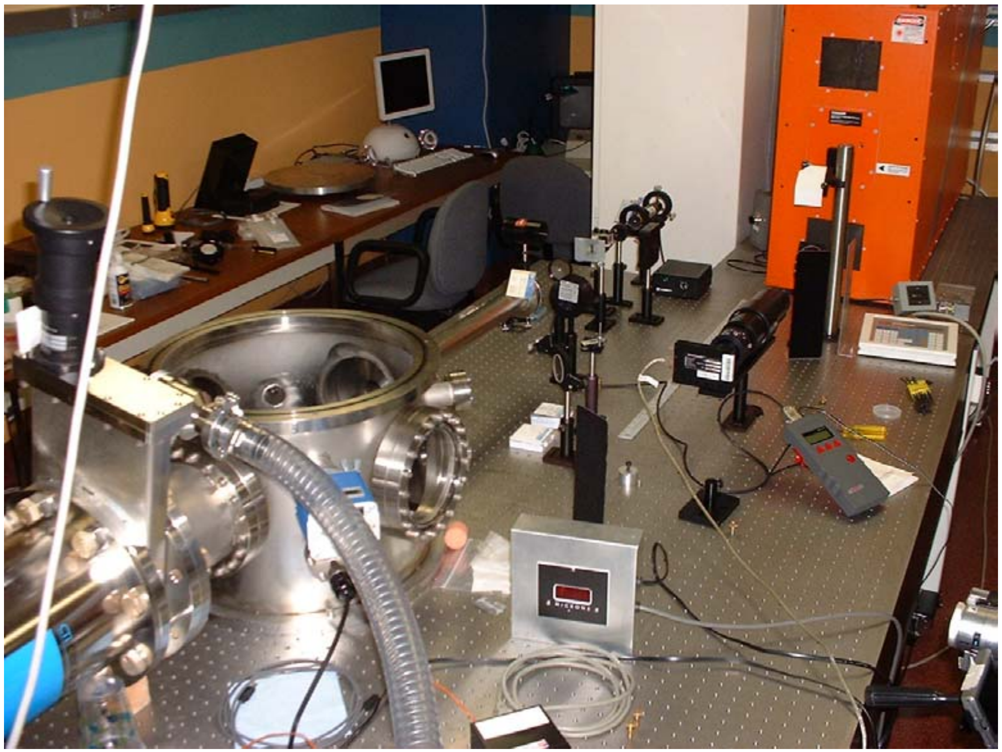
The end game for aluminum GIMM fabrication & laser-induced damage testing



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UC San Diego

HAPL Project Meeting
NRL
3–4 March 2005

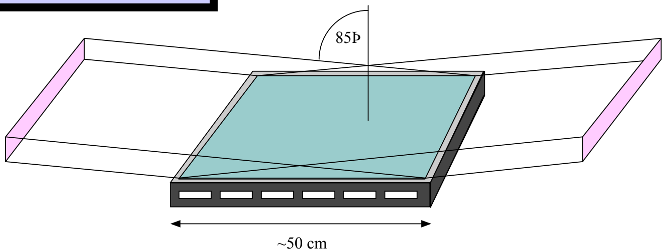
http://aries.ucsd.edu/HAPL

The steps to develop a final optic for a Laser IFE power plant (1 of 2)

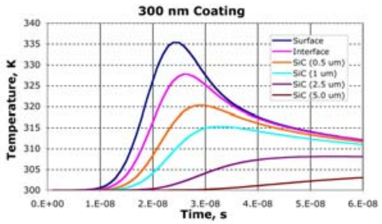
1. "Front runner" final optic – Al coated SiC GIMM:
UV reflectivity, industrial base, radiation resistance

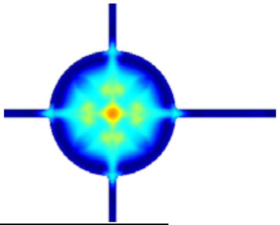
Key Issues:

- *Shallow angle stability*
- *Laser damage resistance goal = 5 J/cm², 10^8 shots*
- *Contamination*
- *Optical quality*
- *Fabrication*
- *Radiation resistance*



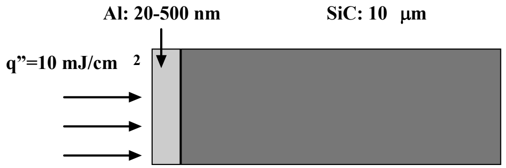
2. Characterize threats to mirror:
LIDT, radiation transport, contaminants



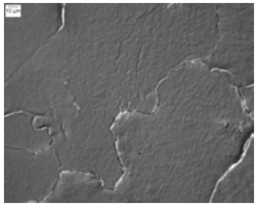


3. Perform research to explore damage mechanisms, lifetime and mitigation

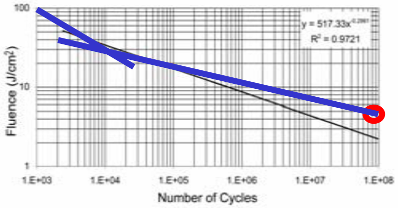
Bonding/coating



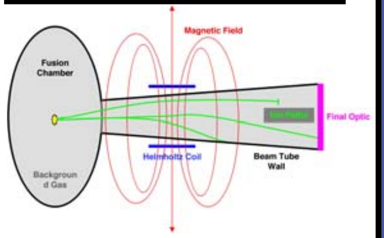
Microstructure



Fatigue

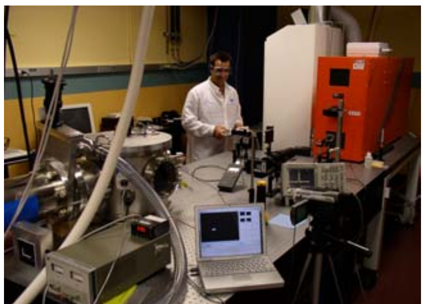


Ion mitigation



The steps to develop a final optic for a Laser IFE power plant (2 of 2)

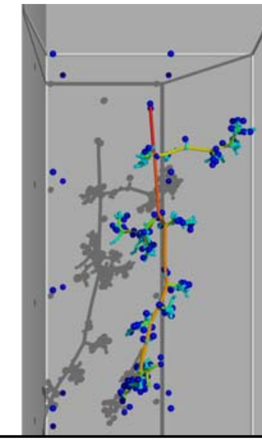
4. Verify durability through exposure experiments



