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A perspective on environmentally-induced cracking

R.M. Latanision
Exponent, Inc., USA, rlatanision@exponent.com

A.K. Vasudevan
ONR Retired, USA

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A Perspective on Environmentally-Induced Cracking

R.M. Latanision
Senior Fellow
Exponent – Failure Analysis Associates, and
Director (Emeritus) The H.H. Uhlig Corrosion Laboratory
Massachusetts Institute of Technology

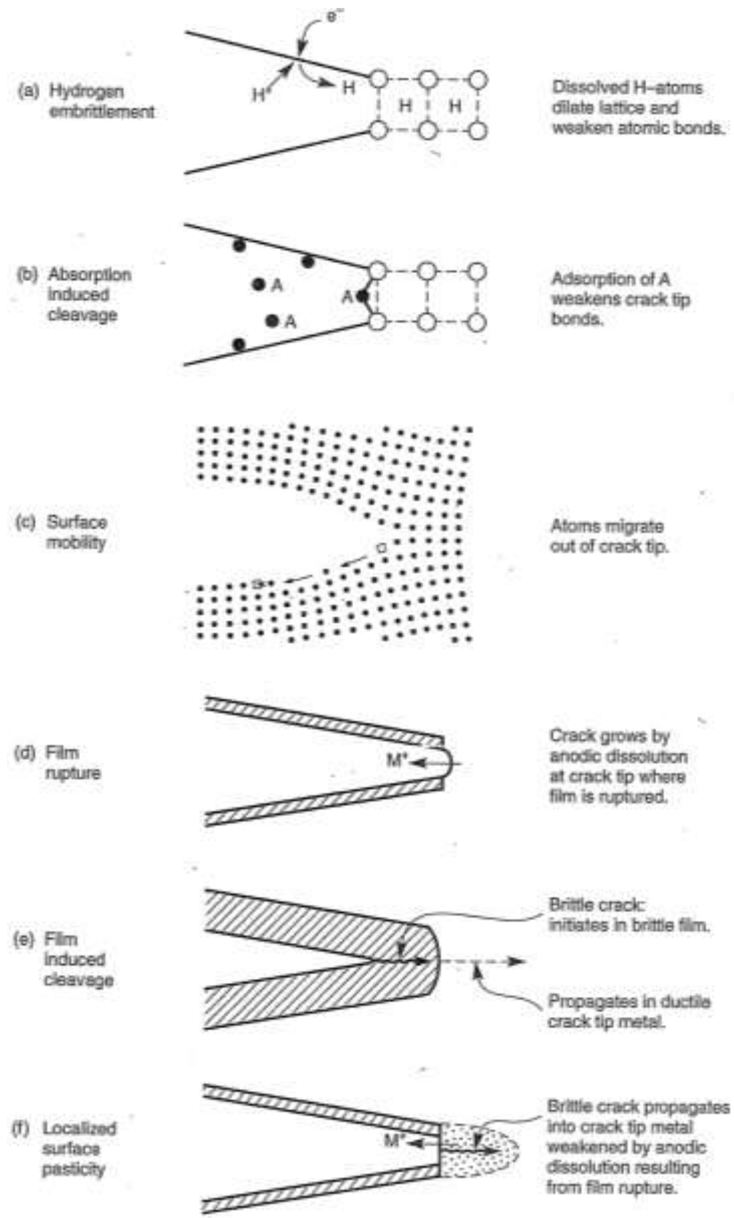
Environmentally-Induced Cracking Phenomena

- Hydrogen Induced cracking
- Liquid Metal Embrittlement
- Static Fatigue of Silicate Glass
- Accelerated Crazing of Polymers in Organics Media
- Corrosion Fatigue
- Stress Corrosion Cracking
    - Chloride Cracking
    - Caustic Cracking
    - Season Cracking
    - Sulfide Cracking
    - Others

The phenomenology is well understood, but the mechanisms remain unclear. Corrosion is not involved in many phenomena that are described as SCC.

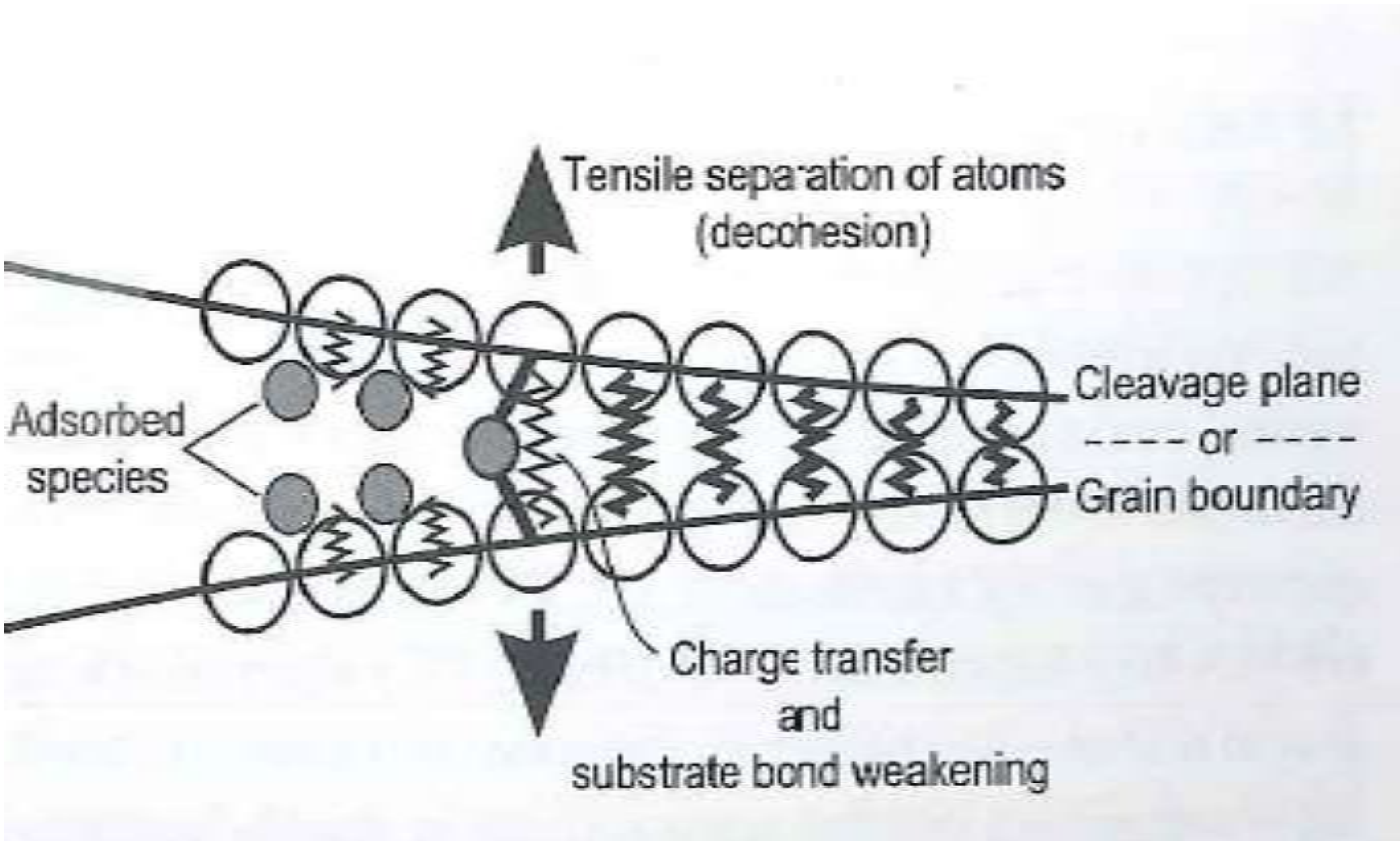
Schematic Summary of Some Proposed Mechanisms

