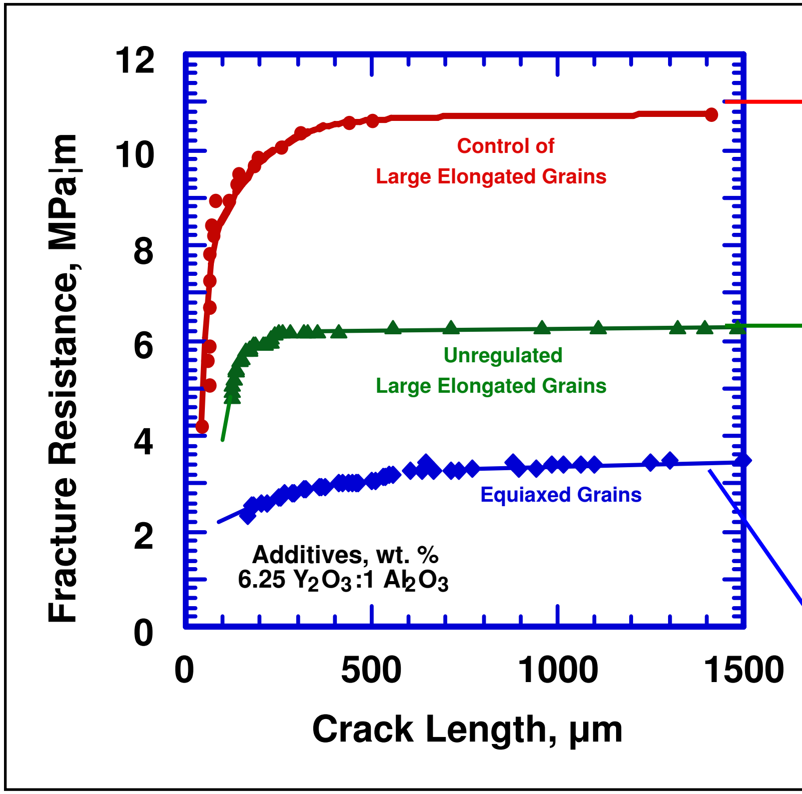
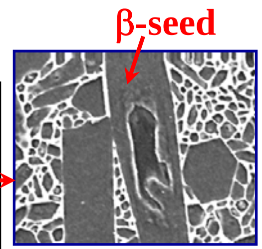
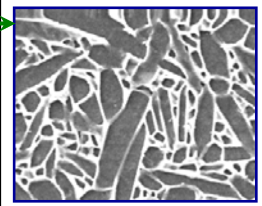
Mechanical Performance of Advanced Ceramics Can be Improved by Engineering the Microstructure (Size and Fraction of Elongated Grains)

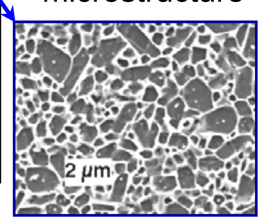




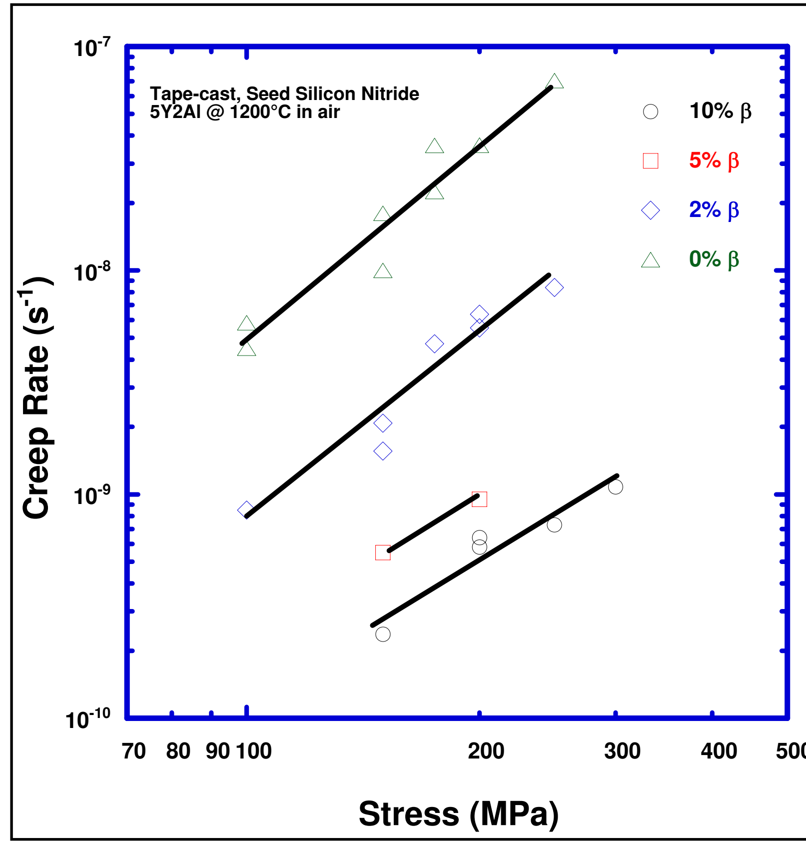
σ_f = 1400 MPa
Controlled
microstructure



