Progress on Laser Induced Damage Studies of Grazing Incidence Metal Mirrors

Mark S. Tillack
T. K. Mau
Mofreh Zaghloul

UCSD

Laser-IFE Program Workshop
May 31-June 1, 2001
Naval Research Laboratory

Statement of Purpose and Deliverables

Statement of purpose

Our research seeks to develop improved understanding of damage mechanisms and to demonstrate acceptable performance of grazing incidence metal mirrors, with an emphasis on the most critical concerns for laser fusion. Through both experimentation and modeling we will demonstrate the limitations on the operation of reflective optics for IFE chambers under prototypical environmental conditions.

Deliverables (2 mo. delayed funding):

Measure LIDT at grazing incidence with smooth surfaces.	Sept. 1, 2001
Model reflectivity and wavefront changes of smooth surfaces.	Sept. 1, 2001
Measure effects of defects and surface contaminants on reflectivity, LIDT and wavefront.	April 1, 2002
Model reflectivity and wavefront changes due to defects and contamination.	April 1, 2002

Budget: $330k

UCSD

Outline

1. Experiments

a. Mirror fabrication and characterization

b. Beam characterization

c. Reflectometry

– reflectivity at shallow angles

– in-situ damage monitoring

d. Damage results at grazing angles

– Al 6061

– Al 1100

2. Modeling

a. Scattering results

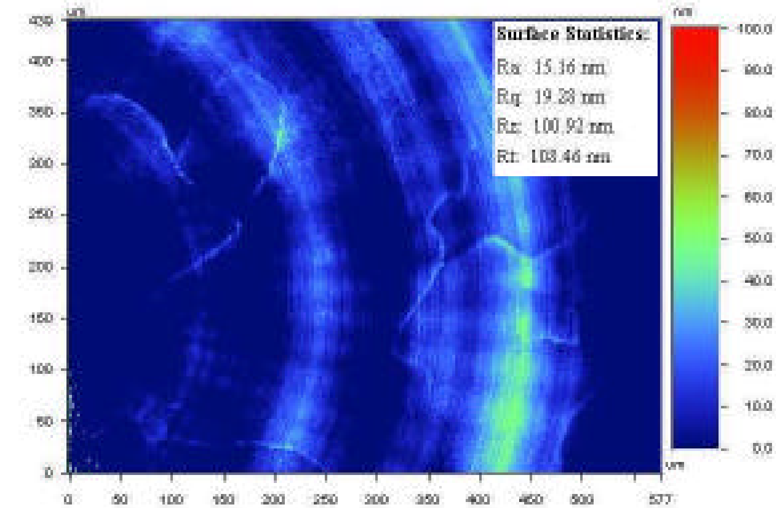
b. ZEMAX

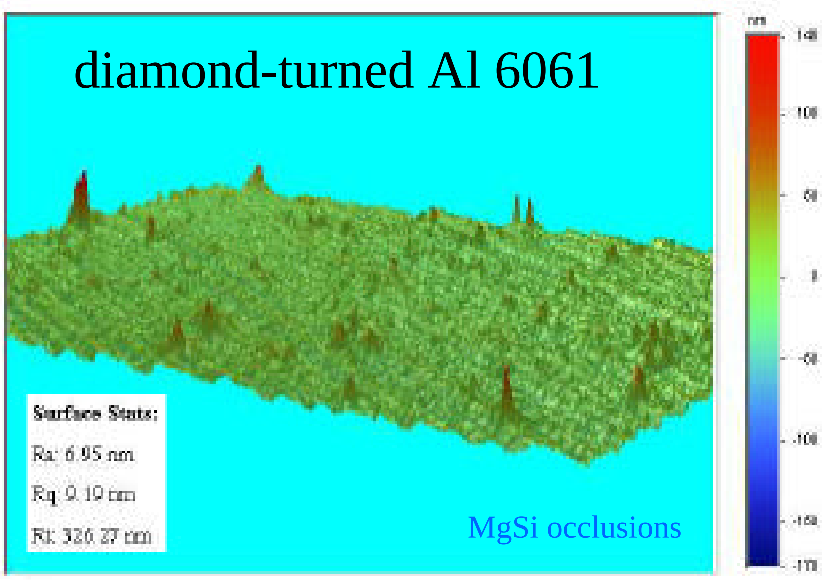
3. Future plans

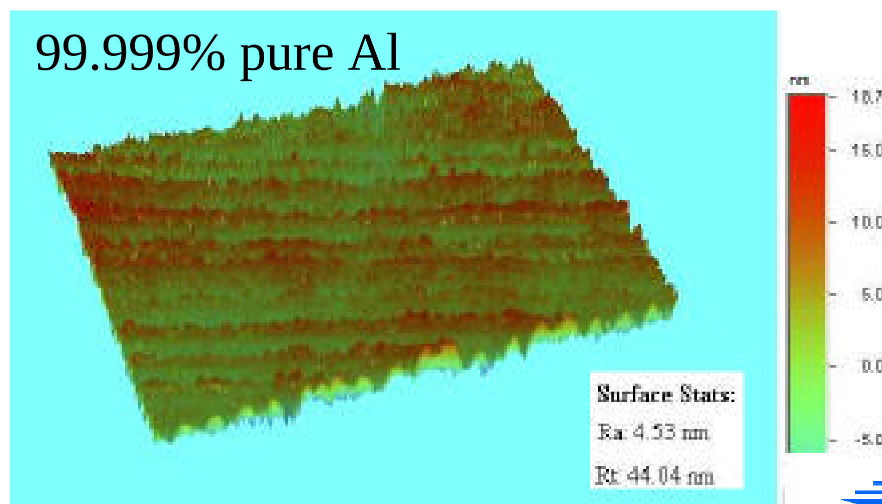
UCSD

Several new surface types have been fabricated:
1. Diamond-turned flats

Al 1100







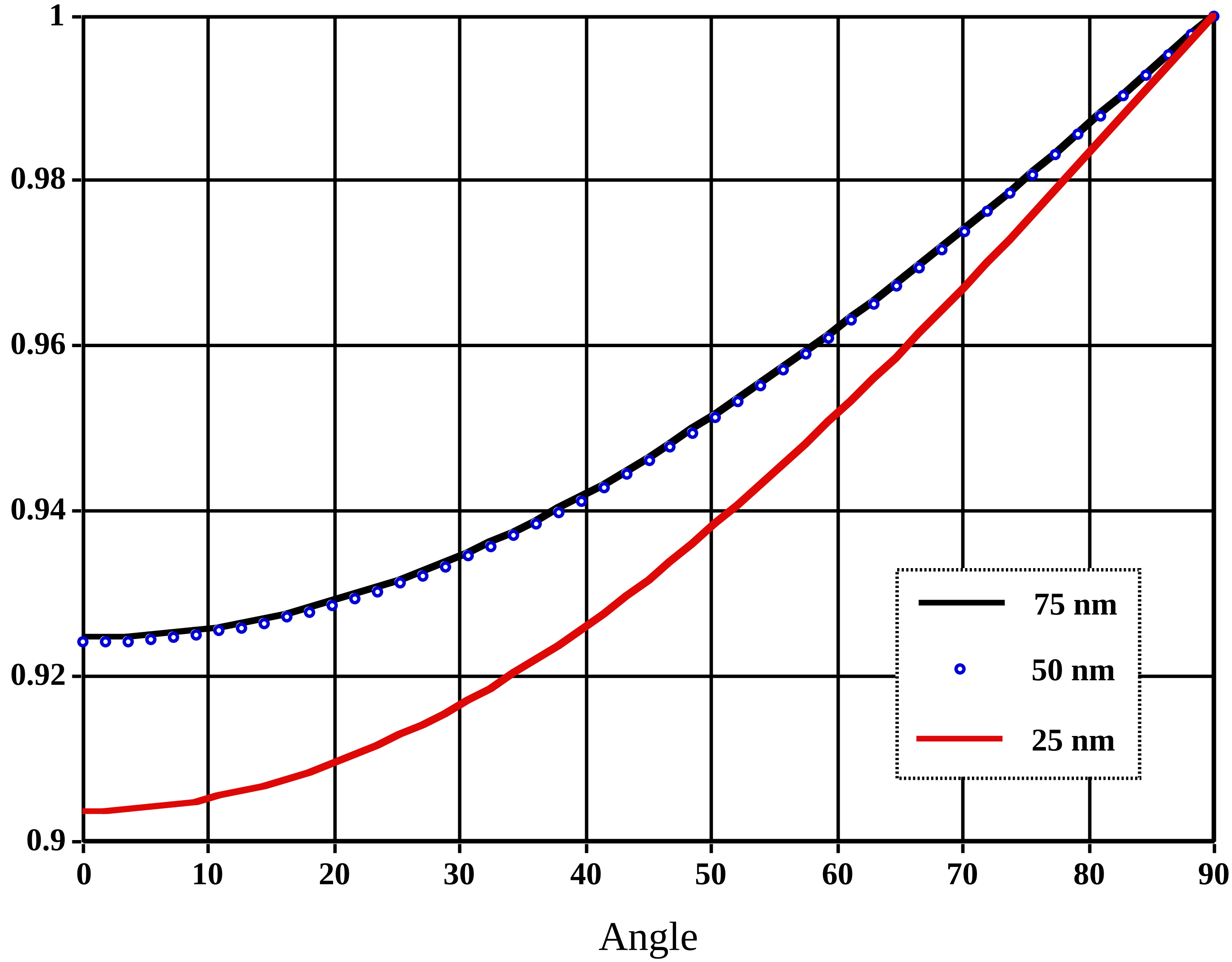
UCSD

Several new surface types have been fabricated:
2. Sputter coated substrates

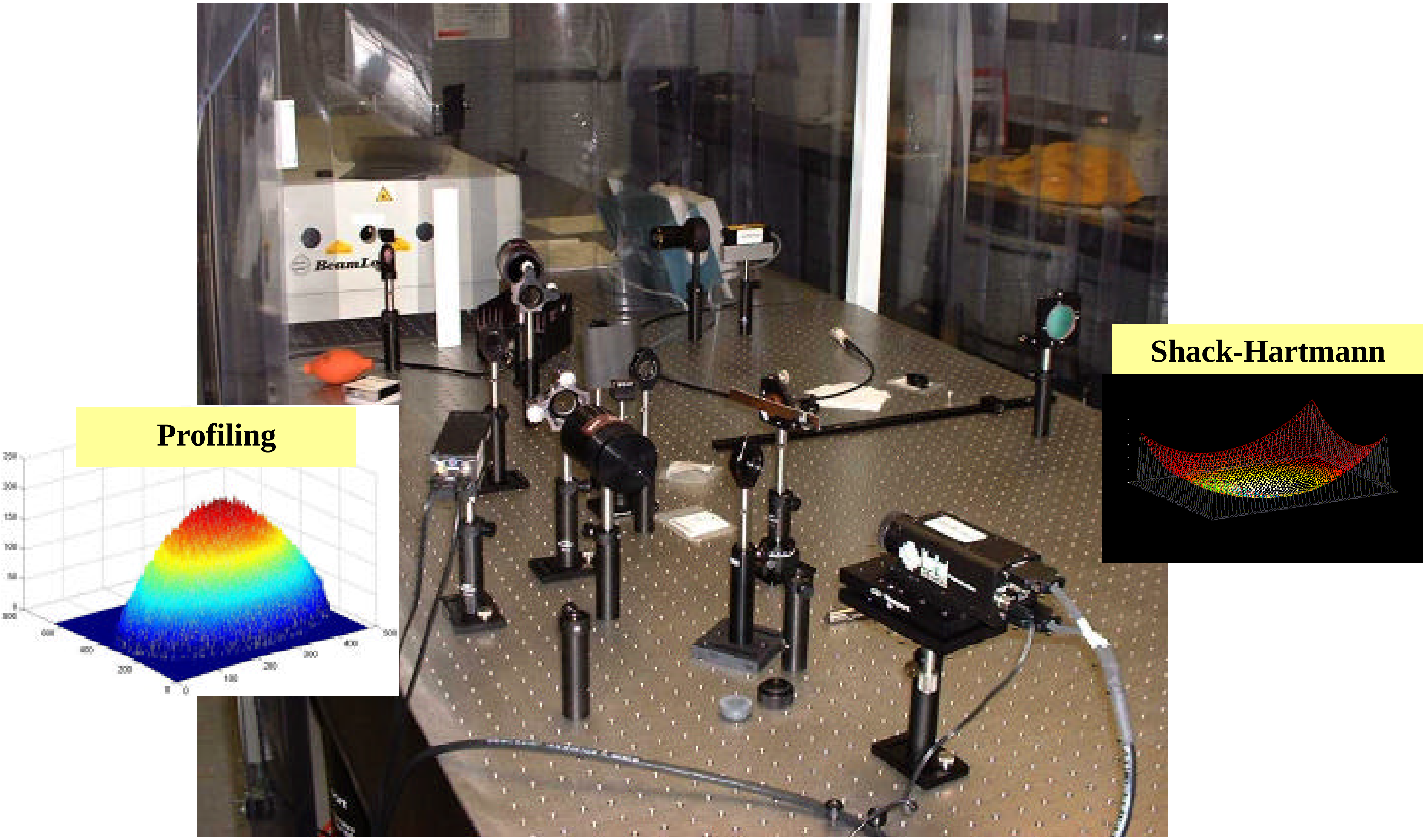
- Ordinary Si wafers aren't flat enough (15 microns)
- Large polished substrates are expensive
- However, substrates can be recycled