(from D.A. Jones, *Principles and Prevention of Corrosion,* 1996)



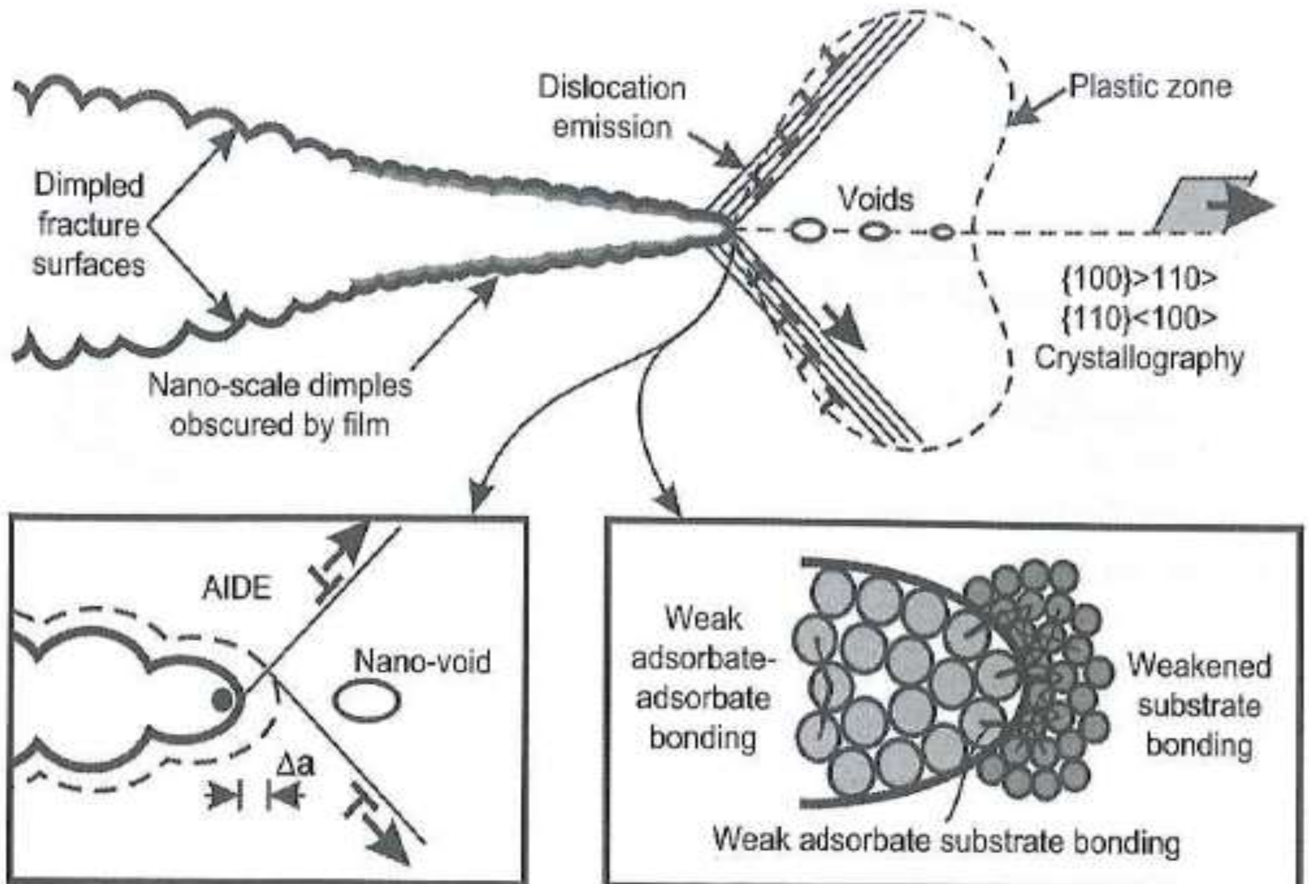
Schematic of Adsorption-Induced Cracking

(from S. Lynch, *Corr. Rev*. , 30, 63 (2012))



