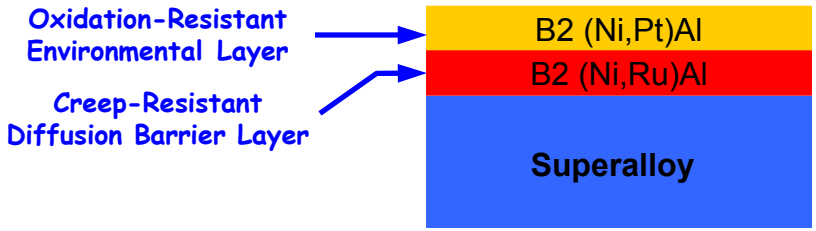
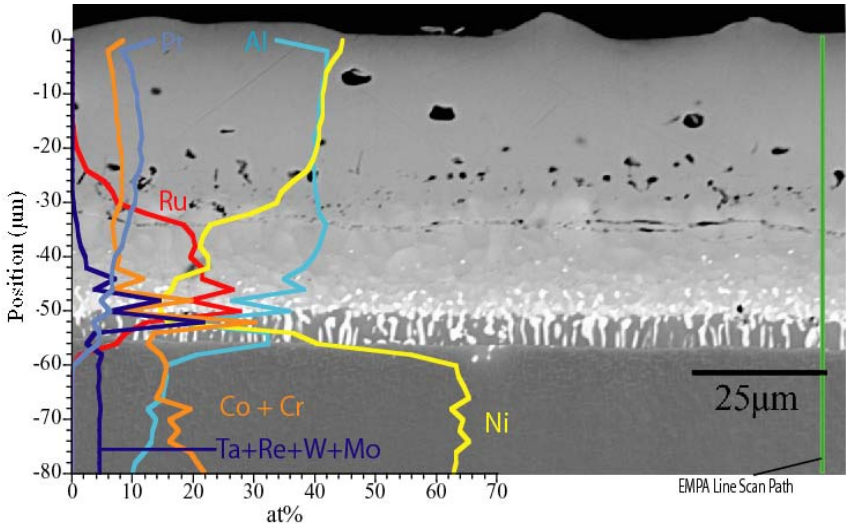
Layered Multifunctional PGM based Bond Coats

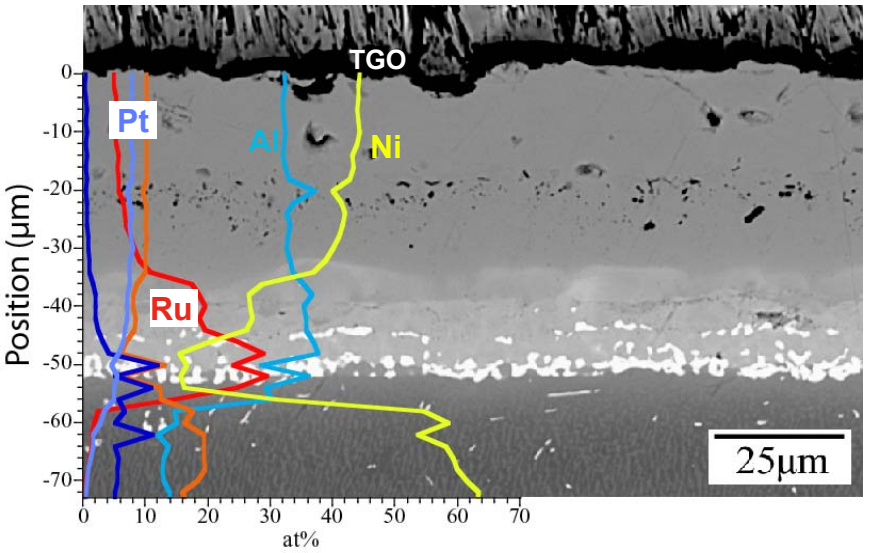
B. Tryon, T.M. Pollock (UM),
J. Yang, C.G. Levi (UCSB), K. Murphy (Howmet)
Collaborations with J. Nicholls (Cranfield),
J. Ågren (KTH) and M. Rühle (MPI-MF).

