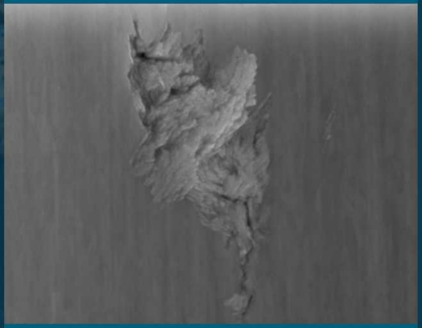
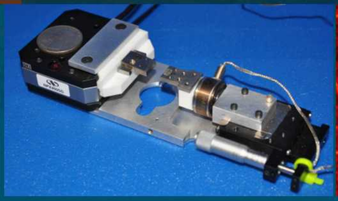
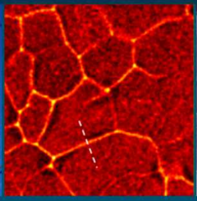
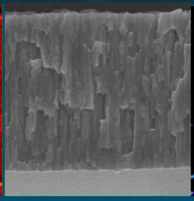
SAND2020-2457PE

Watching High-cycle Fatigue in Nanocrystalline Pt and Pt-Au









TMS 2020:

Fatigue in Materials: Fundamentals, Multiscale Characterizations and Computational Modeling

PRESENTED BY

Nathan M. Heckman, Christopher M. Barr, Khalid Hattar, David P. Adams, Timothy A. Furnish, Brad L. Boyce

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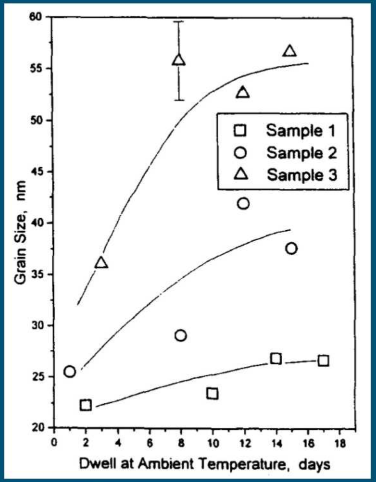
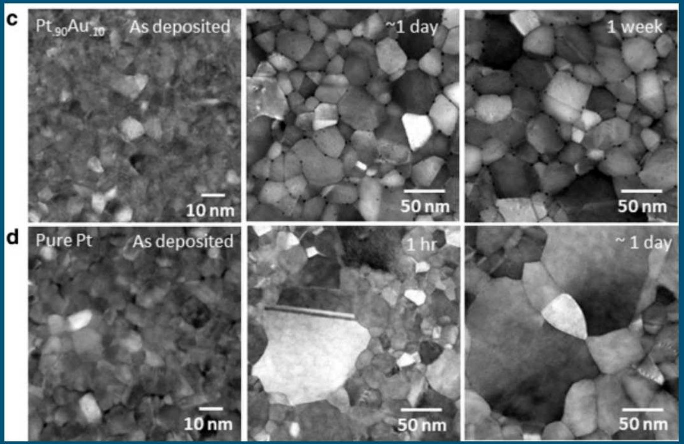
Motivation – solute segregated nanocrystalline alloys



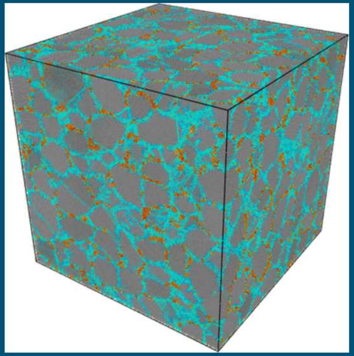
Gertsman, V.Y. and Birringer, R., *Scr. Metall. Mater*. 1994

Room temperature grain growth in pure nanocrystalline Cu



Lu, P. et al. *Materialia*, 2019

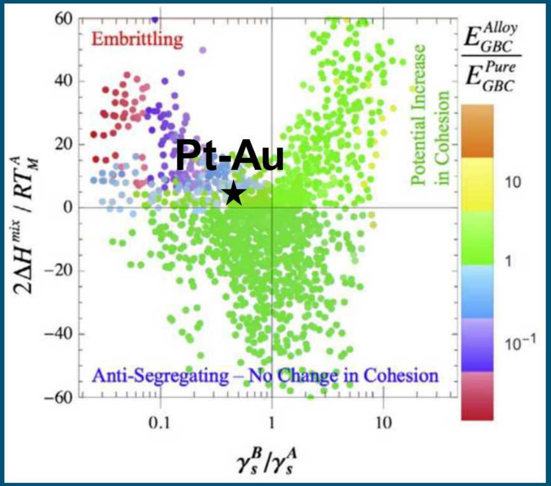
Improved thermal stability



FCC Pt Non-FCC Pt Au

O'Brien, C.J. et al., *J. Mater. Sci*. 2018

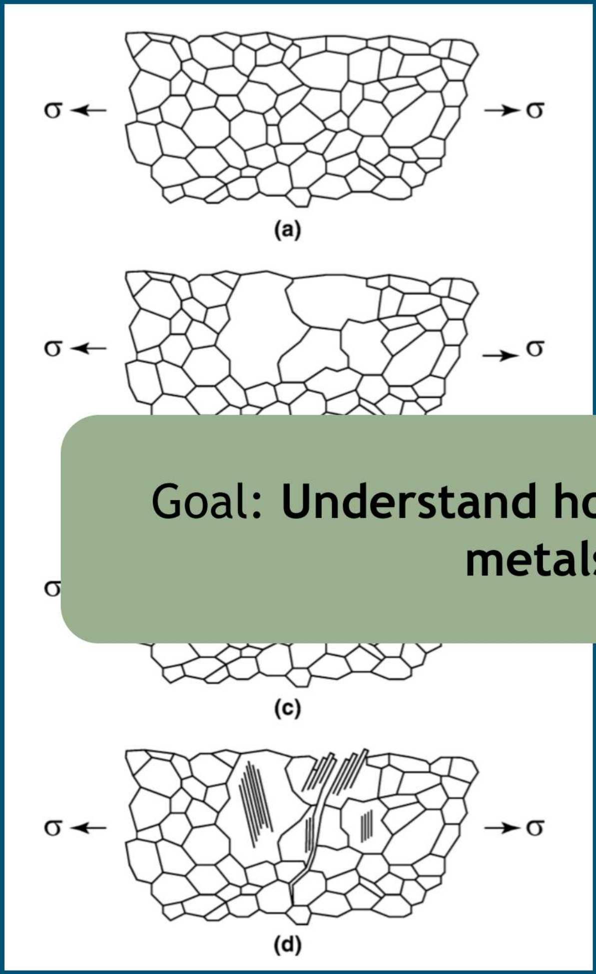
Stabilization through grain boundary segregation



Gibson, M.A., Schuh, C.A., *Acta Materialia*, 2019

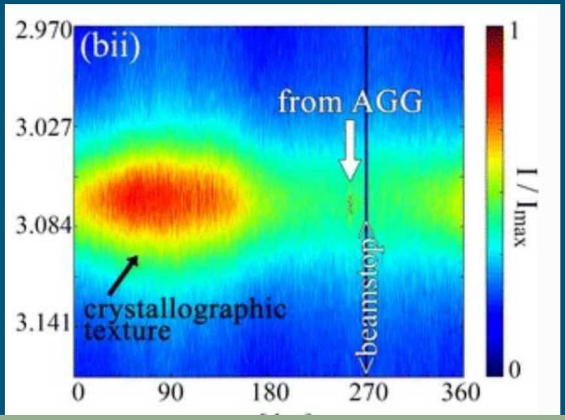
At the cost of grain boundary embrittlement