10 Hz KrF laser
UCSD (LIDT)

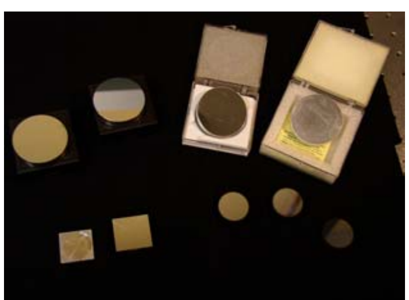
XAPPER
LLNL (x-rays)

ion accelerator, LLNL



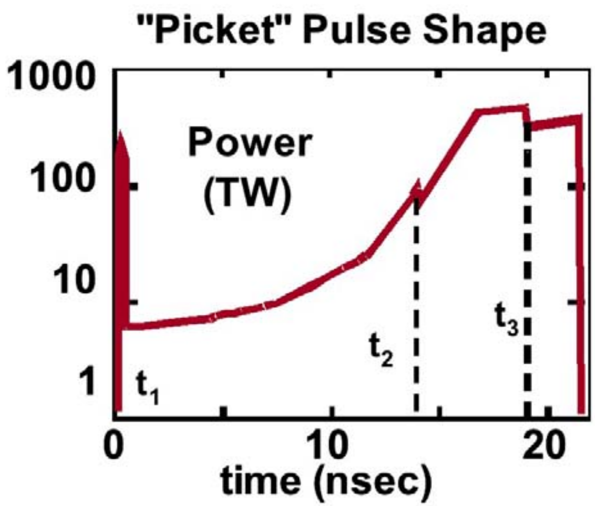
neutron modeling
and exposures

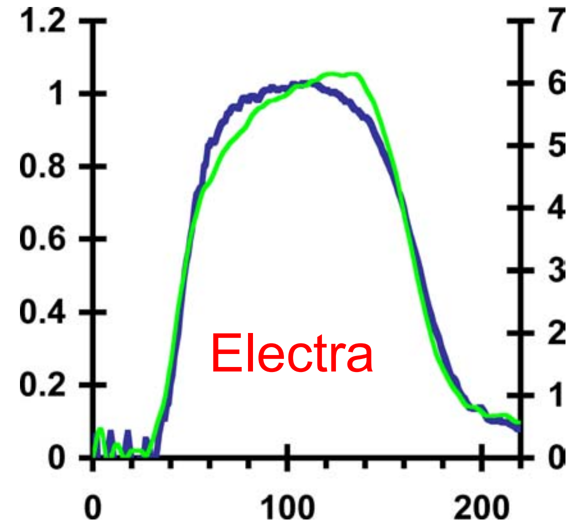
5. Develop fabrication techniques and advanced concepts

