Oxidation assisted crack growth in gas turbine materials

Micromechanical testing of thermally grown oxide layer in Allvac 718plus

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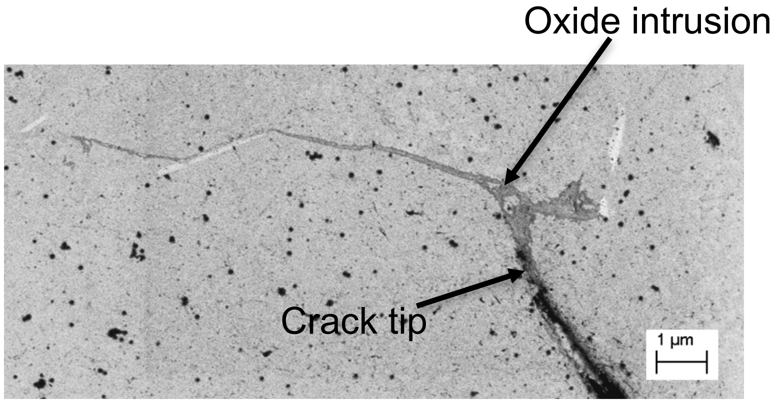
OUTLINE

- Aim and motivation.
- Method development.
- Next steps.
- Summary.

Oxidation induced crack growth

- The original problem is the increased crack propagation rates during dwell-fatigue at high temperatures
- Several mechanisms proposed, but most recent evidence points towards stress assisted grain boundary oxidation (SAGBO), which involves fracture of oxide intrusion ahead of crack tip
- The major unknown in the most promising physically based model for the dwell-fatigue crack growth threshold is the fracture strain of the oxide (ε_f)
- **We want to develop methods to measure the fracture strain of grain boundary oxides in order to predict the threshold**



Step-by-step approach

Experimental characterization

1. Measuring fracture strength of surface oxides at **room temperature**
2. Measuring fracture strength of surface oxides at **elevated temperatures**
3. Measuring fracture strength of grain boundary oxides at **room temperature**
4. Measuring fracture strength of grain boundary oxides at **elevated temperatures**

Model development

1. Modelling of oxide fracture in bi-crystals
2. Modelling of oxide fracture in poly-crystals

Ultimate goal
Coupling to oxidation models for simulating oxidation induced crack propagation in arbitrary poly-crystal microstructures

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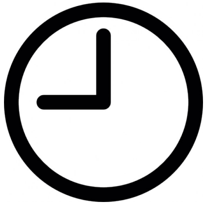
Fracture strength of thermally grown sub-micron oxide scales

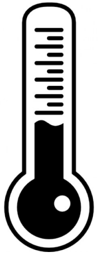
Method development

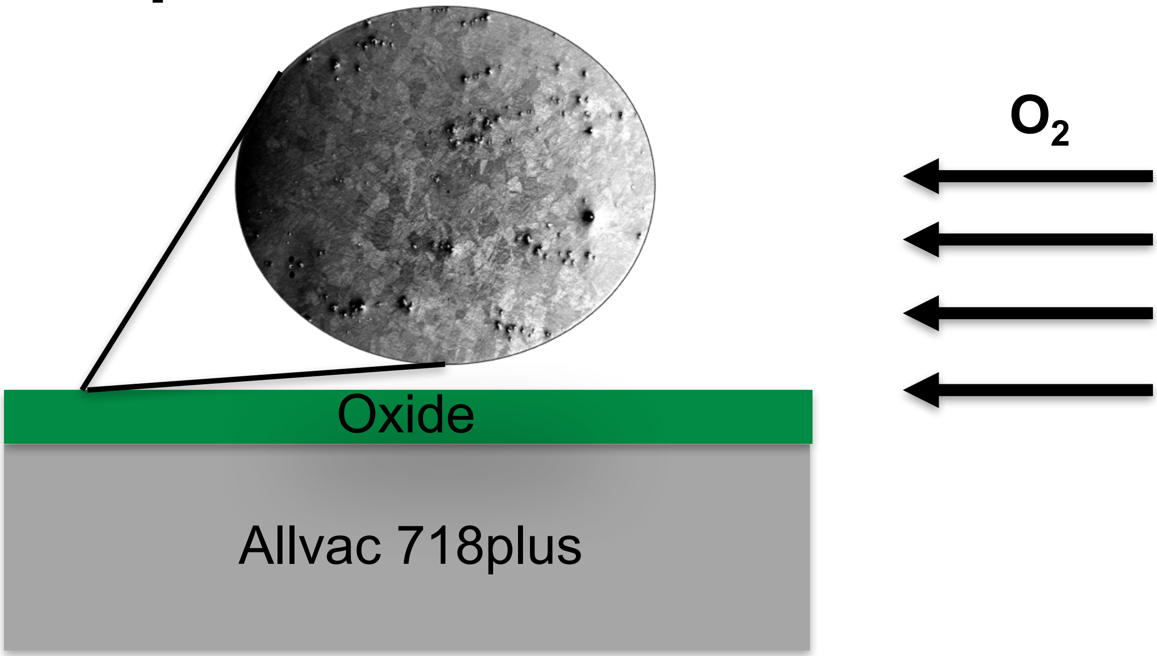
Thermally grown oxide – High temperature oxidation