UCSD

Minimum Thickness of Sputtered Al Needed



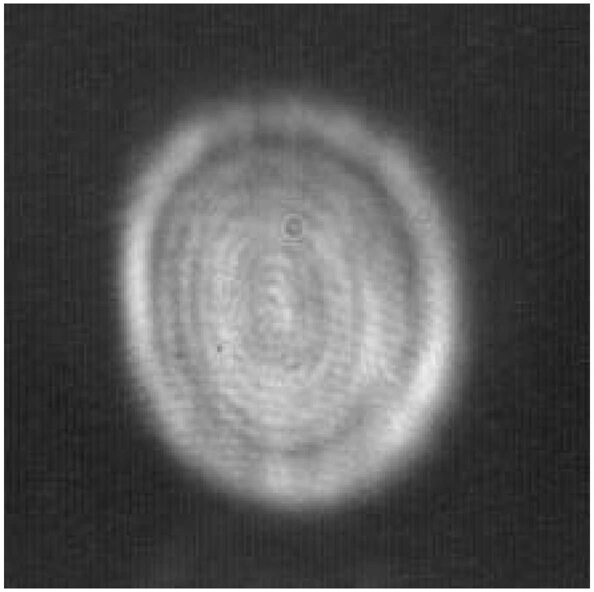
Beam characterization has been installed