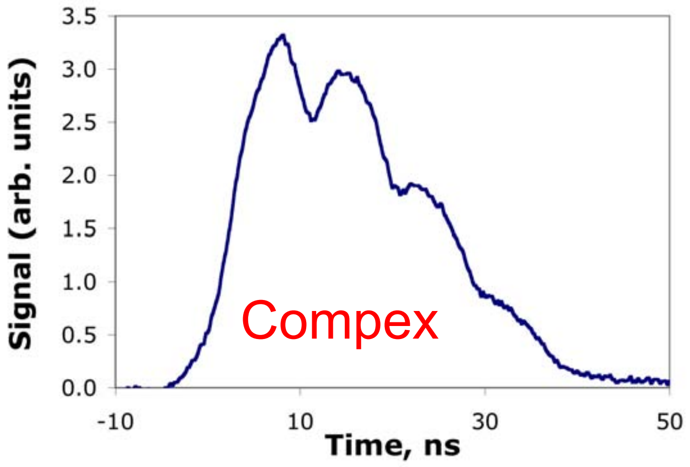


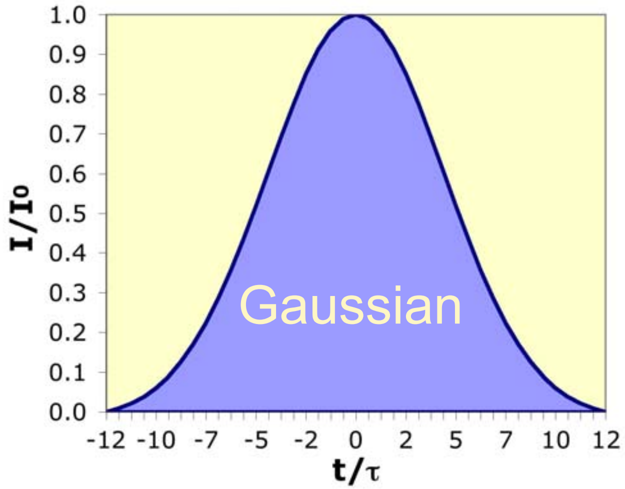
6. Perform full-scale testing

Aluminum temperature and gradient were analyzed for 10 mJ/cm² energy pulses

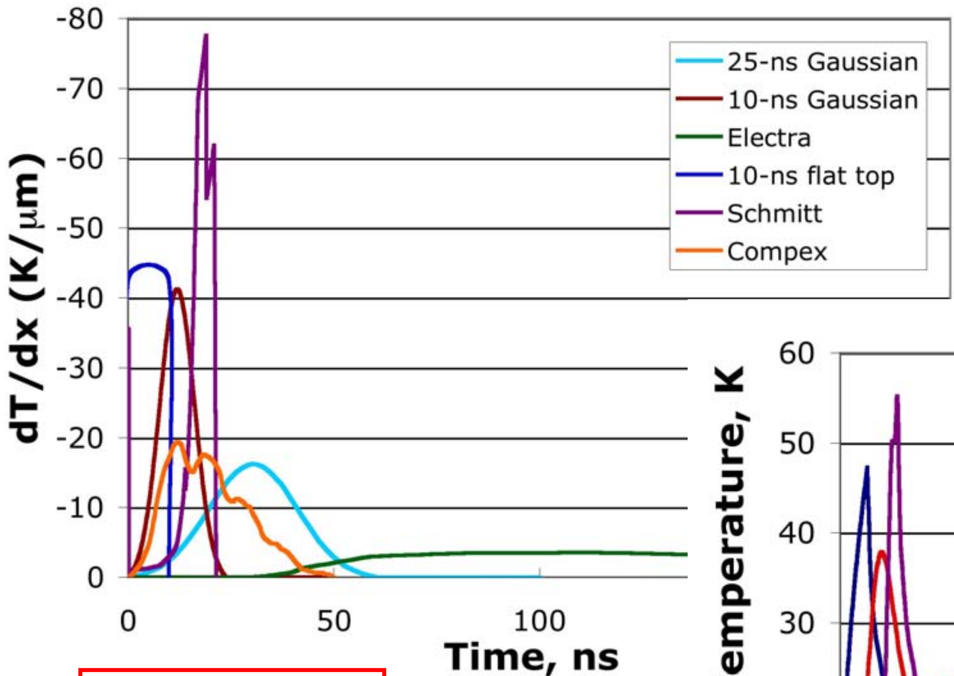








A power plant heat source will be more damaging than our simulation sources

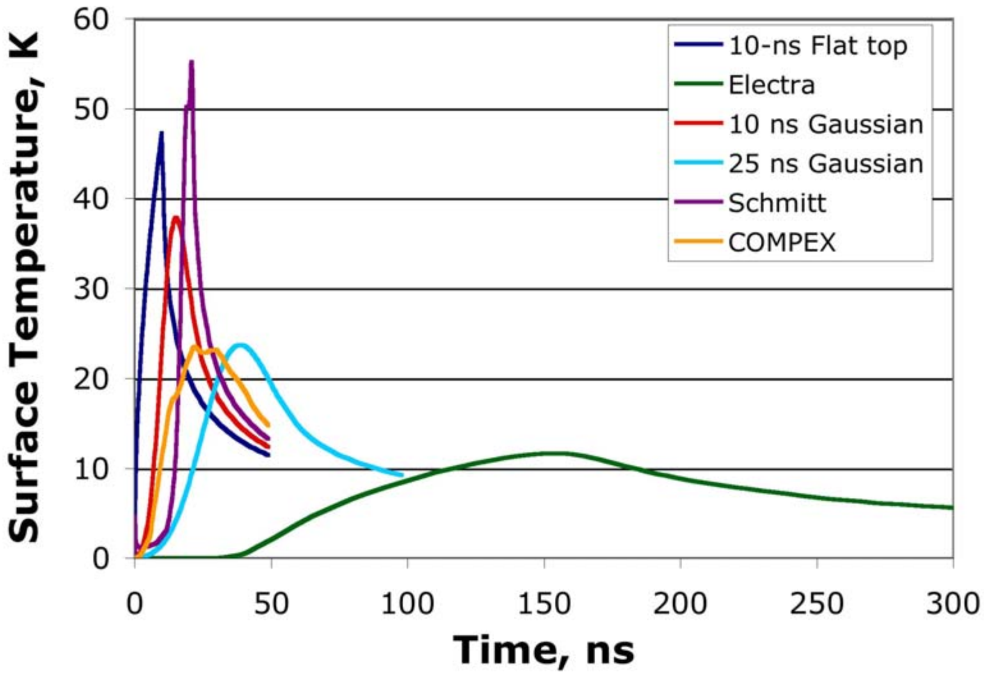


$dT/dx \sim t$

20 ns → 5 ns
factor of 4

20 ns → 5 ns
factor of 2

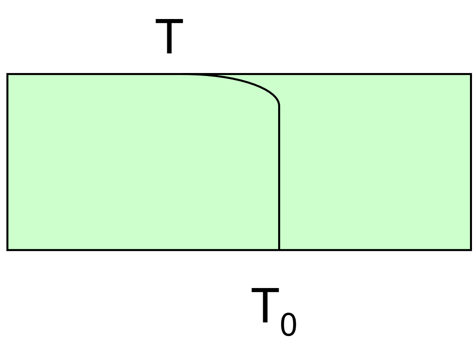
$T \sim t^{1/2}$



Fortunately, the peak thermal stress is proportional to the surface temperature

$$\sigma_{xx} = \frac{1}{1-\nu}\left[-\alpha E T + \frac{1}{2h} N_T + \frac{3z}{2h^3} M_T\right]$$

$$N_T = \alpha E \int_{-h}^{h} T\, dz \qquad M_T = \alpha E \int_{-h}^{h} T z\, dz$$

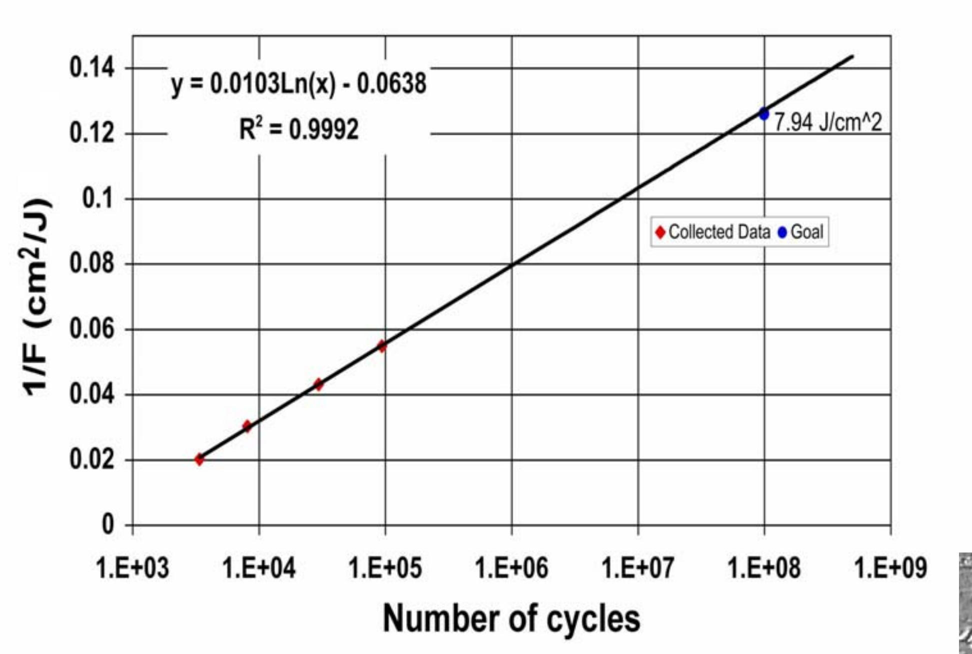


the heat-affected zone is small, so $M \sim 0$ and $N \sim 2h\alpha E T_0$

$$\sigma_{xx} = \frac{\alpha E}{1-\nu}\left(T_0 - T\right)$$

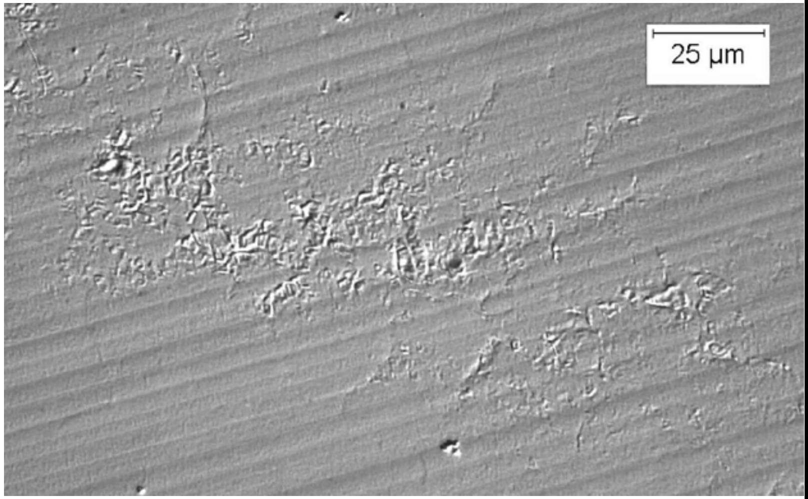
Conclusion: scaling to a power plant elevates our goal to ~10 J/cm^2 at 3x10^8 shots

