Picosecond Thermal Dynamics in an Underdense Plasma Measured with Thomson Scattering

Experimental data
Temperature versus time

- $3.3 \times 10^{18}$
- $8.4 \times 10^{18}$
- $1.05 \times 10^{19}$
- $2.29 \times 10^{19}$
- $2.35 \times 10^{19}$

Time (ps)

Te (eV)

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59th Annual Meeting of the American Physical Society
Division of Plasma Physics
Milwaukee, WI
23–27 October 2017
Time-resolved Thomson scattering shows that the temperature conditions for a Raman amplifier are highly dependent on plasma density

- A pulse-front-tilt compensated streaked spectrometer was utilized for the first time to measure underdense plasma thermal dynamics
- The electron-heating rate and plateau temperature are found to increase with higher densities
- The electron temperature was observed to rise from an initial 5 eV to a plateau temperature in 23 ps
Collaborators


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Electron temperature introduces kinetic effects (wave breaking, particle trapping, Landau damping), which strongly reduce the efficiency of Raman amplification.

**OSIRIS simulations**

1-D, constant pump, constant density, seed meets nonlinear regime

- $T_e = 0$ eV
- $T_e = 100$ eV
- $T_e = 400$ eV

Kinetic effects change the parameter regime for optimal efficiency in a Raman amplifier.

An underdense plasma experimental system was constructed to make precise measurements of plasma temperature, nonlinear/driven plasma waves, and laser propagation.

- **Pump**
  - $\lambda = 1053$ nm
  - $E = 1.27$ J
  - $\Delta t = 55$ ps

- **Thomson-scattering probe**
  - $\lambda = 527$ nm
  - $E = 0.5$ J
  - $\Delta t = 40$ ps
An H$_2$ gas cell was used to create a 4-mm-long homogenous plasma and characterized using interferometry and Thomson scattering.
A novel high-throughput \((f/5)\), ultrafast picosecond Thomson-scattering system\(^*\) was required to measure the evolution of the plasma conditions.

\[
\Delta t = \frac{N\lambda}{c}
\]

**Table:**

<table>
<thead>
<tr>
<th>Resolving Power</th>
<th>(G) ((\text{ll/mm}))</th>
<th>(\frac{dx}{d\lambda}) ((\text{mm/nm}))</th>
<th>(d) (mm)</th>
<th>(f#)</th>
<th>(\Delta t) (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>20,000 (0.025 nm)</td>
<td>300</td>
<td>0.125</td>
<td>65</td>
<td>5</td>
</tr>
<tr>
<td>Ultrafast</td>
<td>600 (1 nm)</td>
<td>300</td>
<td>0.125</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

The electron temperature and density can be determined by scattering from thermal electron plasma waves.

\[ n_e = 3 \times 10^{18} \text{ cm}^{-3}, \theta_s = 90^\circ, Z = 1 \]

Predicted Thomson-scattering spectra
The Thomson-scattering data were fit late in time to find both the electron temperature and density.

Keeping the electron density constant, the Thomson spectra were fit for all earlier times by changing the plasma temperature.

$T_e = 50 \text{ eV}; \, n_e = 8.4 \times 10^{18} \text{ cm}^{-3}$

*EPW: electron plasma wave
**IAW: ion-acoustic wave
The heating rates and temperature plateaus were measured as a function of density for a $2 \times 10^{14}$ W/cm$^2$ pump laser.

As opposed to a free parameter, the temperature in a Raman amplifier is determined by the plasma density for a fixed pump intensity.
Time-resolved Thomson scattering shows that the temperature conditions for a Raman amplifier are highly dependent on plasma density.

- A pulse-front-tilt compensated streaked spectrometer was utilized for the first time to measure underdense plasma thermal dynamics.
- The electron-heating rate and plateau temperature are found to increase with higher densities.
- The electron temperature was observed to rise from an initial 5 eV to a plateau temperature in 23 ps.