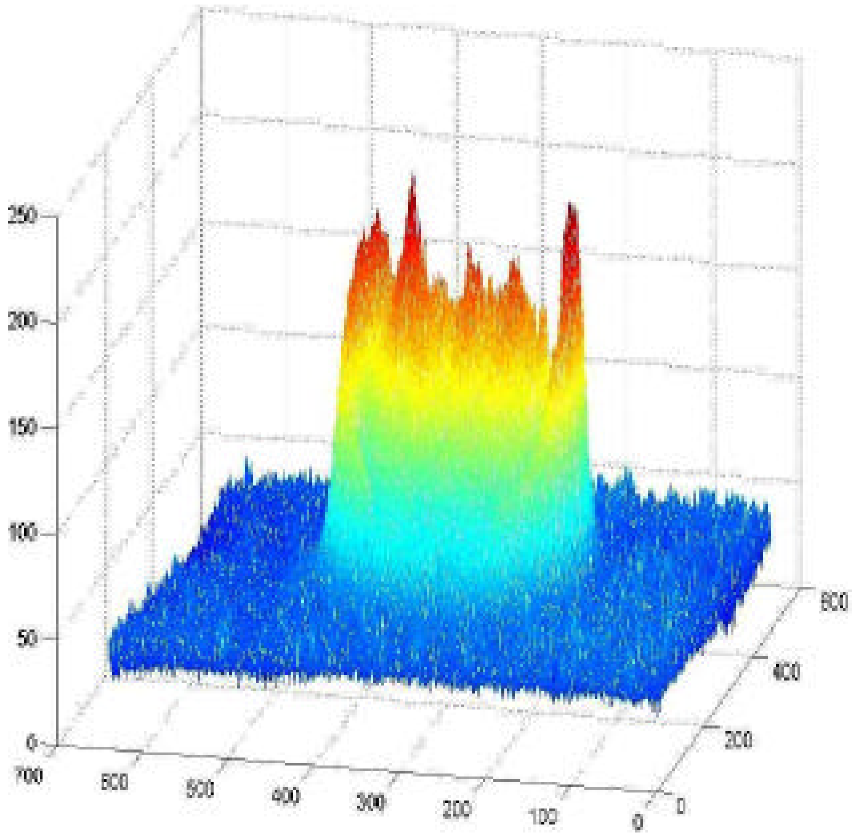


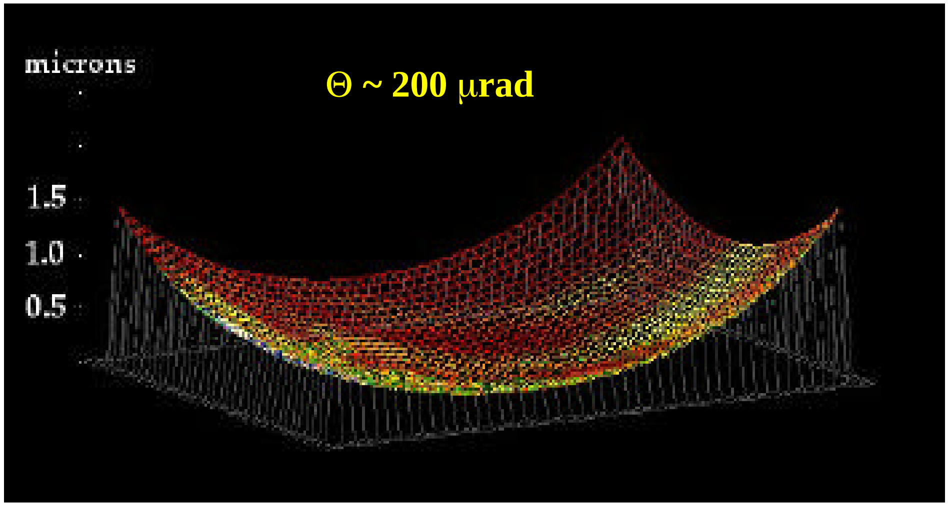
Profiling

Shack-Hartmann

Spatial profile and wavefront of the Nd:YAG laser

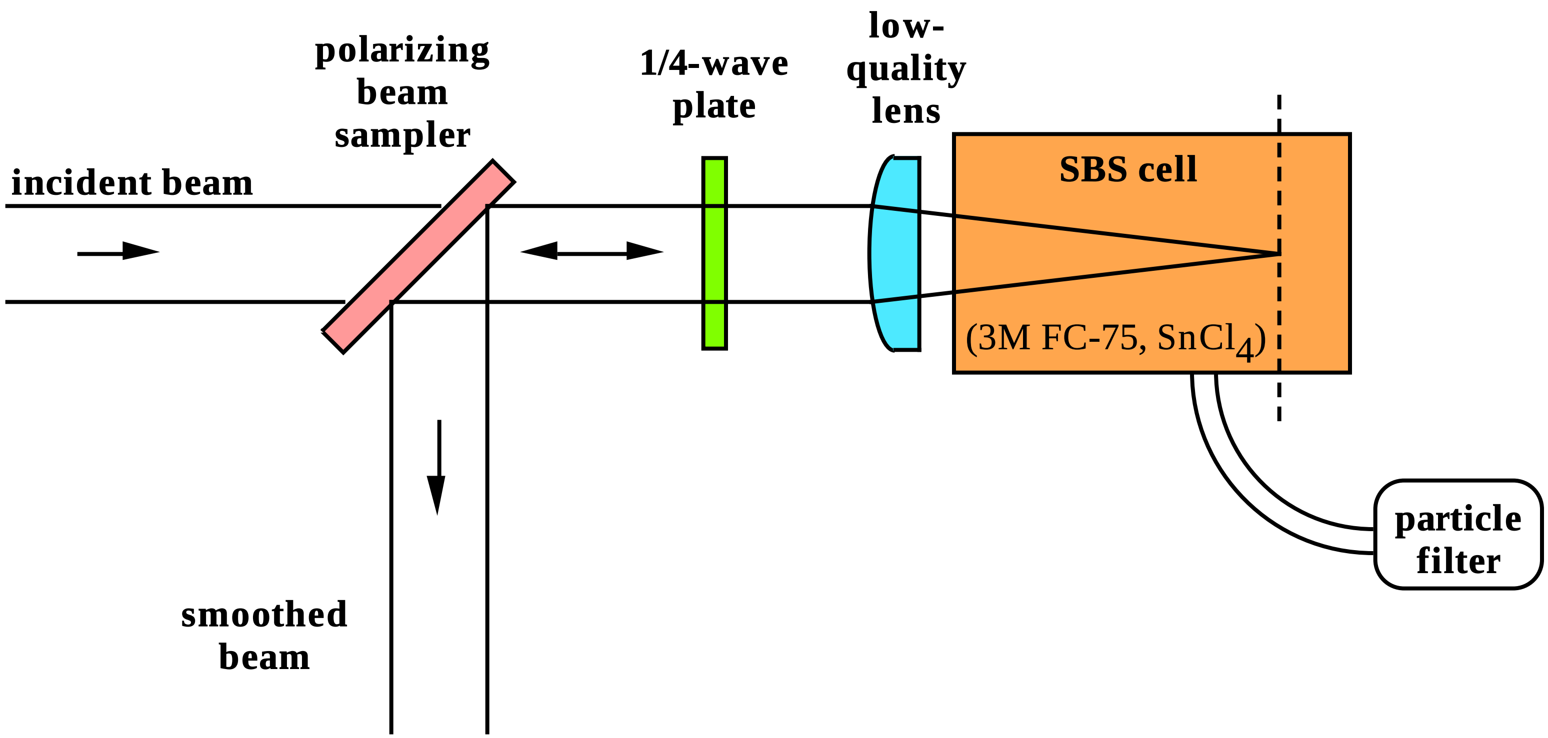






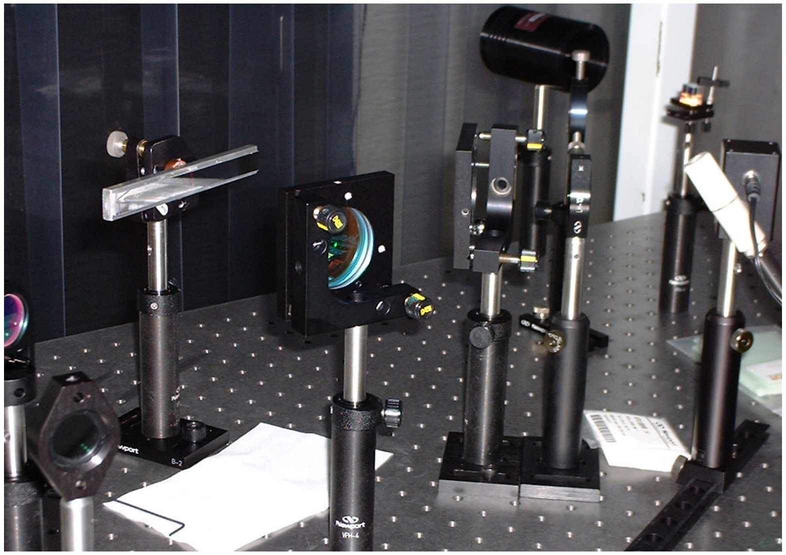
