1. Introduction
   1. Ultrafast dynamics in condensed matter
      1. Timescales and processes in solids
   2. Attosecond Transient Absorption Spectroscopy (ATAS)
      1. Overview of the technique
         1. Induced dipole picture (gas phase)
         2. XUV probe of population transfer/state changing picture (condensed phase)
         3. Why are you doing it with HHG? Contrast HHG vs synchrotron. Include figure of pulse duration vs photon energy, showing different light sources (synchrotrons, HHG sources, XFEL, etc.)
         4. Comparison of absorptive to reflective measurements
            1. Complex refractive index
            2. Sample requirements and preparation
            3. Pointing stability (in reflection, sample is an XUV optic)
      2. Previous work, what is the state of the art?
         1. Previous ATAS/ATRS measurements in Ge, Si, etc.
         2. Motivation for long-wavelength studies in condensed matter
      3. What is physically observable via ATAS, and what isn’t?
         1. Limited k-space information (requires single crystal)
         2. Transmission geometry measures Im[n], not Re[n]
      4. Interpretation of data
         1. Most common method: TD-DFT
   3. High harmonic generation (discussed in context of XUV light source)
      1. 3-step model, temporal & spectral profile of light
      2. Phase matching considerations (with an eye towards increasing flux)
         1. Pressure-length product
         2. HHG yield vs wavelength scaling
         3. Optimal phase matching pressure vs wavelength
   4. IR Beam Shaping Using a Binary Phase Mask
2. Experimental Apparatus
   1. Introduction
      1. Overview of TABLe, including main parts of beamline. Refer reader to Steve’s thesis for details on target chamber & photon spectrometer.
   2. Laser system
      1. SpitFire/OPA description & specifications
      2. Beam routing from laser bay to TABLe
      3. Active pointing correction
   3. Vacuum system
      1. The need for vacuum (XUV propagation, air-sensitive equipment)
      2. Design goals
      3. Manufacturing Considerations
      4. Vacuum System Details
         1. Individual chambers
         2. Rough vacuum & OMRON safety systems
   4. XUV Optics
      1. Design goals
      2. Fresnel Reflection from a Rough Surface
      3. Aberration-Free Focusing
      4. Metallic Filters
   5. IR Optics
      1. Generation Arm
      2. Pump Arm
      3. Aligning into the TABLe interferometer
   6. XUV Photon Spectrometer
      1. Optical Description
      2. Spectral Calibration
         1. 1-Source Harmonic Counting
         2. 2-Source Harmonic Counting
         3. Ar Fano Resonances
         4. The Jacobian
3. XUV light source design and apparatus performance
   1. The need for high XUV flux in ATAS experiments
   2. HHG gas sources
      1. Gas flow considerations
      2. Free expansion nozzle
      3. Low pressure cell (LPC)
      4. High pressure cell (HPC)
      5. Amsterdam pulsed piezo valve
   3. Characterization of XUV source
      1. Knife edge measurements at XUV focus
      2. XUV-IR spatial overlap
         1. Sensitivity of ATAS signal to misalignment of XUV/IR focal spots (simulations)
         2. Sensitivity of XUV-IR overlap integral to interferometer’s input pointing (simulations)
      3. Harmonic yield stability
      4. XUV spectra optimized for various HHG conditions
      5. Measured transmission of metallic filters (Al, Zr)
      6. Ground state measurements of condensed matter samples
         1. Silicon
         2. Diamond
         3. Silicon nitride
         4. WS2
         5. Germanium
         6. WPOMs
         7. Cr2O3
   4. Characterization of interferometric stability
      1. Dietrich’s RABBIT data
      2. Two-omega oscillations in Argon
   5. Scaling of MCP response (yield & noise) with MCP voltage
4. ATAS experiments in Germanium
   1. Introduction
   2. Experimental considerations
      1. Sample requirements
         1. Thickness, large area
      2. Rastering of sample through focus to avoid heating, charge build-up
      3. XUV maps of samples
      4. IR propagation in thin films (TMM calculations, starting with *LightPipes* output)
      5. Orbital-resolved excitation probability vs wavelength (band structure calculations)
      6. Laser damage
      7. Estimation of excited carrier density
   3. Optimizing experimental ATAS parameters for Germanium
      1. Rep. rate (avoiding ms-scale excitation)
      2. IR pulse energy
      3. Harmonic spectrum (2-color, wavelength)
      4. Optimized ATAS Ge experimental results
      5. Post-experiment analysis: verification we didn’t permanently damage sample
   4. Data analysis
      1. Description of data pipeline
         1. Going from a 2D image to a 1D spectra
            1. Background subtraction
            2. Selecting a divergence window
            3. Normalization by exposure time, divergence window
            4. Integration over divergence window
         2. Energy calibration
         3. calculation
      2. Systematic noise sources in our experiment
         1. Harmonic yield drift
         2. Dark counts, background subtraction & ambient light
         3. Laser-induced sample damage
         4. Nonlinear MCP/P response?
      3. Methods to numerically correct for harmonic drift / noise
         1. Descriptive statistics: correlation between harmonic drifts
         2. Broad energy range harmonic normalization (doesn’t work that well)
         3. nearest-neighbor harmonic normalization (works best)
         4. SVD of harmonic spectra?
         5. Other methods?
      4. Frequency filtering to remove oscillations
   5. Physical interpretation of spectra (following Leone)
      1. Decomposition of spectral response
      2. Description of observed dynamics
5. Conclusion
   1. Experimental outlook, potential improvements to system
      1. Reflective focusing for generation & pump arms
      2. In-situ imaging of XUV/IR overlap
      3. Closed-loop control over HM2 pointing
      4. Optical improvements to minimize XUV/IR focal spot misalignment (guided by simulations)
      5. Isolated attosecond pulses for XUV continuum
      6. In-vacuo condensed matter sample cooling with gas jet to reduce sample heating
      7. Motorized retroreflector to study ps-scale dynamics
      8. Simultaneous XUV reference measurement (w/o sample)
      9. Simultaneous photoelectron & photoabsorption measurements
      10. Moving laser system closer to TABLe, or propagating under vacuum
      11. Replacing target chamber with doubly-differentially pumped chamber (for gas & liquid phase experiments)
      12. Upgrade HPC RV pump to a dry pump
6. Appendix
   1. How to use the vacuum system
      1. OMRON safety system
      2. pump down, venting, gate valve operation, arming & emergency venting
   2. How to use the High Pressure Cell
   3. Required maintenance
      1. Turbo pumps
      2. Rough pumps
      3. Spitfire (gratings, fluids, filters)