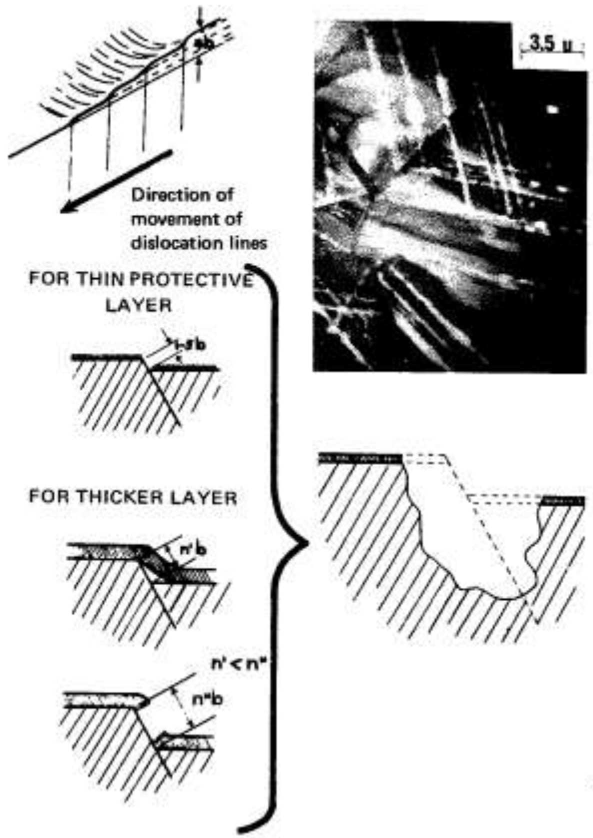
Schematic of Adsorption-Induced Dislocation Emission

(from Lynch, *Corr. Rev.* , 30, 63 (2012))



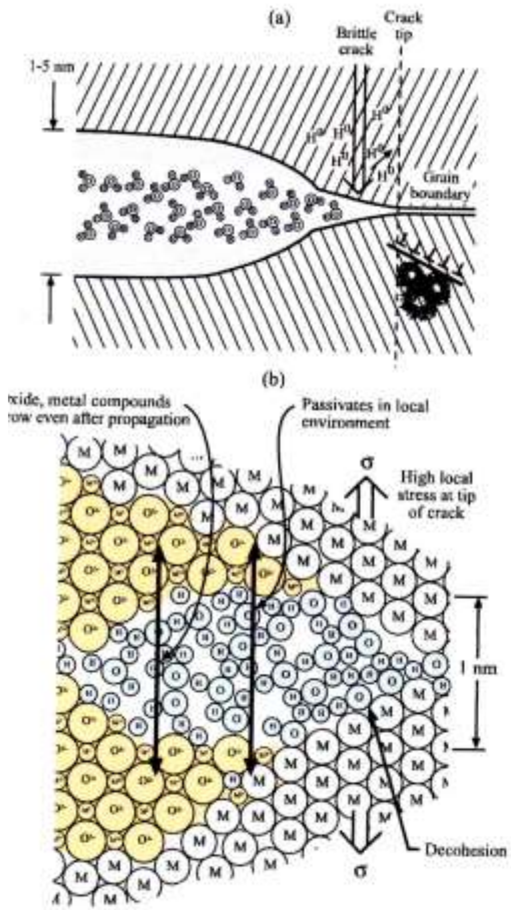
Schematic of Slip Step Dissolution

(Latanision and Staehle, *SCC of Fe-Cr-Ni Alloys,*1969)



Schematic of (a) a "tight crack", (b) an atomistic description of a brittle crack event at the crack tip, (c) options for producing brittle events at the crack tip

(from Staehle, *Corr. Rev.* , 28, 1 (2010)).



(c)

Apparent Options for Crack Advance

- Surface energy lowering embrittles
- Brittle films due to dealloying
- Oxygen diffusion in grain boundary
- Hydrogen facilitates movement of dislocations which causes barriers to fail
- Cold-work embrittled layer at edge of plastic zone–further embrittled by hydrogen
- Vacancy from dissolution produce crack nucleus
- Brittleness due to surface-film formation
- Film break and repassivation
- Film thinning and increased reactivity

Environments Which Lead to Cracking of Certain Alloys

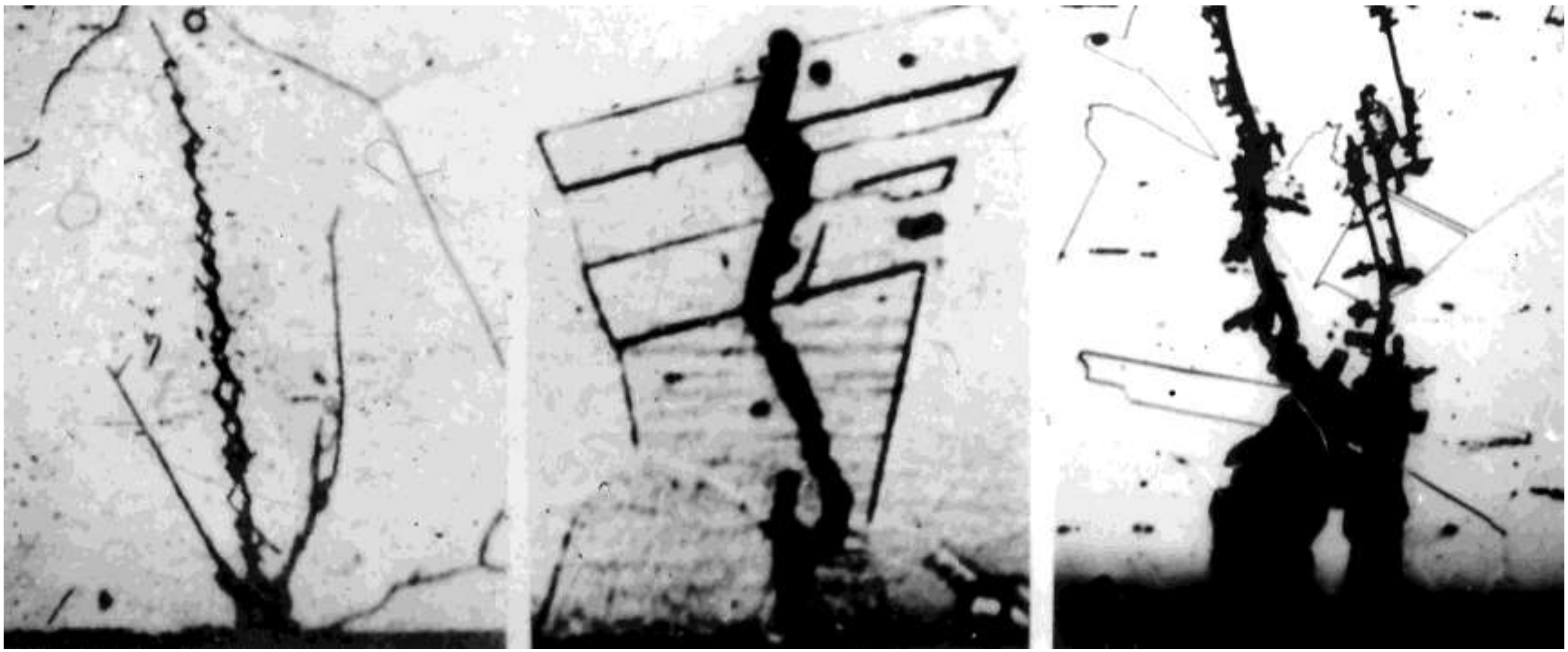
Aluminum Alloys	Seawater (chloride and other halides)
Copper Alloys	Ammoniated aqueous solutions
Nickel Alloys	Caustics, high purity water, H_2S
Mild Steels	Caustics, nitrates, anhydrous ammonia, carbonate/bicarbonate mixtures
High Strength Steels	Water, moist air, H_2S
Stainless Steels (austenitic)	Caustics, halides
Titanium Alloys	Seawater, halides, CCl4, N2O4, methanol

