

COE CST Tenth Annual Technical Meeting

241: High Temperature, Optical Sapphire Pressure Sensors

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Center of Excellence for
Commercial Space Transportation



Agenda

- Team Members
- Task Description
- Schedule
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- Results
- Conclusions and Future Work

Team Members

- People

- William S. Oates and Rajan Kumar
- Jakob Consoliver-Zack



- Organizations

- Florida Center for Advanced Aero-Propulsion
- FAMU-FSU College of Engineering



Task Description

- Development of high temperature pressure sensors (~1300°C)
 - Applications: Structural health monitoring, morphing surface control, combustion control
- Challenge: Sensor material limits, manufacturing
 - Sapphire used in prior research
 - Difficult to machine, multiple components
 - Laser machining affects material properties
 - Debonding of diaphragm is common failure mechanism
- Opportunity: High temperature mechanical characterization methods.
 - Understand laser machined properties
 - Conduct interface fracture and high temperature experiments to infer material properties and sensor performance.

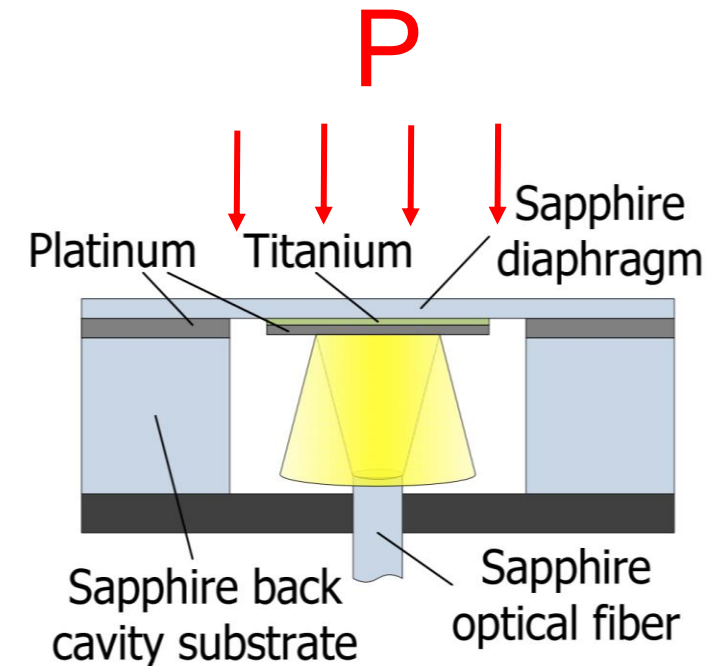


Figure 1: Example Sensor

Schedule

- Conduct multi-axial x-ray measurements of laser machined sapphire—done
- Infer lattice properties, residual strain, and residual stress from laser machining—on-going
- Develop experimental set-up for interfacial fracture characterization—on-going
- Modify furnace internal structure for high temperature fracture measurements—planning stages
- Conduct high temperature fracture measurements—planning stages

Goals

- Understand changes in sapphire properties as a function of laser machining
 - What is the internal residual stress and strain? Defect structures?
 - Critical to develop reliable sensors that can operate over a broad temperature range
- Understand bonding characteristics between sapphire and high temperature metals
 - Quantify strength and toughness of sapphire/platinum and refractory metal interfaces
 - Important to understand manufacturing pressure and temperature required to achieve a robust bond for high temperature sensing

Results

- Examination of all data sets shows a very consistent strain state.
 - A single outlier is being further investigated
- Use of Bayesian UQ allows for a much greater reduction of uncertainty than conventional error methods.

