


National Aeronautics and Space Administration



Monitoring Delamination of Thermal Barrier Coatings by Combined Photoluminescence Piezospectroscopy and Upconversion Luminescence Imaging Techniques

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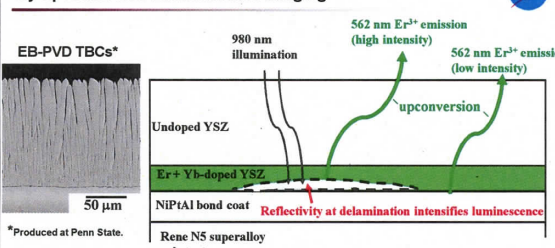
Professional Aeronautics Program
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Combined Piezospectroscopic Imaging (PSI) and Upconversion Luminescence Imaging Techniques



- Background
 - PSI and upconversion luminescence imaging have been demonstrated useful for monitoring TBC delamination progression.
- Objective
 - Directly compare TBC delamination monitoring using both PSI & upconversion luminescence imaging on same specimens.
 - Furnace-cycling induced delamination.
 - Indentation-induced delamination at different stages of furnace cyclic life.

Detecting TBC Delamination by Upconversion Luminescence Imaging


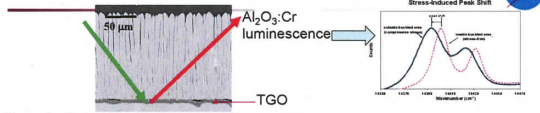



EB-PVD TBCs*
50 μm

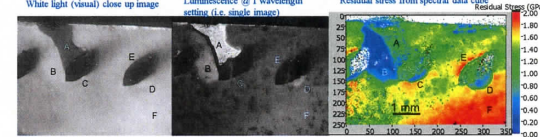
*Produced at Penn State.

- Er³⁺ produces upconversion luminescence at 562 nm with near-zero background for strong delamination contrast.
- Yb³⁺ absorbs 980 nm excitation and excites luminescence in Er³⁺ by energy transfer.
- Delamination contrast achieved because of increased reflection of excitation & emission at TBC/crack interface.

Detecting TBC Delamination by Piezospectroscopic Imaging (PSI)


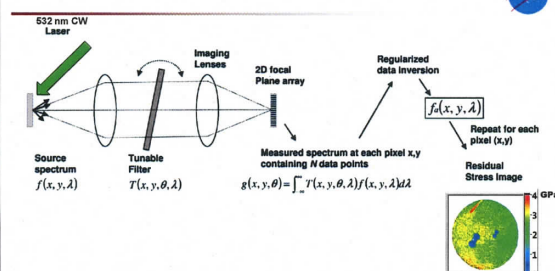
Example of a turbine blade removed from service:



A. Spalled coating
B. Large delamination (low stress)
C. Small delamination (low stress)
D. " " "
E. Intact (high stress)
F. " " "

- Delamination contrast achieved because of changes in TGO stress.


Piezospectroscopic Imaging (PSI)

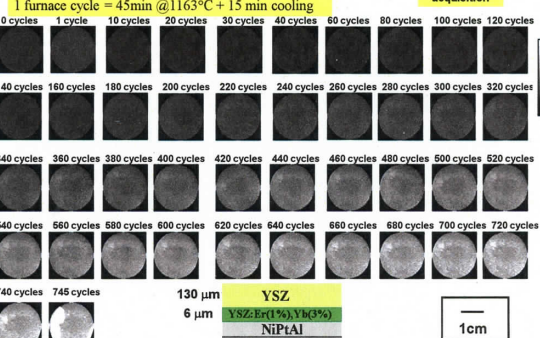
Residual Stress Image (GPa)