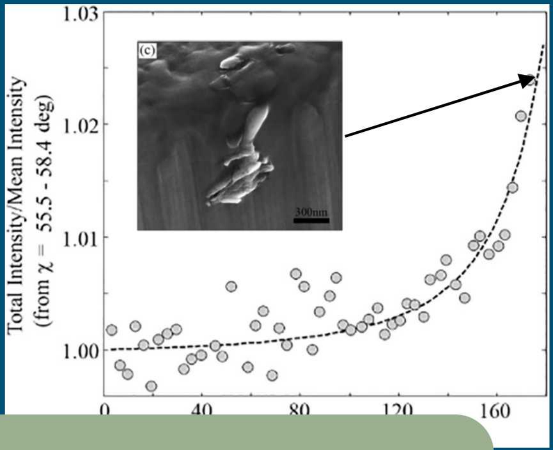
Background – fatigue in nanocrystalline metals



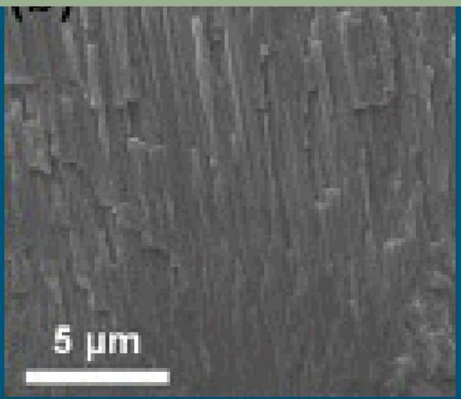
Padilla, H., Boyce, B. *Exp. Mech* 2010

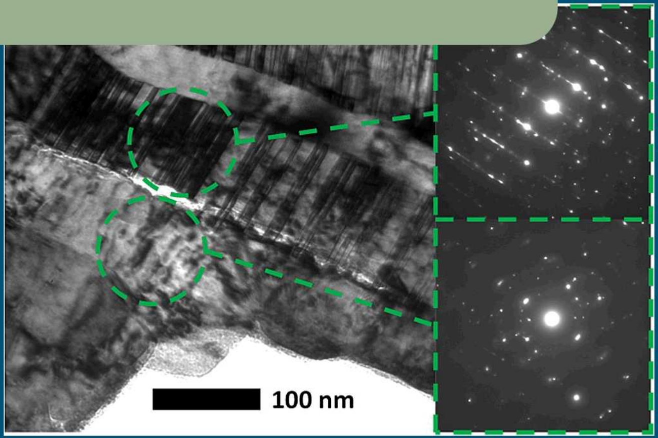
Abnormal grain growth typically observed in simple nanocrystalline FCC metal





Goal: Understand how complex solute segregated nanocrystalline metals behaves under fatigue loading



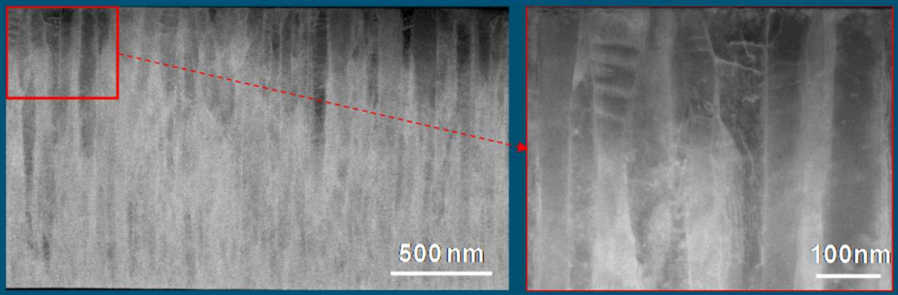


Heckman, NM et al., *Acta Mat*. 2017.

Complex nanocrystalline metals (nanotwinned CuAl) can show other fatigue modes

Material System: Nanocrystalline Pt and Pt-Au

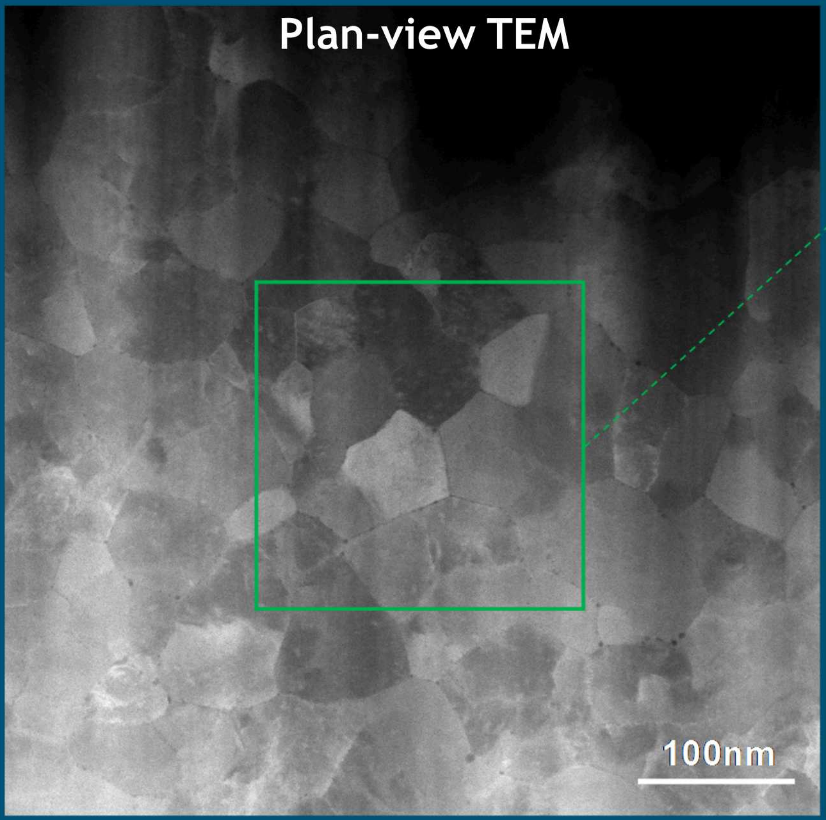
Cross-sectional TEM

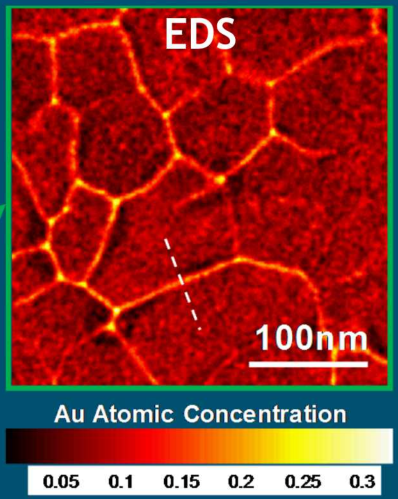


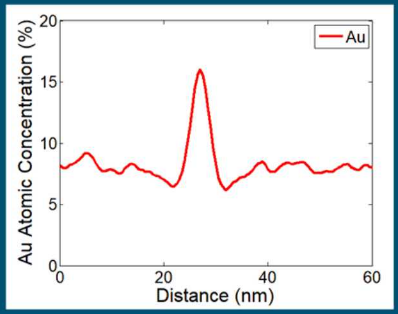
5 µm thick magnetron sputtered films

- Pure Pt, Pt-10at%Au (Pt-10Au)