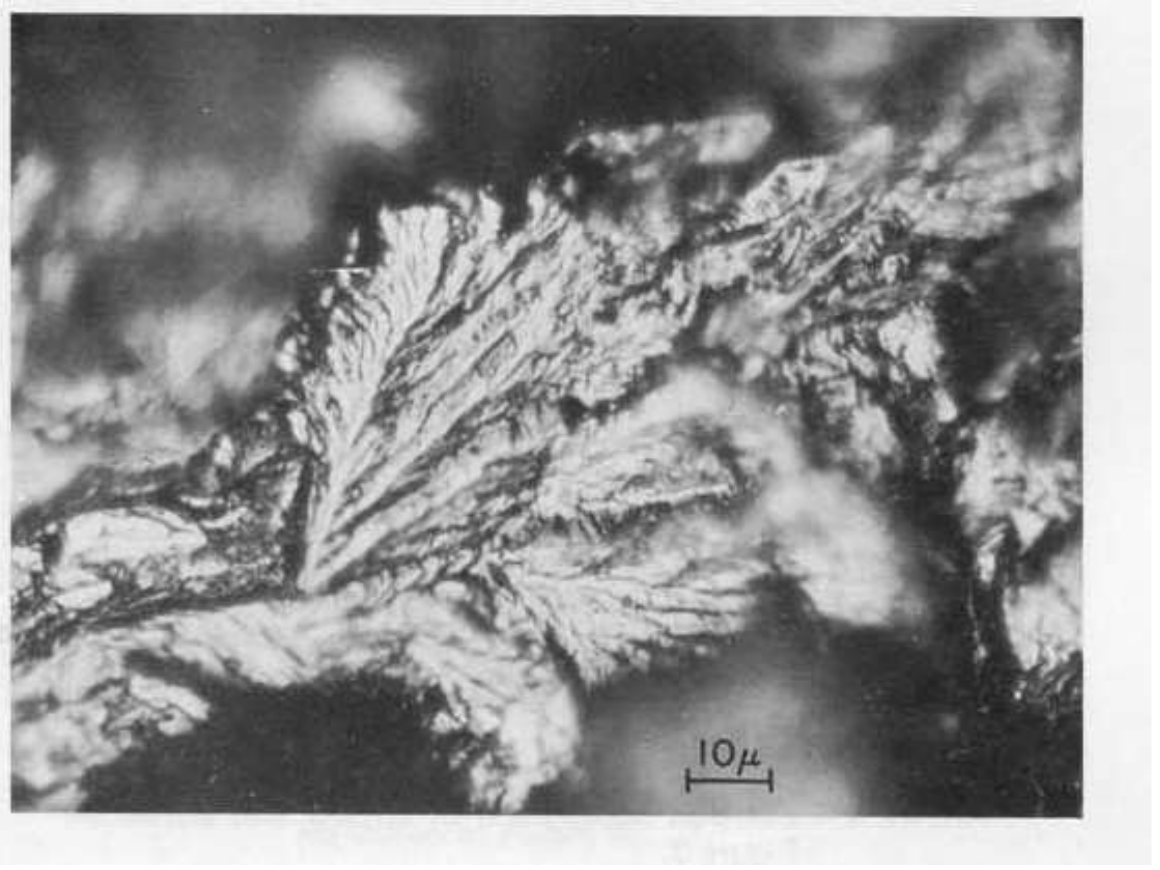
The Following Observations Must be Explained by Any Acceptable Working Theory:

- The pronounced specificity of the damaging environment
- The brittle fracture of ordinarily ductile metallic materials in the presence of specific environmental species
- The general observation that metallic materials that are among the most resistant to uniform corrosion are particularly susceptible
- The crack inhibiting effect of anions added to the damaging environment
- The observation that cracking occurs in zones of natural potential corresponding to active/passive transitions, i.e. critical potentials for cracking.