The unusual diffusion characteristics of Ru, still to be understood, make it possible to create a sub-surface Ru-rich layer from an initial overlay coating of Ru by proper selection of the processing conditions. The exterior NiAl layer may then be alloyed with Pt to optimize oxidation behavior, while the (Ru,Ni)Al underlayer acts as a barrier to the diffusion of undesirable elements (e.g. Ta) from the substrate. Initial assessment reveals adequate cyclic oxidation behavior and reduced interdiffusion. The relevant dynamics are under investigation.



As-Aluminized



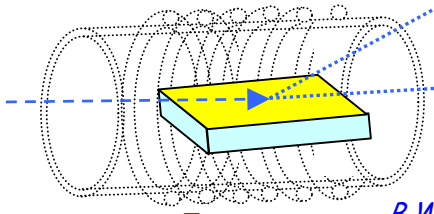


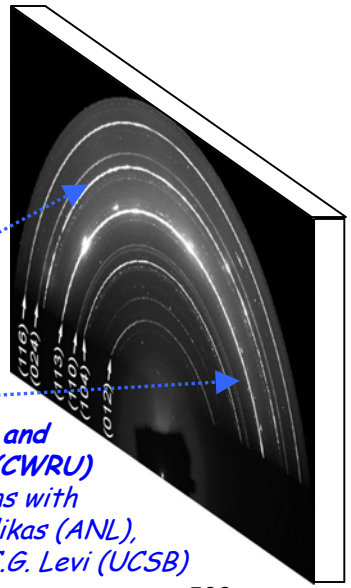
With TBC, Cyclic Oxidation
1100°C/60 cycles

In-situ Measurement of TGO Growth Stress

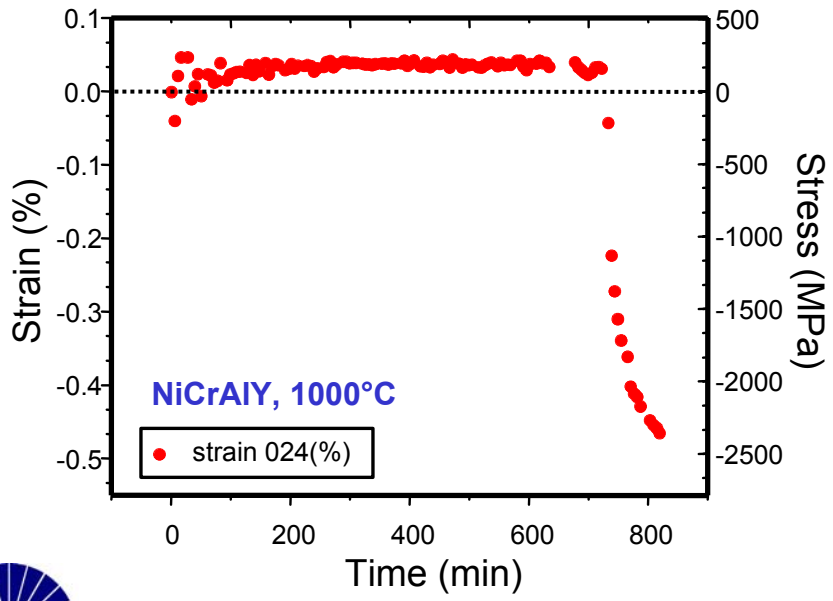
- Elliptical distortions of the diffraction rings in a stressed film occur due to the different in-plane and out-of-plane spacings. This ellipticity is analyzed for strain determination.
- Preliminary results show that the oxide growth strains evolve differently in NiCrAlY and FeCrAlY, the former yielding tensile stresses and the latter compressive. Mechanisms are under investigation.

