Study on UV FEL single shot damage threshold of an Au thin film

Meiyi Wu[1], Qinming Li[1], Mingchang Wang[2], Qinghao Zhu[1], Zhongmin Xu[1], Jiandong Cai[1], Long Huang[1], Bingbing Zhang[1], Runze Qi[3], Zhe Zhang[3], *Wenbin Li[3], *Yinpeng Zhong[1], *Weiqing Zhang[2]

wumy@mail.iasf.ac.cn

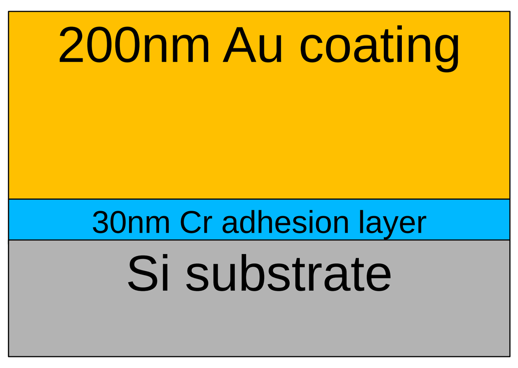
1 Institute of Advanced Science Facilities, Shenzhen 518017, China
2 Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian 116023, China
3 Institute of Precision Optical Engineering, School of Physics Science and Engineering, Tongji University, Shanghai 200092, China

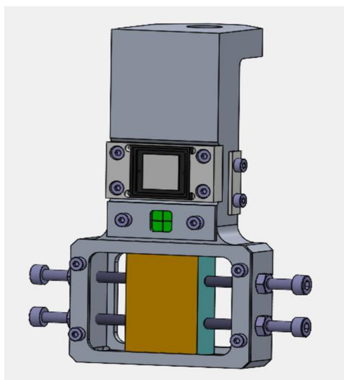
Introduction

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.

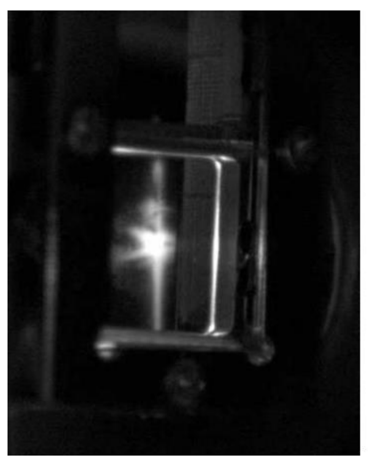
I. Experimental setup

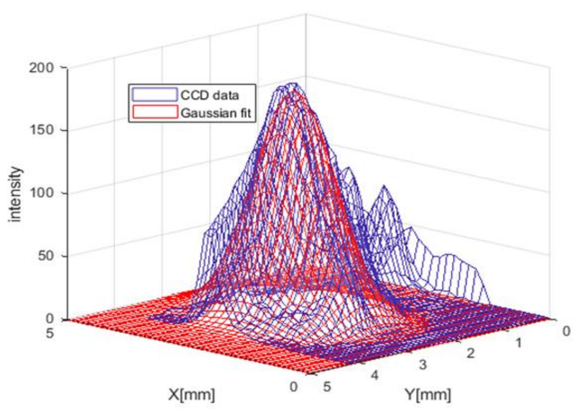
- **Subject: Au coated mirror**





- **Beam size: 0.5 mm in σ of Gaussian**
  - **YAG+CCD measurement with Gaussian fit**
  - **Order of magnitude precision**

