A microphysics model to understand the solid-to-plasma transition of dielectric ablator materials for direct-drive implosions

A. KAR, S. X. HU, and P. B. RADHA
University of Rochester, Laboratory for Laser Energetics

G. DUCHATEAU
Université de Bordeaux-CNRS-CEA, France

Summary

A model to study the transition of polystyrene (CH) from the solid to plasma state has been developed and implemented into the 1-D hydrocode LILAC.

- With this model, the critical surface formation takes place after the target has been irradiated and the laser-imprint mechanism has occurred.
- The model includes multiphoton-ionization, recombination, and impact-ionization schemes that determine the free-electron density in the conduction band of the material.
- By incorporating this model, the spatial profiles of the physical quantities such as pressure and mass density are observed to be different between the microphysics model and the original ad hoc mechanism in LILAC.

An ad hoc model to describe the initial plasma formation for plastic targets has been developed and implemented into a 1-D hydrocode.

Motivation

Currently, the hydrodynamic codes avoid the detailed plasma-formation process.

- Laser energy deposition
- Multiphoton-ionization, impact-ionization, and recombination processes determine the free electron density in the valence band.

Propagating light field

- Multiphoton ionization and tunneling
- Impact ionization
- Recombination

Pictorial representation of a laser-pulse interaction with a solid

Multiphoton ionization and impact ionization increase the electron density, but recombination decreases it.

The dynamics is governed by a rate equation that is coupled to the laser-deposition and the temperature models.

- Until the critical surface formation, the dynamics is governed by the microphysics model.
- Beyond that, the inverse bremsstrahlung absorption is incorporated.

A better understanding of the laser-imprint mechanism and shock timing experiments is possible with the microphysics model.

- Implementation of the microphysics model into 2-D or 3-D hydrocodes will provide a better understanding of the laser-imprint mechanism through an accurate estimation of the laser-absorption profile.
- The results of the microphysics model will help us to understand the results of shock-emergent experiments better.
- Future experiments are being planned to study this phenomena in detail.

Future Directions

- Target is decompressed because of a rise in the electron temperature inside the target.
- The electron temperature inside the target observed in the microphysics model is higher than the ad hoc model.

References

Lower absorption in plastic is observed in the microphysics because of its transparency.
Currently, the hydrodynamic codes avoid the detailed plasma-formation process.

Motivation

At present, the hydrocodes assume an initial plasma state or use the cold-start mechanism in an *ad hoc* mechanism and ignore the detailed plasma-formation process.

Laser light shines on the target

The target is compressed

The target is ignited

The target burns

~4 mm
A model\cite{1} to study the transition of polystyrene (CH) from the solid to plasma state has been developed and implemented into the 1-D hydrocode *LILAC*

- With this model, the critical surface formation takes place after the target has been irradiated and the laser-imprint mechanism has occurred.
- The model includes multiphoton-ionization, recombination, and impact-ionization schemes that determine the free-electron density in the conduction band of the material.
- By incorporating this model, the spatial profiles of the physical quantities such as pressure and mass density are observed to be different between the microphysics model and the original *ad hoc* mechanism in *LILAC*.

A physics-based model to describe the initial plasma formation for plastic targets has been developed and implemented into a 1-D hydrocode.
Multiphoton-ionization, impact-ionization, and recombination processes determine the free electron density in the valence band[1]

Propagating light field

For CH:
Band-gap energy $\sim 4.05$ eV
UV light, $\lambda = 351$ nm, $E = 3.53$ eV
Critical density: $9 \times 10^{21}$ cm$^{-3}$

Multiphoton ionization and impact ionization increase the electron density, but recombination decreases it.
The dynamics is governed by a rate equation that is coupled to the laser-deposition and the temperature models.

- Until the critical surface formation, the dynamics is governed by the microphysics model.
- Beyond that, the inverse bremsstrahlung absorption is incorporated.

Flowchart of microphysics model:

1. **Laser pulse file:**
   - Intensity: $I(t)$ or electric field $E_L(t)$

2. **Rate equation**
   \[
   \frac{d n_{fe}}{dt} = \left( \frac{n_{vb} + n_{fe}}{n_{vb}} \right) W_{PI} + \eta n_{fe} - \frac{n_{fe}}{\tau_r}
   \]

3. **Update electron density, temperatures, and energy density**
   \[n_{fe}(t + \Delta t)\]

4. **Temperature model**
   \[\frac{\partial U}{\partial t} = j . E_L\]

5. **Flowchart elements**:
   - **Keldysh multiphotonization**
   - **Recombination rate**
   - **Impact ionization**
   - **Laser energy deposition**
     - Joule heating

6. **Rate equation parameters**:
   - $W_{PI}$
   - $\tau_r$
   - $\eta$

7. **Transport properties**:
   - $n_{fe}$: electron density
   - $n_{vb}$: valence electron density
   - $U$: energy density
   - $j$: current density
   - $E_L$: electric field
   - $\nu$: collision rate
The critical surface formation takes place after the target has been irradiated and the laser-imprint mechanism has occurred.

The electron density inside the plastic rises because of laser energy deposition.
The electron temperature inside the target observed in the microphysics model is higher than the *ad hoc* model.

The temperature profiles in the ablation region between the two models are comparable.
Microphysics models predict decompression of the target ahead of the shock front because of shinethrough\textsuperscript{[2]}

The target is decompressed because of a rise in the electron temperature inside the target.
Future Directions

A better understanding of the laser-imprint mechanism and shock-timing experiments is possible with the microphysics model

- Implementation of the microphysics model into 2-D or 3-D hydrocodes will provide a better understanding of the laser-imprint mechanism through an accurate estimation of the laser-absorption profiles
- The results of the microphysics model will help us to understand the results of shock-merger experiments better
- Future experiments are being planned to study this phenomena in detail