Chloride Induced Transgranular SCC of Type 304 Stainless Steel

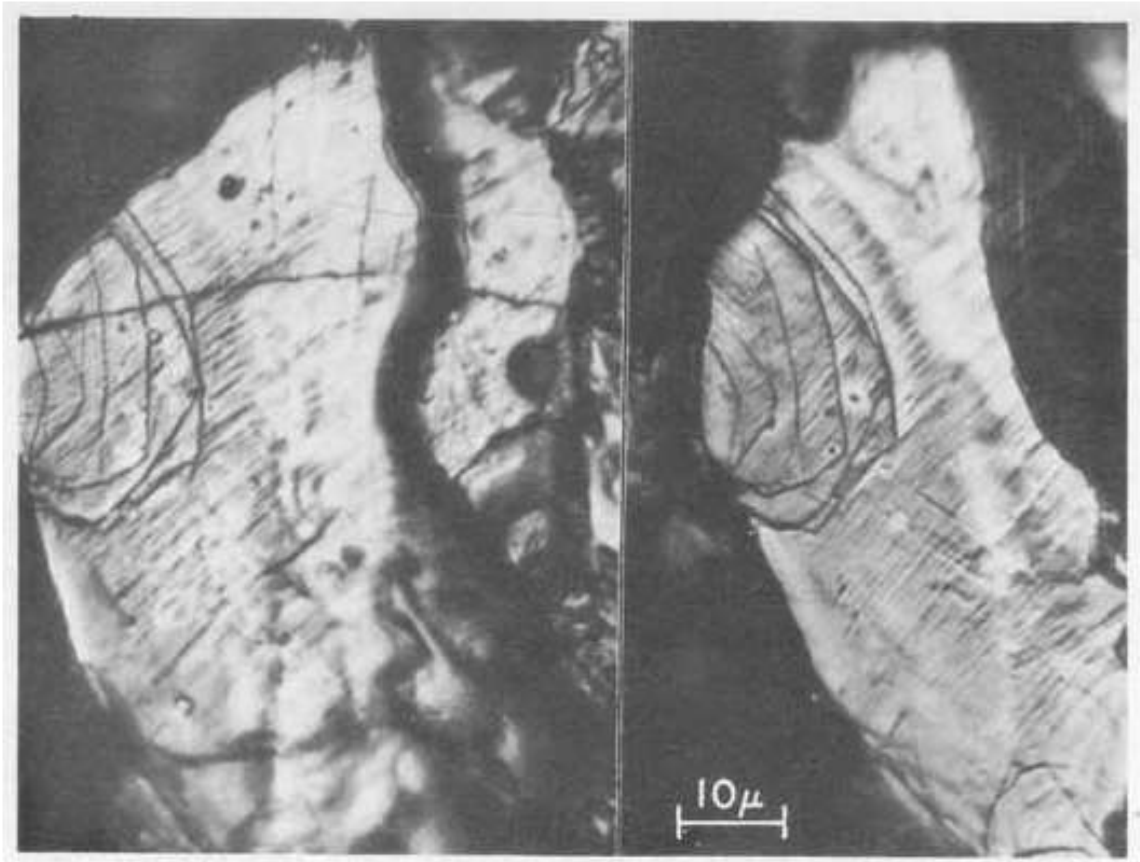
(Latanision and Staehle, *SCC of Fe-Cr-Ni Alloys,1969*)





Morphology of Fracture in 316 Stainless Steel Exposed to Boiling MgCl2

(from Nielsen, *SCC of Fe-Cr-Ni Alloys*, 1969)