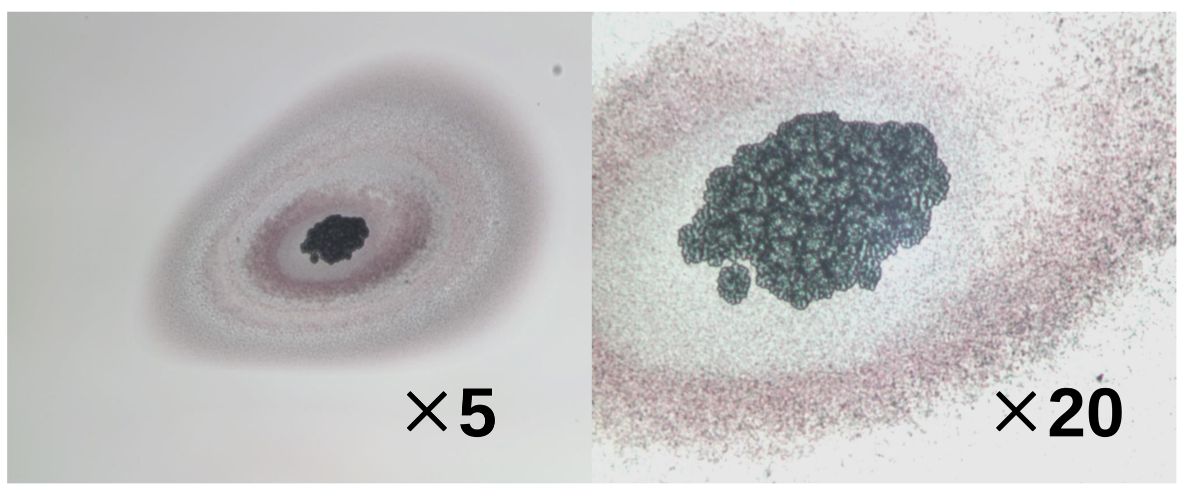




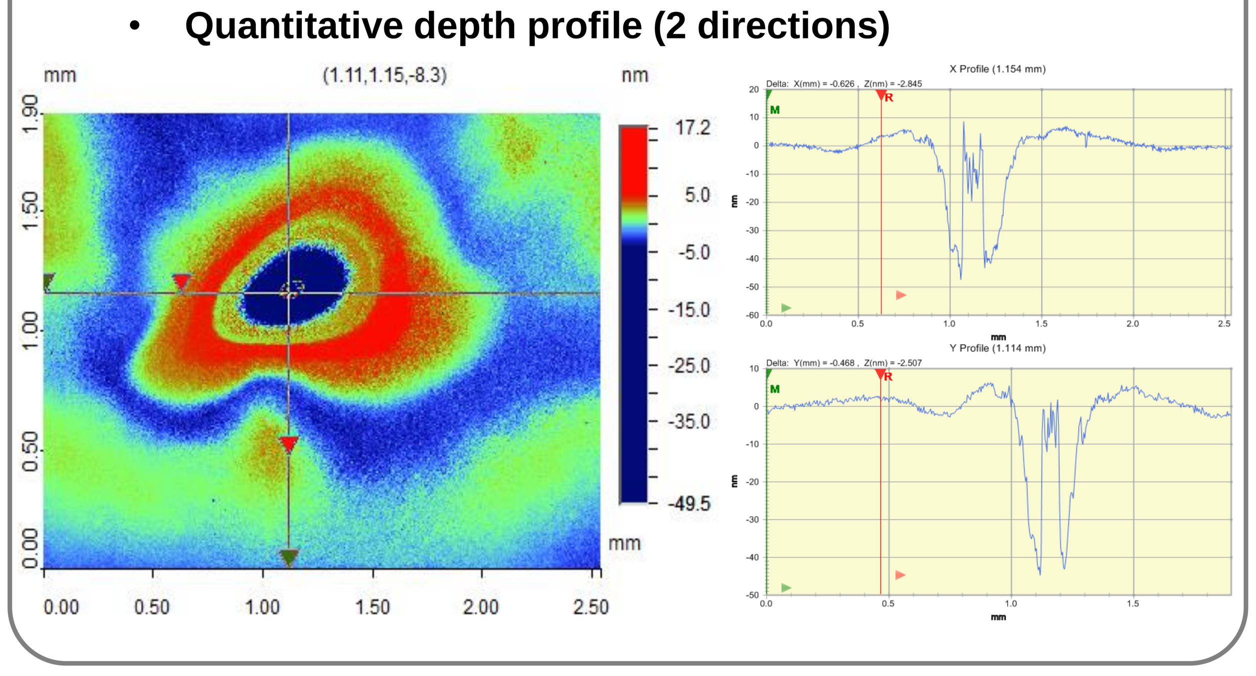
- **Wavelength selection: 121.6 nm**
  - **Working wavelength of the mirror**
  - **Common wavelength for chemical researches in DCLS**
- **20Hz repetition, 2 ps pulse duration, Normal incidence**