σ_f = 850 MPa
Uncontrolled
microstructure



σ_f = 660 MPa
Equiaxed grains

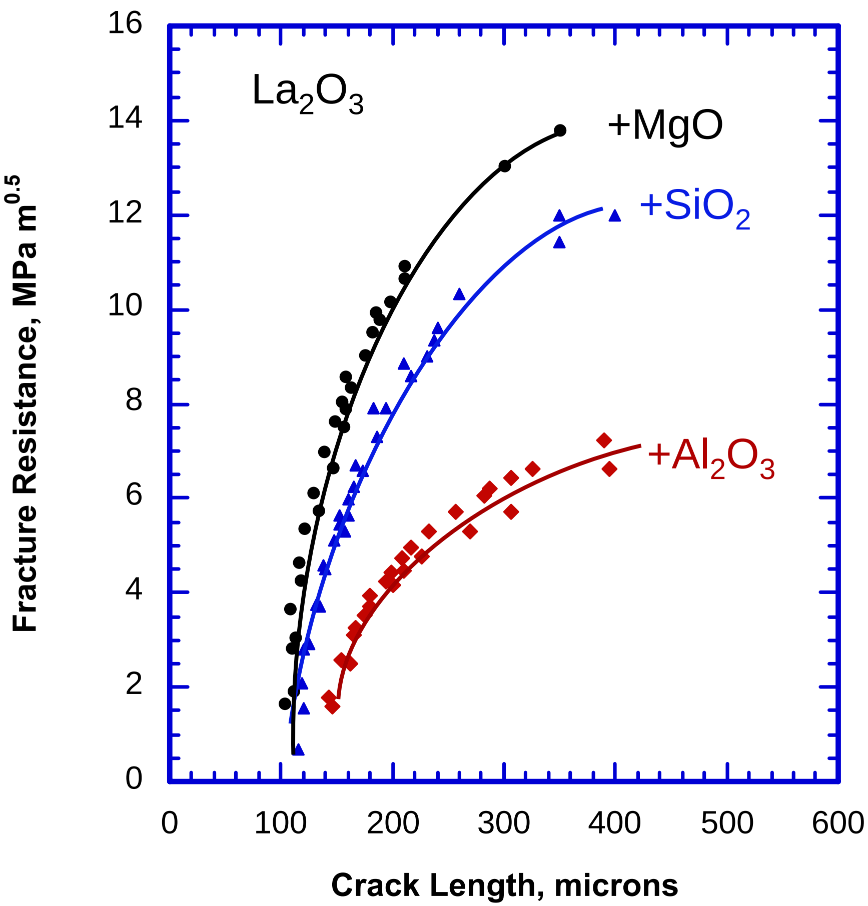


β–particles are nuclei for the formation of large reinforcing grains and are used to control microstructure

