



Thermal Conductivity and Stability of $\text{HfO}_2\text{-Y}_2\text{O}_3$ and $\text{La}_2\text{Zr}_2\text{O}_7$ Evaluated for 1650 °C Thermal/Environmental Barrier Coating Applications

Dongming Zhu

U.S. Army Research Laboratory, Glenn Research Center, Cleveland, Ohio

Narottam P. Bansal and Robert A. Miller

Glenn Research Center, Cleveland, Ohio

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at 301-621-0134
- Telephone the NASA Access Help Desk at 301-621-0390
- Write to:
NASA Access Help Desk
NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076



Thermal Conductivity and Stability of $\text{HfO}_2\text{-Y}_2\text{O}_3$ and $\text{La}_2\text{Zr}_2\text{O}_7$ Evaluated for 1650 °C Thermal/Environmental Barrier Coating Applications

Dongming Zhu

U.S. Army Research Laboratory, Glenn Research Center, Cleveland, Ohio

Narottam P. Bansal and Robert A. Miller

Glenn Research Center, Cleveland, Ohio

Prepared for the
105th Annual Meeting and Exposition of the American Ceramic Society
sponsored by the American Ceramic Society
Nashville, Tennessee, April 27–30, 2003

National Aeronautics and
Space Administration

Glenn Research Center

Acknowledgments

This work was supported by the NASA Ultra-Efficient Engine Technology (UEET) Program. The authors wish to thank Jeffrey I. Eldridge and Charles M. Spuckler at the NASA Glenn Research Center for helpful discussions. The authors are also grateful to George W. Leissler and John A. Setlock at the NASA Glenn Research Center for their assistance in the preparation of plasma-sprayed T/EBC coatings and hot-pressed samples, respectively.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at <http://gltrs.grc.nasa.gov>

THERMAL CONDUCTIVITY AND STABILITY OF HFNIA- AND ZIRCONATE-BASED MATERIALS FOR ADVANCED 1650 °C THERMAL/ENVIRONMENTAL BARRIER COATING APPLICATIONS

Dongming Zhu
U.S. Army Research Laboratory
Glenn Research Center
Cleveland, Ohio

Narottam P. Bansal and Robert A. Miller
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

ABSTRACT

HfO₂-Y₂O₃ and La₂Zr₂O₇ are candidate thermal and environmental barrier coating (T/EBC) materials for gas turbine ceramic matrix composite (CMC) combustor applications because of their relatively low thermal conductivity and high temperature capability. In this paper, thermal conductivity and high temperature stability of hot-pressed and plasma-sprayed specimens with representative partially-stabilized and fully-cubic HfO₂-Y₂O₃ compositions and La₂Zr₂O₇ were evaluated at temperatures up to 1700 °C using a steady-state laser heat-flux technique. Sintering behavior of the plasma-sprayed coatings was determined by monitoring the thermal conductivity increases during a 20-hour test period at various temperatures. Durability and failure mechanisms of the HfO₂-Y₂O₃ and La₂Zr₂O₇ coatings on mullite/SiC hexoloy or SiC/SiC CMC substrates were investigated at 1650 °C under thermal gradient cyclic conditions. Coating design and testing issues for the 1650 °C thermal/environmental barrier coating applications are also discussed.

INTRODUCTION

Thermal and environmental barrier coatings (T/EBCs) will play a crucial role in advanced gas turbine engine systems because of their ability to significantly increase engine operating temperature and reduce cooling, thus greatly help to achieve engine low emission and high efficiency goals. In particular, T/EBCs are being developed for low emission SiC/SiC ceramic matrix composite (CMC) combustor applications by extending the CMC liner and vane temperature capability to 1650 °C (3000 °F) in oxidizing and water vapor containing combustion environments. In order to achieve the engine design and performance goals, the coating systems under development must provide vital thermal and environmental protections for the Si-based components at the gas temperatures exceeding 1760 °C (3200 °F) in the harsh combustion environments, while maintaining the CMC substrate below its temperature limit of 1316 °C (2400 °F). The advanced 1650 °C T/EBC system is required to have significantly increased phase stability, lower lattice and radiation thermal conductivity, and improved sintering and thermal stress resistance under the engine high-heat-flux and severe thermal cycling conditions. Advanced heat-flux testing facilities [1–3] and approaches [3–7] have been established for the 1650 °C coating development. The simulated combustion water-vapor environment is also being incorporated into the heat-flux test capabilities [3].