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**

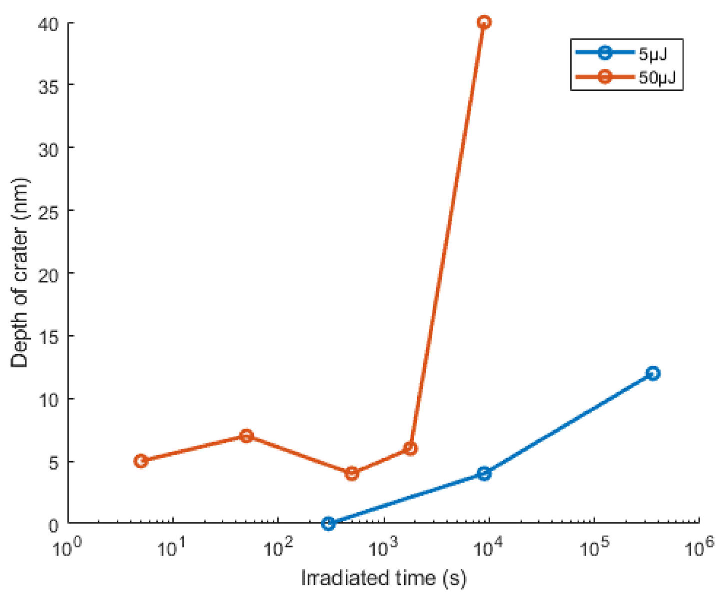


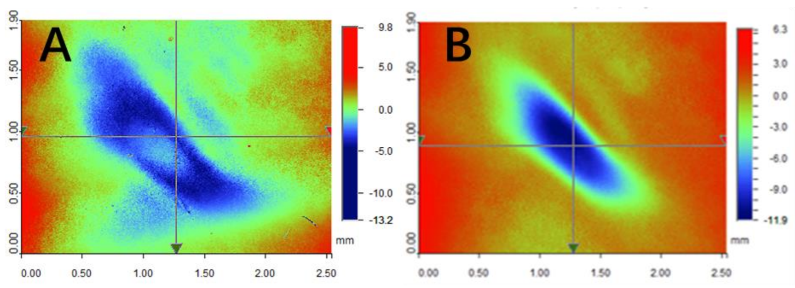
- **Profilometer**
  - **Quantitative depth profile (2 directions)**