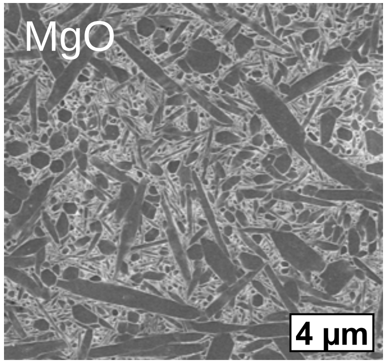
Large reinforcing grains, like discontinuous fibers, help to substantially reduce the stress in the fine-grained matrix, and improve creep resistance

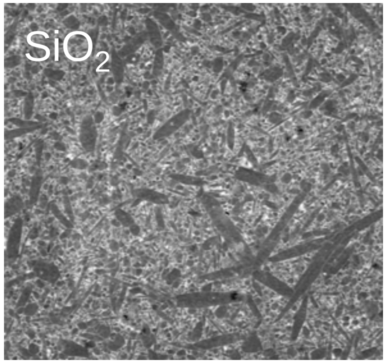
Recent Results Show That Secondary Oxide Additive Substantially Alters Reinforcing Microstructure with Major Impact on Fracture Resistance

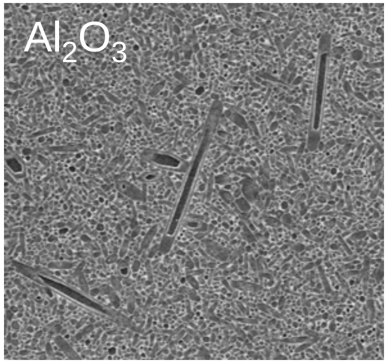
Seeded Si_3N_4 Ceramics



As with RE_2O_3s, MeO_xs alter reinforcing microstructure.







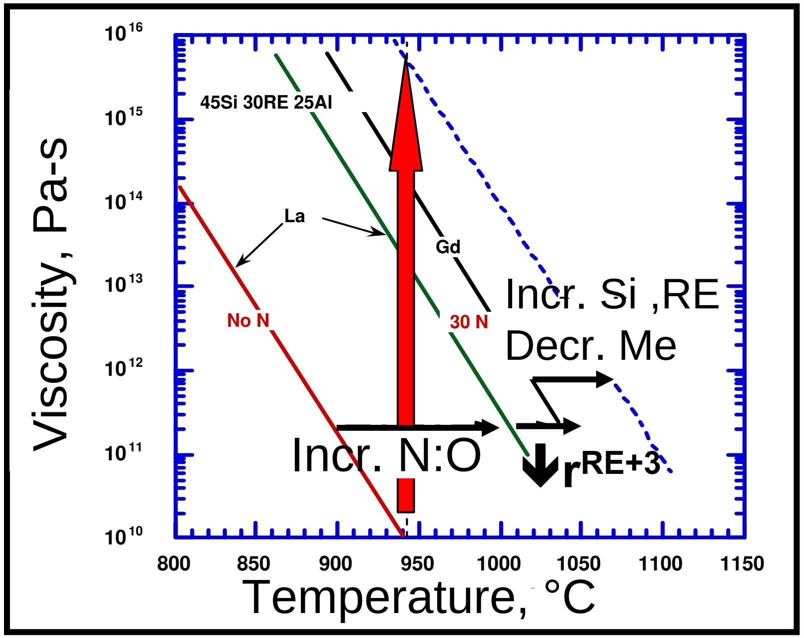
Al_2O_3: Depletion of liquid phase content by SiAlON formation.
MgO replaced by SiO_2: Increase in α to β transformation temperature.

Energy Technologies Will Require Materials to Operate at Higher Temperatures Where Ceramics Will Play an Increasingly Important Role

Si_3N_4 ceramics with Lu_2O_3 sintering aid has the highest known creep resistance,

≤ 1% strain/year @1450°C & 150 MPa.

- **What are the creep mechanisms?**
  - **Deformation of Si_3N_4 grains -- No**
  - ***Flow in amorphous IGF***
  - **Cavitation (Future)**



Increase viscosity of SiREMe Oxynitride glasses ≥ 10^6-fold by:

- **incorporating smaller rare earth**
- **reduced Me (e.g., Al, Mg) content**
- **increased N:O ratio.**

Raman analysis: increased viscosity related to increases in bridging oxygens.

