Technology and Applications of Intense Few-Cycle Mid-Infrared Pulses

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Mid-IR (>3 m) strong-field sources are in the focus of attention of ultrafast laser developers because of the promise for a transformative impact on several application areas. The key advantages over conventional near-IR driver sources are the ^{2} ponderomotive energy scaling, efficient suppression of multiphoton ionization in favor of tunneling ionization, the ability to induce hot electron plasma, and the long duration of the optical period. The notable benefits of employing strong mid-IR fields include: the photon energy scaling of coherent XUV radiation produced via high-order harmonic generation (HHG); time scale expansion for the metrology of bound and continuum wavepackets in molecules; intense directional THz pulse emission in a mid-IR laser plasma; a rich palette of plasmochemical effects such as spontaneous nitrogen gas lasing, etc.

The technology of few-cycle high-energy mid-IR pulses is notoriously challenging due to the lack of suitable broadband laser and parametric gain media, low parametric conversion efficiency, seed and pump source synchronization, compounded by the problems of mid-IR detection, pulse characterization, atmospheric attenuation, etc. This talk will summarize the progress of the Vienna group in the development of various types of long-wavelength few-cycle parametric sources based on femtosecond diode-pumped Yb sources and picoseconds Nd front-ends. Two approaches to building next-generation strong-field systems in the mid-IR for driving secondary radiation sources will be detailed: i) a single-color =4 m and the prototype =6 m scheme and ii) a multicolor carrier-envelope phase-locked driver covering several octaves and comprising the idler (=3 m), signal (1.5 m), pump (1 m) and its harmonics derived from a diode-pumped Yb CPA.

The single-color approach is exemplified by a >100-GW-peak-power 12-mJ ~80-fs hybrid parametric source at 4 m [1]. Applying this laser to HHG driving in the phase-matching geometry, developed in the group of Prof. M. Murnane and Prof. H. Kapteyn at JILA, we were able to jointly demonstrate an efficient extension of spatially and temporally coherent XUV continuum generation into a multi-keV region [2]. The talk will also highlight another breakthrough result achieved with this source the first known generation and characterization of femtosecond mid-IR filamentation in gases, and the emission of J-level backward UV pulses due to ASE in nitrogen from a filament plasma.

The multicolor approach is inspired by the theoretical proposal for an optimized kinetic energy and trajectory control of the HHG electron [3] and is pursued in collaboration with the group of Prof. J. Marangos and Prof. J. Tisch at Imperial College. We will present the current status of the HHG experiment with three locked driver colors and discuss the observations of the photon flux and cutoff frequency extensions. Finally, we will outline the prospects for new applications and technology scaling for advanced ultrafast mid-IR and composite multicolor strong fields.

[1] G. Andriukaitis, et al., 90 GW Peak-Power Few-Cycle Mid-IR Pulses from an Optical Parametric Amplifier tt., 36, 2755 (2011).

[2] T. Popmintchev, et al., A new frontier for nonlinear optics: bright coherent kiloelectronvolt ultrafast X-rays generated on a tabletop Science (in print).

[3] L. E. Chipperfield et al., Ideal Waveform to Generate the Maximum Possible Electron Recollision Energy for Any Given Oscillation Period , Phys. Rev. Lett. 102, 063003 (2009).