Attosecond Optics – From light-field driven electron dynamics to advanced electronics and spectroscopy

Course Code: OSE4520
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Office Hours: TBD
Term: Spring, 2025
Class Schedule: Tuesday and Thursday 10:30 - 11:45
Location: TBD

Course Description: This course introduces the fundamentals and applications of attosecond science, a rapidly advancing field that bridges optics, electronics, and spectroscopy. Initially focused on gas-phase high-harmonic generation and the creation of attosecond pulses, attosecond science has now expanded into solid-state materials, nanostructures, and devices, unlocking exciting new possibilities. Applications include advanced spectroscopy techniques, optical field sampling (a petahertz-fast oscilloscope), ultrafast electronics, and petahertz information processing.

Students will explore ultrafast light-matter interactions, coherent control, and their applications in atomic and condensed matter systems. Topics covered include high-harmonic generation, ultrafast spectroscopy, electric field sampling, and emerging research and industrial directions. The course balances foundational principles with practical applications and future impact.

Course Structure:

- **70% Lecture-Based:** Establishing the theoretical principles of attosecond science, focusing on generation, characterization, and control of ultrafast light pulses.
- **30% Discussion-Based:** Engaging with recent publications, patents, and review articles to explore cutting-edge advancements and practical exercises.

By the end of the course, students will be prepared to contribute to cutting-edge research in attosecond science, ultrafast electronics, optics, and industrial applications.

Learning Objectives

By the end of this course, students will:

1. Understand the interaction of intense laser pulses with matter, including light-field driven electron dynamics in solids and at nanostructures.
2. Understand the principles of attosecond pulse generation and characterization.
3. Explore applications of attosecond science in spectroscopy, imaging, electronics, and quantum technologies.
4. Develop computational skills for modeling ultrafast phenomena.

Prerequisites

- Graduate-level knowledge of quantum mechanics and electromagnetism.
- Familiarity with Fourier optics and ultrafast laser systems is recommended.

Course Topics

1. **Introduction to Attosecond Physics**
   - Historical background
   - Attosecond timescales and phenomena
   - Brief review of Lasers
   - Brief review of quantum mechanics
2. **Attosecond Pulse Generation**
   - Gas-phase high-harmonic generation (HHG)
   - Phase matching and carrier-envelope phase stabilization
   - Techniques for generating isolated attosecond pulses
3. **Characterization of Laser Pulses, Including Attosecond Pulses**
   - Frequency-resolved optical gating (FROG)
   - Reconstruction of attosecond beating by interference of two-photon transitions (RABBITT)

4. **Light-Matter Interactions in Solids**
    - From linear and nonlinear optics to non-perturbative light-matter interaction
    - Solid-state high-harmonic generation
    - Sub-cycle electron dynamics and quantum interference
    - Floquet engineering and quantum control
5. **Applications of Attosecond Science**
    - Attosecond transient absorption spectroscopy
    - Solid-state high-harmonic generation
    - Petahertz Electronics
    - Electric Field Sampling
6. **Future Trends and Challenges**