P. F. Becher and M. K. Ferber, *J. Am. Ceram. Soc.*, 87(7) 1274-79 (2004).
P.F. Becher, M.K. Ferber, L. Riester, S.B. Waters, M.J. Hoffmann, R.L. Satet, J. Non-Cryst. Solids (2004)

Characterization of Complex-Shaped Microturbine Components is Critical for Probabilistic Component Verification and Life Prediction Assessment

United Technologies Research Center

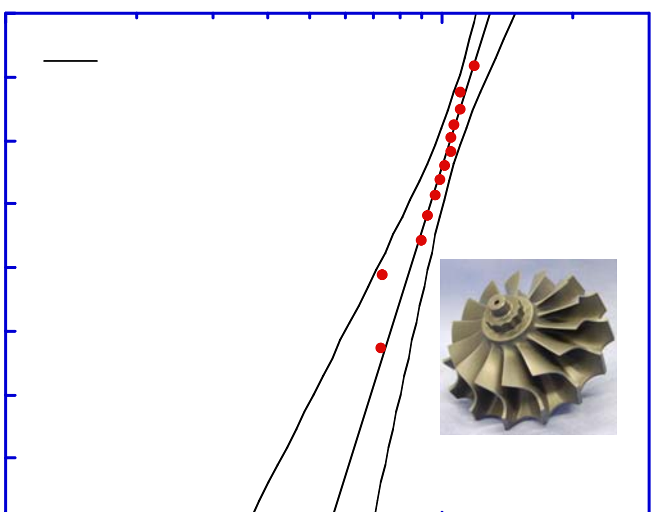
GE Global Research

IR PowerWorks

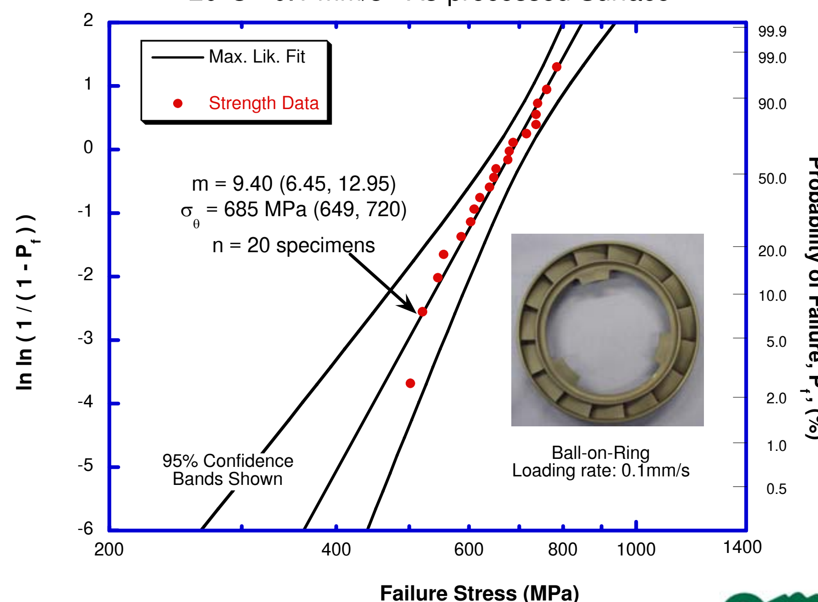
Capstone

SAINT-GOBAIN CERAMICS & PLASTICS

KYOCERA



Kyocera SN282 Vane Ring
Uncensored Biaxial Strength Distribution
20°C - 0.1 mm/s - As-processed Surface