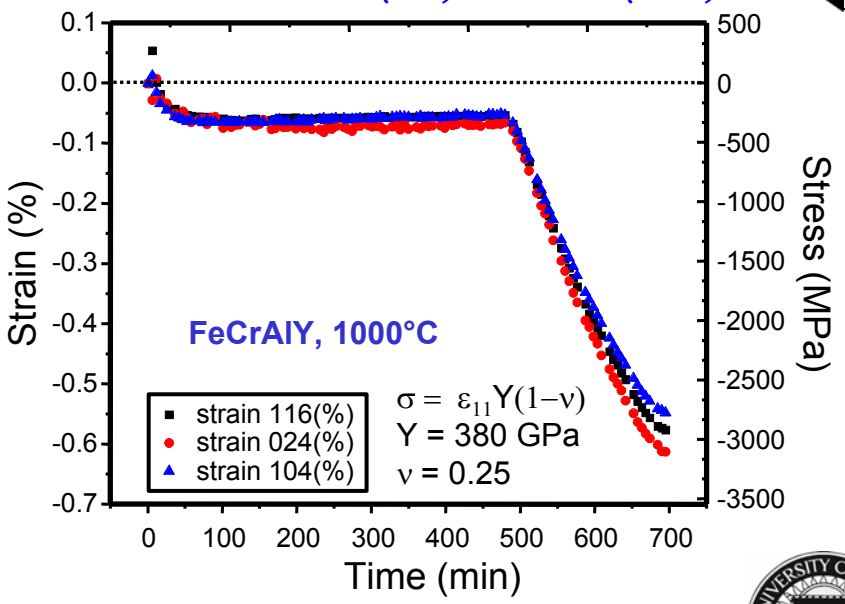
21.6 keV beam at APS/ANL
Sample oxidized in air
Grazing incident beam (~3-5°)
Debye-Scherrer patterns recorded on Image Plate Detector



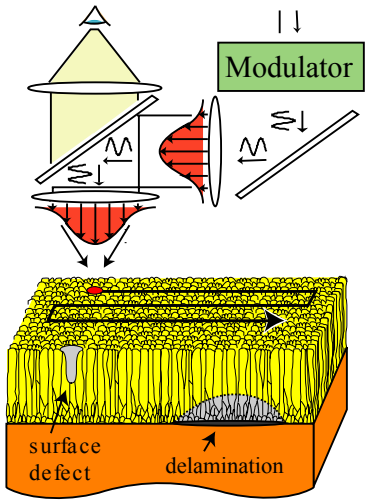


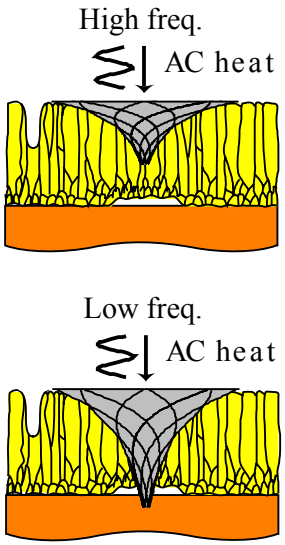
A. Reddy and A.H. Heuer (CWRU)
Collaborations with B.W. Veal, A. Paulikas (ANL), M. Rühle (MPI) and C.G. Levi (UCSB)

