Integrated Target Reflectivity Analysis

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ARIES Project Meeting

March 8-9, 2001

Livermore, California
OUTLINE

• Motivation

• Modeling Approach

• Results for four metal films (Au, Ag, Pd, Pt)

• Frequency and temperature dependence of optical properties of metal films

• Future Plans
Motivation for Target Reflectivity Calculations

- Target heat reflectivity is computed at UCSD to provide input to target heating analysis carried out at General Atomics.

- Before irradiation by the driver beam, the target must be protected from external heat so that:

  \[ T_{\text{fuel}} < \text{DT triple point (21 K)} \]

- Proposed target composition: Au / GDP / solid DT / vapor DT

- Sombrero study showed:

  Radiation heating from chamber wall
  >> Convective heat transfer from chamber gas
Modeling Approach

• Objective is to calculate inertial fusion target reflectance of heat radiated from chamber wall.

• Assume incident radiation spectrum to be blackbody.

• Use four-layer (vac/film/polymer/DT) Fresnel model to calculate intensity reflectivity for each wavelength and angle of incidence.

• Include both S- and P-polarization components. Assuming random polarization mix, we have for reflectivity:

\[ R(\lambda, \theta) = 0.5 \left( R_S + R_P \right) \]

• Calculate reflectivity averaged over incident angle by

\[ \langle R(\lambda) \rangle_\theta = 2 \int_0^{\pi/2} d\theta R(\lambda, \theta) \sin \theta \cos \theta \]

• Integrate over radiation spectrum to obtain total reflectivity:

\[ \mathcal{R}(T) = \pi \int_0^\infty d\lambda \langle R(\lambda) \rangle_\theta \lambda^4 b^\dagger(\lambda, T) / \sigma T^4 \]

\[ \sigma \]

\[ W \]
Optical Properties for Four Coating Materials

- Complex refractive index: \( n = n + i \ k \)
- **Gold** data are from Woollam Co. ( \( 0.4 < \lambda < 20 \ \mu m \) )
- **Silver**, **Palladium** and **Platinum** data are from Handbook of Optical Constants of Solids ( \( 0.4 < \lambda < \sim 10 \ \mu m \))
- Search for data into FIR regime.
- Target reflectivity is obtained by integrating over available spectrum.

\[
n = n + i \ k
\]
Optical Properties of Polymer and DT Ice

- **Polymer (GDP):**
  - **Visible spectrum:** \( n(\lambda) = A_n + B_n \lambda^{-2} + C_n \lambda^{-4} \) (Cauchy)
    \[ k(\lambda) = A_k \exp\{1.24B_k(1/\lambda - 1/C_k)\} \] (Urbach)
  - The fitting coefficients are supplied by Woollam Co.
  - **Infrared spectrum:** Multiple oscillator model (More info from Woollam)
    Extend Cauchy/Urbach fit

- **DT Ice:**
  - Have not uncovered any optical database yet.
  - Assume substrate to be Silicon with \( n = 4.47, \ k = 1.12 \).
Angle-averaged Reflectivity for Four Metal Films

- Both gold and silver show sharp decrease in reflectivity \( < R (\lambda) >_\theta \) towards visible range of wavelengths.
Gold and Silver Films Provide High Reflectivity

- Gold and silver films have very similar reflectivities (integrated over database spectrum).
- Reflectivity decreases with wall temperature, as peak radiated wavelength moves towards visible regime.
- Maximum reflectivity ($\sim 0.98$) is reached when film thickness $\geq 0.07$ µm.
Palladium and Platinum have Poor Reflective Properties

- Reflectivities for Palladium and Platinum films are much lower than Gold or Silver for the same thickness.
- Spectrum-integrated reflectivity is much more sensitive to wall temperature.

![Graph showing reflectivity of Palladium and Platinum](image-url)
Target Reflectivity is Insensitive to Plastic Shell Thickness

- At low wall temperature, there is a ~ 0.2% variation of R with GDP thickness; no variation at higher temperature, for 0.03 µm film thickness.

\[ \text{Gold thickness} = 0.03 \, \mu m \]
\[ \text{Silicon substrate} \]
\[ \text{GDP thickness} = 0.5 \, \mu m \]
\[ > 1.5 \, \mu m \]
Temperature and Frequency Dependence of Reflectivity

• For a conductor, dielectric response to external EM field is dominated by “free” electrons, and \( n = n (1 + i \kappa) \) [\( \kappa \): attenuation index]
  \[
n^2 (1 - \kappa^2) = \mu \varepsilon
  \]
  \[
n^2 \kappa = \frac{2\pi \mu \sigma}{\omega} , \text{ where } \sigma = \frac{Ne^2}{m(\gamma - i \omega)}
  \]
  and \( \gamma = 1/\tau \), \( \tau \) is time between collisions. Typically, \( \gamma \sim 10^{14} \text{ s}^{-1} \).

• For low frequencies (FIR), \( \gamma << \omega \), \( \sigma \) is the dc conductivity, and is real.
  - Transition of optical properties into FIR range.

• For high frequencies (uv and visible), \( \gamma >> \omega \), and assuming \( \mu = 1 \),
  \[
n^2 (1 - \kappa^2) \sim 1 - \left(\frac{\omega_p}{\omega}\right)^2
  \]
  \[
n^2 \kappa \sim 0.5 \gamma \omega_p^2 / \omega^3
  \]

• Temperature dependence:
  - Low frequencies: dependence of \( \sigma_{dc} \) on temperature
  
  - High frequencies:
    (1) At low temperature, \( \gamma \) is determined by impurities and imperfections
    (2) At ordinary temperature, \( \gamma \) is dominated by electron-phonon scattering, \( i.e., \) electron interaction with lattice vibrations.
FUTURE PLANS

- Incorporate Fresnel multi-layer model into target heating calculations at General Atomics
  - Use results as a heating source term
  - Extend spectrum to FIR range
  - Local heat deposition calculations (to verify assumptions made).

- Continue search for optical properties of solid DT

- Extrapolate results to lower temperatures
  - $n$ and $\kappa$ values at room temperature have been used