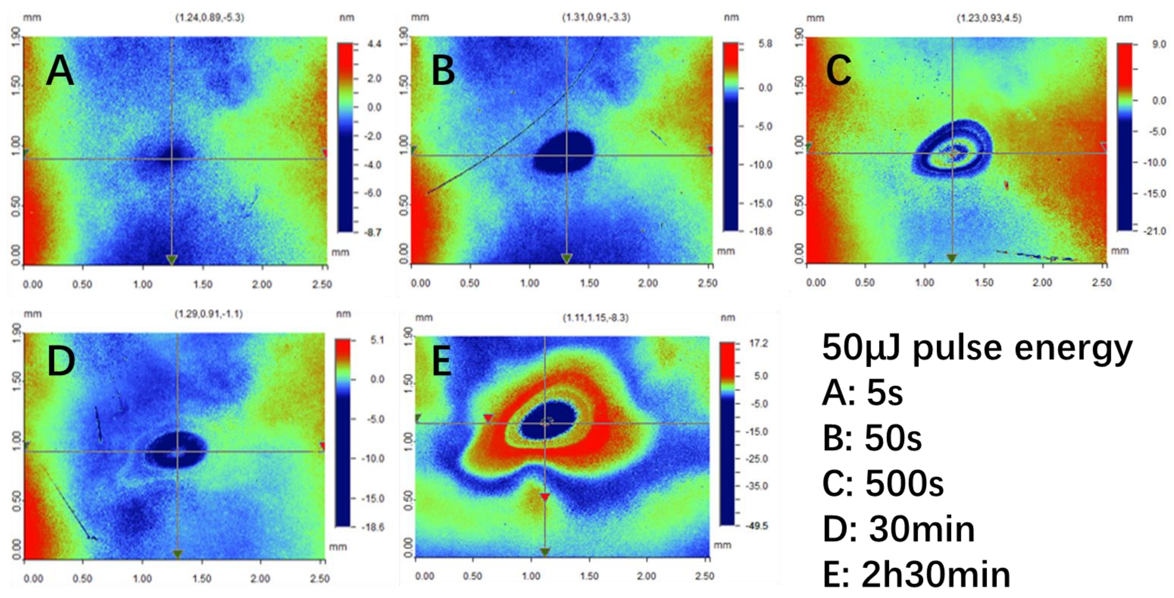
III. Result Overview

- **Accumulation of crater depth observed**
  - **Still considered single shot (20Hz)**
- **Threshold is lower than 5µJ pulse energy (~2mJ/cm²)**
  - **Damage of diffraction order observed**





5µJ pulse energy
A: 2h30min
B: 10h



50µJ pulse energy
A: 5s
B: 50s
C: 500s
D: 30min
E: 2h30min

IV. Theoretical approaches

1. **Single-shot damage threshold calculation**
   - **Damage should occur when pulse energy>233 µJ**

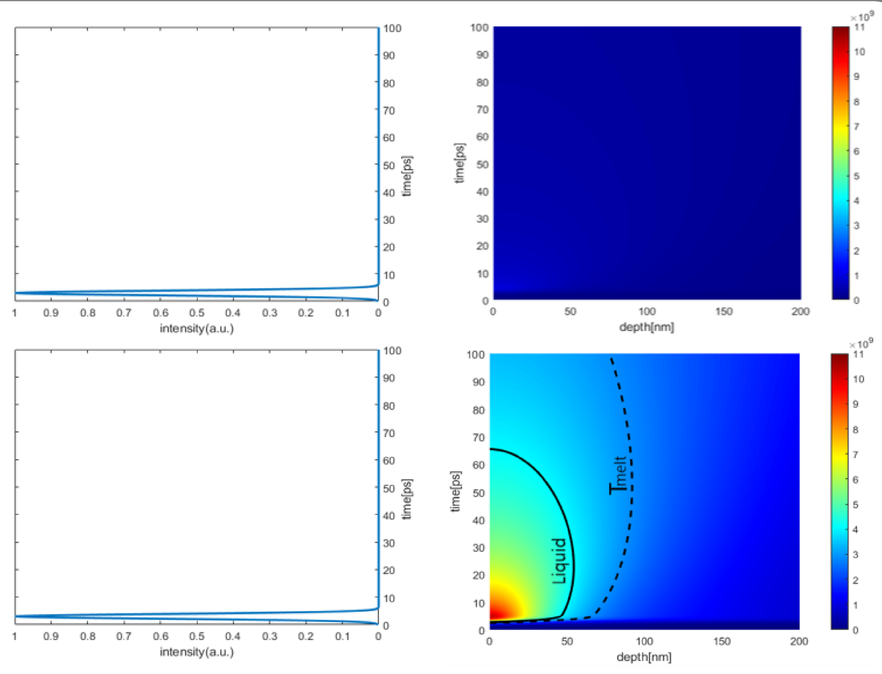
$$\begin{cases} W_{melt} = 3k_B T_{melt} \\ W_{atom} = \dfrac{4\ln 2(1-R)W_{pulse}\, m \sin\theta}{\pi b_{fwhm}^2 d\rho_m} \end{cases}$$