In order to develop a T/EBC system for the 1650 °C Si-based CMCs, a multi-functional coating concept may be considered. Figure 1 shows an advanced coating design concept for the 1650 °C T/EBC system for CMC combustor applications. The top layer is a high-temperature capability ceramic thermal barrier coating. This top coating layer will provide the major thermal protection for the sub-coating systems and CMC substrate, and also act as the first-stage radiation barrier by reducing the transmission of the infrared thermal radiation from the combustion gas environment and form the higher temperature coating surface. The second layer is an energy dissipation layer that will act as a “bond coat” to tailor the thermal expansion mismatch and reduce the thermal stress of the coating system. The third layer is a secondary radiation barrier and thermal control layer. The sophisticated coating compositions and structures will provide combined high reflectivity and diffusion barrier functions. The fourth layer will be an improved stability environmental barrier coating system for the CMC substrate.

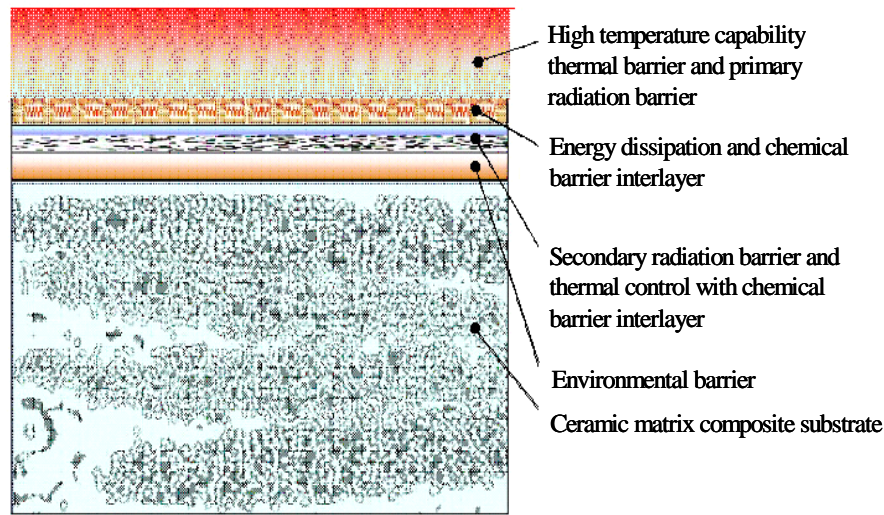


Figure 1.—An advanced coating design concept for the 1650 °C T/EBC system for CMC combustor applications.

The purpose of this paper is to investigate the thermal conductivity and stability of candidate T/EBC top-layer materials, $\text{HfO}_2\text{-Y}_2\text{O}_3$ and $\text{La}_2\text{Zr}_2\text{O}_7$, under high temperature thermal gradient conditions using a steady-state heat-flux test approach. Both the hot-pressed and plasma-sprayed $\text{HfO}_2\text{-Y}_2\text{O}_3$ and $\text{La}_2\text{Zr}_2\text{O}_7$ were investigated. The emphasis is placed on the lattice and radiation thermal conductivity, sintering, and cyclic durability of the $\text{HfO}_2\text{-Y}_2\text{O}_3$ and $\text{La}_2\text{Zr}_2\text{O}_7$ under the 1650 °C thermal gradient test conditions. The temperature capability of $\text{HfO}_2\text{-Y}_2\text{O}_3$ (with the Y_2O_3 dopant concentration ranging from 5 to 25 mol%) and $\text{La}_2\text{Zr}_2\text{O}_7$ systems on thermal conductivity and the phase stability is evaluated. Coating design and testing issues for the 1650 °C thermal/environmental barrier coating applications will also be discussed.

MATERIALS AND EXPERIMENTAL METHODS

Materials

Thermal conductivity of five $\text{HfO}_2\text{-Y}_2\text{O}_3$ compositions, i.e., HfO_2 doped with 5, 10, 15, 20, and 25 mol% Y_2O_3 , respectively, and $\text{La}_2\text{Zr}_2\text{O}_7$ were investigated at high temperatures using a steady-state laser heat flux test technique. The test specimens were either hot-pressed disks (25.4 mm in diameter, 2-4 mm in thickness), or plasma-sprayed coatings (254-400 μm in thickness). The hot-pressed specimens were fabricated at 1500 °C for an hour under 30 MPa pressure primarily by using spray-dried powders. For the $\text{La}_2\text{Zr}_2\text{O}_7$ material, sol-gel derived, fine particle sized powder was also used to make very high density hot-pressed specimens.