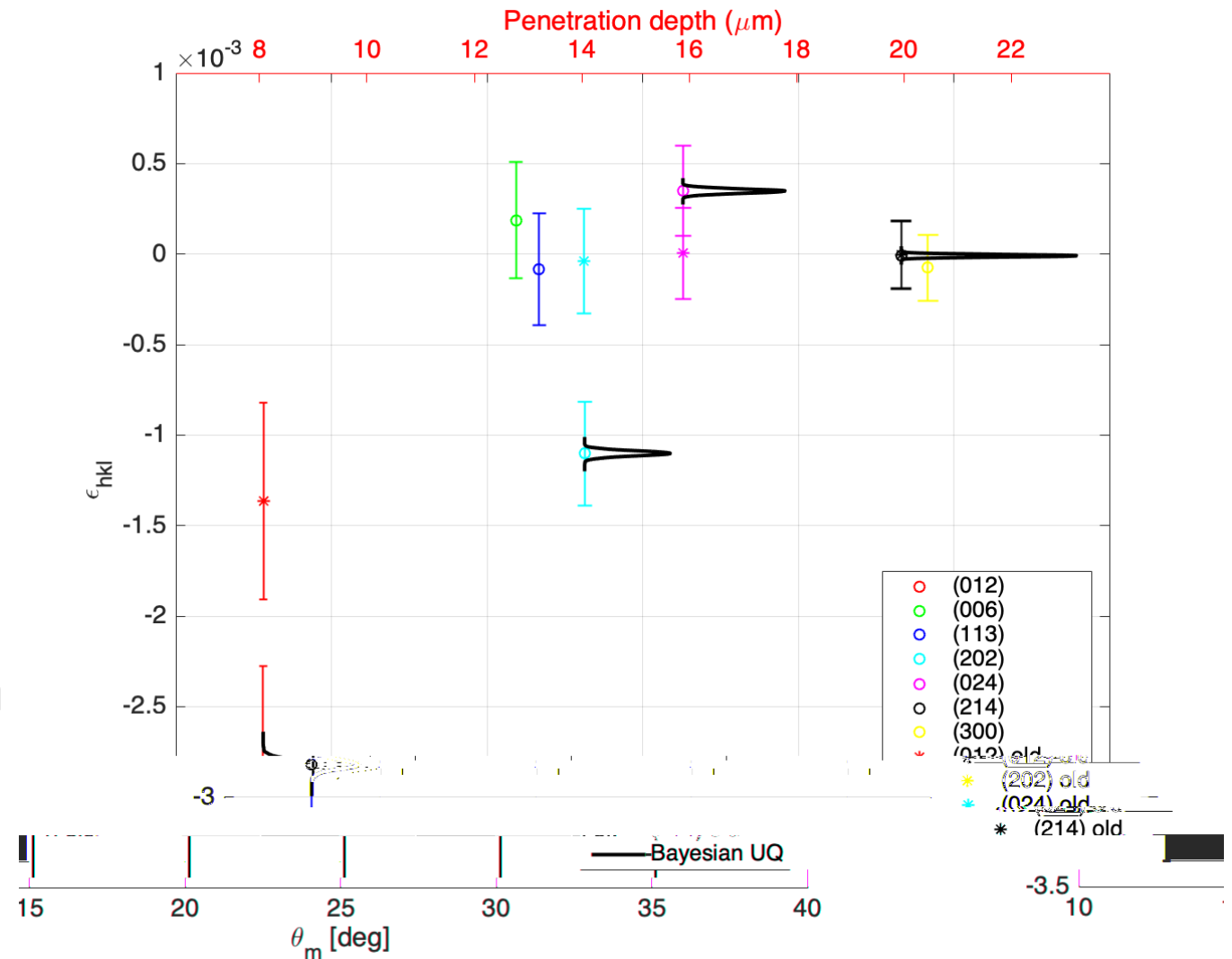


Figure 2: Computed strain in plane direction with conventional uncertainty given by error bars vs Bayesian UQ

Results

- Scan of the (104) plane could provide additional data of the strain state at depth.
- Decay of strain state can be approximated using exponential decay according to Beers' Law.
 - t : depth into machined zone
 - l_c : penetration length of machined region