~40 nm mean grain width



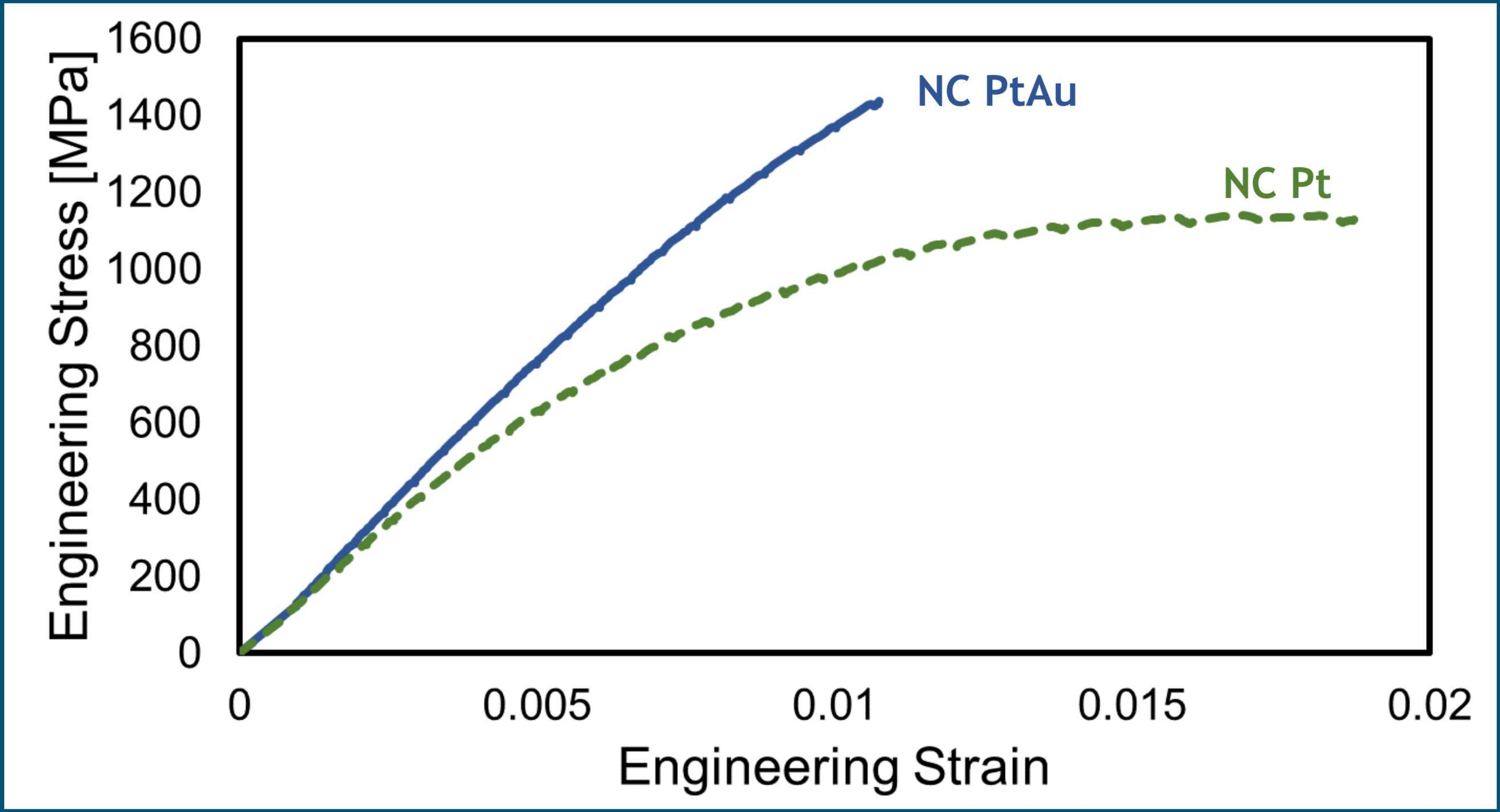




Au segregation to boundary observed in as-sputtered films

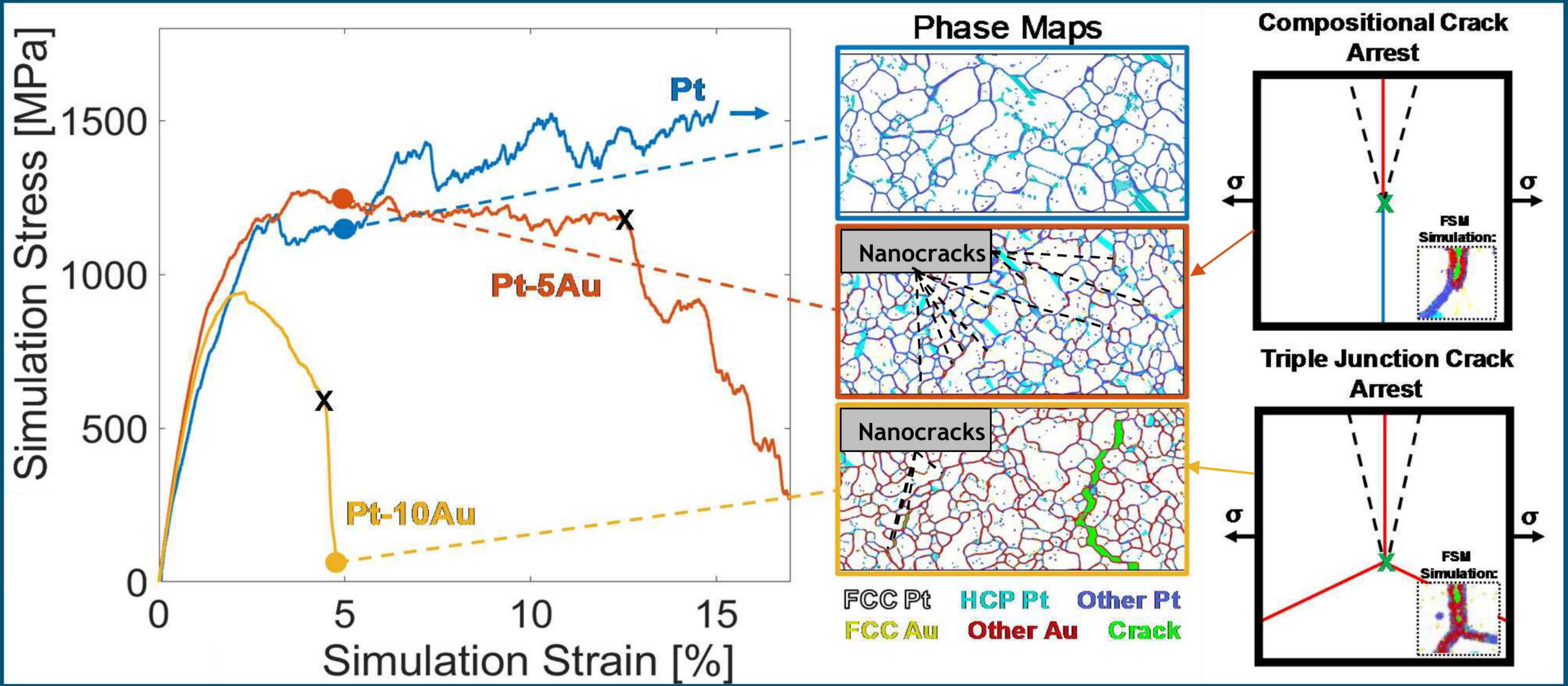
Heckman, Nathan M. et al. *Nanoscale* 2018

NC Pt and PtAu – Monotonic Tensile Properties



NC PtAu system shows improved strength, however reduced ductility compared to NC Pt