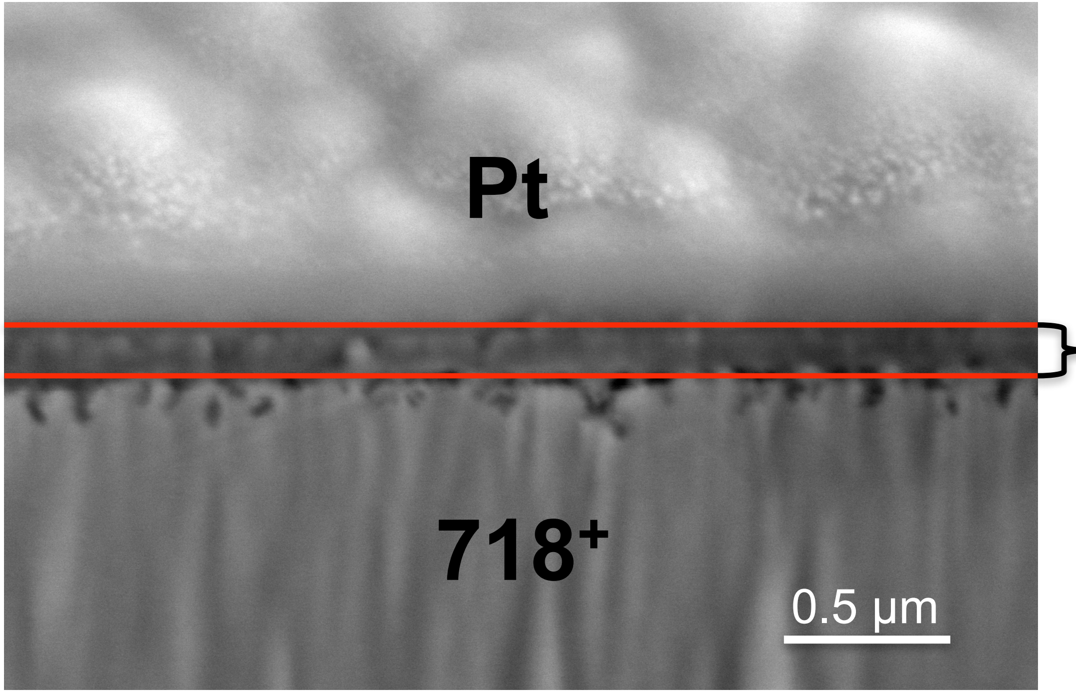


100h,
500h

700 °C



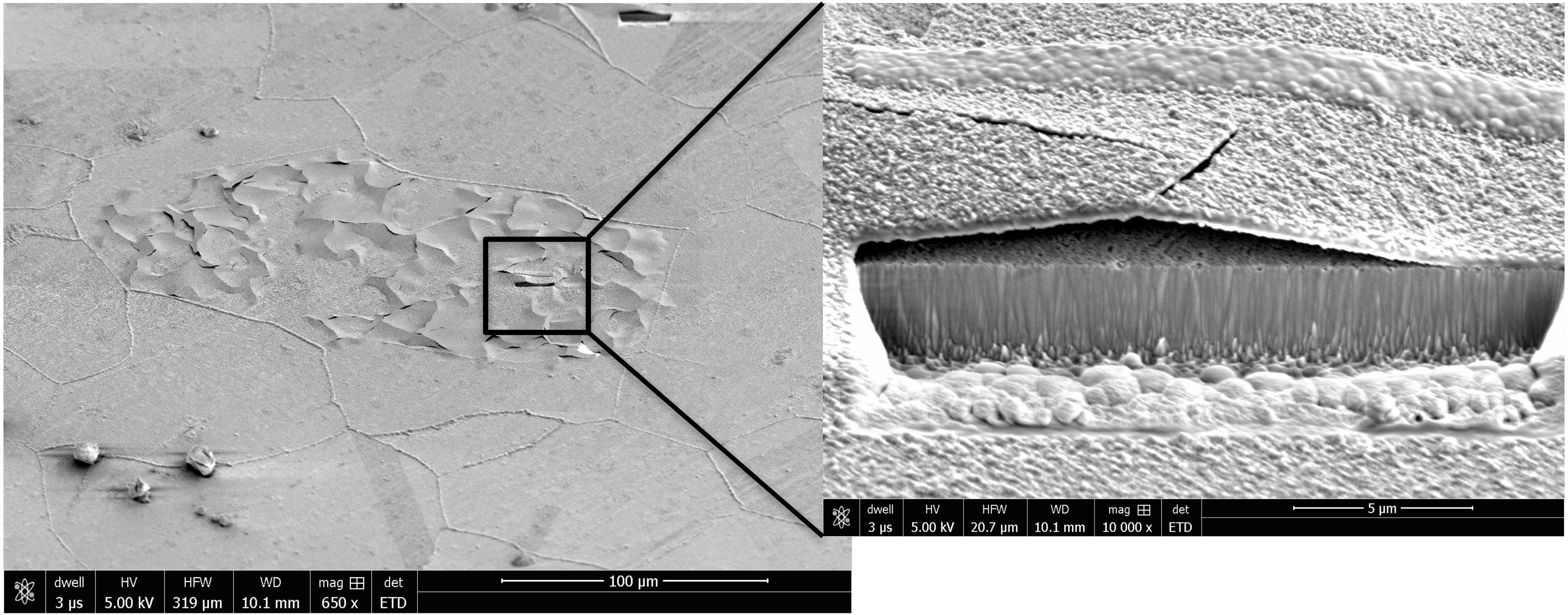




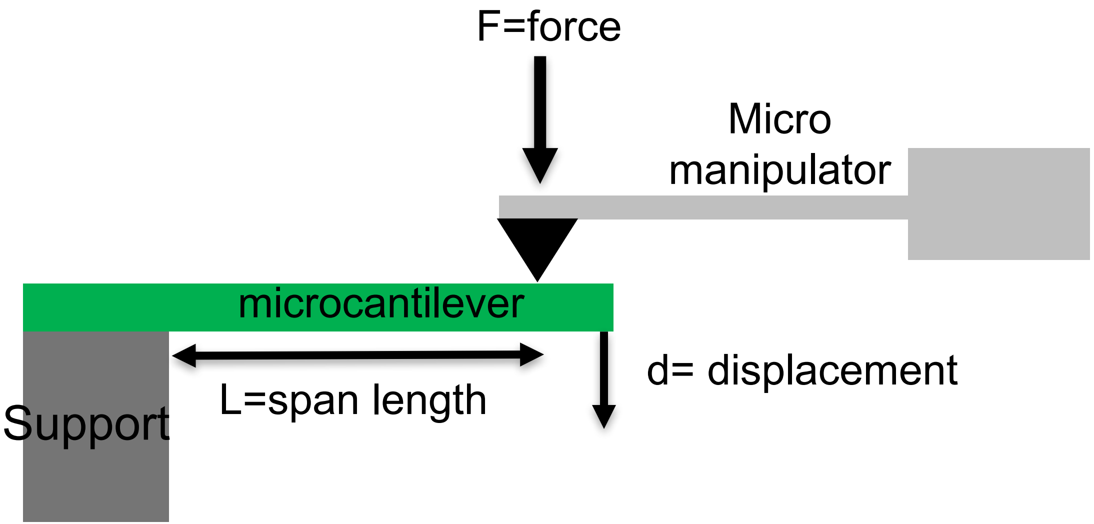
Oxide layer

- Cr rich oxide.
- ≈200 nm for 100h.
- ≈400 nm for 500h.