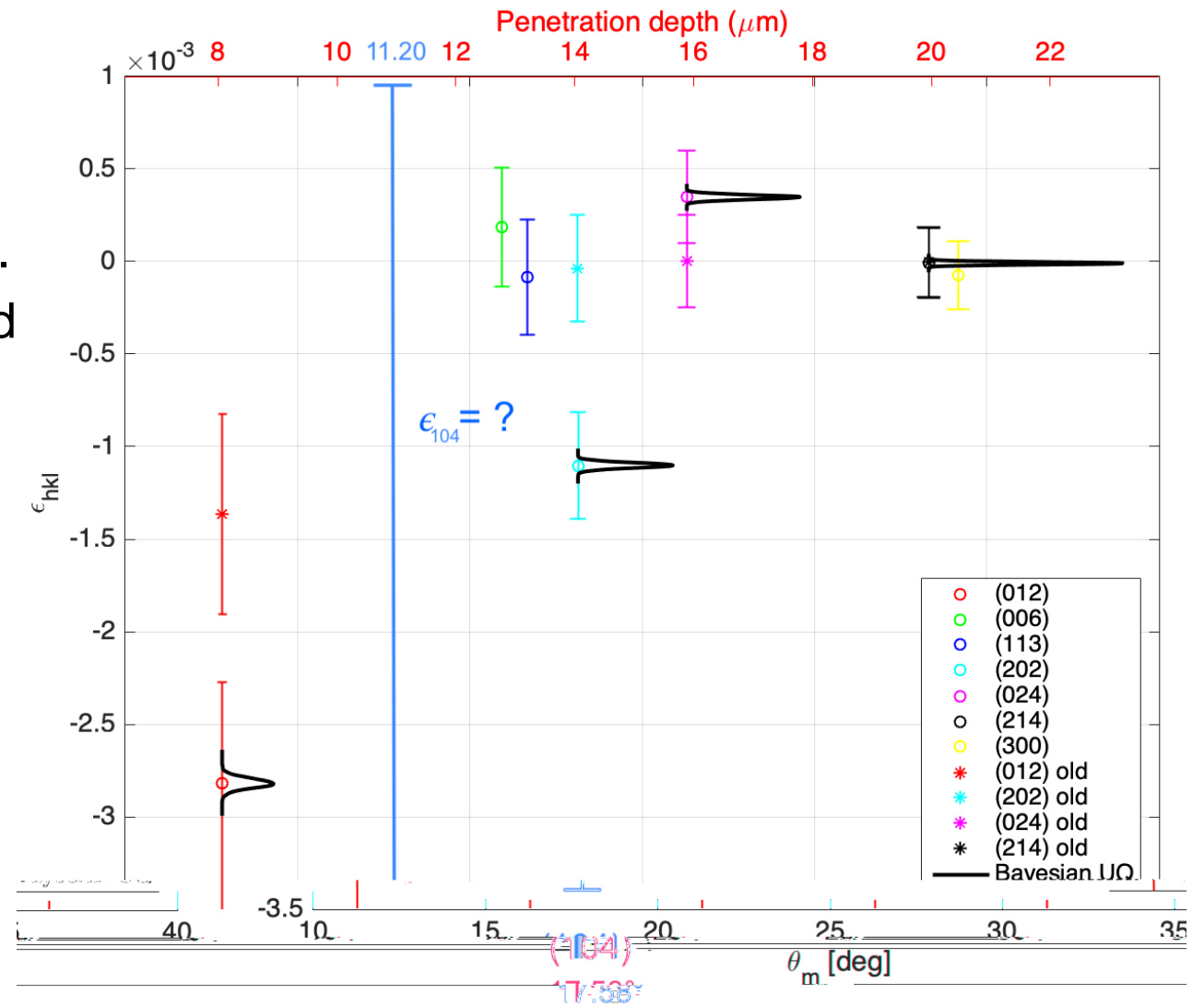
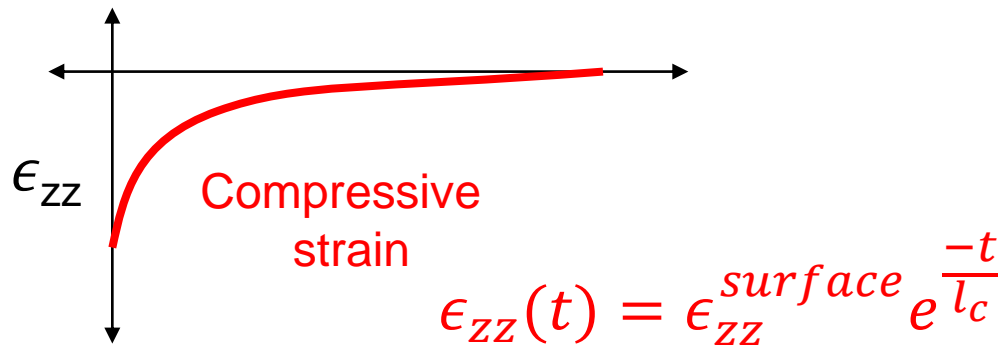
