The role of hot electrons in the dynamics of a laser-driven strong converging shock

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Outline

• **Shock ignition experimental campaigns in LLE**
  - Experiment on strong shock generation in the converging geometry
  - Choice of an ablator material for efficient hot electron generation
  - Correlation of SRS and hot electron generation

• **Modeling with the CHIC code**
  - Comparison with the LILAC simulations without hot electrons
  - Generation of hot electrons with the CHIC code
  - Effect of hot electrons on the shock pressure
  - Hot electron preheat
Experiments on strong shock generation in a solid sphere

A series of experiments on strong shock generation has been accomplished on the Omega facility in spherical geometry. Enhanced hot electron generation is prompted by switching off laser temporal smoothing (SSD). The shock amplitude is evaluated from the measured laser energy absorption and the X-ray flash delay.

Laser intensity $\sim 6 \times 10^{15} \text{ W/cm}^2$ @ 351 nm, laser energy 22 – 26 kJ
Higher local intensities were achieved with a stationary non-smoothed laser energy distribution.

Correlation of the hot electron production and SRS

R Nora et al, PRL 2015
W Theobald et al Phys Plasmas 2015
Hot electron generation dependence on the ablator material

- Correlation of the hot electron generation and SRS in different ablators
- Anti-correlation of the hot electron generation with the flash time
- The expected SRS threshold $\sim (7 - 9) \times 10^{14}$ W/cm$^2$ does not depend on the ablator material

Ion acoustic wave damping on the light (hydrogen) ions is identified as the cause for a stronger SRS and enhanced hot electron production.
Numerical modeling of strong shock generation and propagation: SSD on

Numerical modeling of the strong shock experiments was conducted with the radiation hydrodynamics codes LILAC (LLE) and CHIC (CELIA)
The criteria for comparison were: (i) the shock timing (x-ray flash); (ii) the absorbed laser energy; (iii) the number of hot electrons
Two cases were considered: SSD on and SSD off: the shot #72676 (SSD on) was modeled without hot electrons – both codes produced the same results:

Absorption: 61% (exp), 60% (CHIC f=4%), 57% (LILAC f=8%)
Nonlinear laser-plasma interaction package in CHIC

Radiation hydrodynamics code CHIC includes a laser propagation module in the paraxial complex geometrical optics approximation which provides access to the local instantaneous value of the laser intensity in plasma. It is coupled to the module describing the fast electron generation and transport due to the resonance absorption and the parametric instabilities SRS and TPD. It allows to evaluate the role of hot electrons in laser plasma interactions: shock wave generation and target preheat.


Parameters of the model are chosen from the results of kinetic simulations and experiments.
Numerical modeling of strong shock generation and propagation: SSD off

Numerical modeling of was conducted with the radiation hydrodynamics code CHIC (CELIA) accounting for the resonance absorption, SRS and TPD.

The criteria for comparison were: (i) the shock timing (X-ray flash); (ii) the absorbed laser energy; (iii) the number of hot electrons.

The shot #73648 (SSD off) was modeled with hot electrons: 9% of the incident laser energy.

Absorption: 71% (exp), 69% (CHIC $f=4\%$, 60% collisional absorption).

Hot electrons: RAB = 1.6%, SRS = 5.4%, TPD = 2%.

Reflection = 31% (11% SRS).

Flash time 2.44 ns.
Hot electron energy deposition: SSD off

Hot electron sources are diverging, nevertheless some of them reach the target center: the areal density of the target of 40 mg/cm² corresponds to the stopping range of 200 keV electrons (1% of SRS and 6% of TPD).

Hot electrons are transporting energy beyond the ablation layer.
Absorption: 69% = 60% collisional absorption + 9% hot electrons

Angular divergence of hot electrons

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The contribution of hot electrons is evidenced in the pressure evolution in the target.

Generation of hot electrons increases the shock pressure by 100 Mbar:
laser driven shock

\[ P_{abl} = 12\left(\frac{A}{2Z}\right)^{1/3}\left(\frac{I_{las}}{\lambda}\right)^{2/3} \]

hot electron driven shock

\[ P_{HE} = 37\rho_{e}^{1/3}I_{HE}^{2/3} \]

But the hot electron preheat decreases the shock strength.
Effect of the hot electron preheat

SRS electrons dominate preheat to the temperature $\sim 30 \text{ eV}$ (20J = 1\% of the total energy SRS electrons)
This results in the reduced shock strength by $100\times$

Danger for the shell implosion: internal ablation and the hot spot cooling

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Conclusions

• Need for a new Shock Ignition target design: shell areal density > 60 mg/cm²
• Validation of the HE model in dedicated experiments
• Development of the improved HE model: effect of electric and magnetic fields
• 3D laser energy deposition and electron transport
• Effects of hot electron transport on the hydrodynamic instabilities