Laser Plasma as a Source of Intense, Single Attosecond Pulses via High-Order Harmonic Generation

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Shorter & Shorter

Attosecond phenomena: electron motion

Period of the first Bohr orbit: 150 attoseconds
Three-Step Model of High-Order Harmonic Generation

1. High E field of laser ionizes atom
2. Electron starts to oscillate in laser field
3. Electron recollides with atom, and emits harmonics

A source for attosecond pulses
Attosecond pulse train by HHG

Experimental Observation
HHG Spectrum: Discrete Spectral Lines

Wavelength

Driving fs Pulse

Gas

E(t)

HHG

tunnel ionization + re-collision

HHG as pulse Train

Half Cycle

Experimental Observation
HHG Spectrum: Discrete Spectral Lines
Discrete harmonic orders in the plateau

Spatial analogy of pulse train interference

Single slit

Double slit

Multi slit

Diffraction patterns (spatial frequency)
The Goal

- Intense, Single Attosecond Pulses
  - Single Attosecond Pulse
    - (= Broad Bandwidth; ~ 20 eV)
  - High Intensity (> 1 \(\mu J\))
    - (= High Efficiency)
Plasma Harmonics

An Alternative to High Intensity Harmonic Generation

High-Intensity Ultrashort Pulse Laser

Low-Intensity ps Pulse Laser

Solid Target

Harmonics
Reconstruction of attosecond beating by the interference of two photons transitions (RABITT)

Modified CEA RABITT SET UP

Elouga Bom et al., Opt. Exp. 19, 3677 (2011)
RABITT method for electric field reconstruction

- Case of chromium plasma

Sidebands from two photons two Colors transitions in the detection gas.

Elouga Bom et al., Opt. Exp. 19, 3677 (2011)
Plasma harmonics are also Attosecond pulses

Reconstructed electric field of chromium harmonic spectrum

$\Delta \tau_{\text{FWHM}} = 360 \text{ as}$

360 as measured using low laser pump intensity ($4 \times 10^{14} \text{ Wcm}^{-2}$)

Elouga Bom et al., Opt. Exp. 19, 3677 (2011)
Intense Quasi-monochromatic Harmonics from Indium Ablation

- Conversion efficiency of $10^{-4}$
- Energy of 13th harmonic near 1 µJ
- 10 µJ harmonics possible with ALLS


**Intense but Narrow-band**
C\textsubscript{60} Harmonics

Prepulse: $5 \times 10^9$ W cm\textsuperscript{-2}
Main pulse: $1 \times 10^{14}$ W cm\textsuperscript{-2}

13\textsuperscript{th} harmonic from C\textsubscript{60} is several times stronger than that from Indium … efficiency > $10^{-4}$

… but the harmonic intensity rapidly decreases, due to target degradation

The problem of using nanoparticles is the instability of the signal.

By creating plasma at the same position on the target, the harmonic signal decreases fast and disappears after 6 s.

*Intense and Broad-band but Unstable*
Intense Harmonics from Pencil Lead

Pump: ~ 10 mJ Ti:sapphire laser

Composition (XPS)

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>C</th>
<th>O</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point A</td>
<td>6.0%</td>
<td>30.6%</td>
<td>47.0%</td>
<td>16.4%</td>
</tr>
<tr>
<td>Point B</td>
<td>1.6%</td>
<td>69.2%</td>
<td>23.8%</td>
<td>5.4%</td>
</tr>
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Bulk Carbon Targets as a Source for Intense Harmonics

Pump: ~ 10 mJ Ti:sapphire laser

Harmonic signal from solid targets remains constant for at least 5 minutes.

**Intense, Broad-band and Stable**
Why are carbon harmonics so intense?

- SEM image of carbon bulk plasma deposition on silicon substrate shows that plasma created from bulk carbon targets contains a large number of nanoparticles.

- Therefore, it seems that for HHG in bulk carbon the fs laser interacts with nanoparticles, rather than ions as for most of solid targets.

Shorter fs-pulse to get a single atto-pulse

- With ~25 fs pulses
- With ~10 fs pulses
- With ~5 fs pulses

Harmonic generation

Super continuum at near cutoff

Traditional method: generation of single atto-second pulses
Polarization gating for a single atto-pulse

Double Optical Gating

\[ T_g = 0.3 \frac{\tau_p^2}{T_d} \]

- \( T_g \): Gating width
- \( \tau_p \): pulse duration
- \( T_d \): delay for polarization gating
Step 1: Comparing Harmonics from Carbon Plasma and Argon Gas Cell

Pump: ~ 1.4 mJ (25 fs) & 0.7 mJ (8 fs) Ti:sapphire laser

Ar: 0.262 nJ; C: 2.49 nJ
Step 2: Generating Continuum Harmonics from Carbon Plasma

8 fs Ar

15H

17H

19H

8 fs C

Carbon DOG
Thank You

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