UCSD

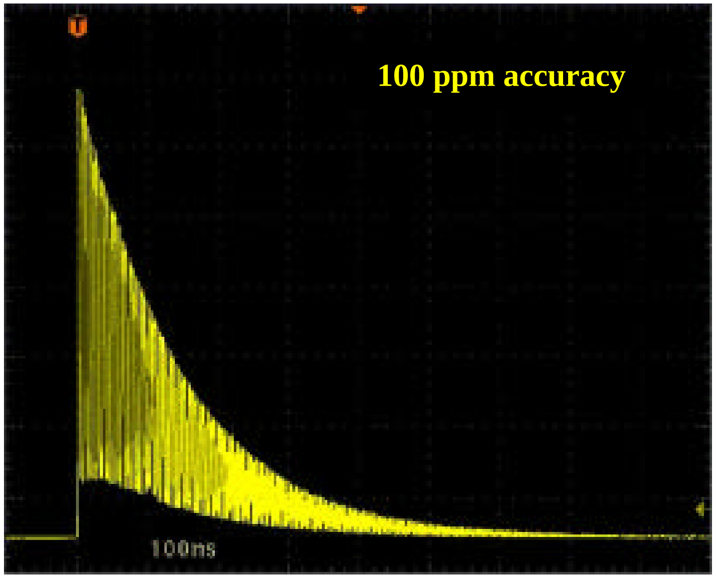
Beam Smoothing with SBS

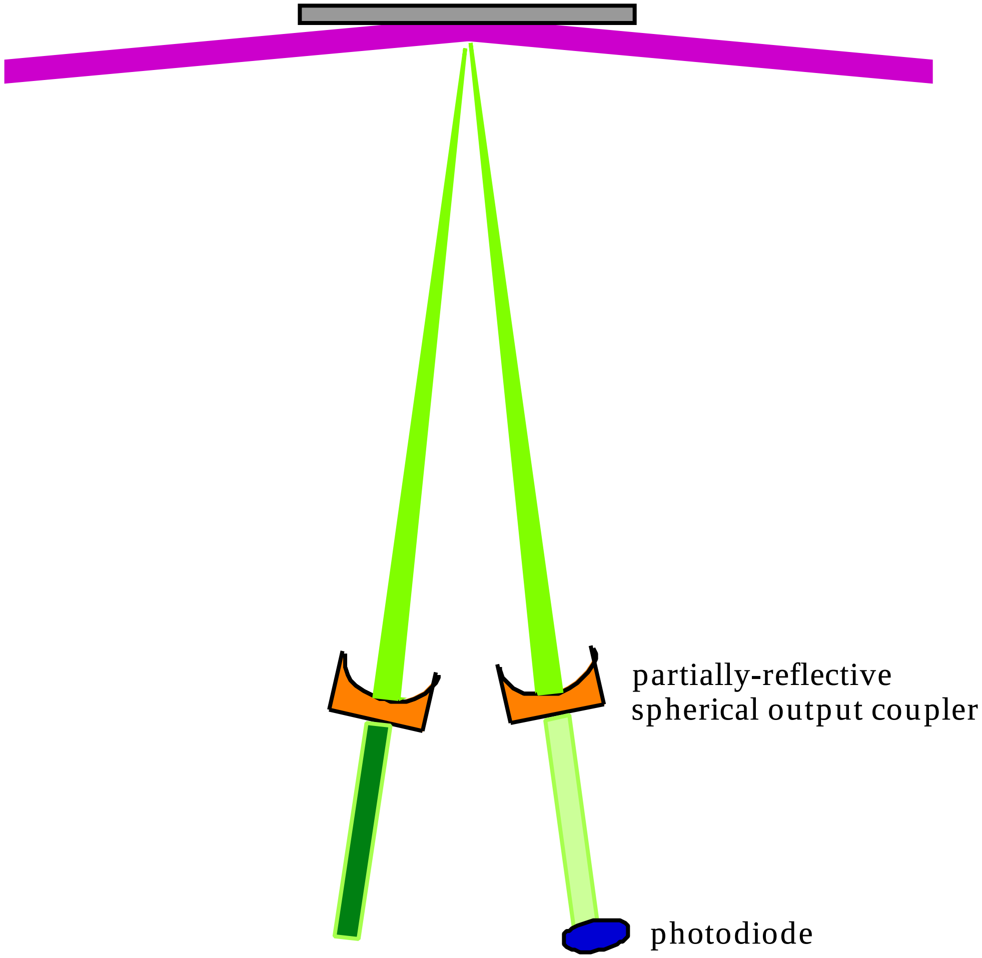


UCSD

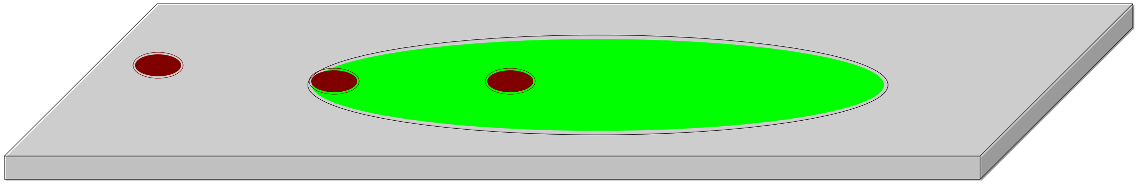
The reflectometer is fully functional and used for in-situ surface monitoring