Damage should occur when: $W_{atom} > W_{melt}$

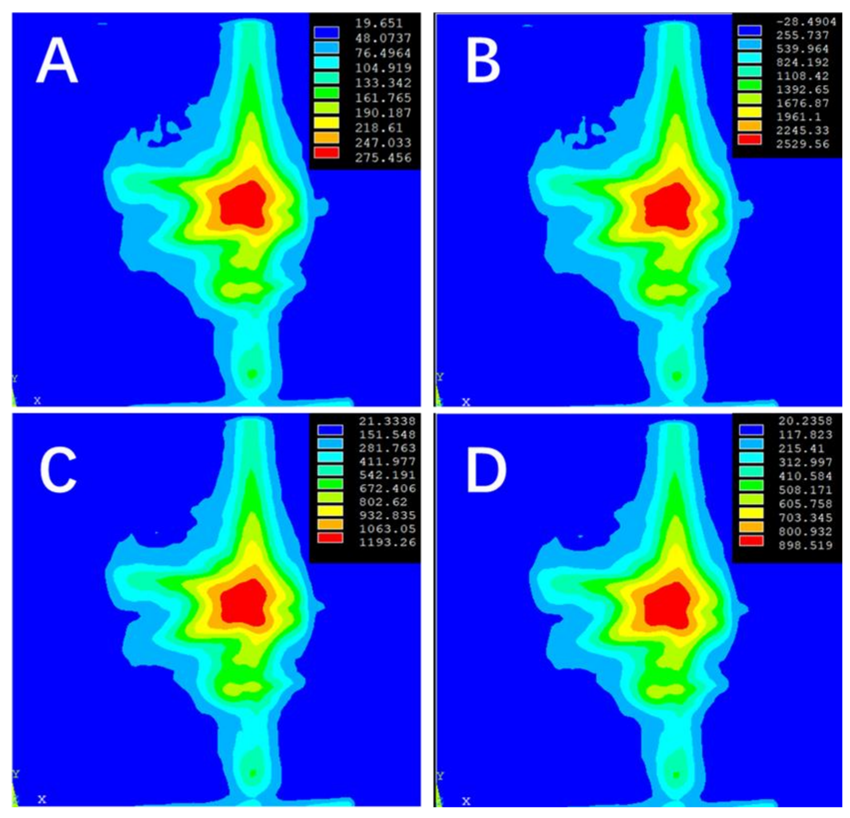
2. **One-dimensional thermal diffusion [1]**
   - **Simulation indicates that damage should occur for 50µJ pulse energy, but not for 5µJ pulse energy**

$$\begin{cases} h_{melt} = C(T)(T-T_0) \\ h_{liquid} = h_{melt} + \Delta h_{latent\ heat} \end{cases} \qquad \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(\frac{K}{C}\frac{\partial h}{\partial x}\right) + S$$

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



One-dimensional thermal diffusion simulation



Finite element analysis of temperature distribution

Conclusion

- **SSDT is NOT found for Au thin film @121.6nm FEL beam irradiation**
  - **It should be lower than 5µJ pulse energy (~2mJ/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.**

[1] Sobierajski, R. *et al*. Role of Heat Accumulation in the Multi-Shot Damage of Silicon Irradiated with Femtosecond XUV Pulses at a 1 MHz Repetition Rate. Opt. Express 2016, 24 (14), 15468. https://doi.org/10.1364/OE.24.015468.

PhotonMEADOW23 Trieste, Italy 12-14 September 2023