Introduction

We evaluate the damage threshold of an Au coated flat mirror, which is one of the reflective optics installed on FEL-1 beamline of Dalian Coherent Light Source (DCLS), upon far UV free electron laser (FEL) irradiation. The surface of the coating is characterized by profilometer and optical microscope. We present also theoretical approach of the phenomenon by applying single-shot damage threshold calculation, one-dimensional thermal diffusion model as well as finite element analysis with ANSYS to the case.

I. Experimental setup

- Subject: Au coated mirror
  - 200nm Au coating
  - Si substrate
- Beam size: 0.5 mm in σ of Gaussian
  - YAG+CCD measurement with Gaussian fit
  - Order of magnitude precision
- Wavelength selection: 121.6 nm
  - Working wavelength of the mirror
  - Common wavelength for chemical researches in DCLS
- 20Hz repetition, 2 ps pulse duration, Normal incidence

II. Surface characterization

- An example for 50μJ@2h30min case
  - Optical microscope
    - Shockwave: typical ultrafast pulse-matter interaction
    - Rise at the center: not the substrate, possible C coated
  - Profilometer
    - Quantitative depth profile (2 directions)

III. Result Overview

- Accumulation of crater depth observed
  - Still considered single shot (20Hz)
- Threshold is lower than 5μJ pulse energy (~2μJ/cm²)
  - Damage of diffraction order observed
- Finite element analysis of temperature distribution
- Damage should occur for 50μJ pulse energy (~2μJ/cm²)

IV. Theoretical approaches

1. Single-shot damage threshold calculation
   - Damage should occur when pulse energy>233 μJ
     \[ W_{\text{melt}} = 3K_BT_{\text{melt}} \]
     \[ W_{\text{atom}} = 4\ln(2)(1-R)W_{\text{pulse}}msin\theta \]
     \[ \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}(K\frac{\partial h}{\partial x}) + S \]
   - Damage should occur when: \( W_{\text{atom}} > W_{\text{melt}} \)

2. One-dimensional thermal diffusion [1]
   - Simulation indicates that damage should occur for 50μJ pulse energy, but not for 5μJ pulse energy
     \[ h_{\text{melt}} = C(T)(T - T_0) \]
     \[ h_{\text{liquid}} = h_{\text{melt}} + \Delta h_{\text{latent heat}} \]
   - Finite element analysis of temperature distribution

3. Finite element analysis of temperature distribution
   - Simulation indicates that damage should occur for 50μJ pulse energy, but not for 5μJ pulse energy

Conclusion

- SSDT is NOT found for Au thin film @121.6nm FEL beam irradiation
- It should be lower than 5μJ pulse energy (~2μJ/cm²)
- Further measurements are planned
- Experimental measurements differ from theoretical predictions.
- SSDT calculation indicates that even 50μJ pulse energy will not cause damage
- 1D thermal diffusion and FEA indicate that damage should occur for 50μJ case and not for 5μJ case.