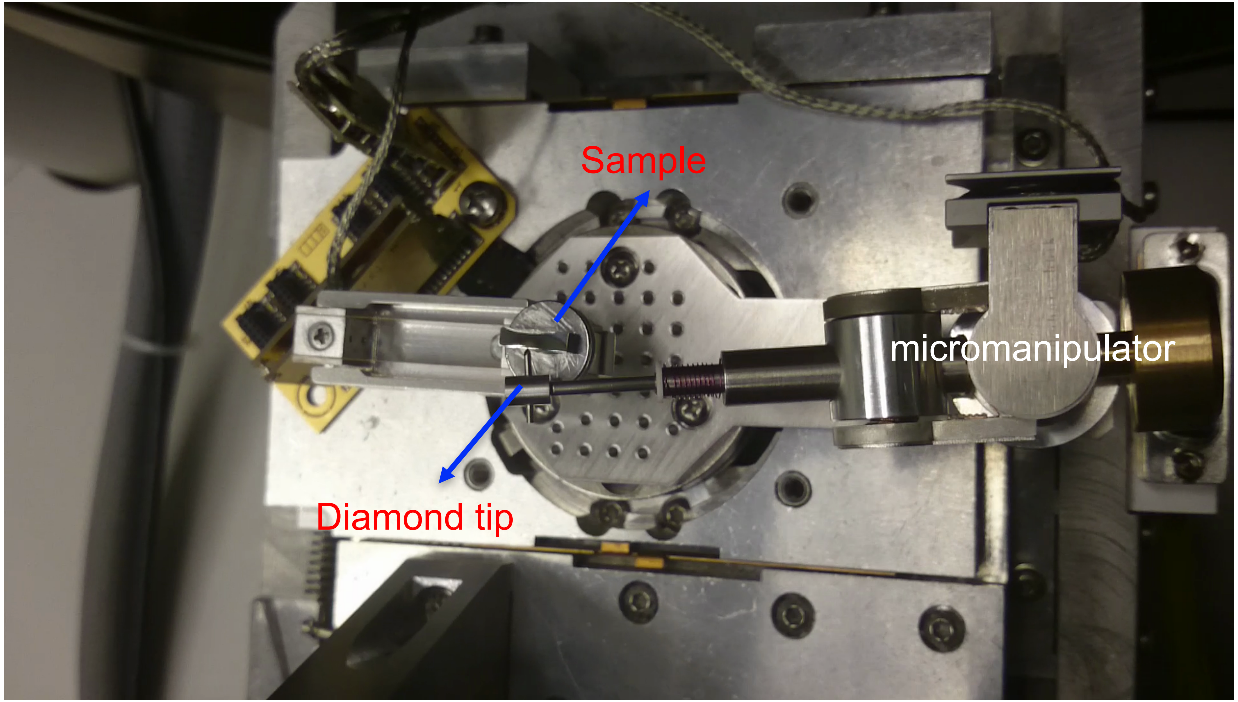
Poor adhesion of oxide (500h)