Upconversion Luminescence Images During Interrupted Furnace Cycling

EB-PVD TBC with YSZ:Er(1%), Yb(3%) Base Layer



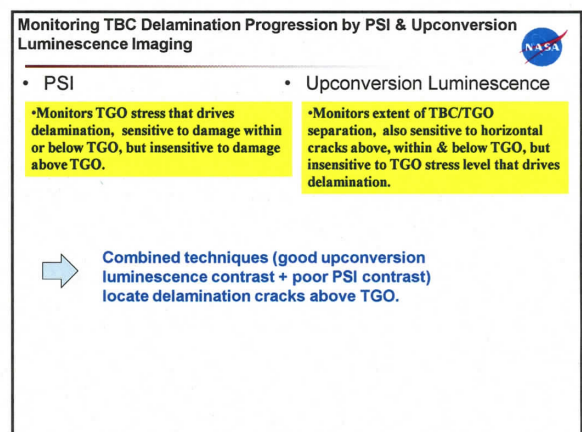
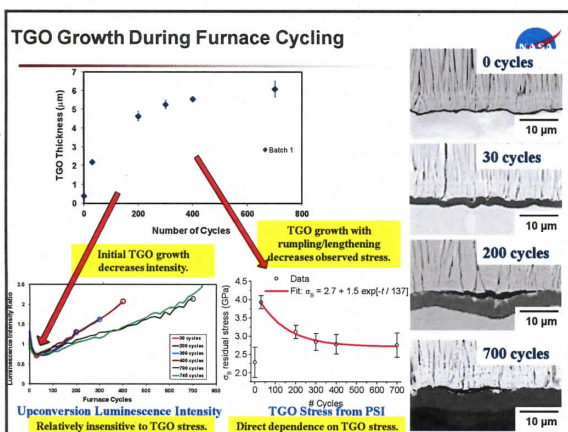
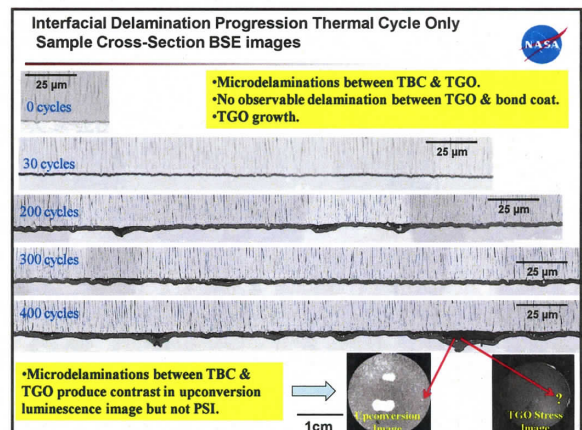
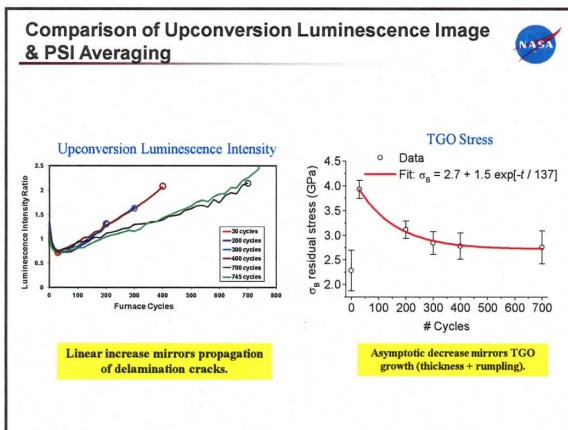
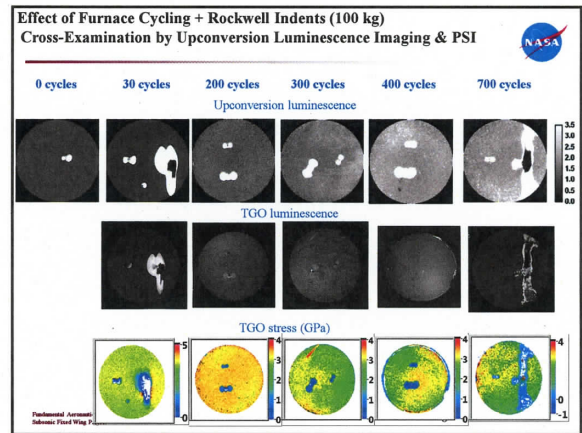
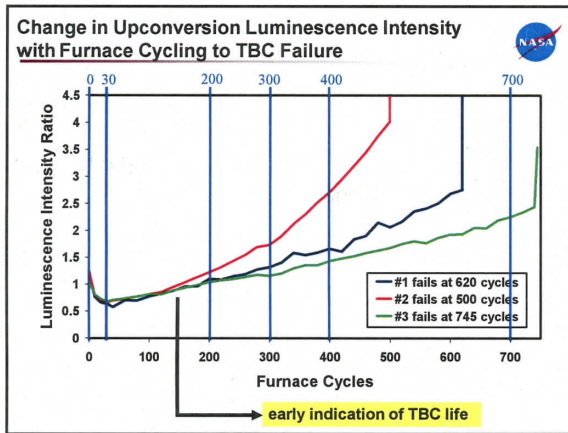
1 furnace cycle = 45min @ 1163°C + 15 min cooling
7.5 sec acquisition