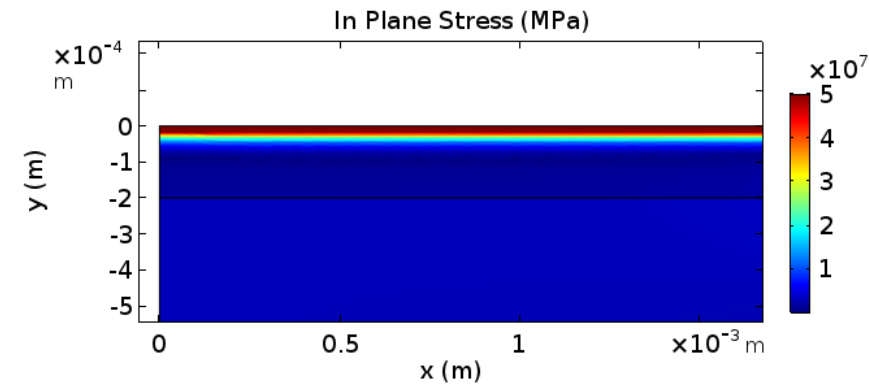
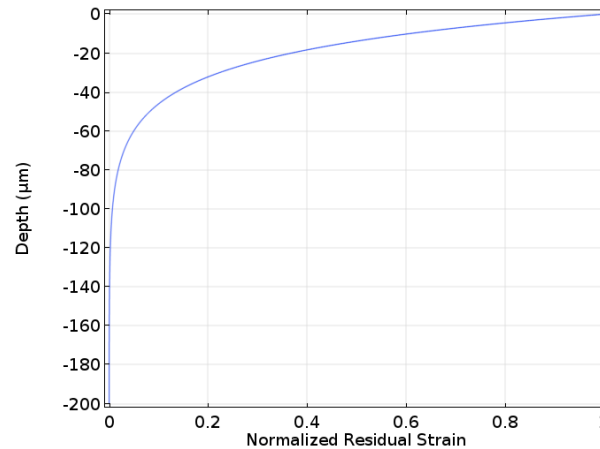
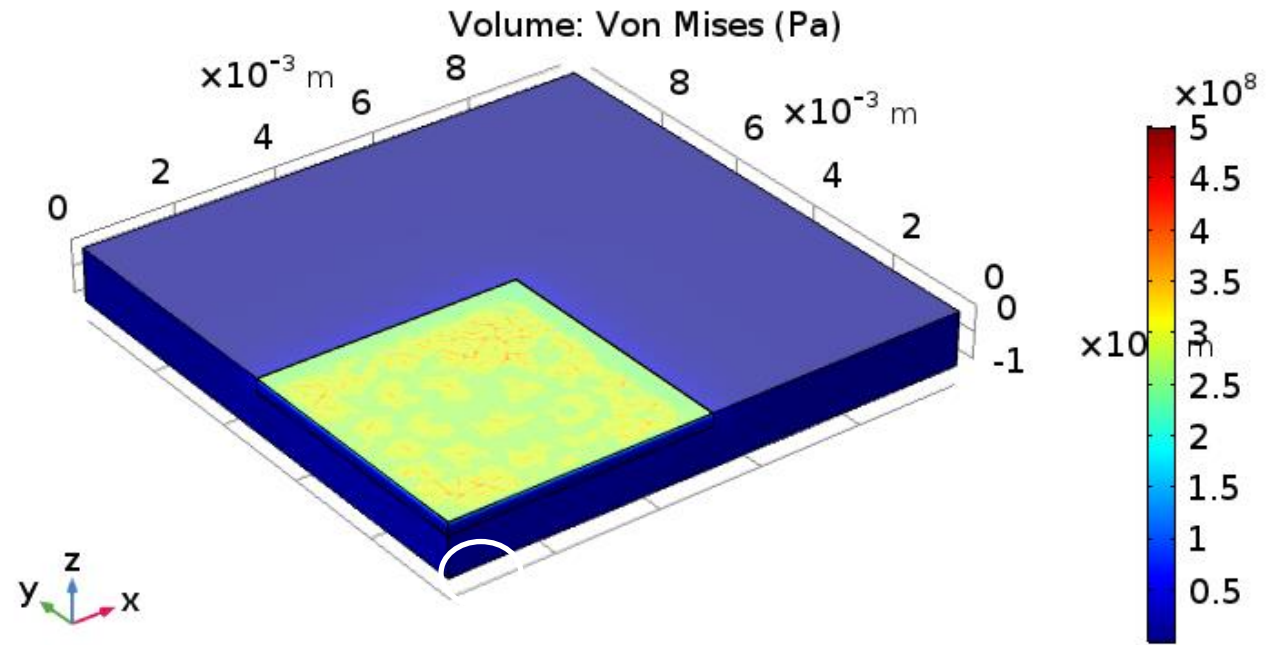