Electroplating probably won't make it



Alumiplated mirrors

- pure Al
- 10-20 μm grains too big
- yield strength too low

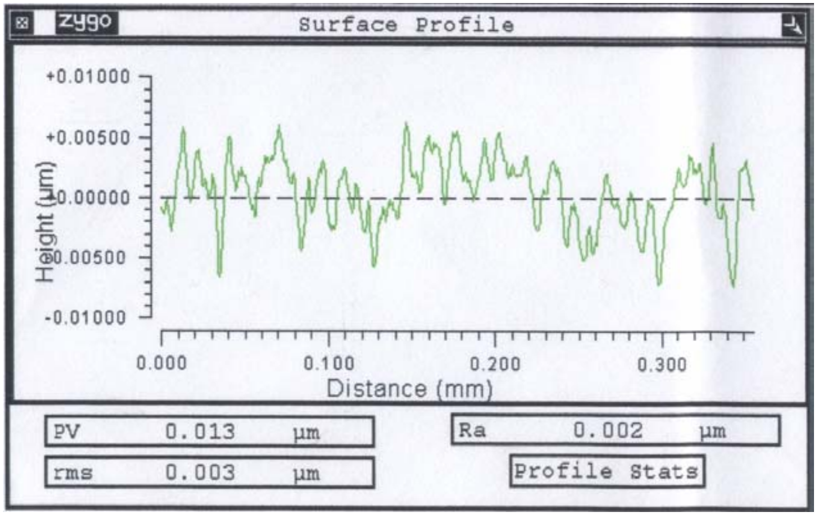


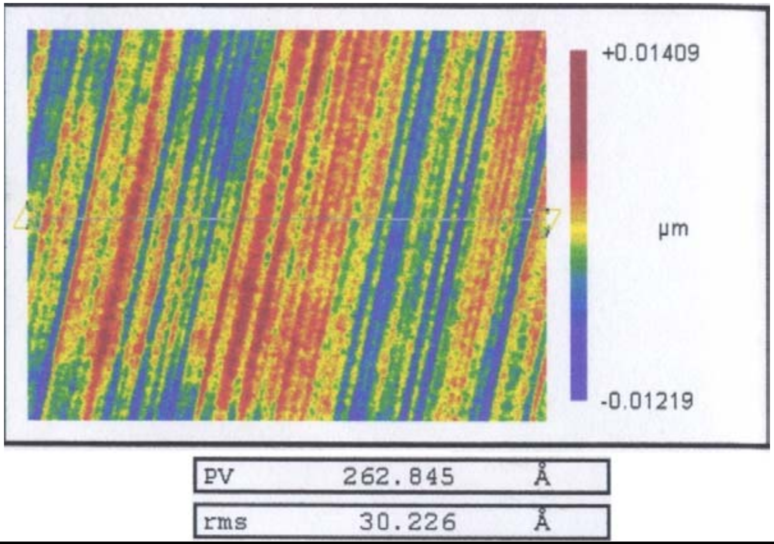
Failure was predicted previously at ~8 J/cm^2 unscaled, 4 J/cm^2 scaled

With any safety factor, this is too low

Status of mirror fabrication and testing

- Electroplated Al remains our 'reference' candidate
  - Readily available
  - Diamond-turning to *<5 nm rms* (II-VI and Schafer Corp.)
- We are acquiring a database of F *vs.* N, including statistics
  - Trying to apply Palmgren-Miner for accelerated testing
- Through subcontractors, our goal is to improve the damage resistance by a factor of 2





Strategy to maximize mirror lifetime: 2 M's, 2C'2

Cut
Clarity
Color
Carats

Morphology:

No surface features >λ/4

- High quality diamond turning
- Post-polishing?

Microstructure:

No grain structures or precipitates >λ/4

- Use thin film deposition

Ultimately these will evolve into a set of specs for vendors.

In addition, we will specify procedures for pre-conditioning, testing and verification.

Coating:

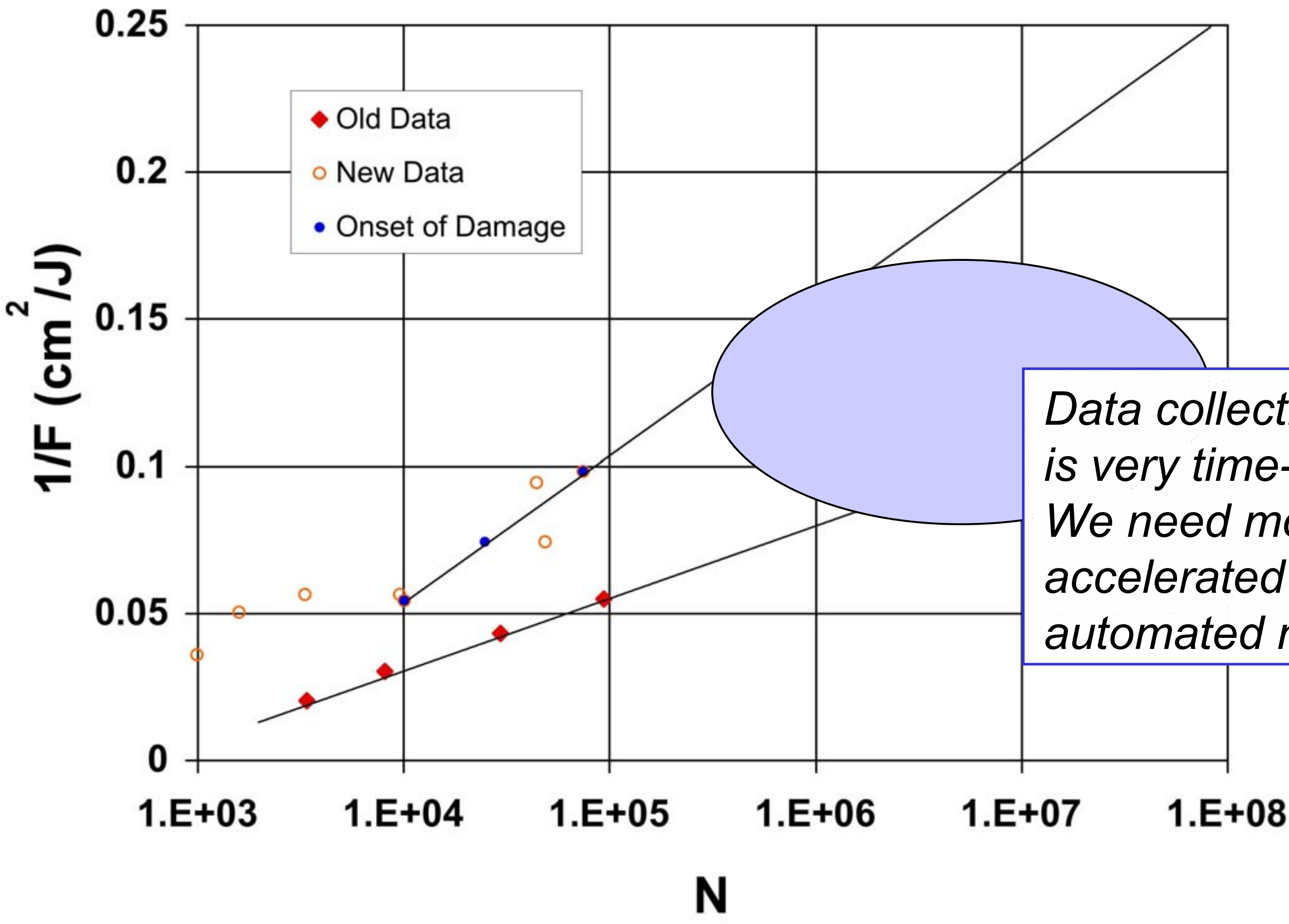
No material interface within 10-20 μm of the surface

