Double Optical Gating for attosecond pulse generation

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Why attosecond pulses?

Attosec.  \(10^{-18}\) s

femtosec.  \(10^{-15}\) s

picosec.  \(10^{-12}\) s

Time

Electron dynamics

Vibration

Rotation
Why attosecond?
Electron dynamics timescale

- 1 a.u. of time is 24 attosecond
- Attosecond light is soft x-ray

\[
\tau (fs) \approx \frac{1.825}{\Delta E (eV)}
\]

\[
\Delta E = 73eV
\]
Conventional laser is limited to fs

- Transform-limited Gaussian pulse

\[ \tau (fs) \Delta E (eV) \approx 1.83 \]

- Visible light: 400-700 nm = 1.33 eV, 2.7 fs
- The bandwidth is too narrow
High order harmonic generation

Discovery by Rhodes & L’Huillier, 1987

20 fs laser ($h\nu = 1.5$ eV)

Ar gas

$10^{14}$ W/cm$^2$

XUV ($h\nu \sim 100$ eV)

Harmonics 27

Harmonic order

Energy

Photon energy (eV)
Laser harmonic generation

Intensity

Perturbative

Nonperturbative (plateau)

Harmonic order

1 3 5 7 9 11...
Three steps in one laser cycle
Proposed by Corkum & Kulander, 1993

1. Electron emission (tunneling ionization)
2. Acceleration (in E field of laser)
3. Attosecond emission (recombination)
Attosecond revolution

Nonperturbative interaction (HHG)

Atto pulse generated by few-cycle lasers

Demonstrated by Krauz, 2001

Single isolated pulse 80 as (2008)

Pump laser:
3.3 fs, ~0.5 mJ

Attosecond pulse train

85 eV  135 eV
Attosecond research at KSU: 2001

- 0 attoseconds
- 0 photons
Our goals:
1. Generate 24 attosecond isolated pulses
2. With multi-cycle lasers (10-20 fs)

- 1 a.u of time is 24 attosecond
- Bandwidth: 73 eV

\[ \tau(fs) \approx \frac{1.8}{\Delta E(eV)} \]
\[ \Delta E = 73eV \]
Attosecond pulse train and HHG

Multi-cycle laser

Gas

Atto Pulse Train

Half Cycle

Intensity

1 3 5 7 9 11...

Harmonic order
Extraction of single pulse by gating

Necessary conditions:
- Gatewidth equals to pulse spacing
- Ground state population available in the gate
- Carrier-envelope phase locking

Our approach:
Double optical gating (DOG) = polarization gating + two color gating.
Polarization gating

Multi-cycle laser

XUV pulse train

Gas

Half cycle


Two-color gating

Laser: $\omega$  
Gas  
XUV pulse train  
Half cycle=1.3 fs  


Laser: $\omega + 2\omega$  
Gas  
Full cycle=2.6 fs  

Double Optical Gating

Electric fields (relative)

- SHG field
- Double gating driving field
- Driving field
- Gating field

Time (fs)

Driving fields

- Gate

Cycle

(d) (e)
Why can DOG work with multi-cycle lasers?

The full cycle gate width with DOG reduces the depletion of the ground state population.
Grating based CPA: 3 mJ, 25 fs
Hollow-core fiber: 1 mJ, 6 fs

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CE phase locking of grating-based CPA

- Separation of two feedback loops
- Long locking time
CEP drift introduced by a grating pair

\[ d \approx 1\mu m \]

\[ \Delta S \]

\[ \Delta G \]

\[ G \]

\[ \Delta \varphi_{CE} = 2 \frac{2\pi}{d} \Delta G \tan[\beta(\omega_0)] \]

CE phase locked by controlling gratings

Phase drift $\Delta \phi_{CE}$ (RMS) = 167 mrad

PZT displacement $\Delta L_{PZT}$ (sd) = 0.52 $\mu$m
Demonstration of DOG with 9 fs laser
XUV spectra generated with gating
Supercontinua generated with DOG and corresponding attosecond pulses

Gilbertson et al, APL 92, 071109 (2008)
Carrier envelope phase

\[ \phi_{CE} \]

Envelope

Electric Field
Effects of carrier-envelope phase on double optical gated spectrum

Mashiko et al, PRL 100, 103906 (2008)
Simulated effects of CE phase

Chang, PRA 76, 051403(R) (2007)
Summary

- CE phase locking of grating based CPA
  - Separation of feedback loops.
  - High laser energy.

- Double optical gating:
  - Isolated as pulse (140 as),
  - Longer driving laser (~10 fs).