In-situ micromanipulator setup

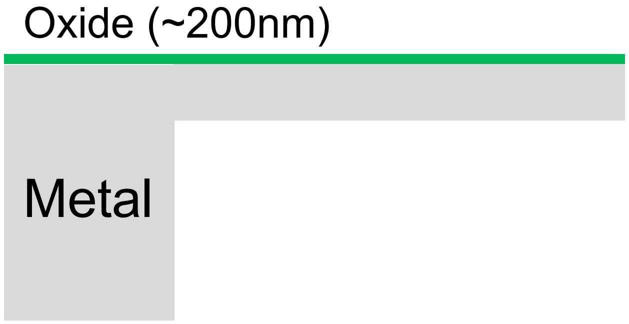


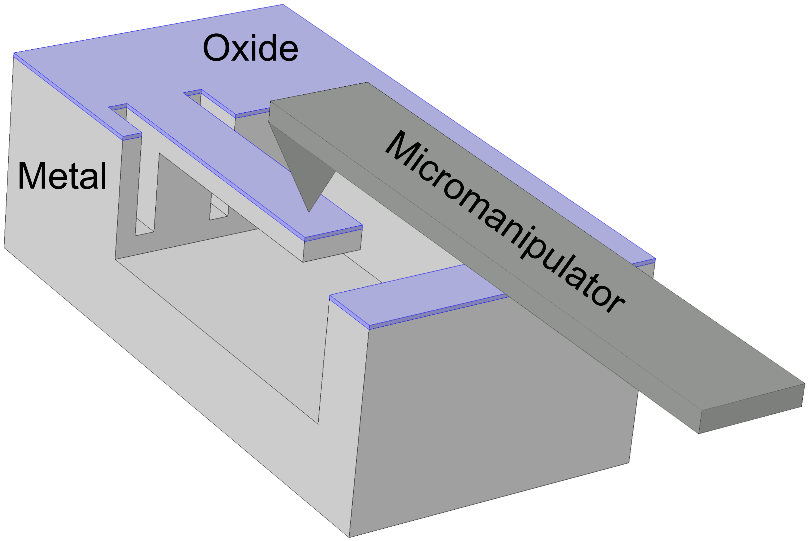
In-situ micromanipulator setup



Microcantilever type I

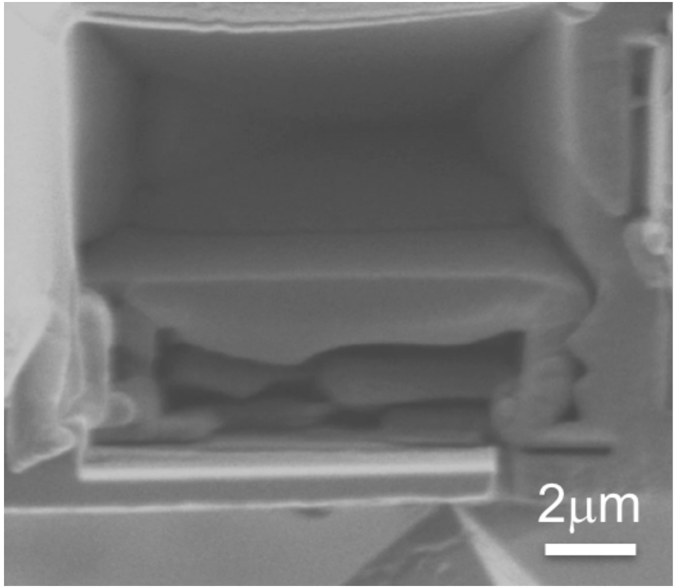
Oxide with base material





Microcantilever type I

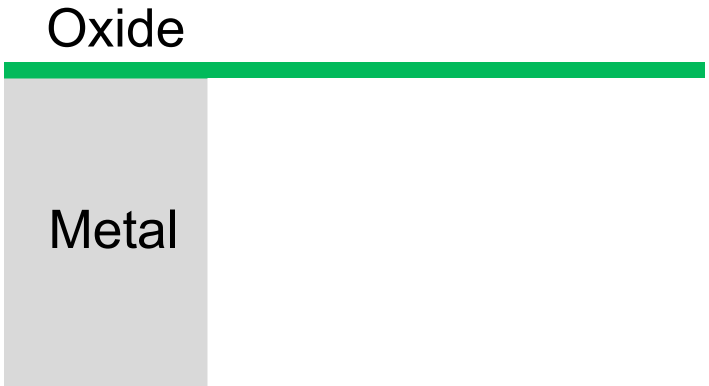
Oxide with base material

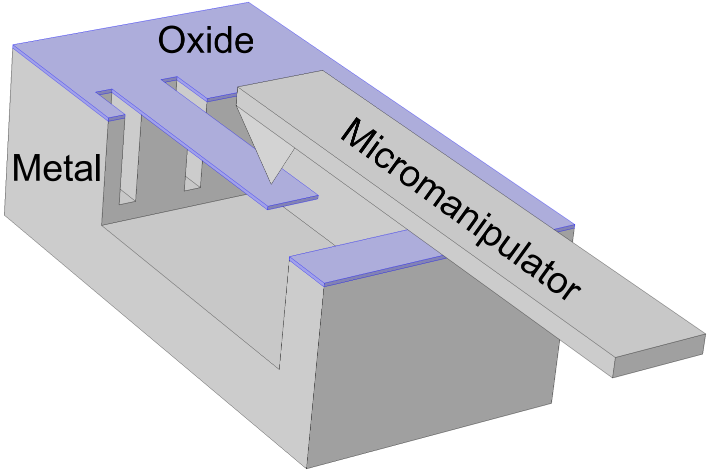


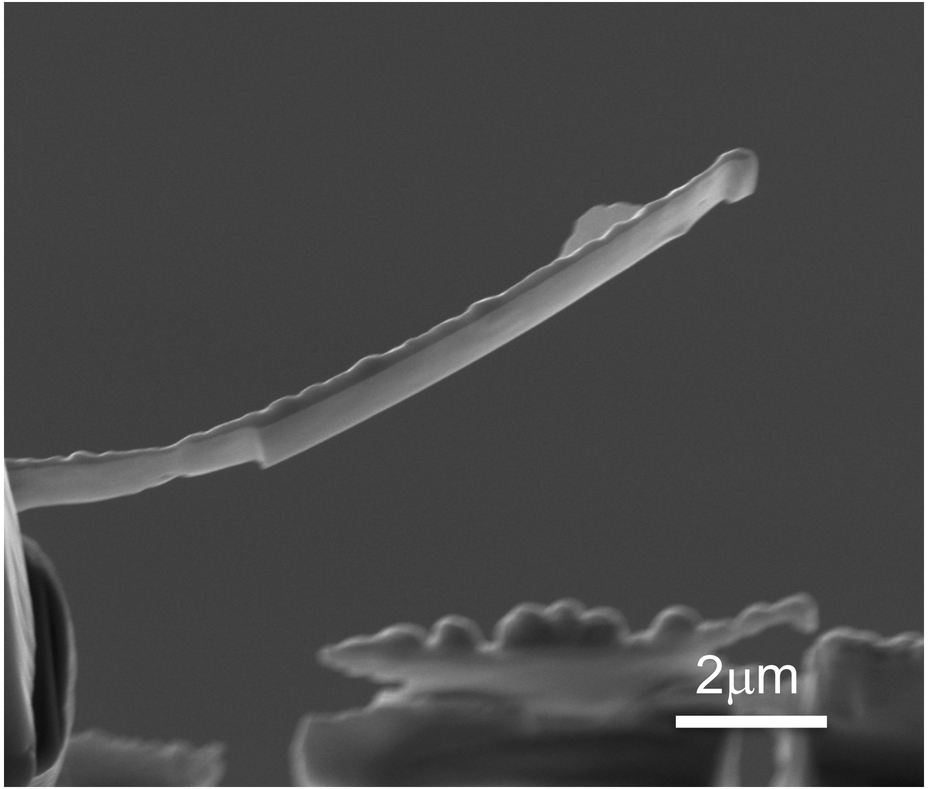
- First attempt with metal and oxide.
- To measure change in force and displacement during oxide fracture.
- Test on thin oxide.
- Oxide 200nm metal 800nm.
- No visible cracks on surface.