NC Pt and PtAu – Embrittlement and Crack Arrest

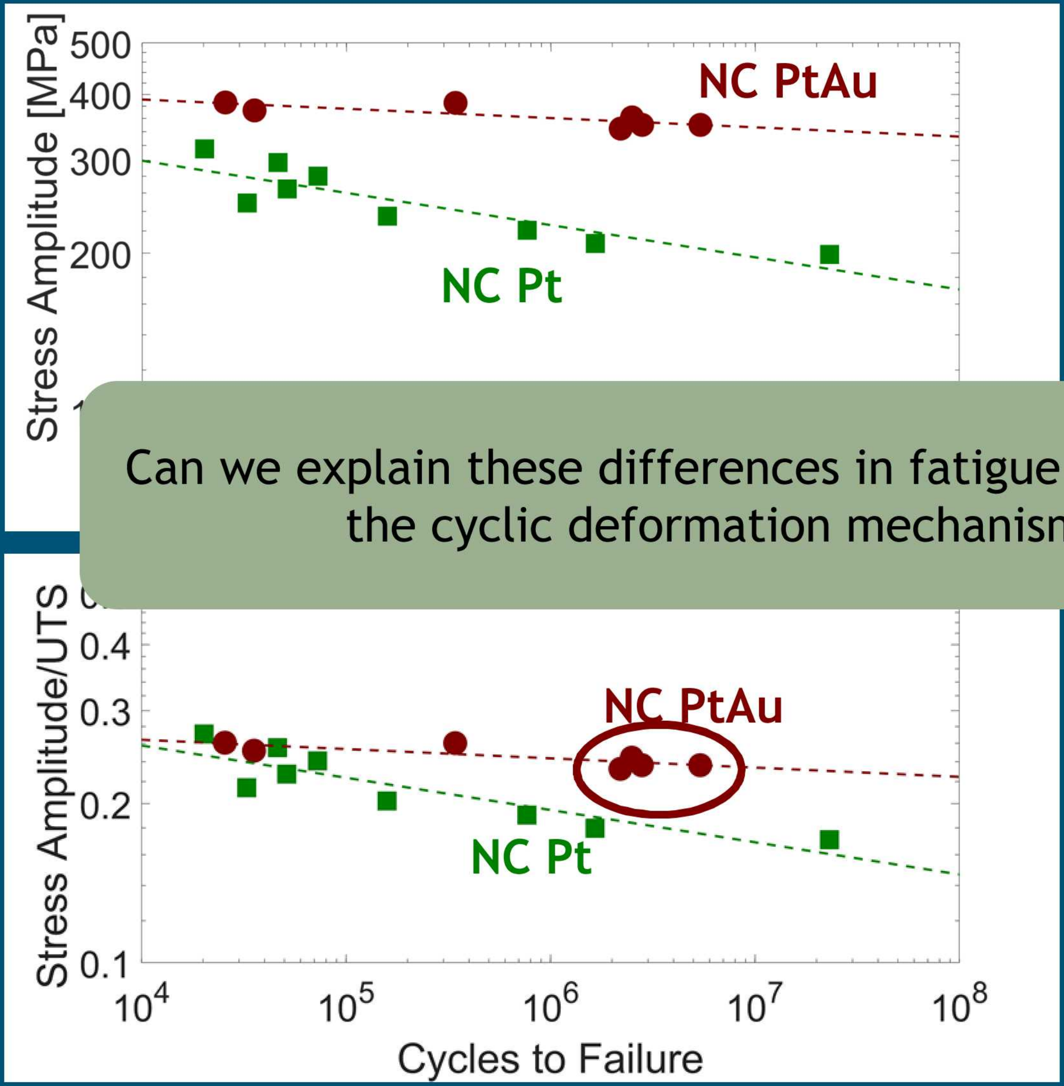


NC PtAu has the potential to maintain some toughness through the formation of nanocrack networks that form due to various crack arrest mechanisms

The experimental PtAu is most similar to Pt-10Au in the simulations, which shows the lowest toughness

Heckman, NM, et al. *Nanoscale* 2018

NC Pt and PtAu – Unnotched Wöhler (S-N) Curves



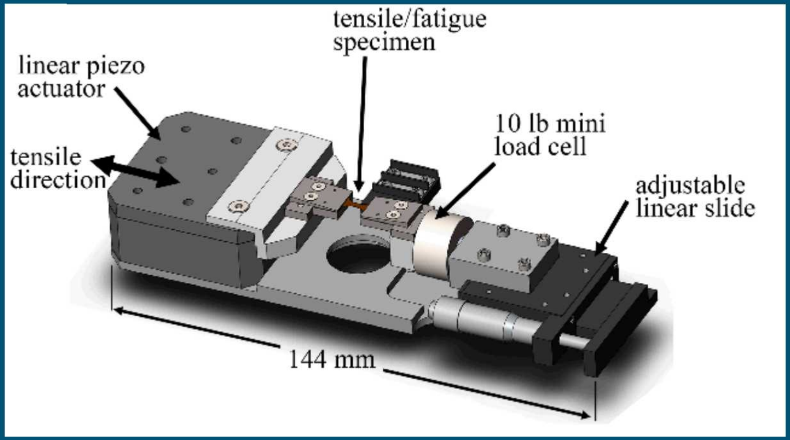
High fatigue strengths in NC PtAu are at least partially due to high tensile strength of material

Can we explain these differences in fatigue properties by understanding the cyclic deformation mechanisms of each system?

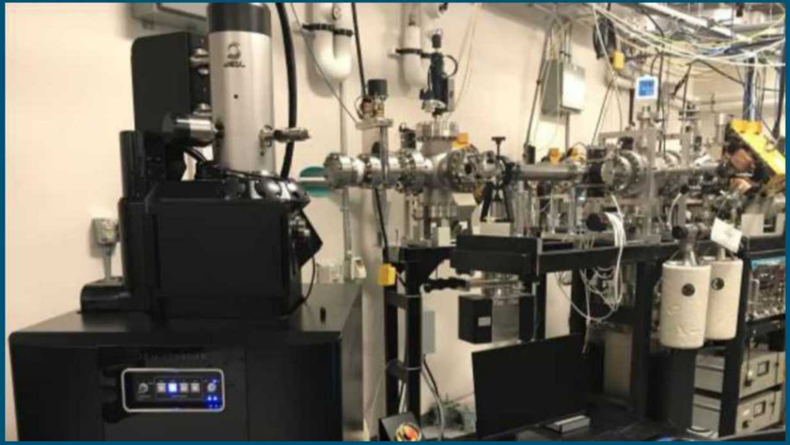
NC PtAu shows relatively high fatigue strengths at higher fatigue lifetimes, with relatively small Basquine slope