- "Thick" thin films followed by surface finishing
- "Thin" thin film on polished Al alloy (on a substrate)

Composition:

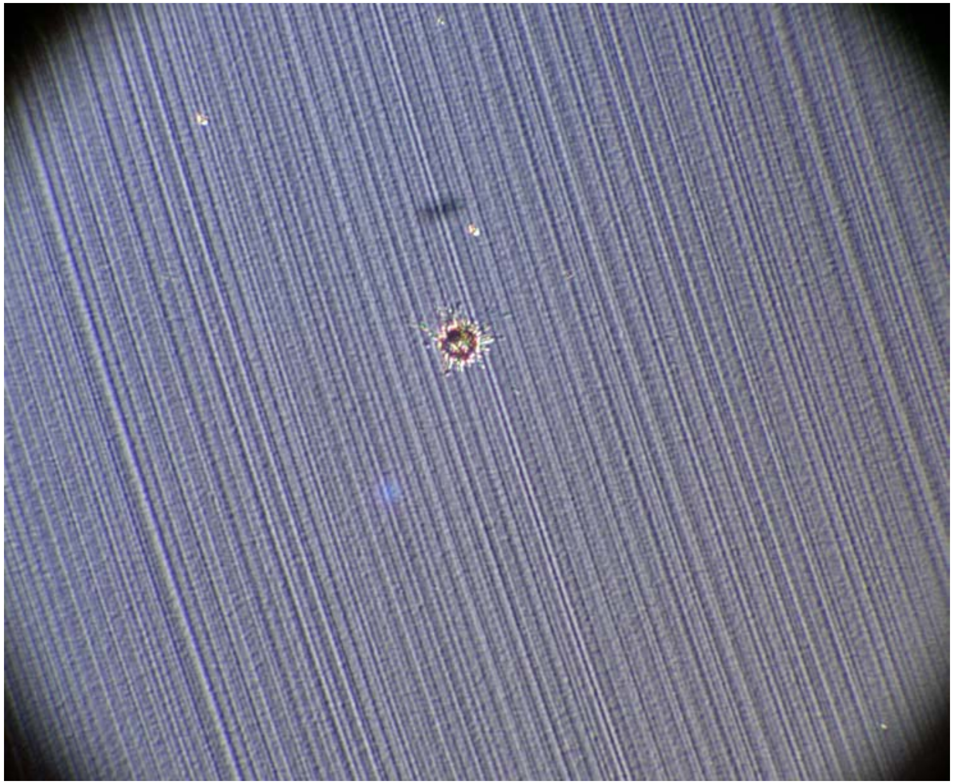
Increased yield strength through alloying

Our latest data suggests different damage mechanisms in different regimes



Data collection out here is very time-consuming. We need more effort on accelerated testing and automated monitoring.

Low cycle (high fluence) failure occurs at weak points in the mirror



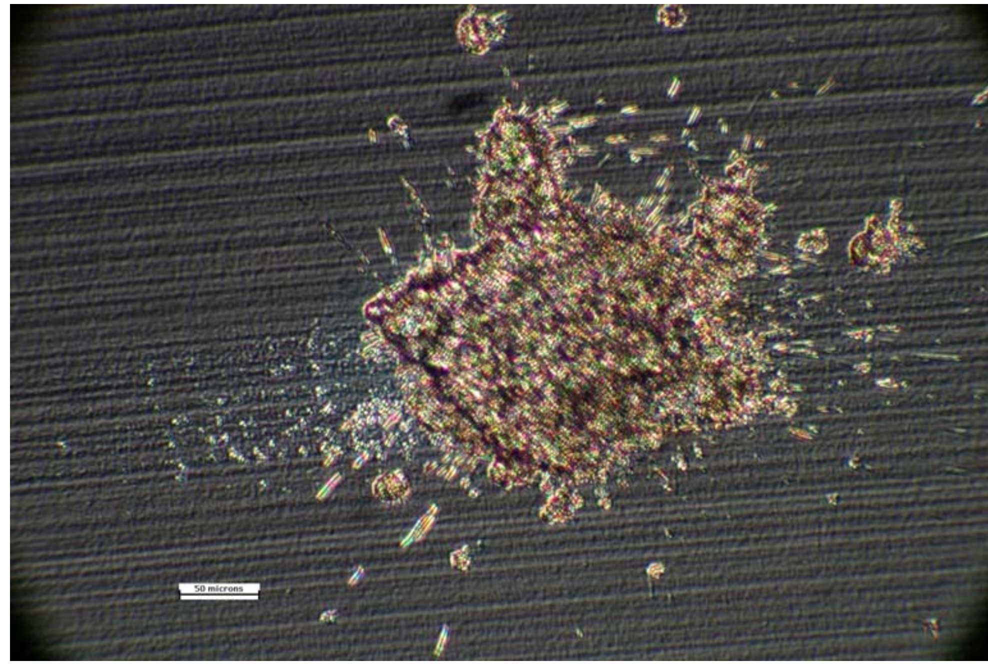
- Localized imperfections appear to be compositional; the morphology is flat
- Variability in surface quality will require large safety factors
- We hope that thin film coatings will be more homogeneous

