ANNUAL PROGRESS SUMMARY

To: technicalreports@afosr.af.mil
Subject: Annual Progress Statement to Dr. Arje Nachman

Contract/Grant Title: Mathematical Modeling and Experimental Validation of Ultrafast Nonlinear Light-Matter Coupling Associated with Filamentation in Transparent Media
Contract/Grant #: FA9550-10-1-0561
Reporting Period: September 30, 2013 to September 29, 2014

Annual accomplishments (200 words max):

The MURI project theory/simulation accomplishments for the past year include: further improvement of a semi-analytic "adiabatic" intense field quantum photoionzation model that yields quantitative agreement with compute intensive 3D quantum Schroedinger simulations, extension of the quantum many-body problem to simultaneously include intense field photoionization coupled with electron-electron, electron-ion and electron-neutral scattering, extension of the many-body theory to study THz absorption/emission of the nonequilibrium electron/ion system, a first prediction of zeptosecond waveform generation via high harmonic generation of mid-IR 9μm intense pulses and asymptotic analysis of weakly nonlinear Bessel-like beams with extension of their linear counterparts to study the influence of a turbulent atmosphere and the first simulation of superintense mid-IR multi-TW self-guided light bullet. Experimental accomplishments include the demonstration of a Bessel dressed beam experiment whereby the filaments length was extended tenfold, fabrication of vortex beam phase plates written in silica capable of withstanding multi mJ pulses and a first demonstration of such multi-TW vortex beam propagation at AFRL, a novel scheme utilizing our "dressing" beam concept to generate intense on-axis Raman emission over extended paths, verification of ionization assisted nonlinear saturation and unprecedented conversion efficiency was demonstrated in HHG experiments in the UV.

Archival publications (published) during reporting period:

1. Xi Chen, P. Polynkin, and M. Kolesik, "Raman effect in self-focusing of few-cycle laser pulses in air," *Optics Letters*. **38**, 2017-2019 (2013)

2. P. Polynkin and M. Kolesik "Critical power for self-focusing in the case of ultrashort laser pulses" *Physics Review A*, **87**, 053829 (2013)

3. B. Pasenow, C. Dineen, M. Brio, J.V. Moloney, S.W. Koch, S. Chen, A. A. Becker and A. Jaron-Becker, "Anisotropic THz-response from strong-field ionized electrons", *Physical Review E*, **87**, 033106 (2013)

4. P. Polynkin, C. Ament, J. Moloney, "Self-focusing of ultraintense femtosecond optical vortices in air", *Physical Review Lett*ers, **111**, 023901 (2013)

5. C. Hernández-García, J. A. Pérez-Hernández, T. Popmintchev, M. M. Murnane, H. C. Kapteyn, A. Jaron-Becker, A. Becker, and L. Plaja "Zeptosecond High Harmonic keV X-Ray Waveforms Driven by Midinfrared Laser Pulses*", Physical Review Lett*ers, **111**, 033002 (2013)

6. J. Andreasen and M. Kolesik "Mid-infrared femtosecond laser pulse filamentation in hollow waveguides: A comparison of simulation methods" *Physical Review E*, **87**, 053303 (2013)

7. Perez-Leija, F. Soto-Eguibar, S. Chavez-Cerda, A. Szameit, H. Moya-Cessa, and D. N. Christodoulides, "Discrete-like diffraction dynamics in free space", *Optics Express*, **21**, 17951 (2013).

8. J. Andreasen, E.M. Wright, M. Kolesik, "Optical Response of Atomic Gases to Ultrafast Pump-Probe Pulses," Quantum Electronics, IEEE Journal of , vol.**49**, no.12, pp.1088,1096, Dec. 2013

9. Jonathan Andreasen, Miroslav Kolesik, "Efficient simulation of unidirectional pulse propagation in high-contrast nonlinear nanowaveguides", Nanoscale Systems: Mathematical Modeling, Theory and Applications. Volume **2**, Pages 157–165, (2013).

10. Whalen, P, Panagiotopolous,P., Kolesik, M., and Moloney, J.V., "Extreme carrier shocking of intense long-wavelength pulses", *Physical Review A*, **89**, 023850 (2014)

11. K. Schuh, J. Hader, J. V. Moloney and S. W. Koch "Influence of many-body interactions during the ionization of gases by short intense optical pulses" *Physical Review E*, **89**, 033103 (2014)

12. K. Schuh, J. Hader, J. V. Moloney and S. W. Koch "Quantum theory of terahertz emission due to ultrashort pulse ionization of gases" *Physical Review* E 88 (6), 063102 (2014)

13. K. Schuh, M. Kolesik, E.M. Wright, and J. V. Moloney "Simple model for the nonlinear optical response of gases in the transparency region" *Opt. Lett*. **29** (17), 5086-5089 2014

14. J. Liu, M. Brio, and J. V. Moloney, "Transformation optics based local mesh refinement for solving Maxwell's equations", *Journal of computational Physics*, **258C**, 359-370 (2014). DOI: 10.1016/j.jcp.2013.10.048.