Method: Automated In-situ SEM Fatigue Tests

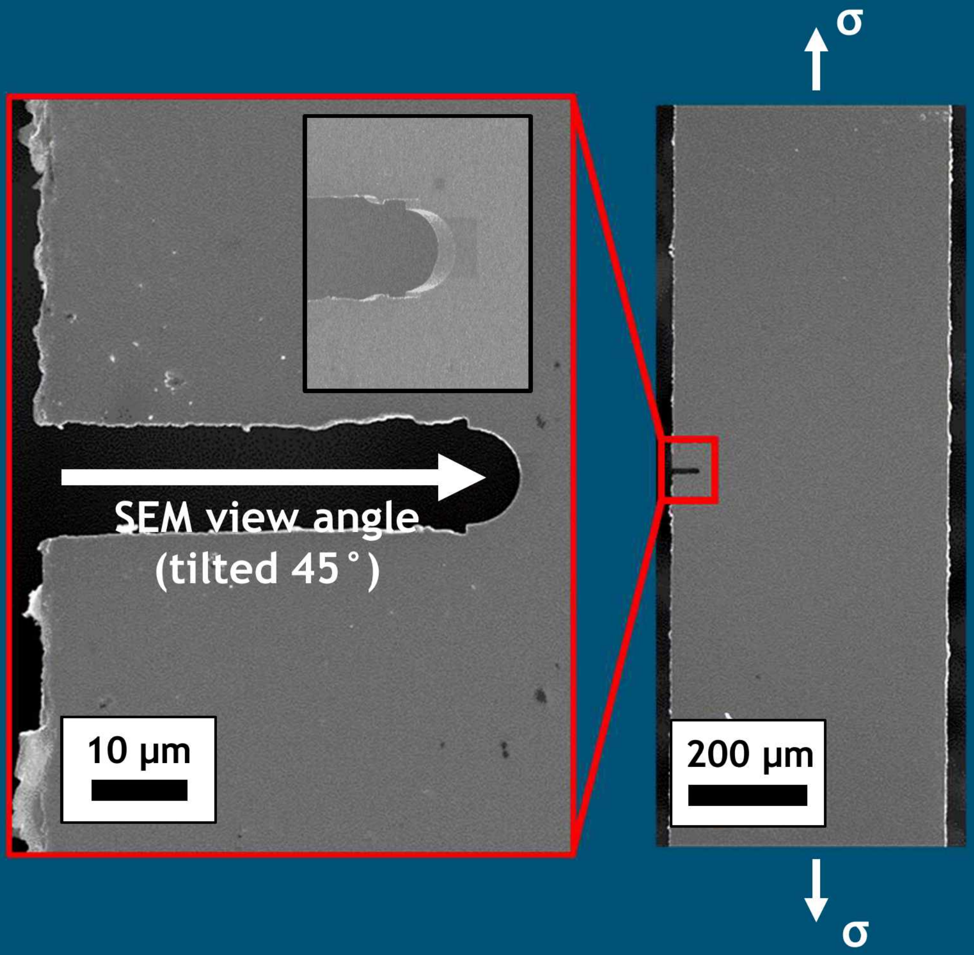
Custom fatigue load frame



I^{3}SEM at Sandia National Labs*

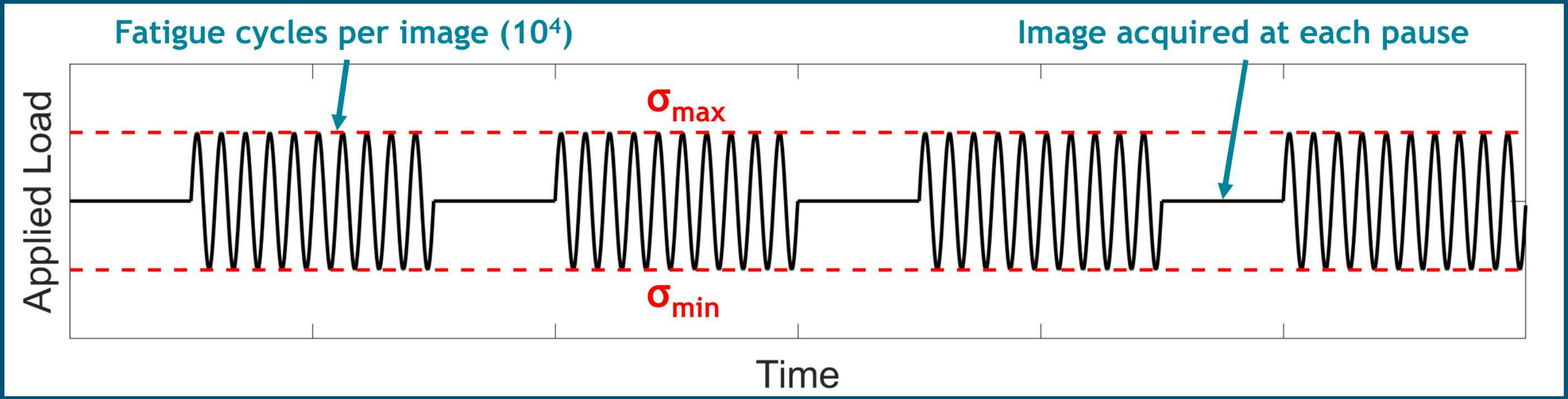


Sample preparation

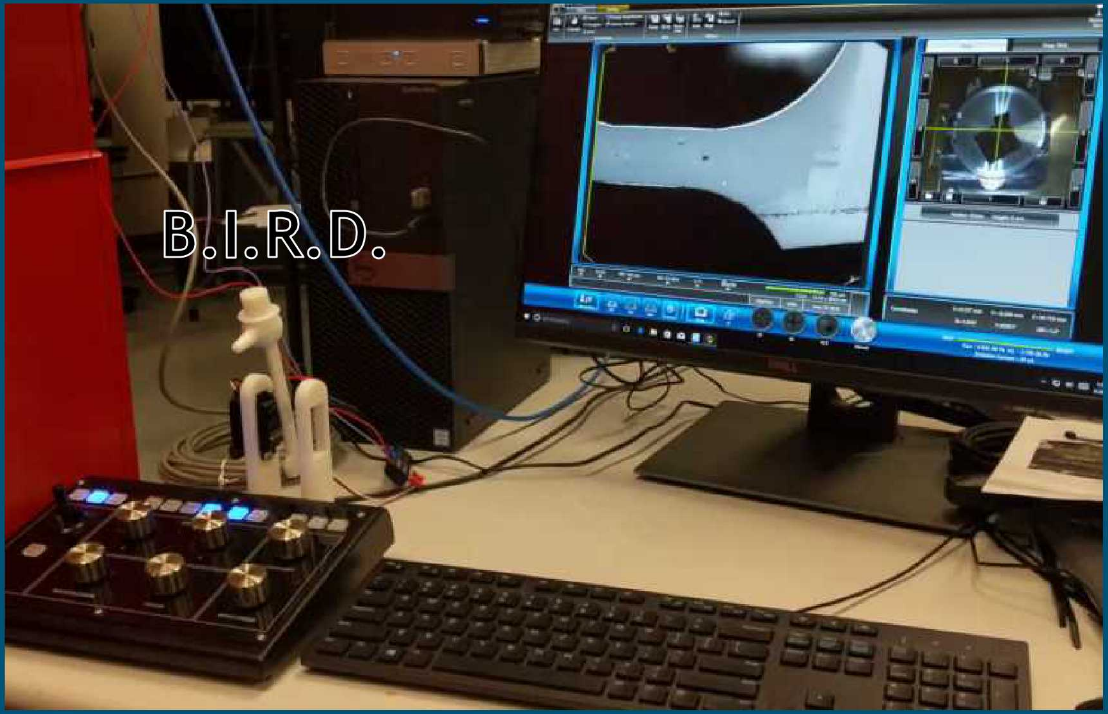


*Accessible as a user instrument through Center for Integrated Nanotechnology (CINT) - Contact Brad Boyce or Khalid Hattar

