigated the effect of the THz field on the HHG process when propagation is included in the calculations. Especially we were looking for favorable conditions to obtain SAP. Therefore we performed a detailed trajectory analysis using an extended model which is suitable to calculate electron trajectories and their phases realized under the influence of an arbitrary shaped laser pulse [6]. Special attention was paid to the study of the effects of the THz radiation on the realized electron trajectories compared to the case when THz field is missing. Detailed phase-matching and harmonic divergence calculations will be the next step in the future collaboration.

Description of the main results obtained

1. While looking for a suitable IR+THz pulse configuration we had three main principles in mind: the single-atom responses calculated with the two methods (SPA vs. Lewenstein integral) has to agree – this is the way we check the correctness of calculations; the THz field has to be strong enough to induce substantial modifications in the HHG compared to the THz field free case; finally, we wanted to choose a parameter range that would be possible to realize experimentally.

Concerning the strength of the THz pulse we limited our investigations to fields weaker than 100 MV/cm peak amplitude based on the data reported in Ref. [7]. The fundamental IR laser pulse is a few-cycle (< 10 fs FWHM) pulse of 800 nm central wavelength and 0.1-1 PW/cm^2 peak intensity. The two components of the HH generating pulse are both linearly polarized with parallel orientation and the same direction of propagation.

2. The first positive result we obtained was a good agreement of the single-atom response obtained with the two different methods of calculation – SPA vs. Lewenstein integral – in the absence of a THz radiation. Standard HH spectra obtained from a fundamental IR few-cycle pulse were recovered. The same agreeing results were obtained when we compared the single-atom spectra and harmonic pulse shapes generated in the THz-assisted case with the two methods. The most important result is that the presence of the THz field can enhance the contribution of the short trajectories to the harmonic yield, while it suppresses some long trajectories. This is a promising result because we know from previous studies that short trajectories are much easier phase-matched with the fundamental during propagation than long trajectories. This result in the presence of the THz field can increase the chances to obtain a strong SAP at the exit of the interaction region.

3. In the presence of the THz field the cutoff of the harmonic spectrum is considerably extended. The harmonic spectrum has now two plateaus: there is an intermediate cutoff which appears at lower order than the cutoff of the HH spectrum generated with the IR pulse alone, while the end of the second plateau (i.e the final cutoff) is extended toward significantly higher harmonic orders compared to the case of HHG with an IR pulse alone. We showed that this cutoff extension is due to trajectories realized in one single optical cycle of the IR pulse.

4. Propagation through a dispersive medium influences the THz component much stronger than the IR component. The plasma contribution to the change in the refractive index experienced by the THz component is substantial, resulting in a highly distorted pulse shape

at the exit of the interaction cell, while due to the strong absorption the THz component is strongly damped during propagation. Since the refractive index experienced by the THz pulse in an ionized medium is considerably larger that that "seen" by the IR component, a strong diphase and walk-off of the two components relative to each other was observed by the end of the interaction region. Finding a favorable geometrical configuration to reduce the destructive effects of the medium upon the THz component will be the subject of further collaboration.

Future collaboration with host institution (if applicable)

In the three weeks period we managed to put the problem, define the exact directions of study concerning the research topic, introduce the needed modifications in the theoretical (computational) models and finally obtain preliminary promising results. For this reason we want to continue the collaboration on this specific topic, intend to obtain valuable results and would like to propose a feasible experimental realization.
On the other hand, during discussions several related issues were raised – worth to go on with further investigations in collaboration.

An institutional framework for collaboration between the grantee's affiliation and the host institution has been established through a Memorandum of Understanding active from 1st February 2010.

Projected publications/articles resulting or to result from the grant

We plan to publish the results obtained from this collaboration in an ISI quoted journal specific to this research field. We commit ourselves to acknowledge the support of ESF in publications resulting from the grantee's work in relation with the topic of this grant.

Other comments

Financing from the ESF was obtained for a 3 weeks period and the exchange mobility was initially scheduled to start on 24th May 2010. The grantee asked for permission to shift the starting date to 31st May and obtained the agreement from the ESF in this sense. The reason for the shift was that the grantee's direct collaborator – Dr. Varjú Katalin – was absent from the host institution on the week 24-30 May.

References

[1] W. Hong, P. Lu, P. Lan, Q. Zhang, X.Wang, *Opt. Exp*. **17**, 5139 (2009)
[2] G. Sansone, C. Vozzi, S. Stagira, and M. Nisoli, *Phys. Rev. A* **70**, 013411 (2004)
[3] E. Priori et al., Phys. Rev. A 61, 063801 (2000)
[4] V. Tosa, H. T. Kim, I. J. Kim, C. H. Nam, *Phys. Rev. A* **71**, 063807 - 063808 (2005)
[5] M. Lewenstein et al., *Phys. Rev. A* **49**, 2117 (1994)
[6] K. Kovacs and V. Tosa, *J. Mod. Opt.* **57** (2010) in press
[7] A. Sell, A Leitenstorfer, and R. Huber, *Opt. Lett.* **33**, 2767 (2008)

Report edited by grantee,
Kovács Katalin
Kovács Katalin

Report read and approved,
Dr. Varjú Katalin
Dr Katalin Varjú

UNIVERSITAS SCIENTIARUM SZEGEDIENSIS · SZEGEDI TUDOMÁNYEGYETEM

DEPARTMENT OF OPTICS AND QUANTUM ELECTRONICS
University of Szeged

Dr. Károly Osvay
Associate Professor
Dóm tér 9, Szeged 6720, Hungary
P.O.B. 406, Szeged 6701, Hungary
Tel: +36 (62) 544-273
Fax: +36 (62) 544-658
E-mail: osvay@physx.u-szeged.hu

To whom it may concern

21st June, 2010

Host Statement

This is to certify that the TeWaTi Laser Group, headed by Dr. Károly Osvay, at the Department of Optics and Quantum Electronics, University of Szeged, Hungary hosted Dr. Katalin Kovács from the National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj-Napoca, Romania in the framework of the ESF Research Networking Program entitled Super-intense laser-matter interactions (SILMI).

The exchange visit was three weeks long in the period **31st May 2010 – 20th June 2010**.

The direct scientific collaborator of Katalin Kovács at the host institution was **Dr. Katalin Varjú**.

During her visit Katalin Kovács has been modeling attosecond pulse (AP) formation via THz-field assisted high-order harmonic generation (HHG) in macroscopic samples of rare gases. The activities carried out in our research group included the followings: (i) finding an experimentally feasible configuration in order to investigate the effect of a weak THz radiation on the formation of APs; (ii) comparing the single-atom response obtained with the saddle-point approximation (SPA) and the Lewenstein integral; (iii) introducing propagation in the model and studying the effects of focusing and dispersion on the combined IR+THz pulse shape, and consequently on HHG and AP formation.

We were glad to initiate this collaboration which we intend to continue. In any publication resulting from the work carried out during this visit the support of the ESF will be acknowledged.

Sincerely yours,

Dr. Katalin Varjú

Dr. Károly Osvay,
Head of TeWaTi Laser Group