Microcantilever type II

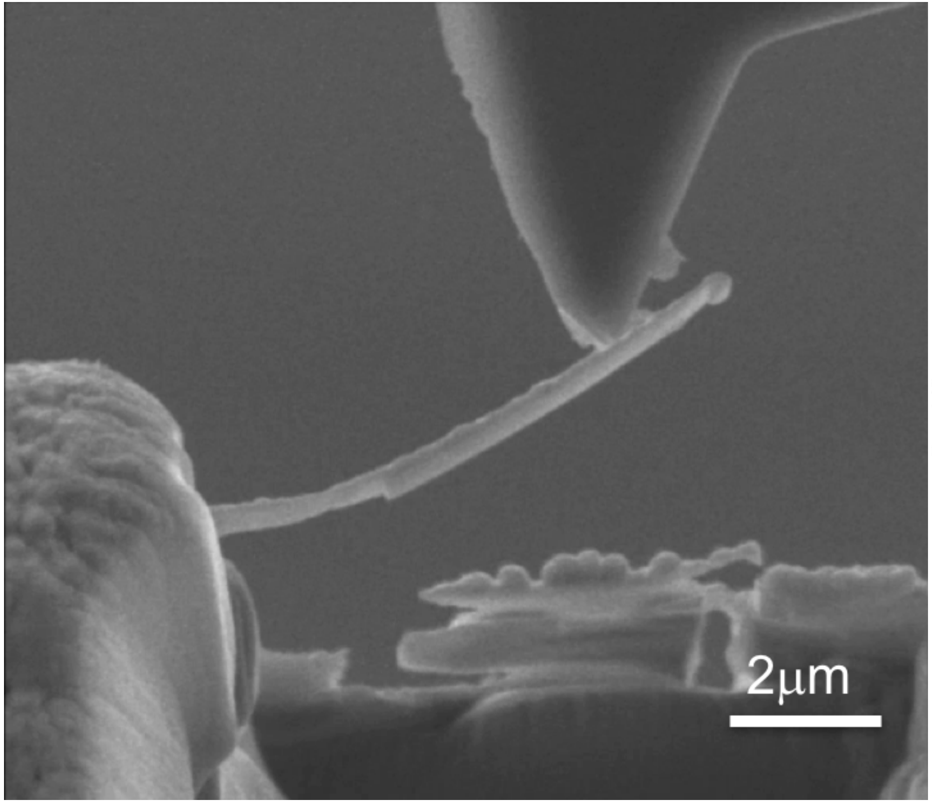
Oxide cantilever – base material removed



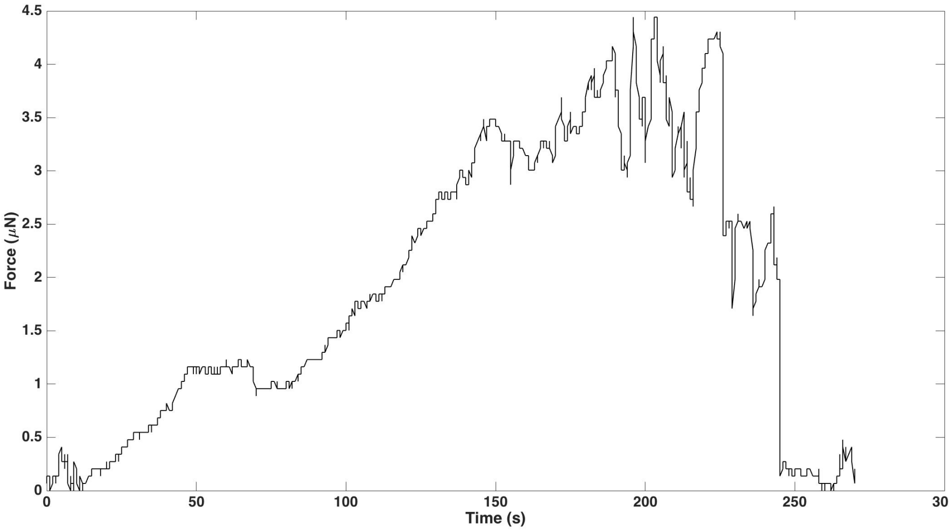




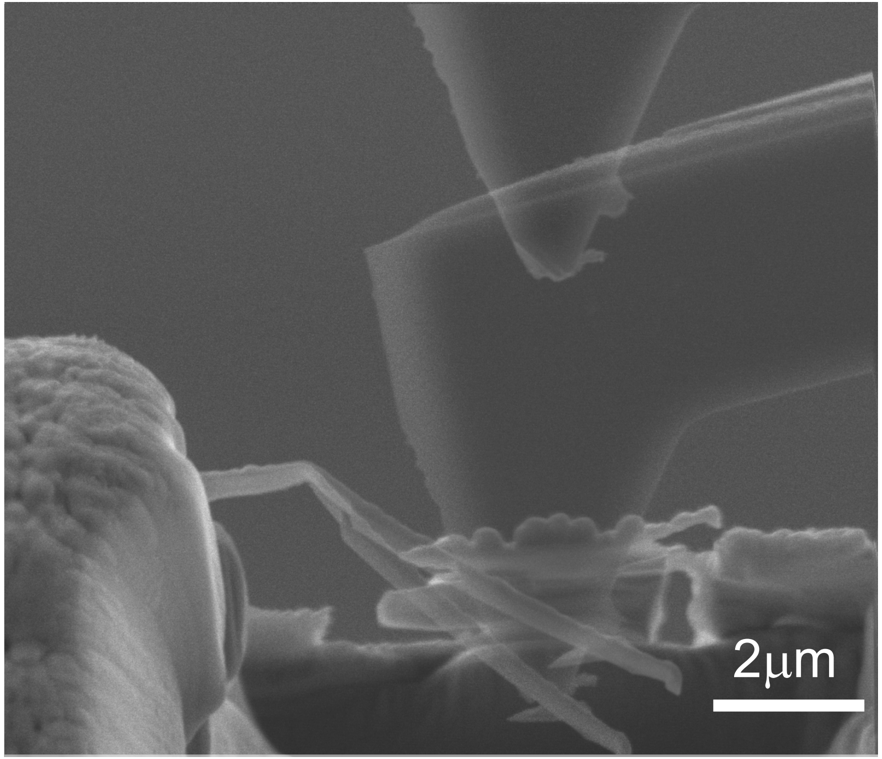
- Curvature due to residual stress.
- Can be used to estimate residual stress gradient.
- Bending during milling.
- Geometry not perfect.