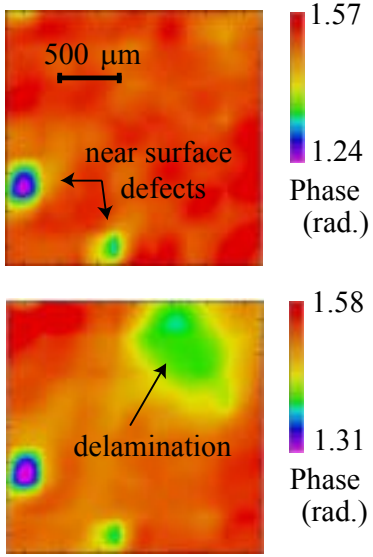


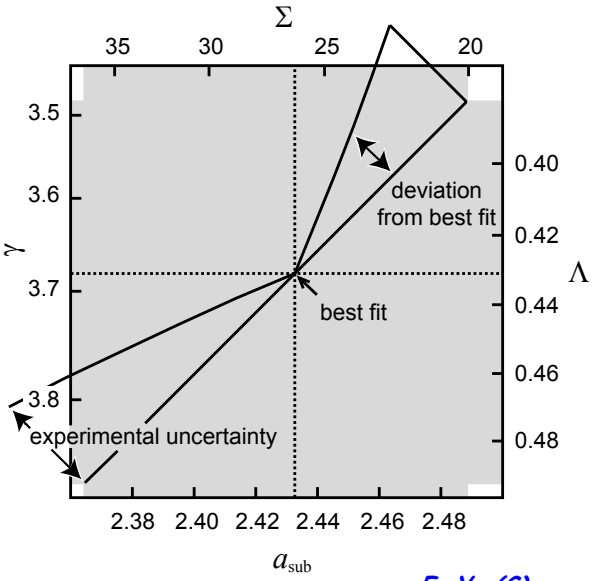


Thermal Performance Monitoring of TBCs









F. Yu (G), T. Seemann (UG), T. Bennett
Collaborations with Mevrel, Nicholls, Clarke and Levi

Nondestructive technique to quantitative determine condition of TBC

Harmonic heating and interrogation of temperature phase through thermal emission

No preparation or geometric requirements of samples

Nonlinear regression analysis to determine thermal and optical properties of the film:

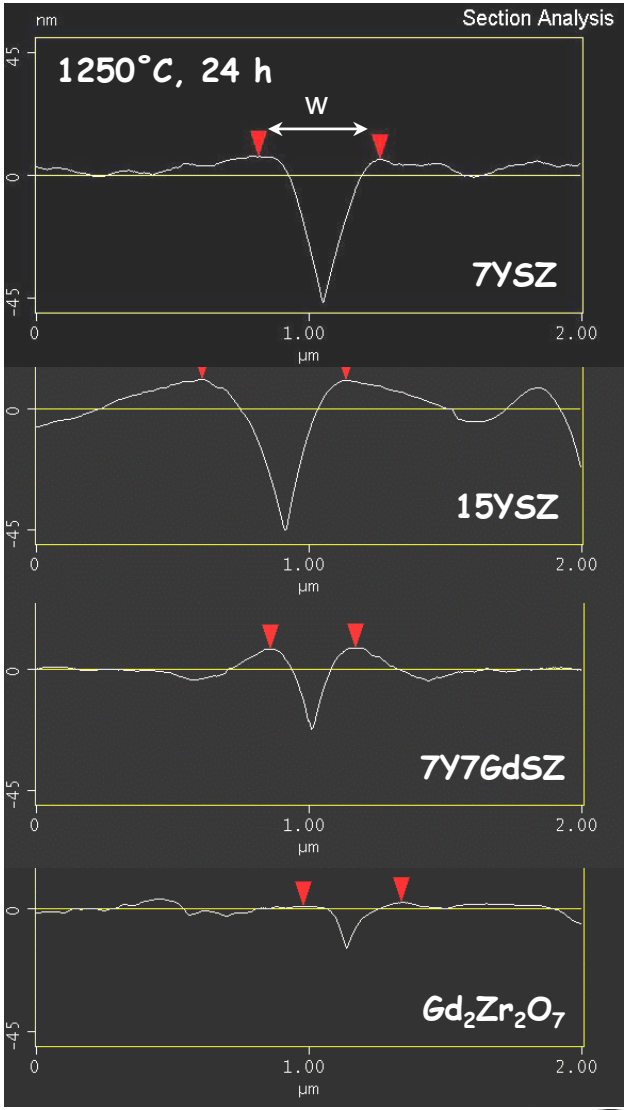
$$a_{sub} = \sqrt{\alpha_{sub}/\alpha_{film}} \qquad \gamma = \sqrt{[k\rho C]_{sub}/[k\rho C]_{film}} \qquad \Lambda = \left(a_{\text{laser}} L\right)^{-1} \qquad \Sigma = \varepsilon_{\text{detector}} \left(a_{\text{detector}} L\right)^{-1}$$

1. **Capable of surface mapping with a spatial resolution that scales with the film thickness**
2. **Laser frequency defines thermal penetration depth sensitivity of measurements**
3. **Enabling technology for life monitoring and aging studies of TBCs on serviceable parts**