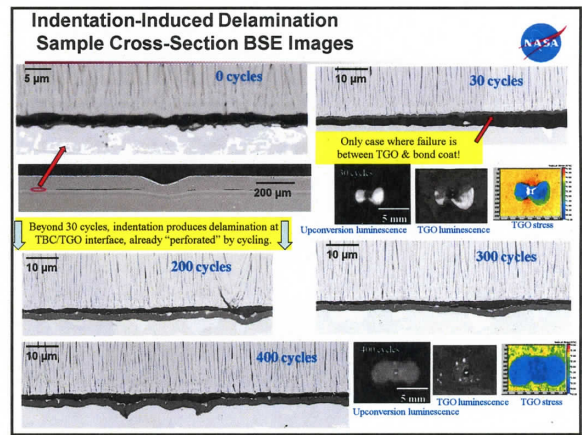
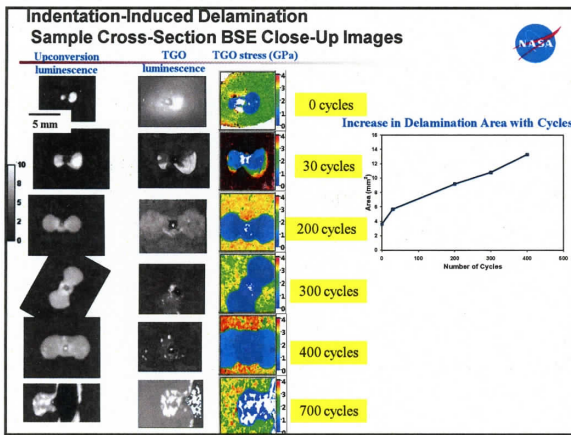


0 cycles 1 cycle 10 cycles 20 cycles 30 cycles 40 cycles 60 cycles 80 cycles 100 cycles 120 cycles
140 cycles 160 cycles 180 cycles 200 cycles 220 cycles 240 cycles 260 cycles 280 cycles 300 cycles 320 cycles
340 cycles 360 cycles 380 cycles 400 cycles 420 cycles 440 cycles 460 cycles 480 cycles 500 cycles 520 cycles
540 cycles 560 cycles 580 cycles 600 cycles 620 cycles 640 cycles 660 cycles 680 cycles 700 cycles 720 cycles
740 cycles 745 cycles

130 μm YSZ
6 μm YSZ:Er(1%), Yb(3%)
NiPtAl
Rene NS

1cm





Monitoring Indentation-Induced Delamination

- **PSI**
 - Luminescence *intensity* shows good delamination contrast only when failure is between TGO & bond coat (30 cycles). Poor contrast when failure is between TBC & TGO).
 - TGO *stress* shows excellent contrast for *all* indents. Stress reduction may be due to deformation of bond coat.
- **Upconversion Luminescence**
 - Excellent delamination contrast for all indents.
 - Poor discrimination between TBC/TGO and TGO/bond coat failure.

• Delamination cracks between TGO & bond coat at 30 cycles.
• Delamination cracks between TBC & TGO at all later stages of cyclic life.

Conclusions

- PSI & upconversion luminescence imaging provide complementary information
 - PSI evaluates delamination-driving TGO stress, but poor at evaluating damage accumulation (especially above TGO).
 - Upconversion luminescence evaluates damage accumulation but gives no indication of delamination-driving TGO stress.
 - Combined PSI & upconversion luminescence imaging allows for better discrimination of delamination failure location than either technique alone.