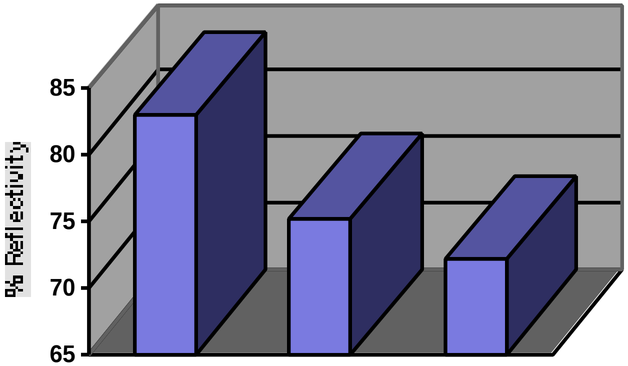




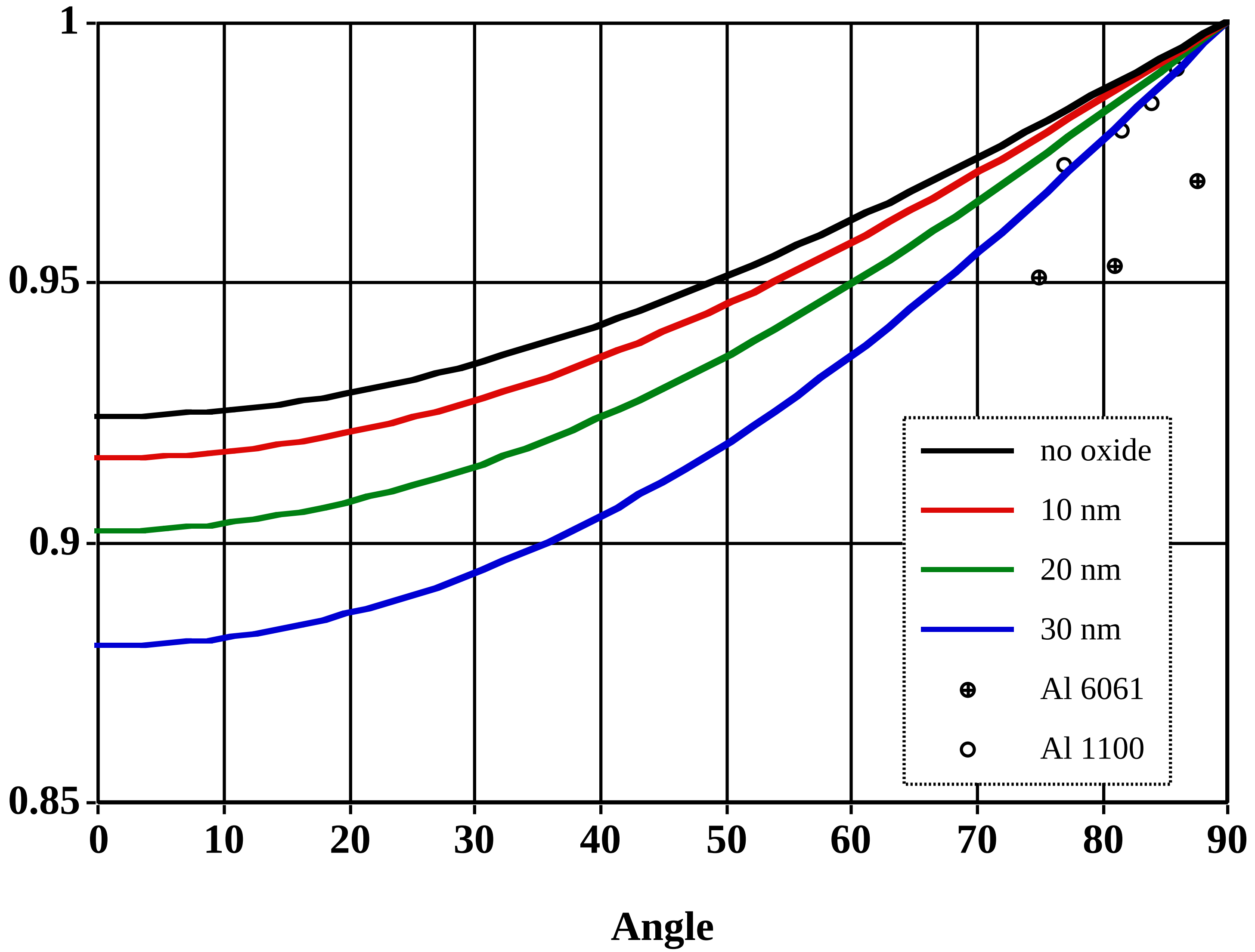


In-situ reflectometry can measure surface changes not visible to the naked eye





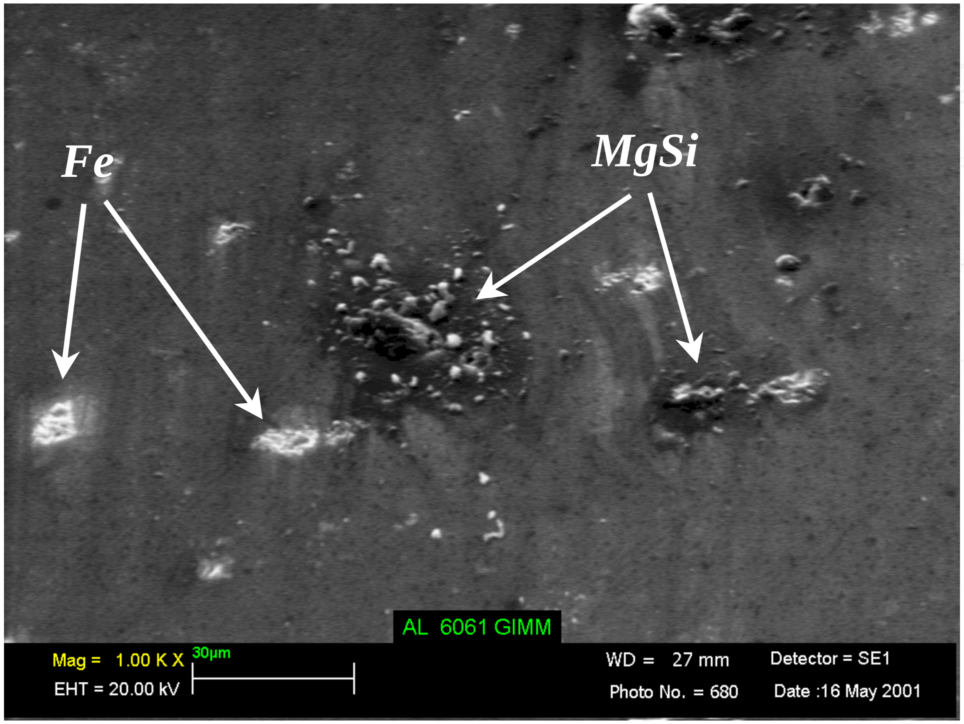
Shallow angle reflectivity measurements of undamaged surfaces



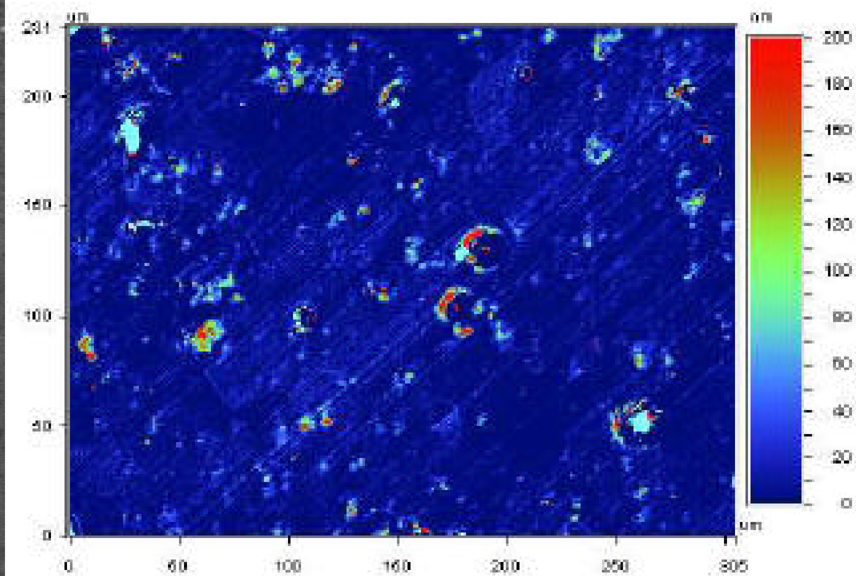
UCSD

Damage to Al 6061 at grazing angle

Several shots at 80˚, 1 J/cm^2 peak



1000x



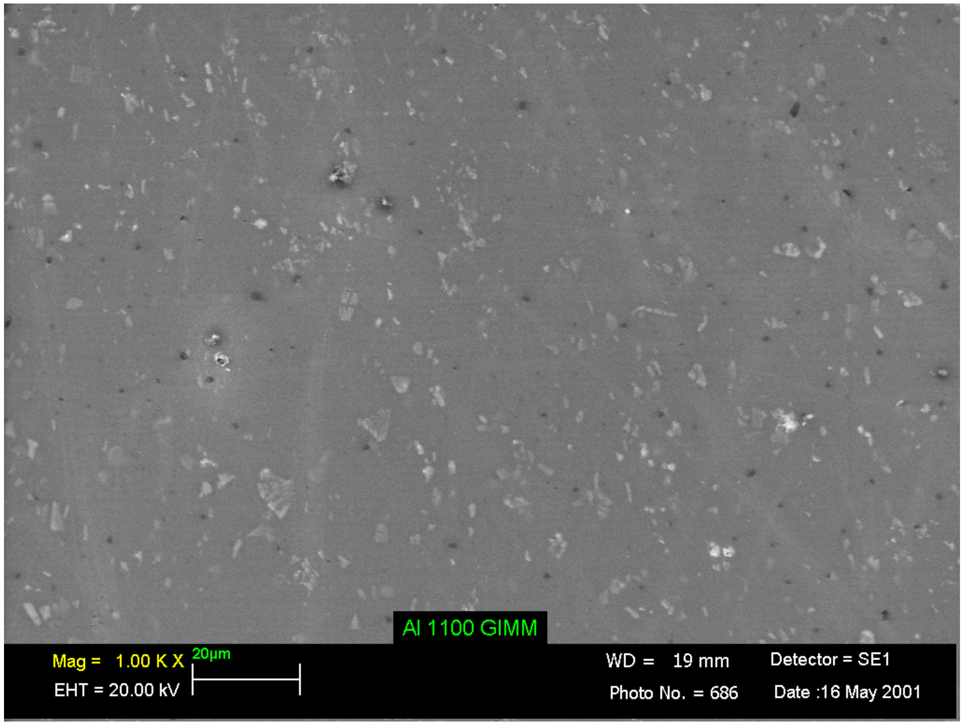
Ra: 19.45 nm
Rq: 47.21 nm
Rz: 1.43 um
Rt: 1.92 um