Effects of Composition on Surface Diffusion in Oxides

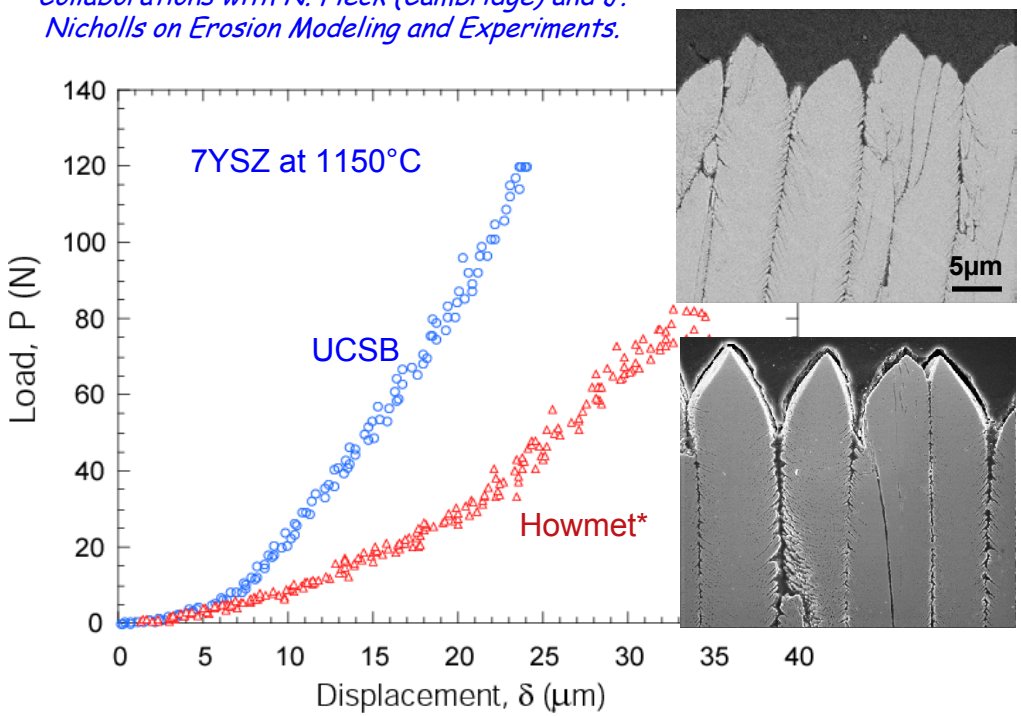
A.S. Gandhi and C.G. Levi (UCSB)
Collaborations with E. Bischoff and M. Rühle (MPI-MF) and A. Heuer (CWRU)

Demands for increasing operating temperature in the gas turbine engine accelerate the morphological evolution and densification of the various forms of porosity in the coating, with deleterious effects on its strain tolerance and thermal conductivity. Little is known about the surface diffusion mechanisms in these oxides and even less on the effects of composition on the diffusion kinetics. The present study attempts to advance our understanding of these issues. The approach involves grain boundary grooving studies on dense coatings with aligned columnar grains, as well as randomly oriented polycrystalline compacts from powders synthesized by reverse co-precipitation of precursor solutions. The grain boundary groove profiles, measured using atomic force microscopy (AFM), are followed as a function of time at elevated temperatures. The images on the right represent the first demonstration of the effect of composition changes on the surface diffusion kinetics in zirconia-based oxides. It is evident that Gd additions considerably slow the diffusion kinetics, which bodes well for the morphological stability of emerging TBC materials based on these compositions. Quantitative evaluation of the surface transport properties of these materials is in progress.