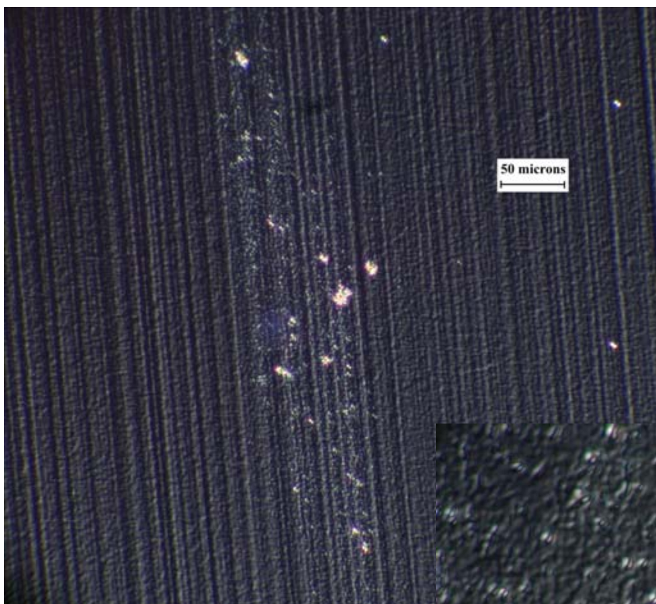
- 6 shots at 26.5 J/cm^2
- No signs of microstructure evolution

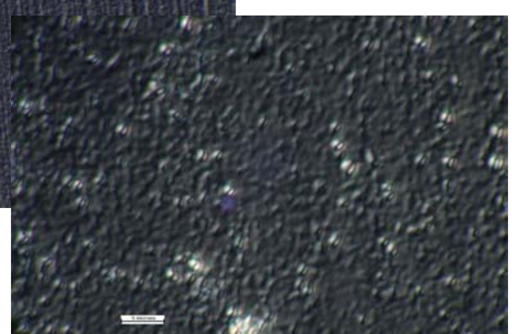
High cycle failure occurs as a result of microstructure evolution

- 50,000 shots at 13.5 J/cm^2

(First evidence of roughening at 25,000 shots)

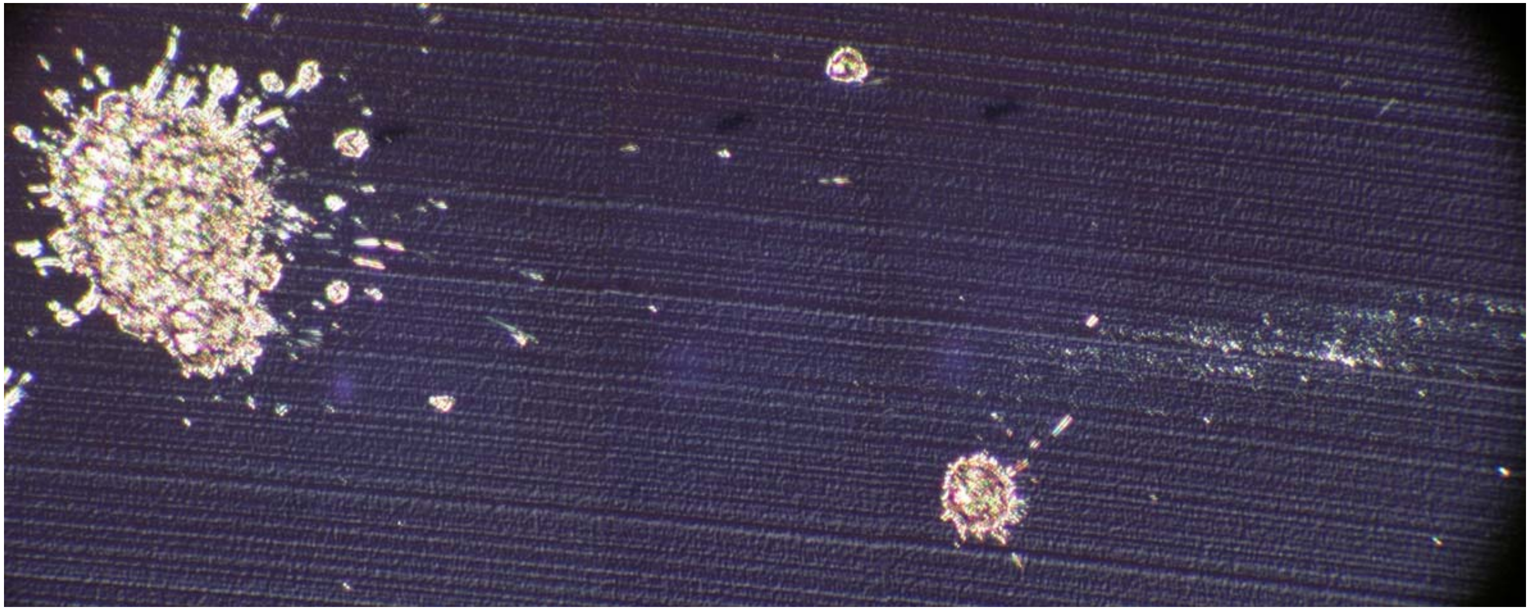






- 75000 shots at 10 J/cm^2
- Testing was terminated before unstable growth of damage site

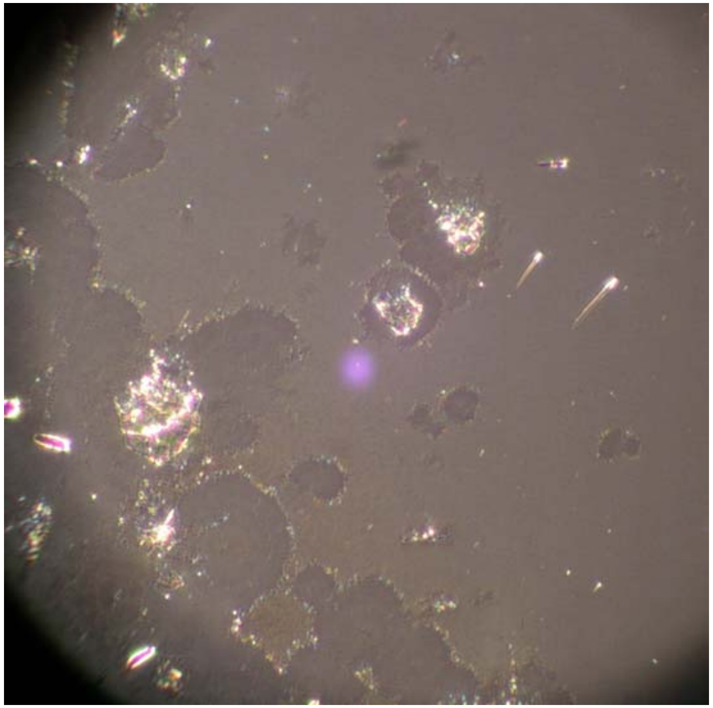
At intermediate fluences, failure can be caused by imperfections or microstructure