The coating specimens were prepared by plasma-spraying the spray-dried, and plasma-reacted powders on either metallic or CMC substrates. For thermal conductivity measurements, the coating specimens with the low-pressure-plasma-sprayed NiCrAlY bond coated René N5 nickel-base superalloy substrates (25.4 mm in diameter and 3.2 mm in thickness) were used. On the other hand, for sintering and 1650 °C cyclic durability testing, complete T/EBC coating systems (including the top oxide coating layer + the mullite/Si or mullite+BSAS/Si) were prepared with either the melt-infiltrated (MI) SiC/SiC CMC (25.4 mm in diameter, 2.2 mm in thickness) or Hexoloy SiC (25.4 mm in diameter, 3.17 mm in thickness) substrates. The phase structures of the coating materials were examined using X-ray diffraction.

Thermal Conductivity Testing

Thermal conductivity testing of the $\text{HfO}_2\text{-Y}_2\text{O}_3$ and $\text{La}_2\text{Zr}_2\text{O}_7$ hot-pressed and coating specimens was carried out using a 3 kW CO_2 laser (wavelength 10.6 μm) high-heat flux rig. A schematic diagram of the test rig is illustrated in

Figure 2. The general test approaches have been described elsewhere [1–4]. In this steady-state laser heat-flux thermal conductivity test, the specimen surface heating was provided by the laser beam, and backside air cooling was used to maintain the desired specimen temperatures. A uniform laser heat-flux was obtained over the 23.9 mm diameter aperture region of the specimen surface by using a beam integrating ZnSe lens with either the specimen or the lens rotation. Platinum wire flat coils (wire diameter 0.38 mm) were used to form thin air gaps between the top aluminum aperture plate and stainless-steel back plate to minimize the specimen heat losses through the fixture. The thermal conductivity of the hot-pressed and coating specimens can be determined from the pass-through heat flux and measured temperature difference through the ceramic specimen (or the ceramic coating) thickness under the steady-state laser heating or thermal cycling conditions by a one-dimensional (one-D) heat transfer model.

RESULTS AND DISCUSSION

Thermal conductivity of hot-pressed specimens HfO₂-Y₂O₃

Figure 3 shows a typical thermal conductivity measurement for the hot-pressed specimens. As can be seen in the example of the HfO₂-20mol%Y₂O₃ coating case, the specimen pass-through heat flux was first slowly increased and then decreased during a heating and cooling cycle by programming the delivered laser power. During the test, the heat flux and cooling can be adjusted to control the temperature difference across the specimen for the conductivity measurements. The corresponding specimen temperature changes, and the temperature difference across the specimen were continuously recorded under given heat flux and cooling conditions. The specimen thermal conductivity was thus obtained as a function of time and temperature.

Figure 4 shows the temperature dependence of the thermal conductivity for the HfO₂-Y₂O₃ hot-pressed specimens. As expected, the HfO₂ materials generally showed the conductivity decrease with increase in temperature. In addition, the thermal conductivity typically showed less temperature dependence with a higher Y₂O₃ dopant content. For the specimens tested at the surface temperature above 1400-1450 °C (such as in the cases of ZrO₂-20mol%Y₂O₃ and ZrO₂-25mol%Y₂O₃), slight conductivity increases were observed when the temperature increases. The conductivity increases with temperature in the high temperature regime can be attributed to the increased radiation heat fluxes, which will result in the increased apparent thermal conductivity [3].

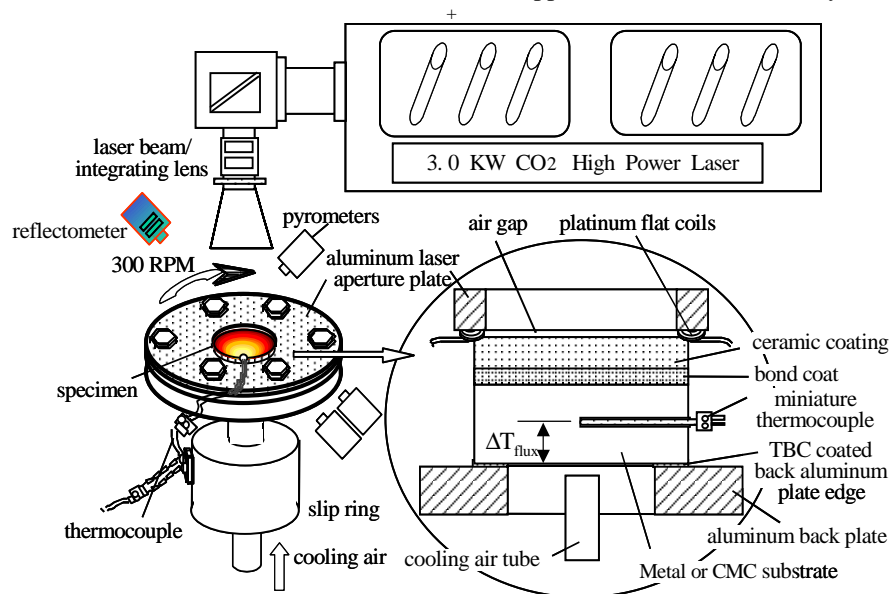


Figure 2.—Schematic diagram showing the laser high-heat-flux rig for determining thermal conductivity and cyclic durability of T/EBC materials. During the test, the ceramic surface and the substrate backside temperatures are measured by infrared pyrometers. The thermal conductivity of the ceramics can be determined from the pass-through heat flux and measured temperature difference through the ceramic specimen (or the ceramic coating) thickness under the steady-state laser heating or thermal cycling conditions by a one-dimensional (one-D) heat transfer model.