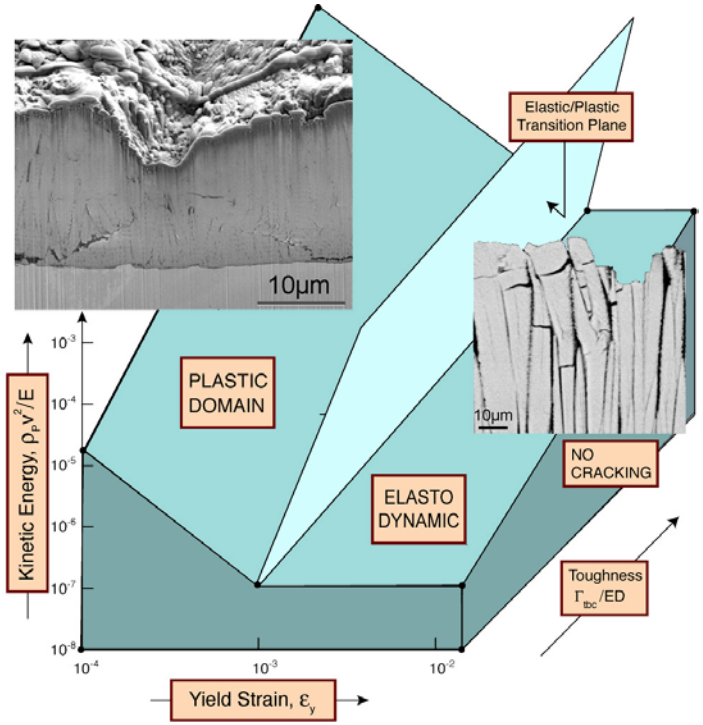


Deformation and Damage of Thermal Barrier Oxides

A. Paterson, M. Watanabe, A.G. Evans, A.S. Gandhi, C.G. Levi, (UCSB),
Collaborations with N. Fleck (Cambridge) and J. Nicholls on Erosion Modeling and Experiments.



Important role of microstructure in deformation behavior of YSZ at high temperature has been identified, with attendant implications to erosion and fracture. Effect appears to be at least as substantial as that of varying composition.



Mechanism map for the onset of material removal by particle impact, denoting the predominance regimes of two distinct damage mechanisms as a function of the relevant dimensionless parameters. The threshold surface is depicted in the intermediate color, with the "safe regime" underneath.

* Sample provided by Dr. Ken Murphy

Education

Two workshops were held during the past year, one at UCSB (Jan.), jointly with a related ONR/MURI, and one at KTH-Stockholm (Jun.). At these workshops students are exposed to the dynamics of multidisciplinary research, interact with their peers and coordinate research plans, present posters and in selected cases give oral presentations. Some statistics:

	Total	Stud.	PD Res	F/U*	Ind/GL
UCSB	81	22	15	10	16
Stockholm	39	11	9	6	6

A second element of the educational experience is the exchange visits. The primary exchanges have been between the US institutions and MPI. Four US students (Rebollo, Leckie, Tryon and Reedy) and two PD (Gandhi & Kraemer) have visited MPI-MF while two MPI students (Bellina and Wang) and one PD (Fabrichnaya) have visited Michigan and UCSB. In addition, a Cranfield PD (Wellman) visited UCSB in a KTH student (Hallstrom) visited Michigan.

Undergraduate students have also participated in research both at UCSB and Michigan, two of them (Albrecht, Seemann) involving exchange visits.

* F/U = Female/Underrepresented groups

Industrial Outreach

Effective interactions have been established with several industrial groups represented in the Industrial Advisory Committee. The companies involved are Alstom, General Electric, Howmet, Pratt & Whitney, Rolls-Royce-Allison, Siemens-Westinghouse and SNECMA.

The enthusiasm of the industrial collaborators for the program is reflected on several fronts. They attend and participate in the workshops, providing valuable input individually during discussion and also as a group. They also provide materials and specimens and, most notably, actual engine hardware that has seen service so that ideas, observations and models can be calibrated against reality. An additional benefit is that the program provides our industry colleagues with a unique forum to discuss issues and concerns on a pre-competitive environment, a rare opportunity for companies in this heavily competitive industry. Finally, there is strong interest in transferring to practice products from the program. Notable examples are erosion models and the non-intrusive techniques for thermal conductivity measurement and microstructural monitoring..