- Damage occurs at a higher fluence compared with normal incidence
- Silicide occlusions in Al 6061 preferentially absorb light, causing explosive ejection and melting
- Fe impurities appear unaffected

UCSD

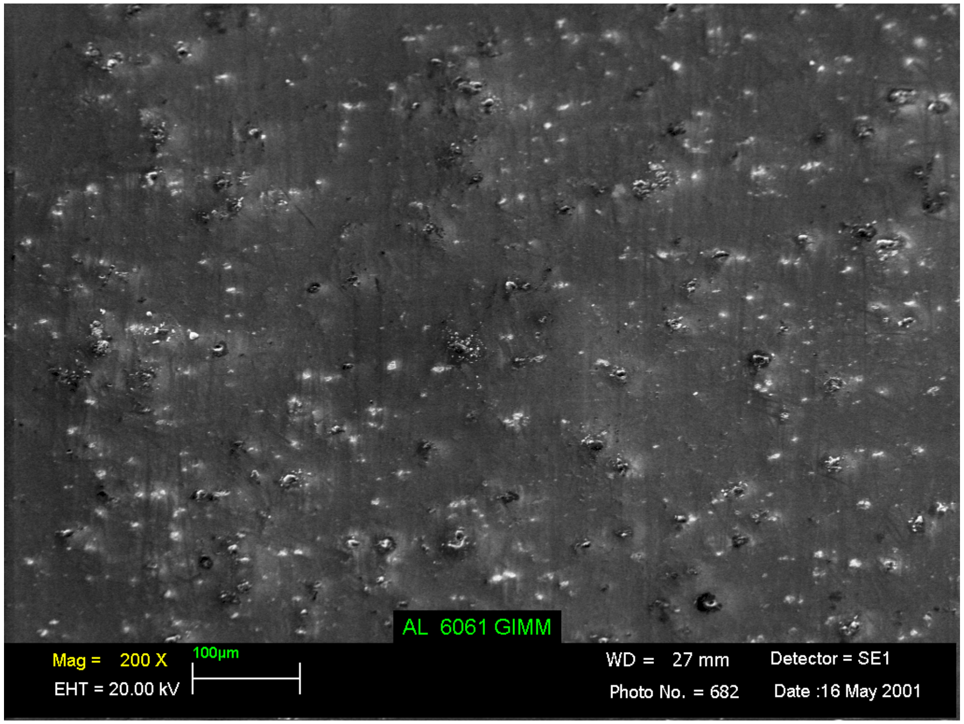
Al 1100 shows no apparent damage at 1 J/cm^2

1000 shots at 85˚, 1 J/cm^2 peak



1000x

Al 6061, for comparison



200x

UCSD

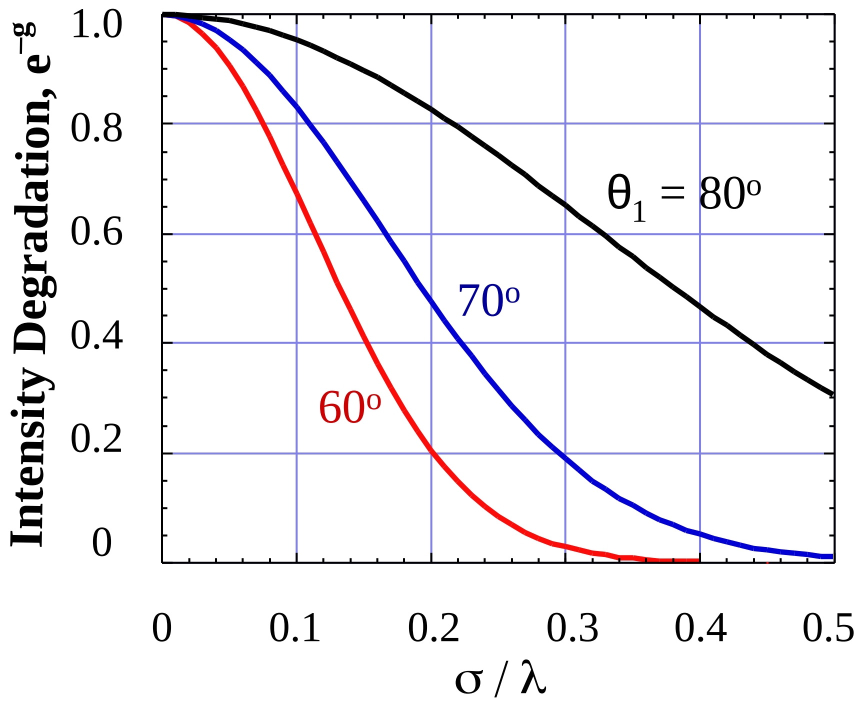
Tools for modeling effects of damage on beam characteristics

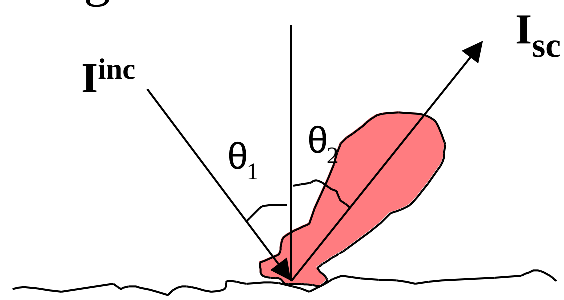
UCSD

Dimensional Defects		Compositional Defects	
Gross deformations, $\delta>\lambda$	Surface morphology, $\delta<\lambda$	Gross surface contamination	Local contamination
CONCERNS			
• Fabrication quality • Neutron swelling • Thermal swelling • Gravity loads	• Laser-induced damage • Thermomechanical damage	• Transmutations • Bulk redeposition	• Aerosol, dust & debris
MODELLING TOOLS			
Optical design software (ZEMAX)	**Scattering by rough surfaces (Kirchhoff)**	**Fresnel multi-layer solver**	Scattering by particles