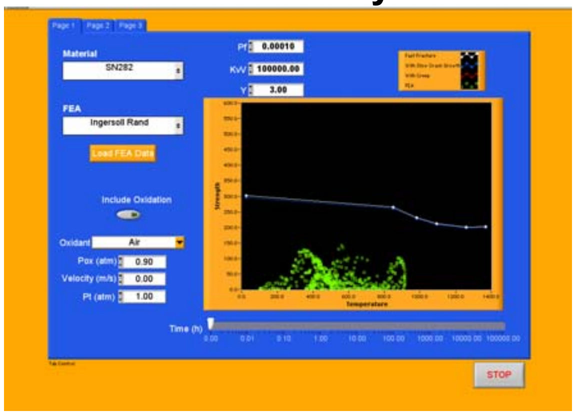


DOE

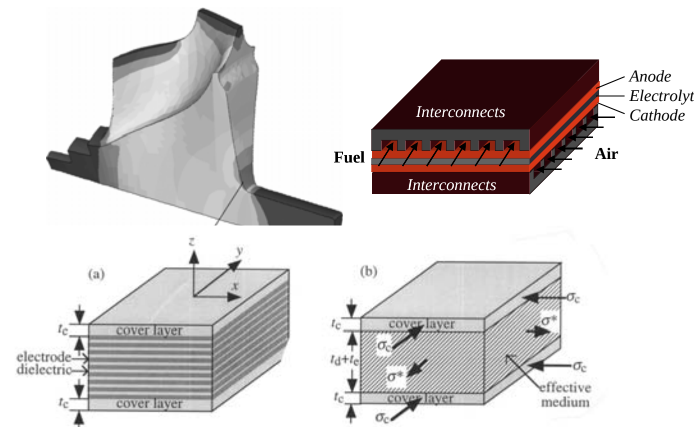
ORNL Oak Ridge National Laboratory

Reliability Assessment Research Established for the Successful Design of Brittle Components for Increased Reliability

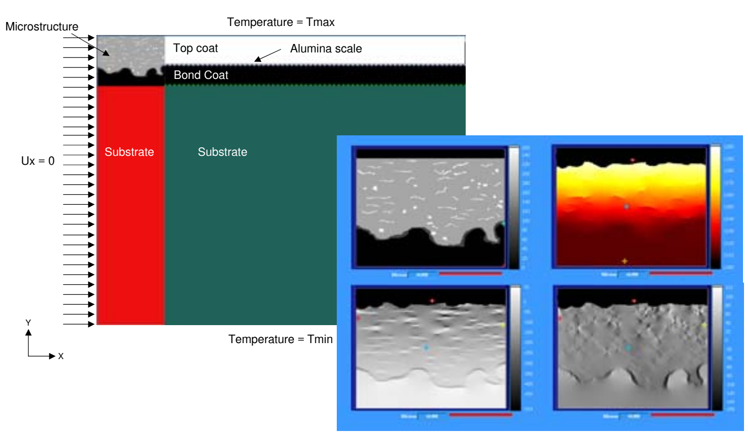
Advanced Algorithms for Predicting Reliability