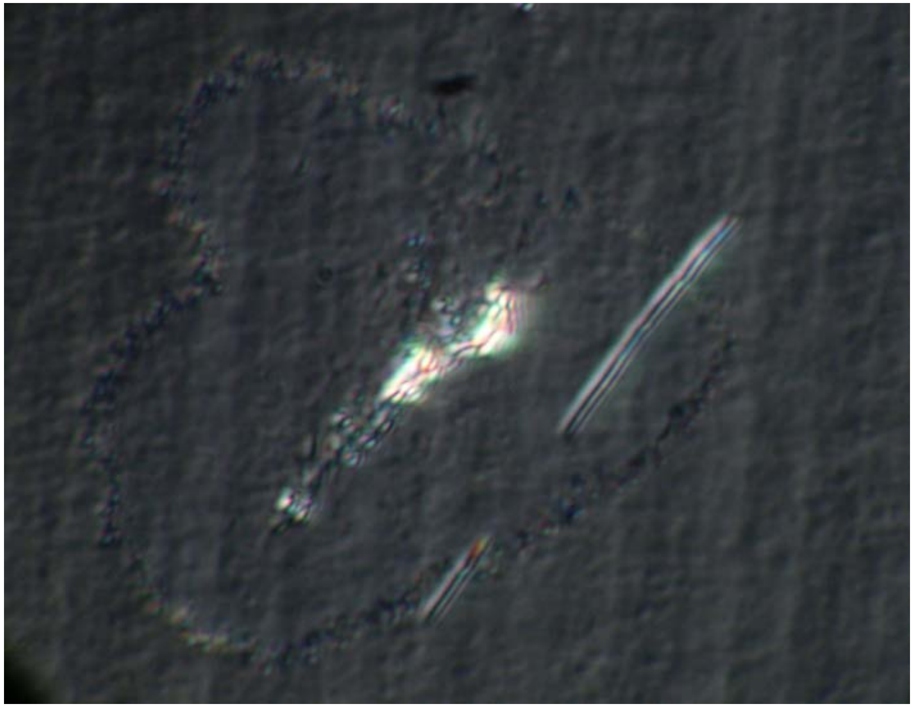


- 10,000 shots at 18.5 J/cm^2
- Roughening started to appear at 5000 shots
- Failure occurred *away* from visible microstructural damage

Additional evidence of dislocation transport in the high cycle regime

- Slip plane transport & grain boundary rotation were observed previously
- This new observation appears to be dislocation loops near damage sites
- Not clear whether this is a *cause* of damage or *effect* of damage



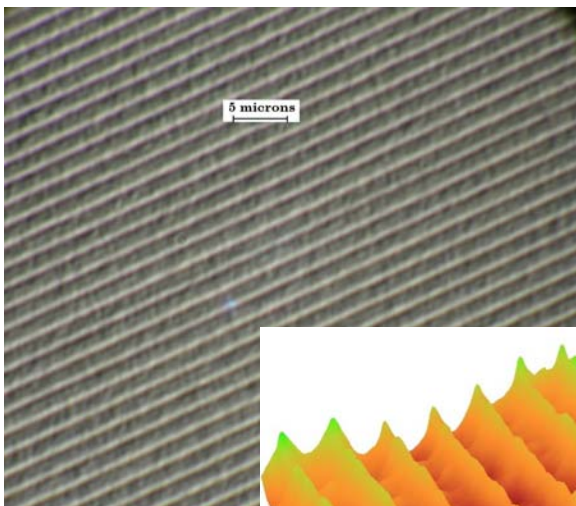


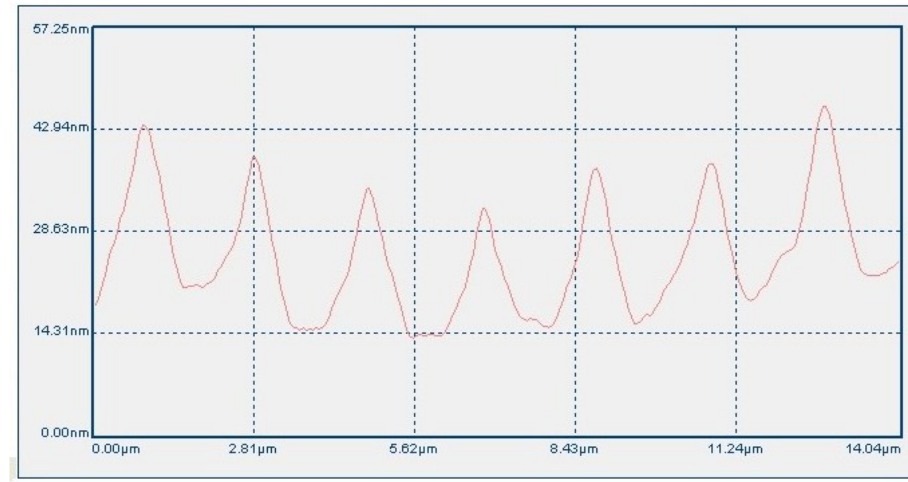
Initial results with thick thin films are promising