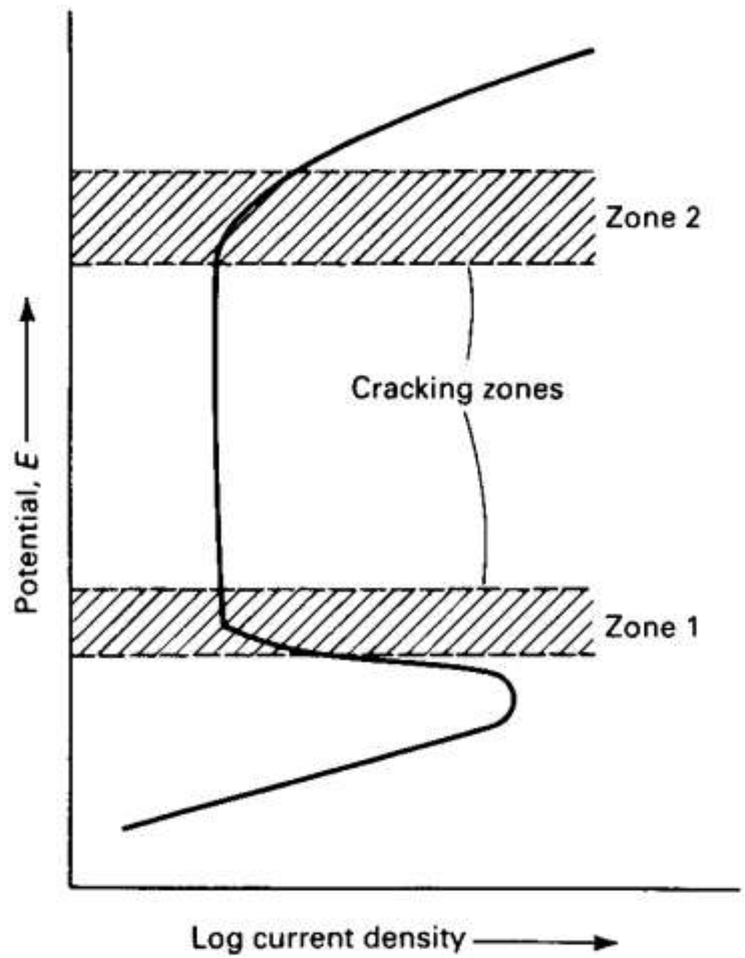


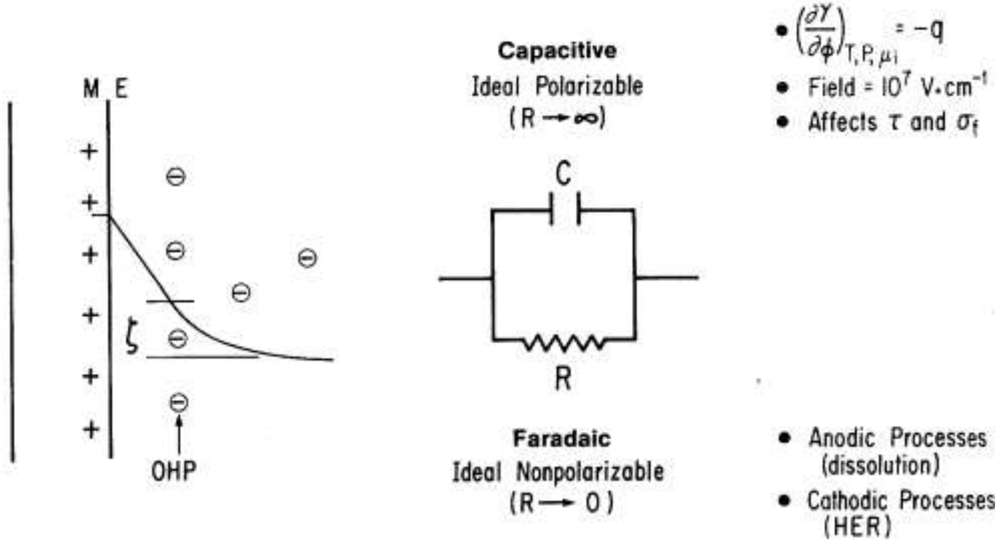
Matching detail in fracture surfaces of 304 Stainless Steel Exposed to Boiling MgCl2

(from Nielsen, *SCC of Fe-Cr-Ni Alloys*, 1969)

Schematic Anodic Polarization Curve Showing Zones of Susceptibility to Cracking

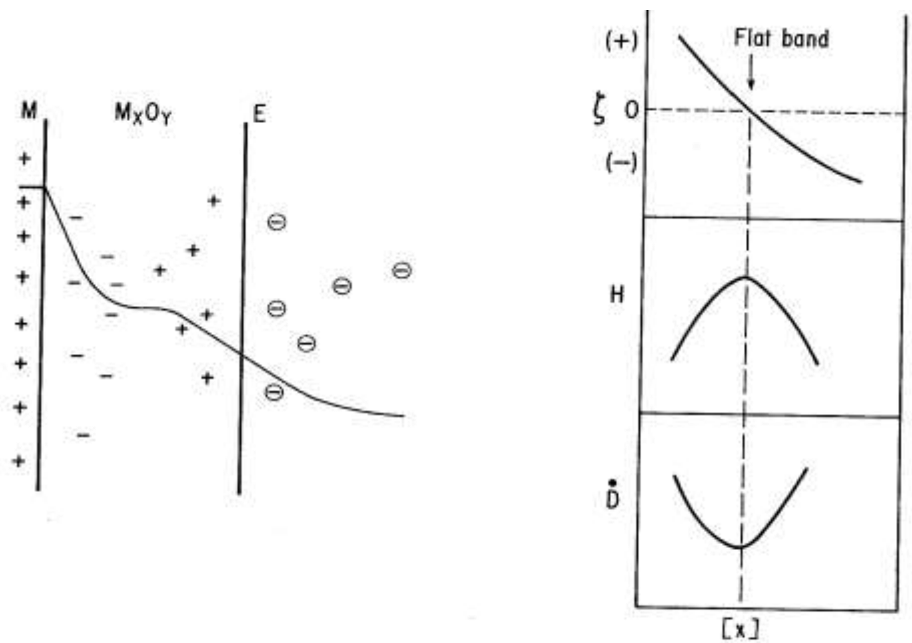
(From R.A. Jones, *ASM Handbook*, Volume 13A: Corrosion)





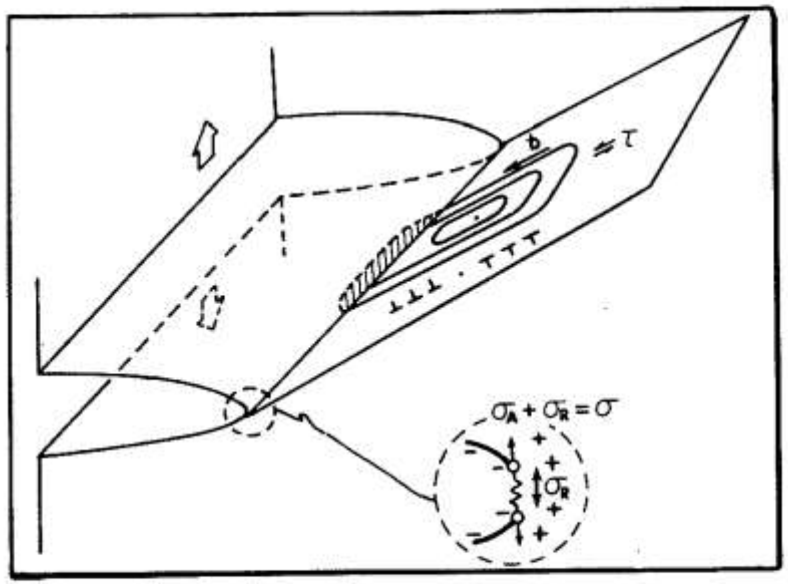
The Charge and Potential Distribution at a Metal-Electrolyte Interface

(From Latanision, *Atomistics of Fracture*, 1983.)



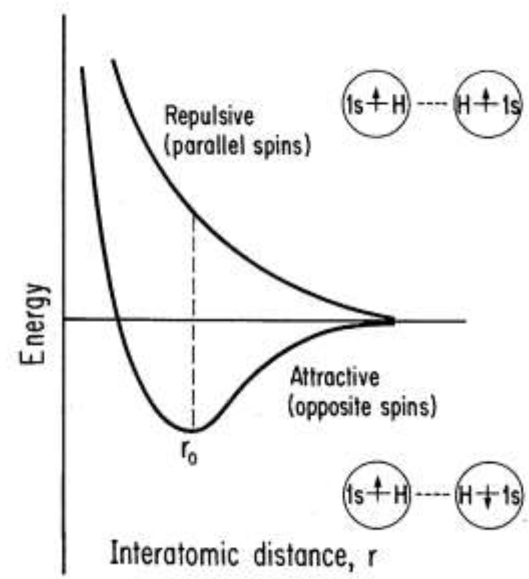
Charge and Potential Distribution at a Metal/Oxide Interface
and Corresponding Mechanical Behavior Effects

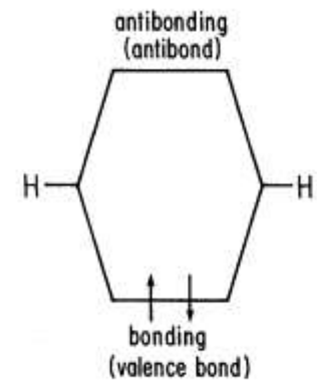
(From Latanision, Atomistics of Fracture, 1983.)