Figure 2: Computed strain in plane direction with potential (104) scan location overlaid.

Results

- Finite Element Analysis (FEA) supports the existence of compressive in-plane stresses on the order of the yield strength of pristine of sapphire.
- Cross section and 1D views shown illustrating stress/strain surface decay from laser machined surface
- Surface compression provides higher global fracture toughness



Results

- Investigation of the fracture interface via FEA shows viable specimen geometries compatible with the existing testing setup.
- Crack length and fracture intensity K_I can be inferred from coupled measured data and FEA modelling.

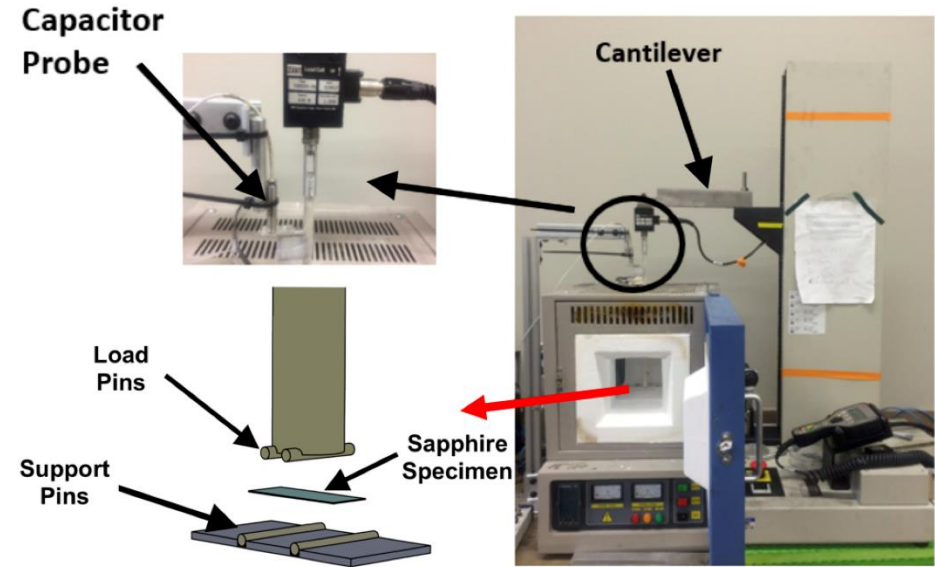


Figure 3: High temperature test setup

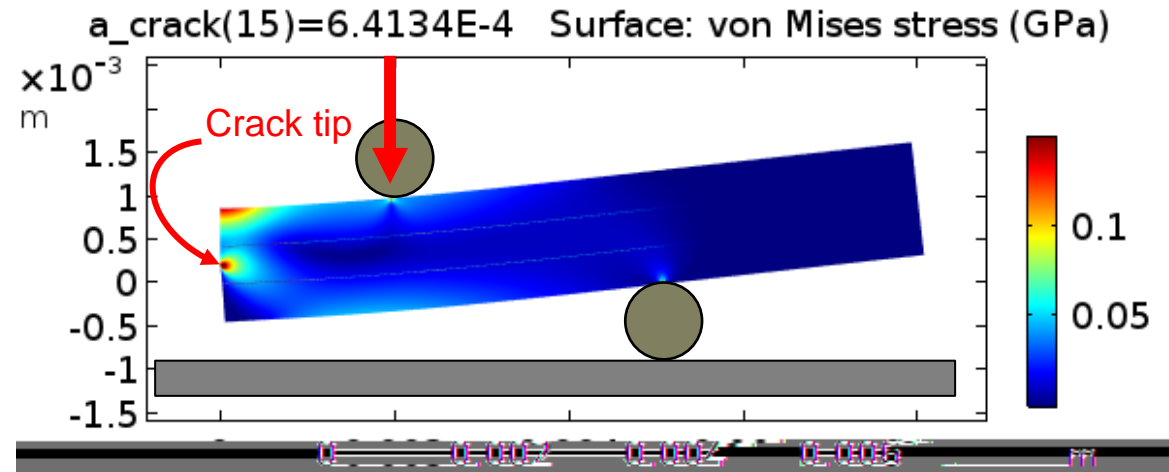


Figure 4: 2D FEA of 5-layer beam with center crack mirrored about $x = 0$ m.

Publications, Presentations, Awards, & Recognitions

PUBLICATIONS:

Consoliver-Zack, J., Rebar, D., Siegrist, T., Oates W. S., "Bayesian Uncertainty Analysis of the Residual Stress in Laser Machined Sapphire", in preparation, 2020.

Bal Singh, H., Consoliver-Zack, J., Oates, W. S., "High-Temperature Mechanical Characterization of Laser-Machined Sapphire for High-Temperature Pressure Sensor Applications," *New Space*, v. 7 (1), 2019.

Conclusions and Future Work

- Multiaxial x-ray data combined with Bayesian inference provided new insight on picosecond laser machined sapphire
 - Large compressive in-plane stress promising for enhanced toughness
 - Additional scan data planned to better infer strain through material thickness
- Models developed to ensure interface fracture can be resolved at temperatures $>1000^{\circ}\text{C}$
 - FEA models and experimental sensor noise evaluated to provide high resolution increments in crack growth per load cycle
 - Refit furnace for high temperature testing
 - Conduct high temperature fracture experiments to characterize interface properties

COE CST ATM10 PRESENTATIONS

- ATM10 Technical Presentations will be a video recording
 - There will be one recording for each active task, made by the grant recipient PI and/or their students
 - Prior tasks could be reviewed, if applicable
- The total duration of this video should be 10-15 minutes
 - Please fill in all information on all template pages
 - You can add slides to this presentation, but please do not exceed the time limit
 - Include photos and pictures whenever possible
- This video should use the set of charts provided in this file
- Please submit your video and the final Technical Presentation PowerPoint file to ken.davidian@faa.gov and fredbowen@orionat.com
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