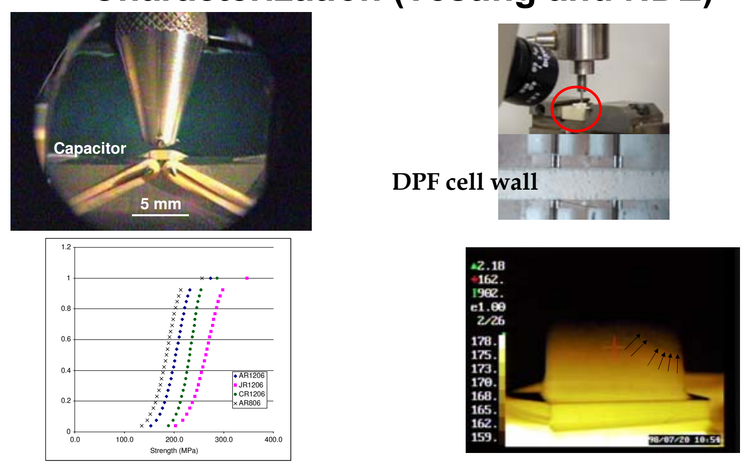
Numerical and Analytical Modeling



Materials Optimization



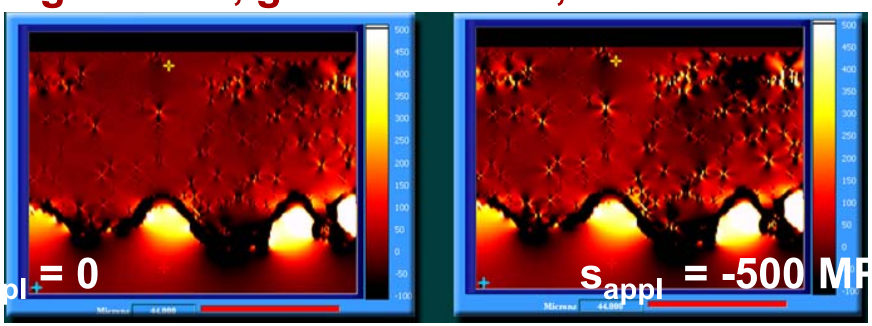
Characterization (Testing and NDE)



μ-FEA Uses Microstructures of Real Materials to Predict Response to External Environments and to Tailor Material's Performance

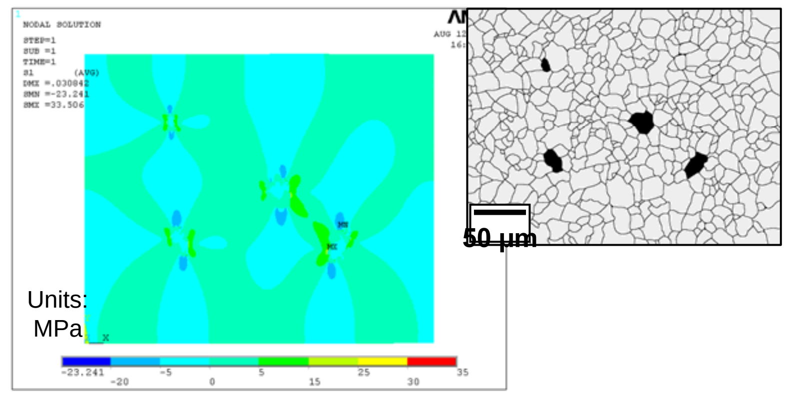
- employs ANSYS as FEA solver thus can analyze:
- linear and non-linear properties
- steady-state and transients (e.g., thermal shock, creep)
- piezoelectric effects
- effects of phase changes & swelling
- probabilistic behavior
- element birth & death (e.g., microcracking)

