Thin film compression & applications to high energies

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Rapid laser evolution

QCD $\sim 10^{35}$ W/cm$^2$
Nonlinear QED: $E \cdot \mathbf{e} \cdot \lambda_e = 2m_e c^2$

Vacuum Polarization
Ultra Relativistic Optics

Relativistic Optics

Bound electrons

- HHG
- Damage

mode locking
Q-switching

Grating Pulse Stretcher
Stretched Pulse
Amplified Pulse
Amplifier
Grating Pulse Compressor
Amplified Short Pulse
Increasing intensity

Intensity = \frac{\text{Energy}}{\text{Time}}
Single cycle generation

\[ n(\omega) \approx n + n_2 I \]

- Self-phase modulation
- Gaussian pulses undergo Kerr nonlinearity adding frequencies
Thin Film Compression

High energy lasers have “flat top” profiles
Laser system at UCI

1 kHz, 35 fs, 0.3 TW
TFC for Gaussian beams
Radiation pressure acceleration

• Circularly polarized light inhibits electron heating

• Radiation pressure directly accelerates electrons

• For thin foils, can displace all electrons, accelerating all ions

• Optimal thickness is \((n_c/n_e) a_0 \lambda\)

Computing Resources

- 592 cores available on GreenPlanet high performance computing center
- Epoch and OSIRIS Particle-in-cell simulations performed
- 3D3V Simulation capabilities
Instabilities for RPA

- 1D assumptions quickly decay
Single cycle ion ion acceleration

4 cycles

1 cycle

High harmonic generation

Single cycle advantages

- Nonlinearity cleans pulse
- Instabilities suppressed in single cycle
- Questions over absorption remain

Single cycle electron acceleration

Theory of wakefield toward extreme energy

\[ \Delta E \approx 2m_0c^2a_0^2\gamma_{\text{ph}}^2 = 2m_0c^2a_0^2 \left( \frac{n_{\text{cr}}}{n_e} \right), \quad \text{when 1D theory applies} \]

\[ n_{\text{cr}} = 10^{21} \text{ (1eV photon)} \]
\[ = 10^{29} \text{ (10keV photon)} \]
\[ n_e = 10^{16} \text{ (gas)} \rightarrow 10^{23} \text{ (solid)} \]

High energy gain requires lower densities and longer lengths

OR … by scaling to shorter wavelengths much higher densities can be used
Critical density

Photon Energy [eV]

Electron Density [cm$^{-3}$]

- $1 \times 10^{21}$
- $1 \times 10^{22}$
- $1 \times 10^{23}$
- $1 \times 10^{24}$
- $1 \times 10^{25}$
- $1 \times 10^{26}$
- $1 \times 10^{27}$
- $1 \times 10^{28}$
Nanowaveguides

Nanotubes

Porous nanomaterial

(a)

(b)

(c)
PIC Simulations

1 nm and 1000 nm laser confined in tubes of diameter $5\lambda_L$ and intensity $a_0 = 10$

Maintaining laser wavelength to plasma wavelength ratio preserves wakefield structure

Since scaling is based over $n_c/n_e$, energy and momentum is maintained but transverse motion is drastically reduced, so emittance is much greater

Photon factories

Photon emission scales with the real electric field while the energy gain scales with the normalized laser amplitude $a_0$. 

![Graphs showing photon emission and energy gain for 1 nm and 1000 nm guided systems.](image)
RPA redux

Short pulse interactions with solids don’t generate high energy electrons, but they generate high currents

Positron generation

Courtesy of K.-Y. Chu

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Thank you for listening!