Specularly reflected intensity is degraded by induced mirror surface roughness

- The effect of induced surface roughness on beam quality was investigated by Kirchhoff wave scattering theory.
- For cumulative laser-induced and thermomechanical damages, we assume Gaussian surface height statistics with rms height σ.





$$\langle I^{sc} \rangle = I_0 e^{-g} + \langle I_d \rangle$$

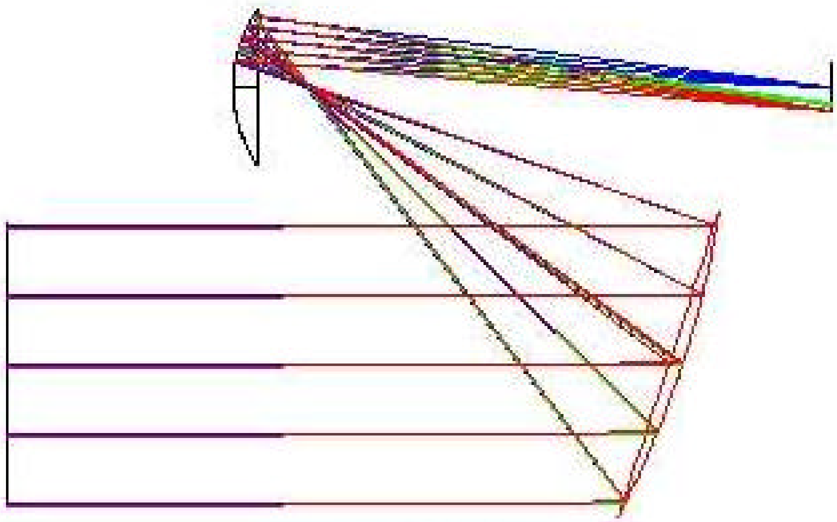
I_o : reflected intensity from smooth surface
I_d : scattered incoherent intensity
g : $(4\pi\sigma\cos\theta_1/\lambda)^2$

e.g., at $\theta_1 = 80^o$, $\sigma/\lambda = 0.1$, $e^{-g} = 0.97$

- **Grazing incidence is less affected by surface roughness**
- **To avoid loss of laser beam intensity, $\sigma / \lambda < 0.01$**

UCSD

Ray Tracing with ZEMAX

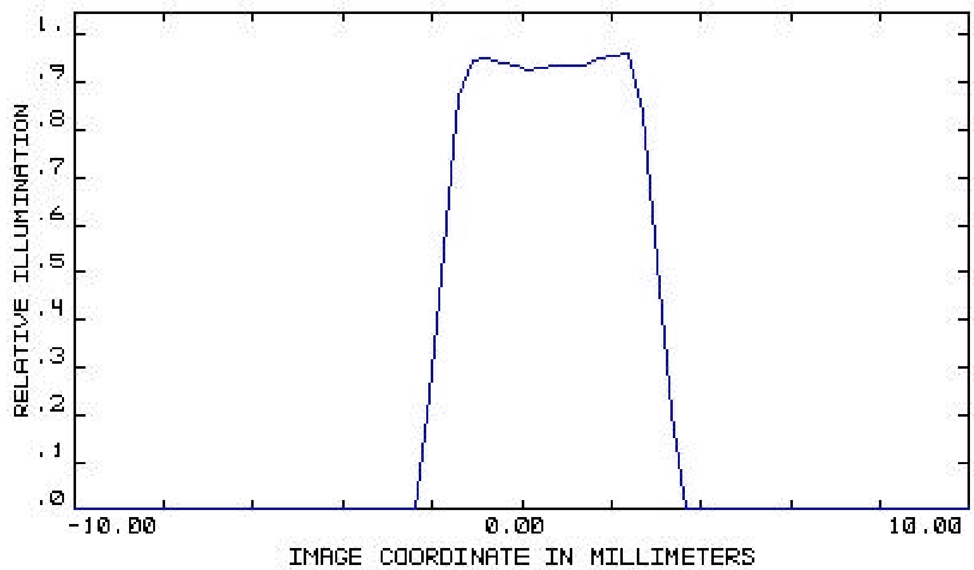


ZEMAX commercial software was installed

Example problem:

Rays at object plane emitted at three angles.

Illumination profile at image plane



Tasks:

- Evaluate surface deformation from expected loads.
- Quantify allowable surface deformation (shape and size) to meet beam propagation requirements (spot size/location, intensity uniformity, absorption).

Goals for next period of performance

- Compare damage on 99.999% Al with Al-1100
- Perform tests at 5 J/cm^2
- Perform sub-threshold irradiation of amorphous Al to explore recrystallization
- Establish methods for creating contaminated surfaces
- Obtain samples for neutron irradiation
    - multi-layer dielectric mirror
    - Al mirror
- Exercise ZEMAX to assess wavefront degradation

UCSD

Final Optic Threats and Planned Research Activities

Final Optic Threat	**Requirement**	**Evaluation**	**Mitigation**
Defects and swelling (γ-rays and neutrons)	Absorption loss <1% Wavefront distortion <0.1 μm	^{60}Co, γ/n° irradiation (Al, SiO_2, CaF_2) PIE Modeling	Annealing Adaptive optics
Optical damage by laser (LIDT)	>5J/cm^2 threshold (normal to beam)	Test Al GIMM Test LIDT of irradiated optics	Optimize surfaces Recondition surfaces
Contamination	Absorption loss <1% >5 J/cm^2 damage threshold	Evaluate losses and damage due to thin films	Calculate effect of gas blocking Evaluate feasibility of fast shutter
Ablation by x-rays	<10^{-4} monolayer per shot	Measure rate for Al, SiO_2 and CaF_2 optics Model very small ablation rates	Evaluate wavefront distortion and pump power for gas puff
Sputtering by ionic debris	<10^{-4} monolayer per shot	Calculate sputtering with existing models and data base	Analyze feasibility of mag. deflection Evaluate gas puff

Final Optics Program Plan

RADIATION DAMAGE *(neutron and gamma effects)*

- Scoping Tests: Irradiation & PIE (incl. annealing)
- Damage modeling
- Extended testing of prime candidates

LASER-INDUCED DAMAGE

- LIDT scoping tests for GIMM, materials development
- Laser damage modeling, 3ω data from NIF
- System Integration

CONTAMINATION THREATS

- Modeling
- Test simulated contaminants
- Mitigation
- System Integration

X-RAY ABLATION

- Scoping tests (laser-based x-ray source)
- Modeling
- Mitigation
- System Integration

ION SPUTTERING

- Calculate sputtering, gas attenuation
- Mitigation
- System Integration

FY 2001 | FY 2002 | FY 2003 | FY 2004 | FY2005

Normal incidence reflectivity of several metals