Method: Automated In-situ SEM Fatigue Tests

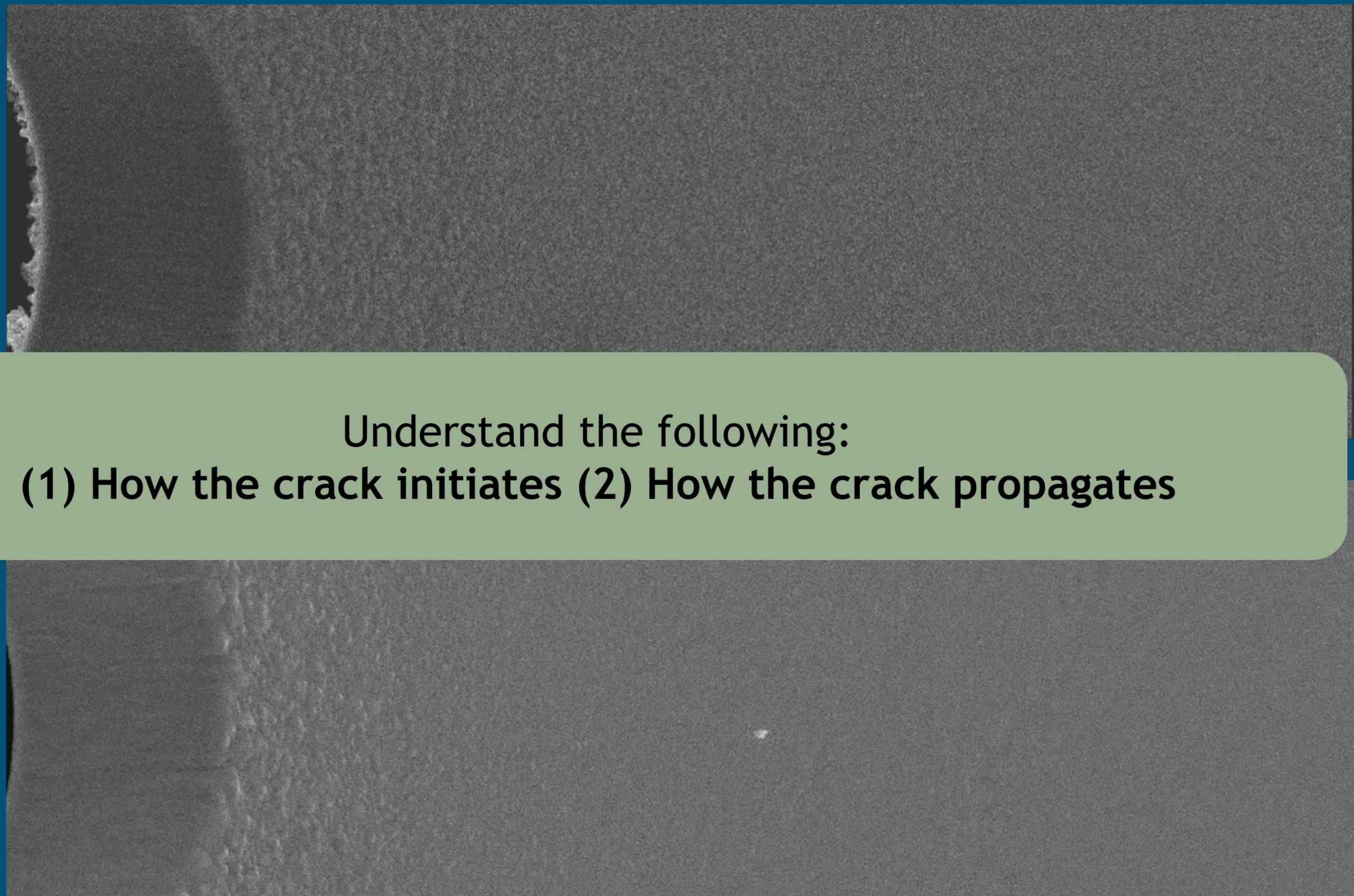


- Automation of entire process with Basic Image Recording Device (**B.I.R.D.**)
- All fatigue tests performed at 30 Hz, $\sigma_{min}/\sigma_{max}=0.3$
- 3-5 tests in 10^6-10^7 cycle regime (varying load) for both Pt and Pt-Au
- Longest test performed: 2.7×10^7 cycles over 15 days



Watching High-cycle Fatigue in Nanocrystalline Pt and Pt-Au

NC PtAu
5.7×10^{6} cycles to failure



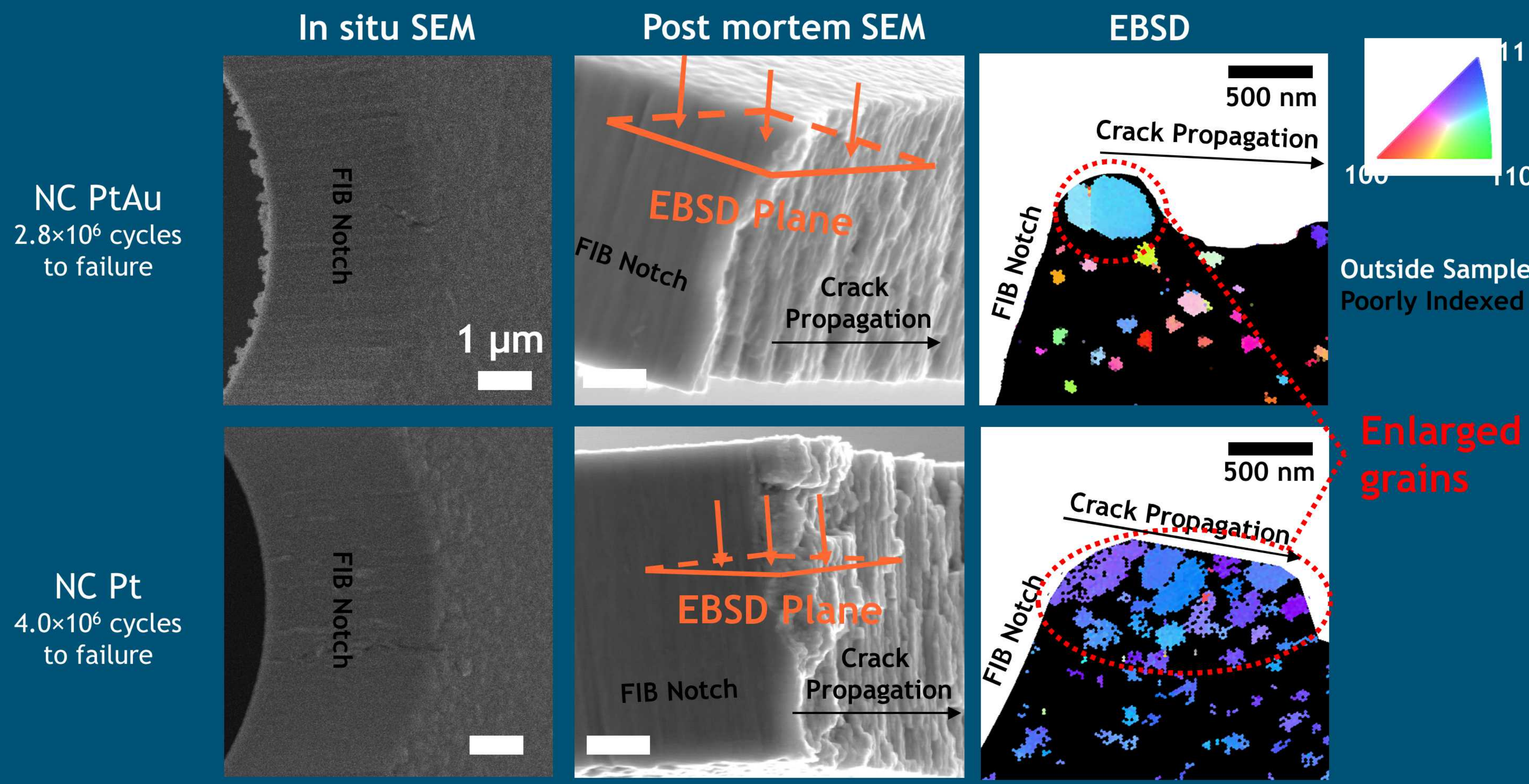
Understand the following:
(1) How the crack initiates (2) How the crack propagates