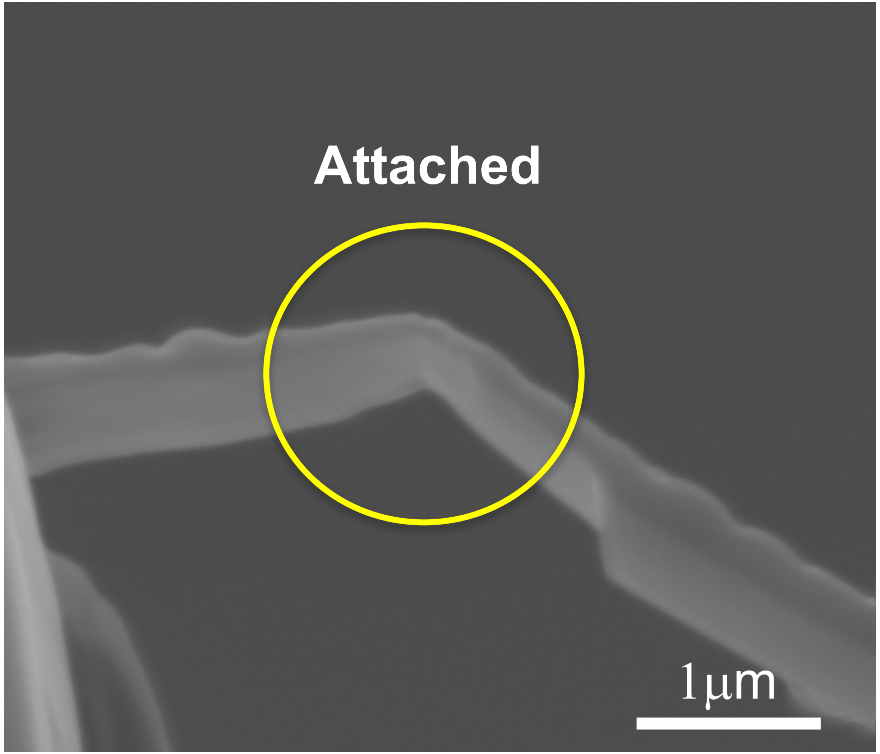


Force vs time



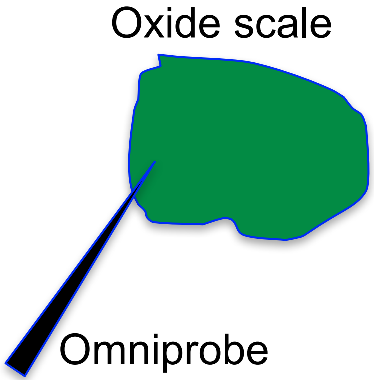
Recovery during unloading

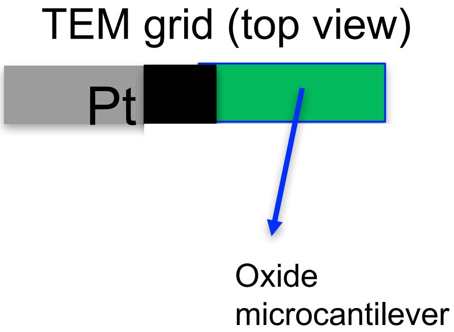


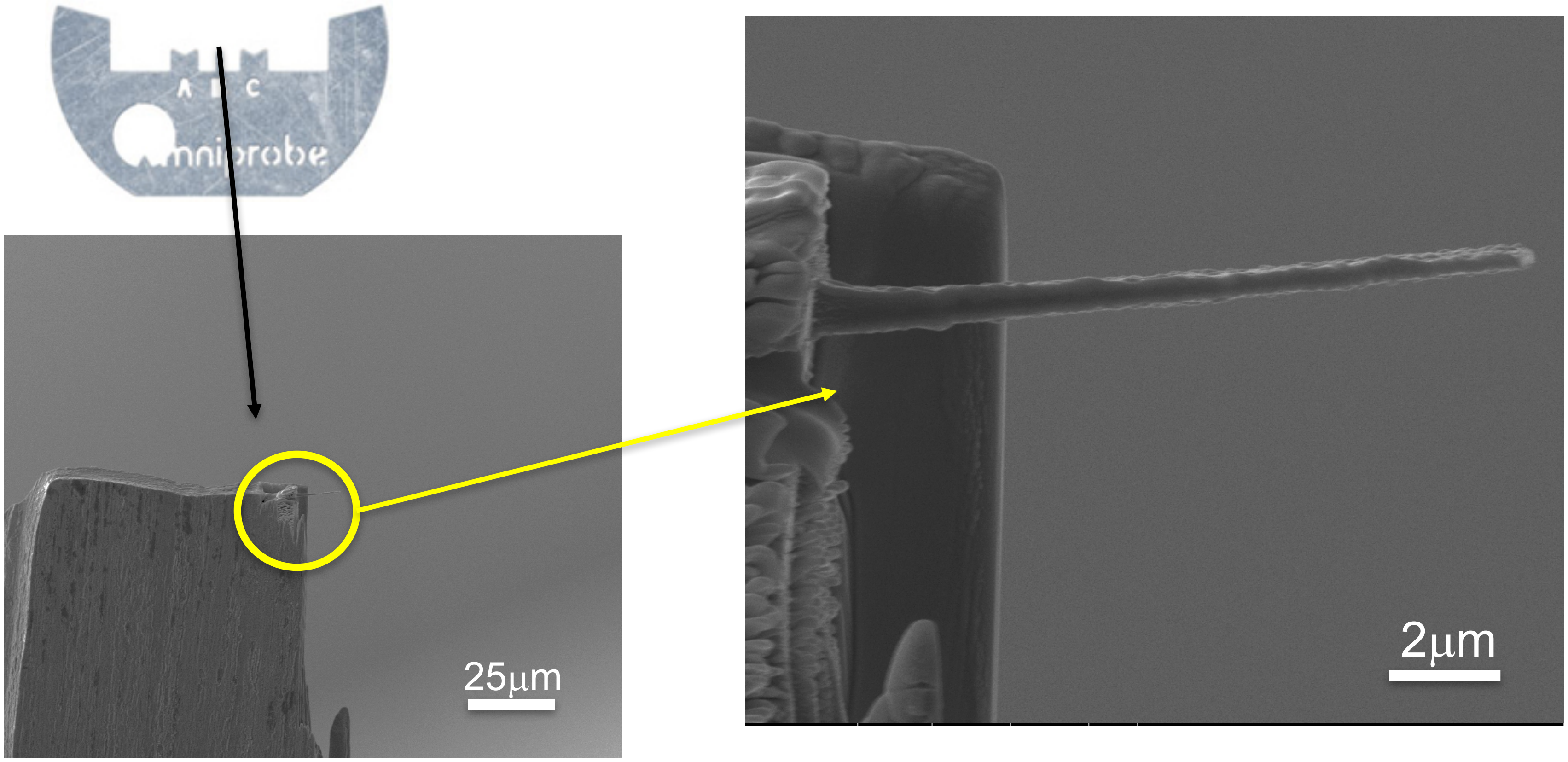


Microcantilever type III

Oxide cantilever – peeled scale

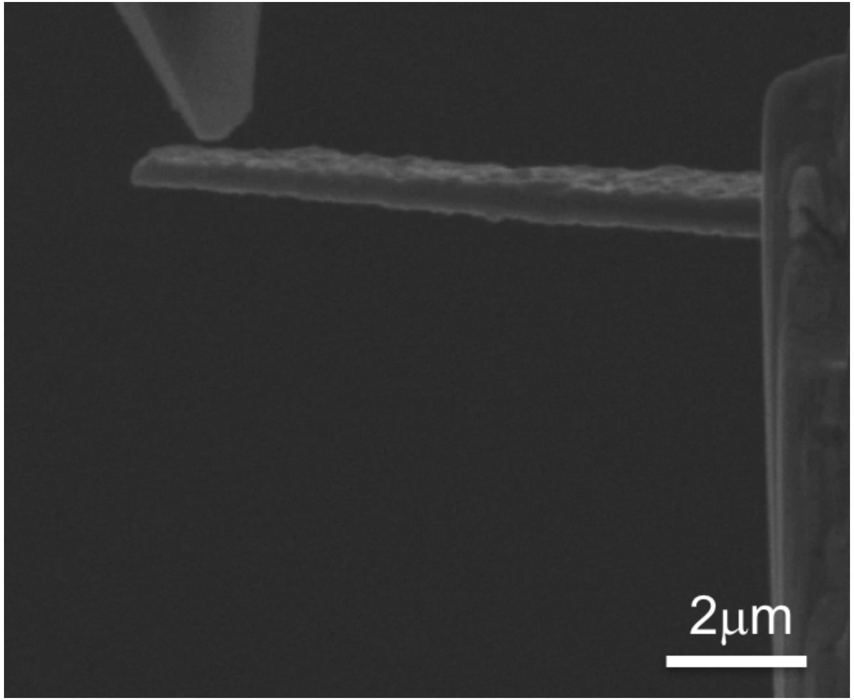




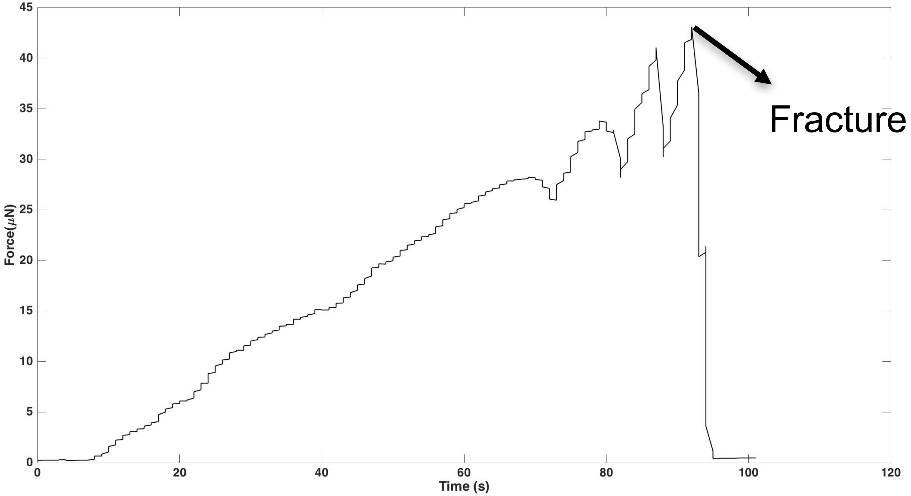

25μm
2μm

Microcantilever type III

Oxide cantilever – peeled scale



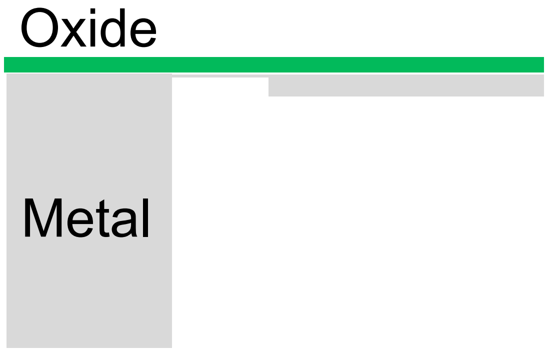
Force vs time

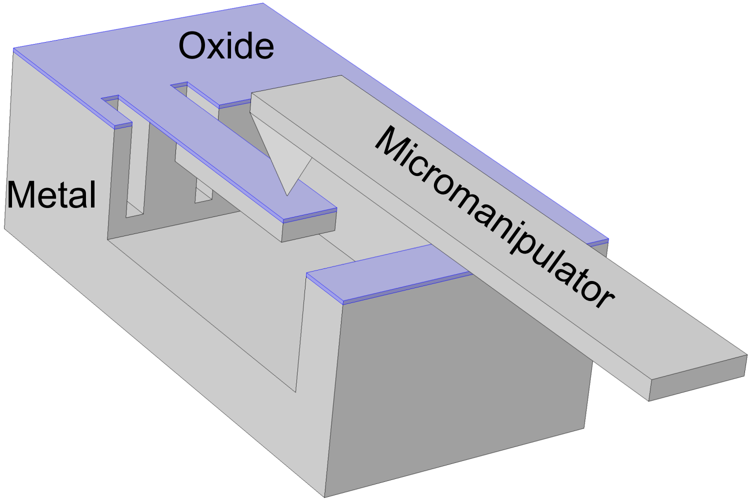


