The Progress of Opacity Measurement in ShengGuang II

XU Yan, PEI Wenbing
Institute of applied physics and computational mathematics
Beijing 100094, China

ZHANG Jiyan, YANG Jiamin
Research Center of Laser Fusion,
CAEP, Mianyang 621900, China
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Introduction

• Opacity quantifies how thermal radiation interacts with matter. All opacity codes contain significant approximations, so there is a requirement to quantify their accuracy.

• Opacity experiments in Laboratory can be carried out in high power lasers facilities.
• The study of opacity requires the simultaneous measurements of the temperature, density, and transmission spectrum.

• A delicate milestone experiment was first carried out on Nova

• A big hohlraum and the gold baffles are used for clean environment and a LTE radiation. The target design and geometry play a central role in the experiment.

• 15 kJ/3ω₀ laser energy

• sample temperature is 48±2 eV.

A platform at Omega to measure opacities from 250-6000 eV at temperatures above 100 eV

• quoted from report of William H. Goldstein
Omega: have measured opacity of mid-Z and high-Z materials at $T_{\text{rad}} \approx 125$ eV

- Density and temperature are in reasonable agreement with Lasnex simulations
- Full characterization of sample enables detailed validation of opacity codes

Ti K-Shell Absorption
(Expansion $\Rightarrow$ density; Ionization $\Rightarrow$ temperature)

*Gap between MCP strips

Oppacity Hohlraum with Sample

Rosseland Mean Backlighter

Opacity Hohlraum with Sample

To $\rho, T$ spectrom.

To Rosseland Mean Spectrometer

Lawrence Livermore National Laboratory
LLNL has revitalized its opacity experimental efforts in anticipation of breakthroughs on NIF and PWs.

2. “Long-Pulse” experiments at Omega and NEL (“NIF Early Light”)
   - Design Calculations + Theory: hot hohlraums, opacity targets, foil samples
   - Capability Development Experiments:
     - Spectrometers, Backlighters, NEL commissioning & Hot Hohlraums
   - Code Physics Validation Experiments: Gd-Al transmission measurements
   - Rosseland Mean Experiments: working towards Ta (etc.) at $T_r > 100$ eV
   - One long-range goal: very high $T_r$, high-Z LTE experiments on NIF

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<tr>
<th>Parameter</th>
<th>Omega Result</th>
<th>NIF Estimate</th>
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<tbody>
<tr>
<td>Density @ Peak Temperature</td>
<td>0.04 to 0.08 g/cc</td>
<td>0.1 to 0.2 g/cc</td>
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<td>Density Uncertainty 30%</td>
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<td>Peak Sample Temperature</td>
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*(enables extrapolation to alternate times via simulations)*
NIF will revolutionize LTE transmission opacity experiments... eventually

Small-scale hohlraum delivers very high temperature X-ray drive onto sample of Fe.

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Design for small laser facility

- SG-II provides only $2.5\text{kJ}/3\omega_0$ laser energy. We can not follow the Nova experiment design.

- New-type of target is proposed. **CH foams** are used instead of gold baffles.
  The CH foam prevents reflected laser and hot high-Z plasma from going into the sample region, but allow x rays to pass through and heat the sample.

- The opacity measurement usually takes place some time later after the heating finishes and the collisions can gradually bring the sample into LTE state.
Schematic of opacity experiment

Airscape
Side Elevation
The self-emission spectrum

- If the high-Z laser plasma comes in the view-way of measurement, it will behave like a long-standing backlit.
- To verify the design, backlit laser was turned off. A photo of the clear Al emission spectrum, not an absorption spectrum is obtained. It proves that a clean environment for measurement is achieved.
Experiment results: Al transmission spectrum

backlighter (Au)

 slit: 300\,\mu m

 slit: 400\,\mu m

\( I_E \quad I_E + I_S \quad I_E + I_Se^{-\tau} \)
Evolvement of the ionization state (Al)
Simulation of the Al opacity experiment

- Simulation predicted that the sample would be heated to near 90eV

![Diagram](image)
The sample state is inferred by fitting the experimental spectrum. The temperature and density are 95eV and 25mg/cc, respectively.
1D expansion: \( \rho l = \rho_0 l_0 \)

Gated radiography

Al ion density

Time delay 1.0ns Sickness: 32um
The gated (200ps) measurement can greatly reduce the influence of time-integrated self-emission.

For short-pulse ($\Delta t$) backlight,

\[ e^{-\tau(Z)} = \frac{\int_0^{\Delta t} I_{\text{recorded}}^\text{CH+Z} dt - \int_0^\infty I_{\text{emission}}^\text{CH+Z} dt}{\int_0^{\Delta t} I_{\text{recorded}}^\text{CH} dt - \int_0^\infty I_{\text{emission}}^\text{CH} dt} \]

The time-resolved self-emission spectrum gives information of plasma.
• For comparison with theoretical models, independent measurement of temperature and electron number density is required.

  Ionization state

  • Ion density → electron density

  temperature

  • Fitting the spectrum

  • Independent measurement
Electronic structure measurements of dense plasmas

G. Gregori, S. H. Glenzer, F. J. Rogers, S. M. Pollaine, and O. L. Landen
Lawrence Livermore National Laboratory, University of California, P.O. Box 808, Livermore, California 94551

C. Blancard, G. Faussurier, and P. Renaudin
Département de Physique Théorique et Appliquée, CEA/DAM Ile-de-France, BP12, 91680 Bruyères-le-Châtel Cedex, France

S. Kuhlbrodt and R. Redmer
Universität Rostock, Fachbereich Physik, Universitätsplatz, 3, D-18051, Rostock, Germany

- C foam 0.72g/cm³
• The x-ray scattering has a very small cross section.
\[ \sigma_\ell = \frac{8\pi}{3} r_0^2 = 6.6 \times 10^{-25} \text{cm}^{-2} \]
• It needs a large number of particles to scatter the probing light in order to get the detectable scattering signals.
• Our sample is very thin in thickness but large in extent. It has plenty of particles in uniform temperature and density, therefore it has a natural advantage for using x-ray scattering for diagnosis.
• The scattering spectra of the aluminum plasmas (104eV, 0.02g/cm³)
• In one shot, we can get the transmission spectra, the plasma temperature and the ionization state.
• The requirements for using the x-ray scattering as diagnosis are rigorous.
• Why Al again?
  Al is an element that usually is used to infer the plasma temperature.

Fitting the spectrum  ↔  Inferred from the scattering spectrum

The temperature of plasma
Summary

• With the this new-type of target, we have established a platform for opacity experiment in relatively smaller laser facility-SG II.

• A platform for more precise opacity data is going to be built.
Thanks