NC Pt
4.0×10^{6} cycles to failure

5 µm

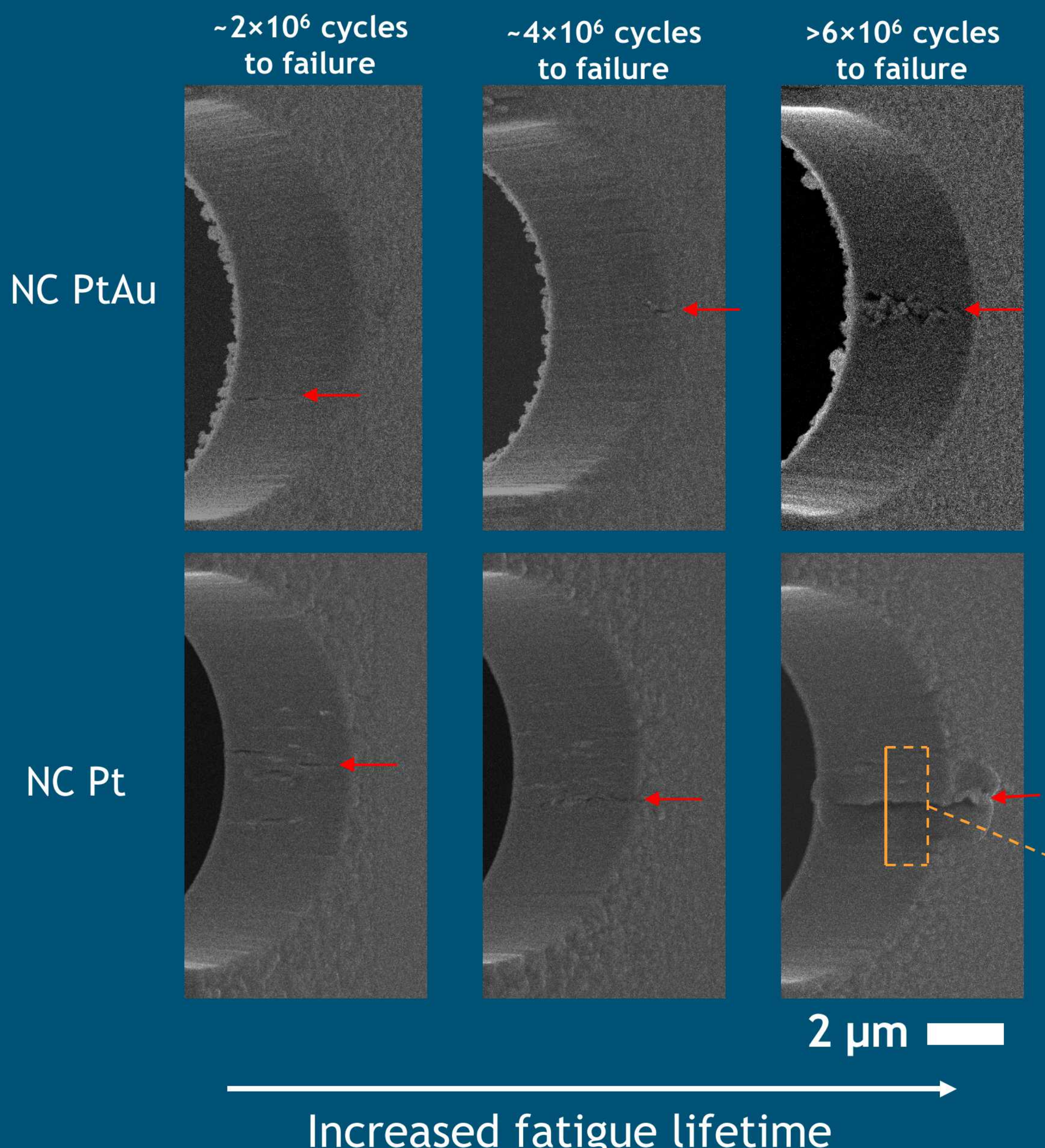
10,000× speed ➔ 3×10^{5} fatigue cycles per second

Crack Initiation: Mechanism

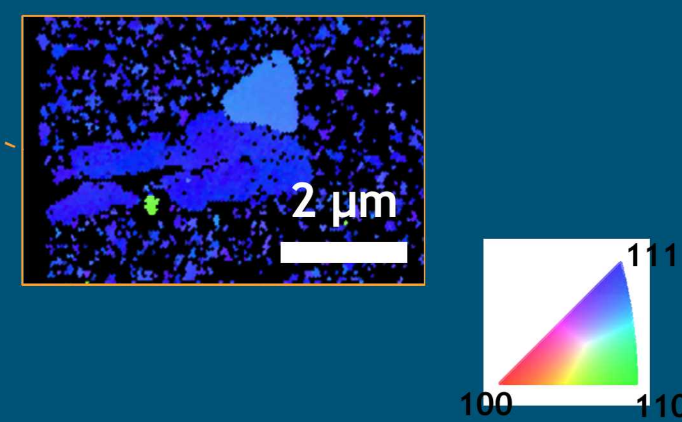


In both NC Pt and PtAu, the crack initiates through abnormal grain growth

Crack Initiation: Size Effects

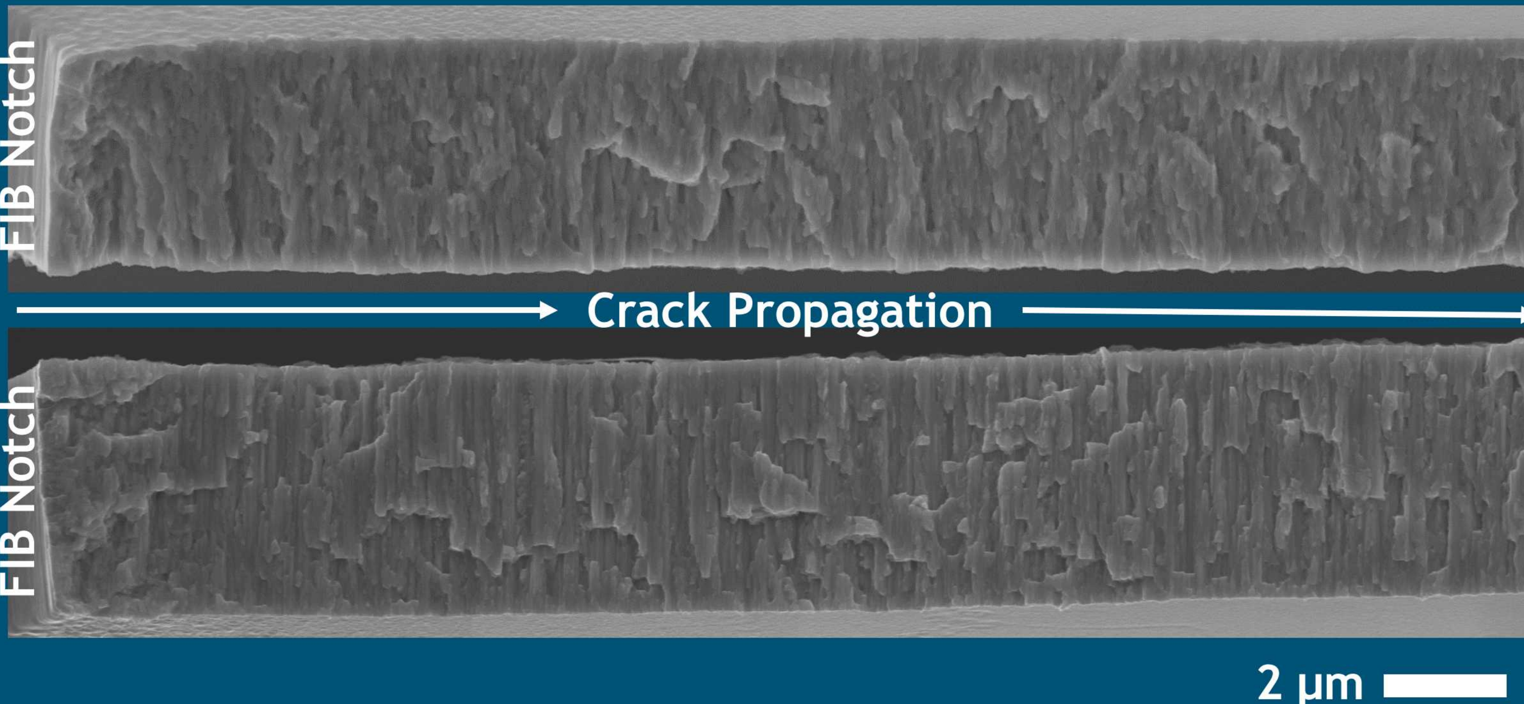


Larger grain growth <u>required</u> prior to crack initiation at lower fatigue stresses/higher fatigue lifetimes