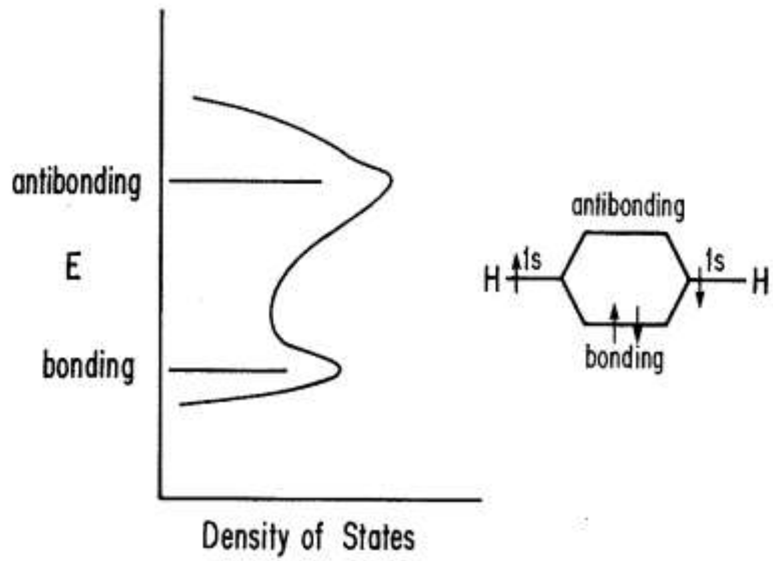
Crack Tip Showing the Possible Influence of the Double Layer on Shear and Fracture Processes.

(From Latanision, *Atomistics of Fracture*, 1983.)





The Energetics of the Hydrogen Molecule



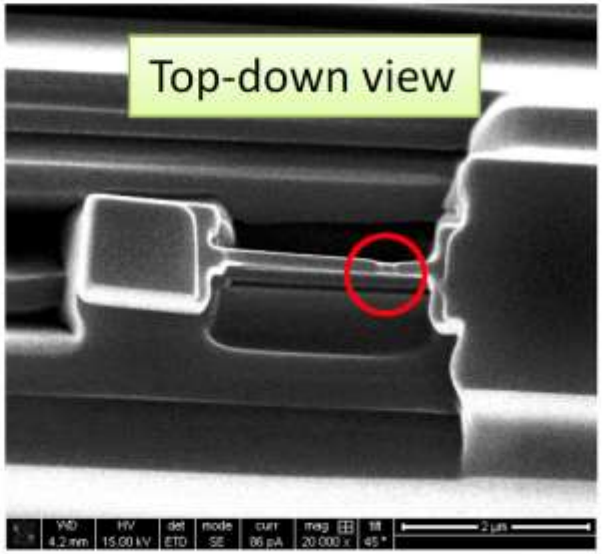
Adsorption of Hydrogen on Metal Surfaces

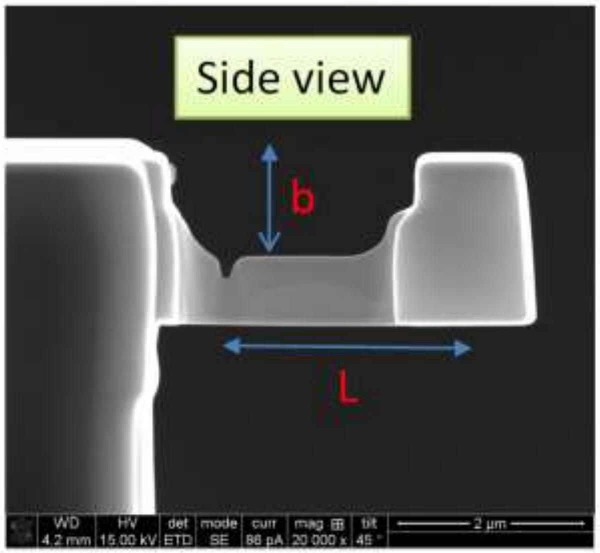
$$Co_2(CO)_8 + H_2 = 2HCo(CO)_4$$

The Dissociation of Cobalt Carbonyl in the Presence of Molecular Hydrogen

Experimental Resolution vs. Computational Fidelity

- Experimental Resolution is on the Order of Atomic Dimensions
  - ATEM, Atom Probe (3D), AES
  - FIB Techniques for Sample Preparation
- Modeling & Simulation Can Now Handle Atomic Scale Dimensions-Volumes of Near Engineering Significance