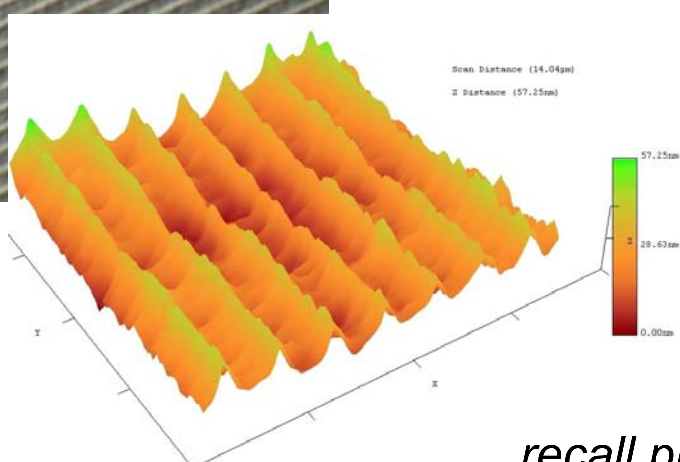
>30 μm evaporative coating on LiF

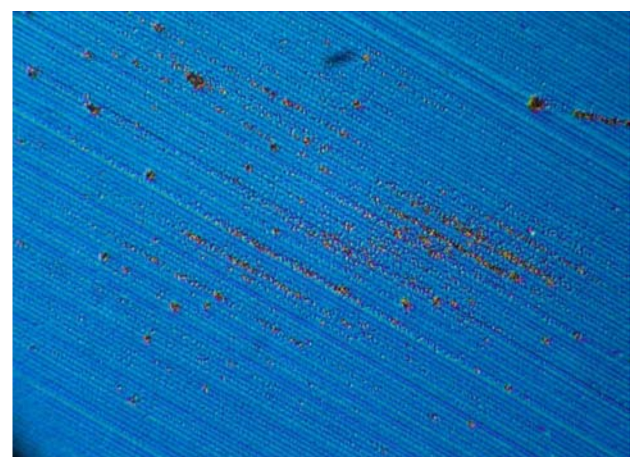
Diamond turned to 6 nm rms

Passed test at 10 J/cm^2, 10^4 shots









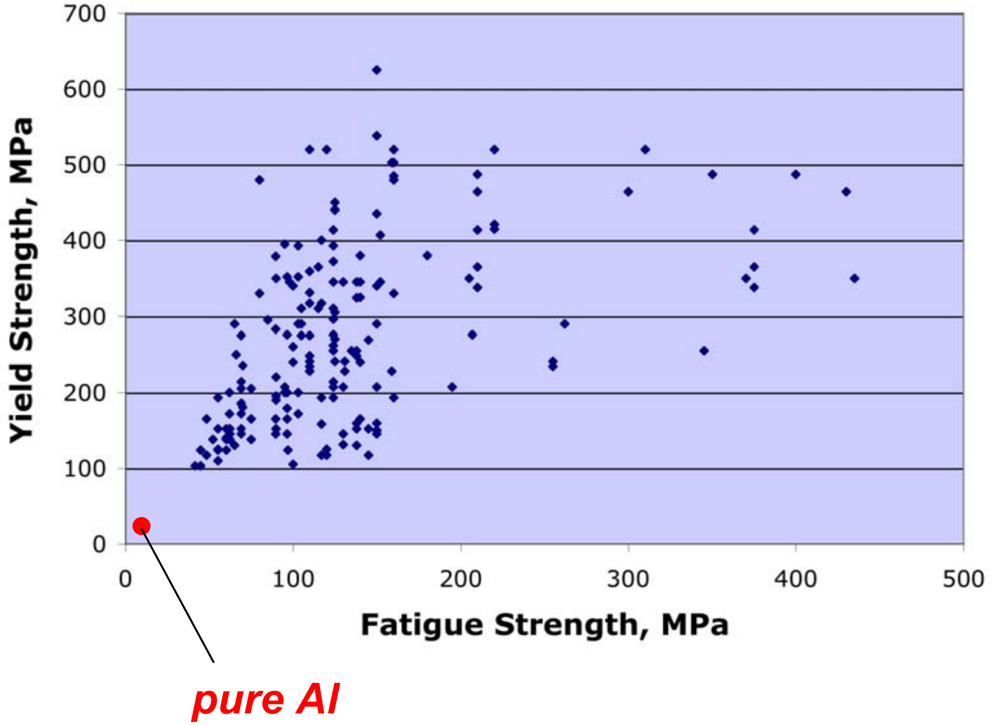
recall prior attempt failed due to poor turning

Solid solution alloys will be created by evaporative coating from pure sputter targets

Mirrors will be fabricated from:
Al + 3%Cu *and* Al + 3%Zn

These were chosen for high yield strength in the annealed state: pure: 20 MPa
2024: 97 MPa
7075: 145 MPa

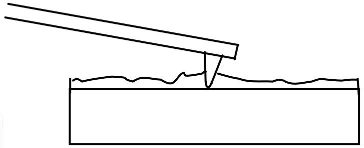
We rejected 1000, 3000 and 5000 because their strength comes from cold working

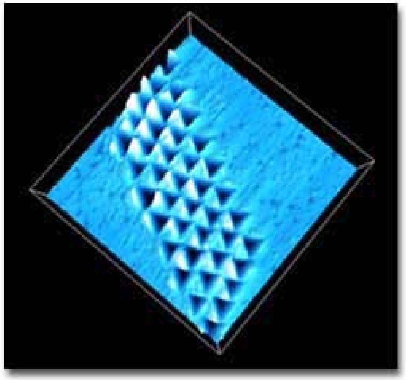


Alloy Series	Main Alloying Elements	Typical uses
1000	Pure Al	
2000	Cu	High strength alloy used in the aerospace industry
3000	Mn	Low- to medium-strength alloys, used in beverage cans and refrigeration tubing
4000	Si	Most mostly welding or brazing filler materials
5000	Mg	Structural applications in sheet or plate metals - weldable
6000	Mg and Si	Heat treatable and commonly used for extrusions, can be crack sensitive.
7000	Zn	High strength aerospace alloys that may have other alloying elements added

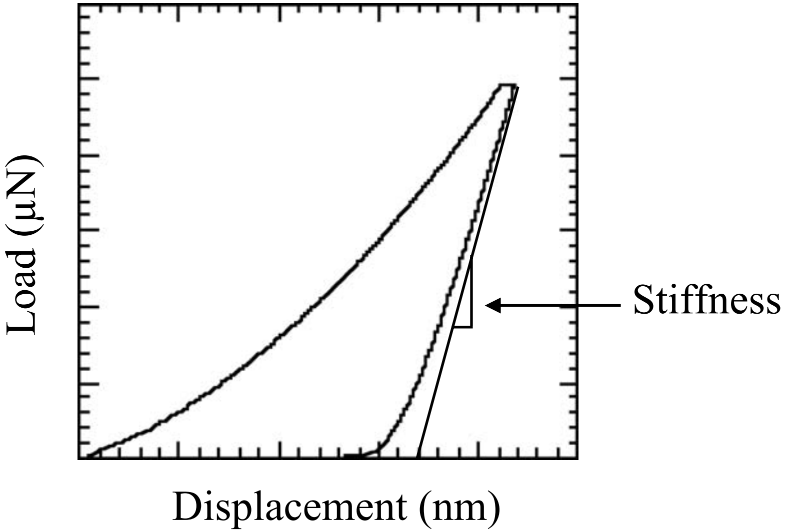
We need a direct method of measuring improvements in mechanical properties and the effects of preconditioning

Elastic and plastic material properties can be obtained from load-displacement data using nanoindentention with our AFM, although the accuracy is limited (*cf.* w/ a nanoindenter).





AFM image of nanoindents on a surface



Mirror fabrication and LIDT testing: How did we get here? Where are we going?

2001 | 2002 | 2003 | 2004 | 2005 | 2006

initial work @ **532 nm**

start

commercial Al alloys

lower limits @**248 nm**, chemistry

KrF

polycrystalline pure Al

thin films

carbon buildup

electroplate success

new lab, cryopump

larger optics (4”)

increased goal

extended database, mirror improvements, full-scale gimmlet testing, radiation damage (LLNL), design integration

Phase I evaluation

alloyed thick thin film mirrors

The end game for mirror fabrication and LIDT testing

1. **Complete damage curve + statistics for II-VI turned, Alumiplated mirrors**

    Establish a baseline for future improvements

2. **Test validity of Palmgren-Miner for laser-induced damage**

    K. Sequoia's Masters thesis

3. **Acquire advanced mirrors and perform screening tests**

    Schafer Corp. is providing advanced mirrors

4. **Complete damage curve + statistics for advanced mirror(s)**

    To be completed this year (we hope)

5. **Demonstrate full-scale GIMMlet at Electra**

    Wait for polarization and pulse shape control

6. **Define vendor specs for power plant mirrors, document**