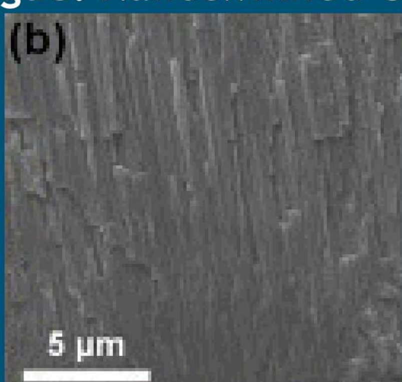
Crack Propagation: Mechanisms

NC PtAu
2.8×10^6 cycles
to failure



NC Pt
4.0×10^6 cycles
to failure

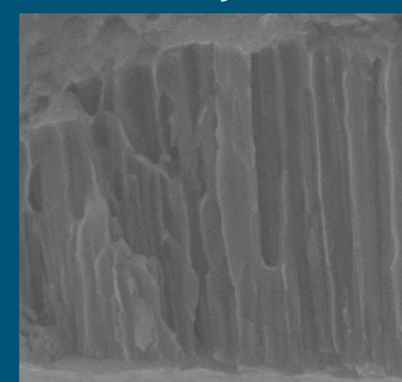
Fatigue: Nanotwinned Cu-Al



Heckman, NM et al., *Acta Mat*. 2017.

Fracture surface morphologies in both systems consistent with intergranular fracture observed in previous studies

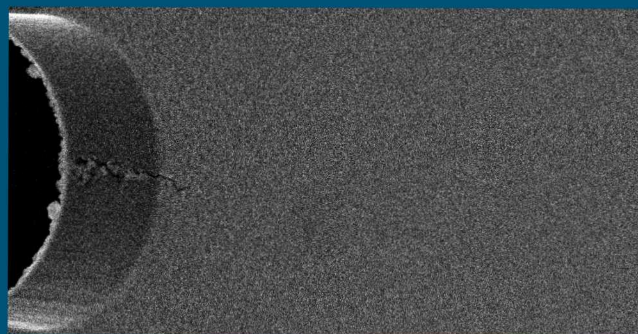
Tension: Nanocrystalline PtAu



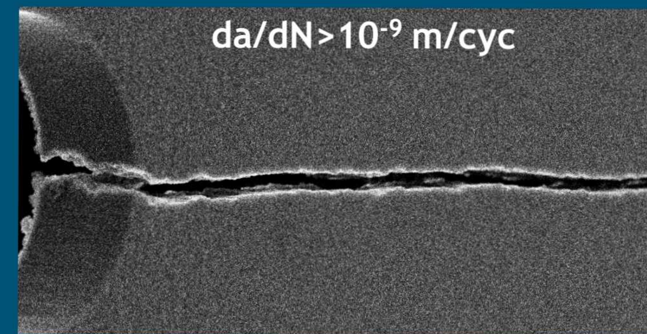
Heckman, NM et al., *Nanoscale* 2018.

Crack Propagation: Rates

NC PtAu
5.0×10^{6} cycles
to failure



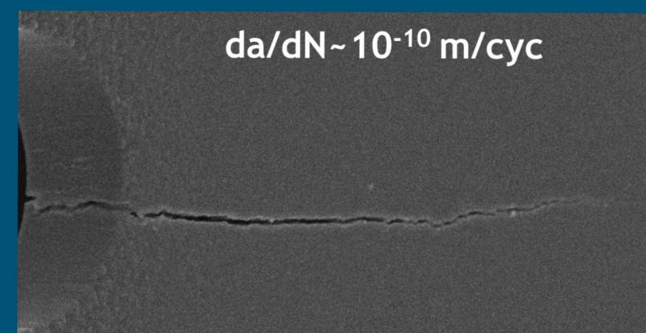
10^{4} cycles →
$\Delta K \sim 3.8$ MPa $\sqrt{m}$



5 µm

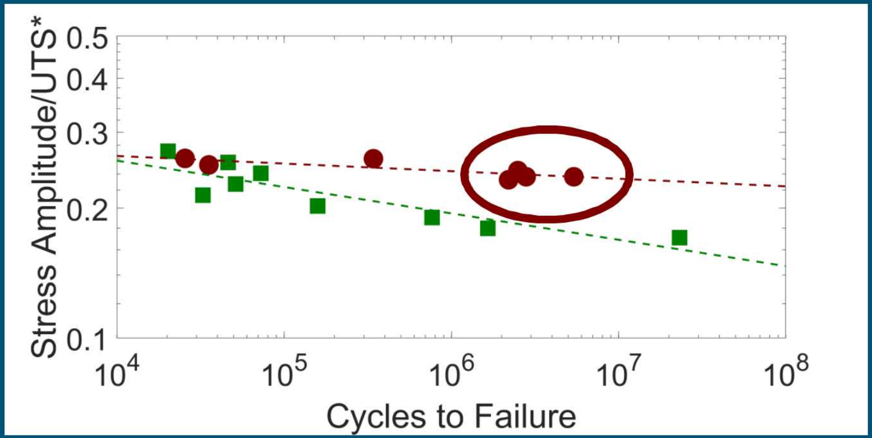
NC Pt
4.0×10^{6} cycles
to failure

10^{5} cycles →
$\Delta K \sim 3.0$ MPa $\sqrt{m}$



In the high cycle fatigue regime, stable crack propagation was much faster in the PtAu system

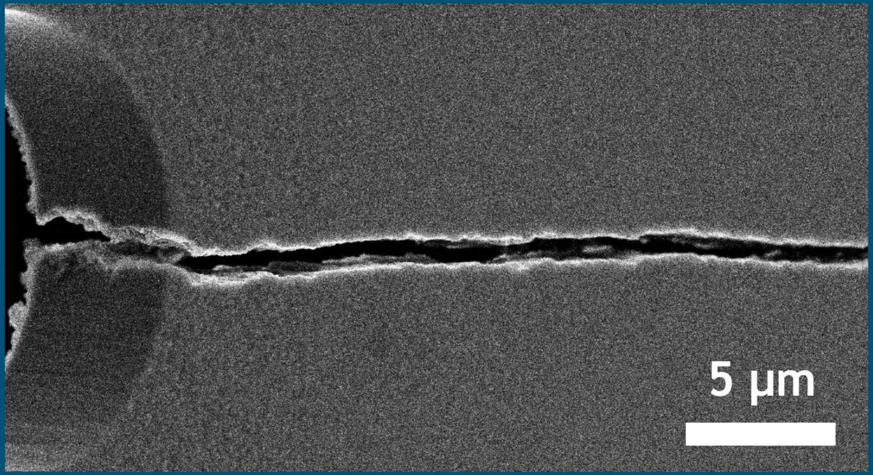
Conclusion: Cyclic vs Monotonic Deformation



High fatigue strength in PtAu, especially at high lifetimes

Larger grain growth required for crack initiation at higher regimes

Higher resistance to grain growth in monotonic loading in NC PtAu



Higher crack growth rates in PtAu

Fracture surfaces consistent with intergranular fracture

Grain boundary embrittlement in NC PtAu due to Au segregation

Future work will further investigate the nanoscale deformation mechanisms through TEM

Thank you!

U.S. DEPARTMENT OF ENERGY | Office of Science

Relevant talk: Watching cracks heal in TEM in nanocrystalline Pt

4:00 PM Invited
Fatigue-crack Healing in Pure Nanocrystalline Pt Enabled by Boundary Evolution: Christopher Barr[1]; Ta Duong[2]; Daniel Bufford[1]; Nathan Heckman[1]; Michael Demkowicz[2]; Khalid Hattar[1]; *Brad Boyce*[1]; [1]Sandia National Laboratories; [2]Texas A&M University