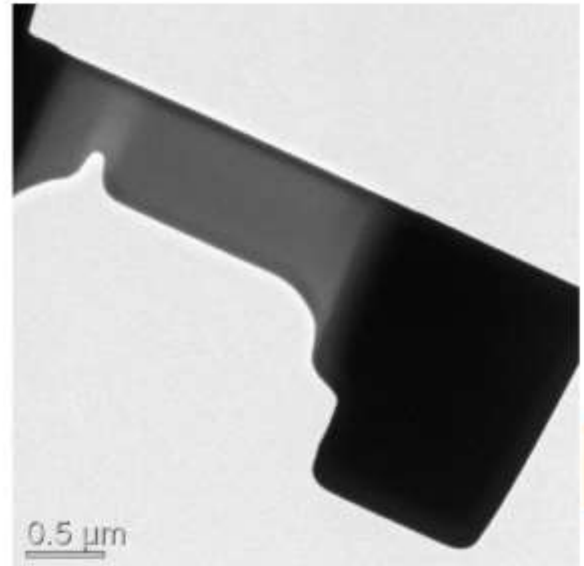




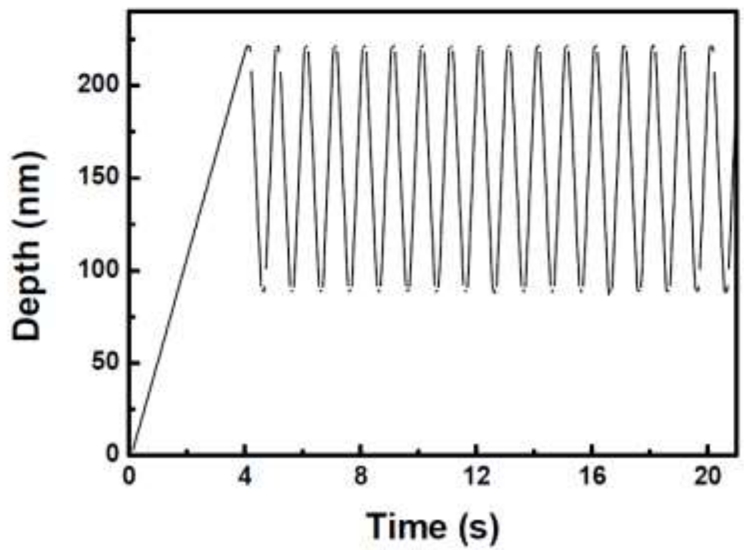
SEM

$Al_{88}Fe_7Gd_5$ MG

Thickness (t)=120 nm
Width (W)=741 nm
Length (L)=2540 nm
a: notch length
W-a=498 nm
b=1115 nm



TEM

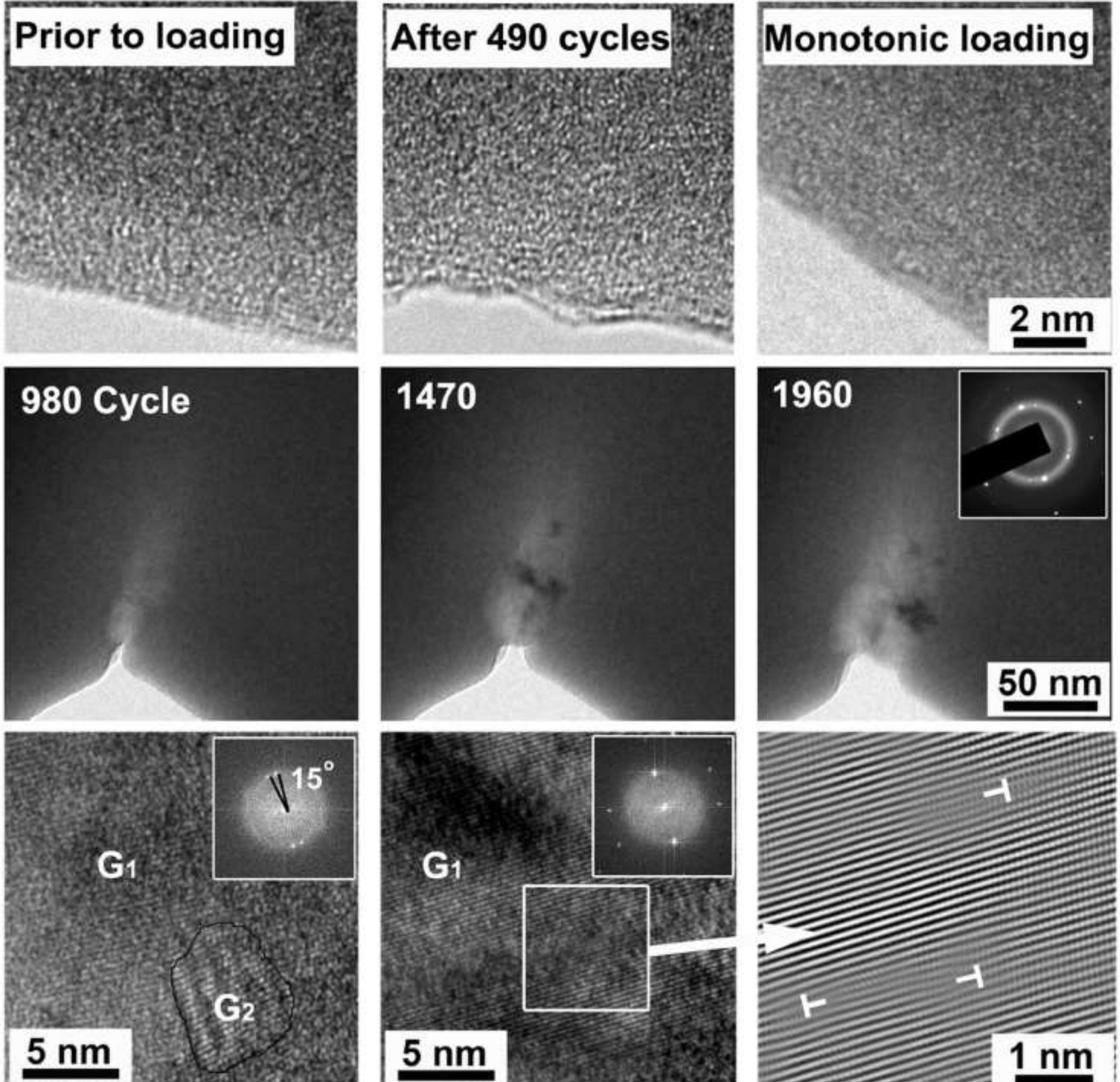


Depth: 88~220 nm;
Frequency: 1 Hz;

Largest cycle No. is less than 500 in one running test;

CAMP NANO
Center for Advancing Materials Performance from the Nanoscale
(Hysitron Applied Research Center in China)

Real-time, high-resolution study of nanocrystallization and fatigue cracking in a cyclically strained metallic glass, *PNAS* **110** (2013) 19725



PNAS **110** (2013) 19725

Li.mit.edu/video

A New Era: Atomistic Analysis of The Material-Environment Interface

The convergence of increased experimental resolution and increased sophistication in modeling and simulation provides extraordinary tools to experimentalists and to modelers. This has the potential to lead to a new era in developing an understanding the atomistics of environmentally-induced fracture.