15. Maik Scheller, Xi Chen, Gombojav O. Ariunbold, Norman Born, Jerome Moloney, Miroslav Kolesik, and Pavel Polynkin, "Raman conversion in intense femtosecond Bessel beams in air", *Physical Review A*, **89**, 053805 (2014).

16. Maik Scheller, Matthew S Mills, Mohammad-Ali Miri, Weibo Cheng, Jerome V. Moloney, Miroslav Kolesik, Pavel Polynkin, Demetrios N Christodoulides, "Externally refuelled optical filaments,"*Nature Photonics 8*, 297-301 (2014)

17. Craig Ament, Lee Johnson, Andreas Schmitt-Sody, Adrian Lucero, Thomas Milster, and Pavel Polynkin, "Generation of multi-terawatt vortex laser beams", *Applied Optics,* **53**, 3359 (2014)

18. M. Kolesik and J.V. Moloney "Modeling and Simulation Techniques in Extreme Nonlinear Optics of Gaseous and Condensed Media" *Rep. Prog. Phys*, 77, 016401 (2014).]

19. A. Spott, A. Jaron-Becker and A. Becker "Ab initio and perturbative calculations of the electric susceptibility of atomic hydrogen" *Physical Review A*, **90**, 013426 (2014).

20. Gemmer, J. A., Venkataramani, S. C., Durfee, C. G., & Moloney, J. V. Optical beam shaping and diffraction free waves: A variational approach. *Physica D: Nonlinear Phenomena*, *283*, 15–28, (2014). doi:10.1016/j.physd.2014.06.003

21. Iliev, M., Meier, A. K., Galloway, B., Adams, D. E., Squier, J. A., & Durfee, C. G. Measurement of energy contrast of amplified ultrashort pulses using cross-polarized wave generation and spectral interferometry. *Optics Express*, ***22***, 17968, (2014).

22. He, F., Zeng, B., Chu, W., Ni, J., Sugioka, K., Cheng, Y., & Durfee, C. G. Characterization and control of peak intensity distribution at the focus of a spatiotemporally focused femtosecond laser beam. *Optics Express*, *22*(8), 9734. (2014). doi:10.1364/OE.22.009734

23. J. Cornelius, J. Liu, and M. Brio, "Finite-difference time-domain simulation of spacetime cloak", *Optics Express*, **22** (10), 12087-12095, 2014.

24. Andrew Spott, Agnieszka A. Jaroń-Becker and Andreas Becker "Ab-initio and perturbative calculations of the electric susceptibility of atomic hydrogen," *Physical Review* A, **90**, 013426 (2014).

25. P. Whalen, P. Panagiotopoulos, M. Kolesik, and J. V. Moloney, "Extreme carrier shocking of intense long-wavelength pulses," *Phys. Rev*. A **89**, 023850 (2014).

26. M. Tarazkar, D.A. Romanov, and R.J. Levis, Higher-order nonlinearity of refractive index: The case of argon, J. *Chem. Phys.* **140**(21), pp. 214316 (1-10) (2014)

27. M Scheller, N Born, W Cheng, P Polynkin, "Channeling the electrical breakdown of air by optically heated plasma filaments",Optica **1** (2), 125-128 (2014)

28. M. Scheller, M. S. Mills, M. A. Miri, W. Cheng, J. V. Moloney, M. Kolesik, P. Polynkin, D.N. Christodoulides, "Externally refuelled optical filaments", *Nature Photonics* **8** (4), 297-301 (2014)

29. M. Scheller, X. Chen, G. O. Ariunbold, N. Born, J. V. Moloney, M. Kolesik, P. Polynkin, "Raman conversion in intense femtosecond Bessel beams in air" *Physical Review* A **89** (5), 053805 (2014)

Changes in research objectives, if any: None

Changes in AFOSR program manager, if any: None

Extensions granted or milestones slipped, if any: None

Include any new discoveries, inventions or patent disclosures during this reporting period (if none, report none):

Popmintchev, T, Popmintchev, D., Murnane, M.M, and Kapteyn,H., "Method for phase-matched generation of coherent VUV, EUV, and x-ray light using VUV-UV-VIS lasers," US Patent Application submitted 2014 (provisional submitted (2013).