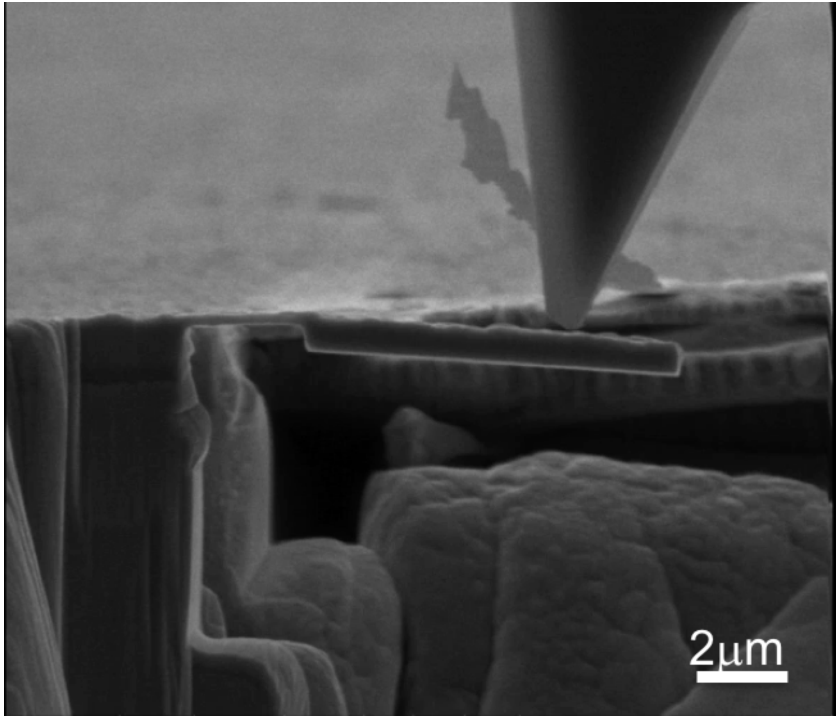
Concerns

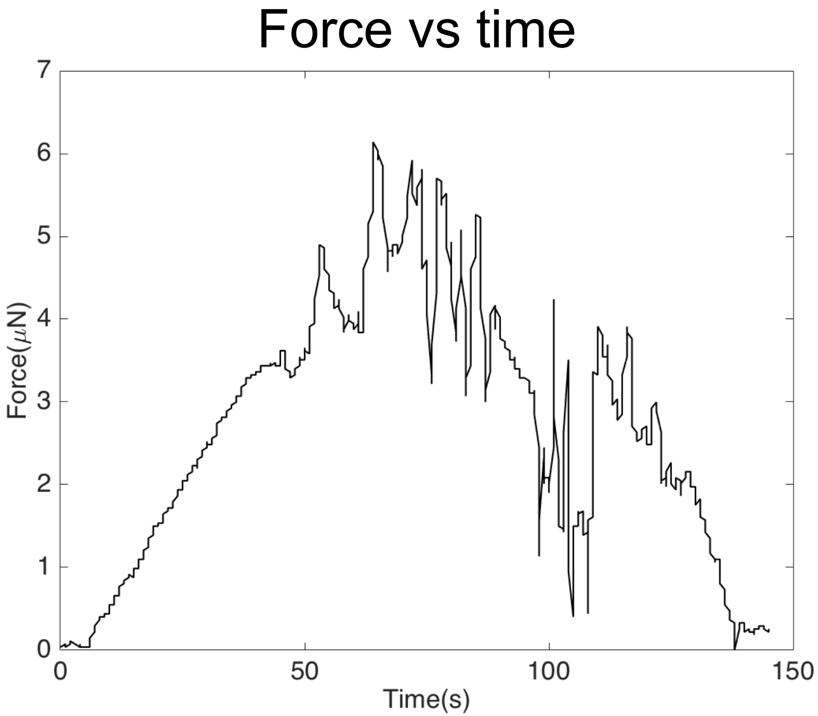
- Structural stability of platinum solder.
- High temperature strength of platinum.
- Geometry of cantilever.

Microcantilever Type IV

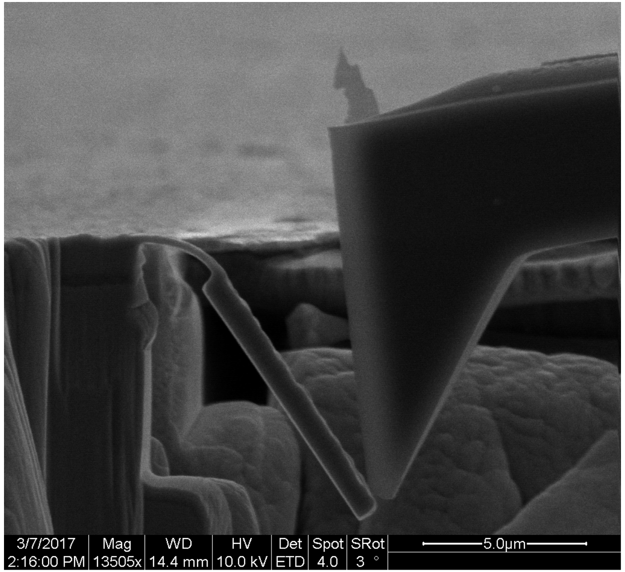


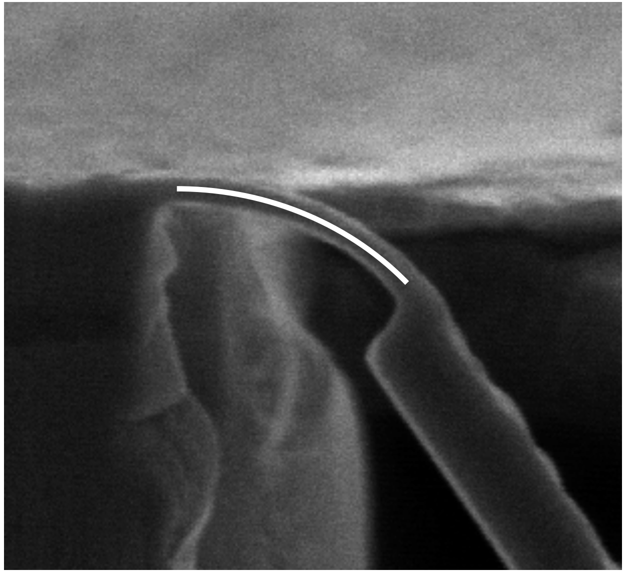



2μm


Force vs time
Force(μN)
Time(s)
0
1
2
3
4
5
6
7
0
50
100
150

Strain and stress estimates





Rough approximation

$$\varepsilon = \frac{h}{2R} \approx 3.3\ \%$$

$$\sigma = E\varepsilon \approx 9\ GPa$$

Next steps

- Detailed characterization of oxide layers (TEM/XRD).
- High temperature testing.
- Testing of pure Chromia (thermally grown, sintered).

Summary

- Testing of oxide microcantilevers to determine fracture properties is possible using current setup.
- Four different methods have been developed for testing.
- Some are more effective than the others.
- High temperature testing needs to be carried out for comparison of properties.
- Testing of pure chromia will be undertaken in order to study a simple system.

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