I. Stresses in TBCs due to thermal gradients, growth of TGO, service

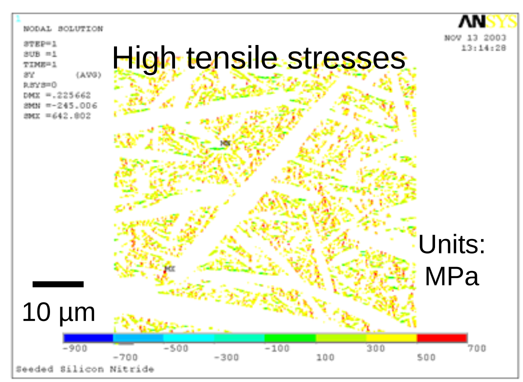


II. How to tailor composition of Si_3N_4 surface to eliminate stresses in EBCs.

III. Stress at Pores due to Poling of Piezoelectrics.



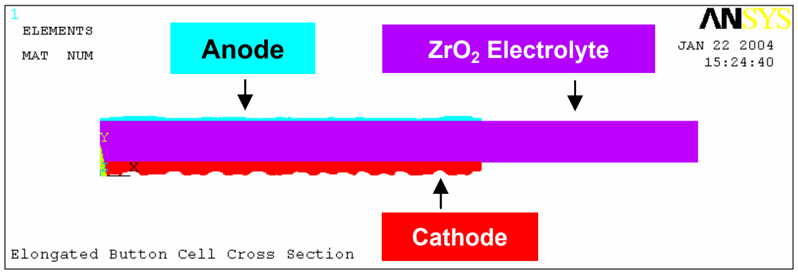
IV. Microstructural- level stresses



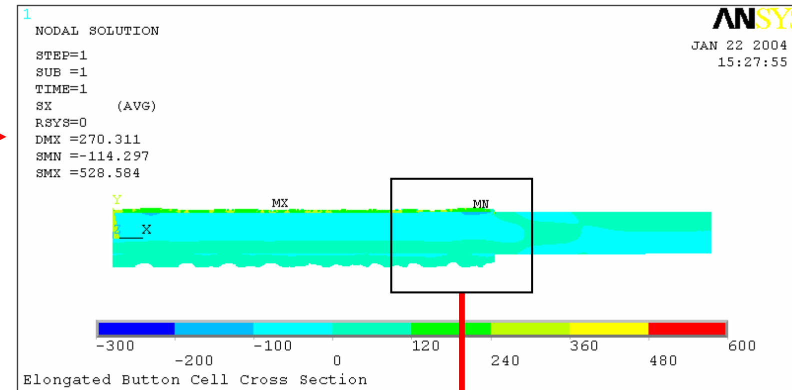
Stress in intergranular film in Si_3N_4

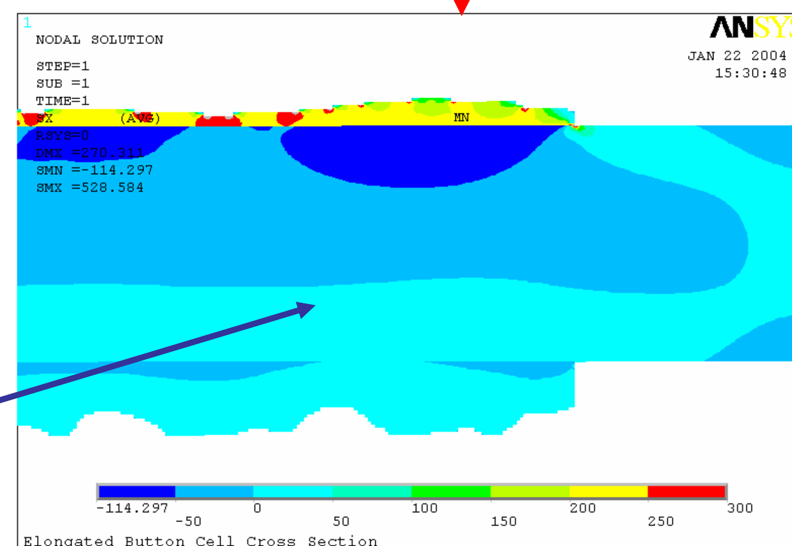
Failure Probability of Stressed ZrO_2 in SOFC (or Ceramic in Membrane) Can Be Determined via μ-FEA

μ-FEA Reconstructed Model of FC Cross-Section

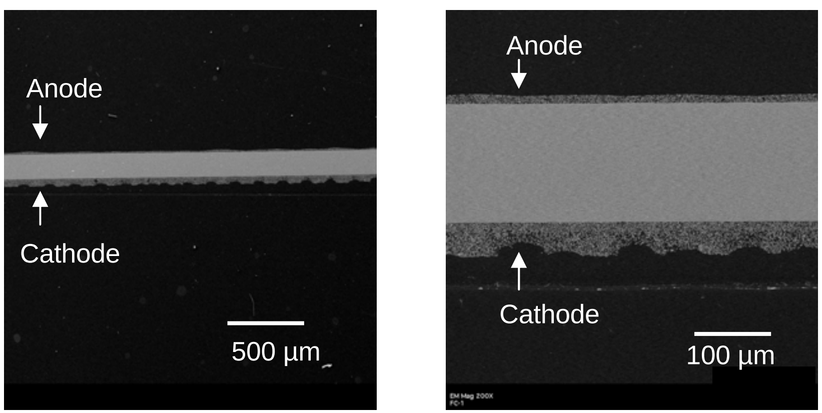


σ_x Residual Stresses at 25°C





SEM Microstructure of FC Cross-Section



Measured Stresses from Raman Spectroscopy to be compared

ORNL
Oak Ridge National Laboratory

C-Sphere Specimen Developed Effectively Characterize the Subsurface Flaws in Ceramic Ball Bearing and Their Influence on Rolling-Contact-Fatigue for Wind Turbine Applications