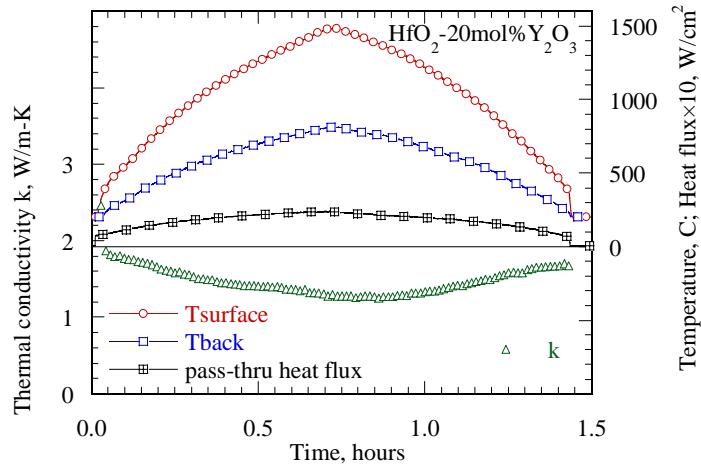


Figure 3.—Typical thermal conductivity measurement for the hot-pressed specimens. During test, the corresponding specimen temperature changes, and the temperature difference across the specimen are continuously recorded. The specimen thermal conductivity is thus obtained as a function of time and temperature.

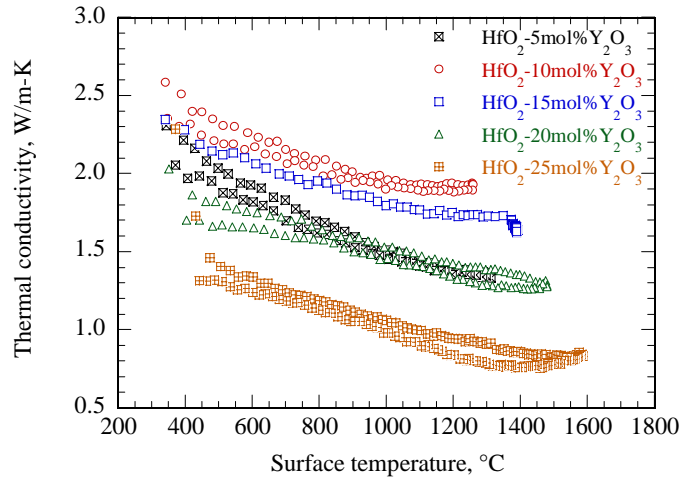


Figure 4.—Thermal conductivity of HfO₂-Y₂O₃ hot-pressed specimens as a function of temperature.

Figure 5 shows measured density and thermal conductivity at 1400 °C of the HfO₂ hot-pressed specimens as a function of Y₂O₃ concentration. The density of the HfO₂ specimens was relatively low (i.e., the porosity was relatively high) due to the relatively large particle size used in this study. The conductivity data scatter was also observed due to the variation in porosity in these hot-processed specimens, with the lower density specimens having lower measured conductivity. Nevertheless, the specimen thermal conductivity showed a general trend to decrease with increase in the yttria-dopant concentration.

La₂Zr₂O₇

Figure 6 shows thermal conductivity of La₂Zr₂O₇ hot-pressed specimens as a function of surface test temperature. The La₂Zr₂O₇ specimens had very low porosity due to the small particle sizes of La₂Zr₂O₇ powder used. In particular, the specimens fabricated with the sol-gel method derived powder achieved the theoretical density. These high density, low porosity La₂Zr₂O₇ specimens showed significant thermal conductivity increases starting at the temperature of 900 °C because of the increased radiation contribution with increasing temperature. The small amount of micro-porosity in the spray-dried powder processed specimen did not affect the lattice thermal conductivity dramatically. However, the micro-porosity in the specimen significantly reduce the radiation conductivity as compared to the almost pore-free, sol-gel powder processed specimens. The conductivity can increase by more than 100% for the very dense specimens because of the increased radiation heat-transfer under thermal gradient conditions.

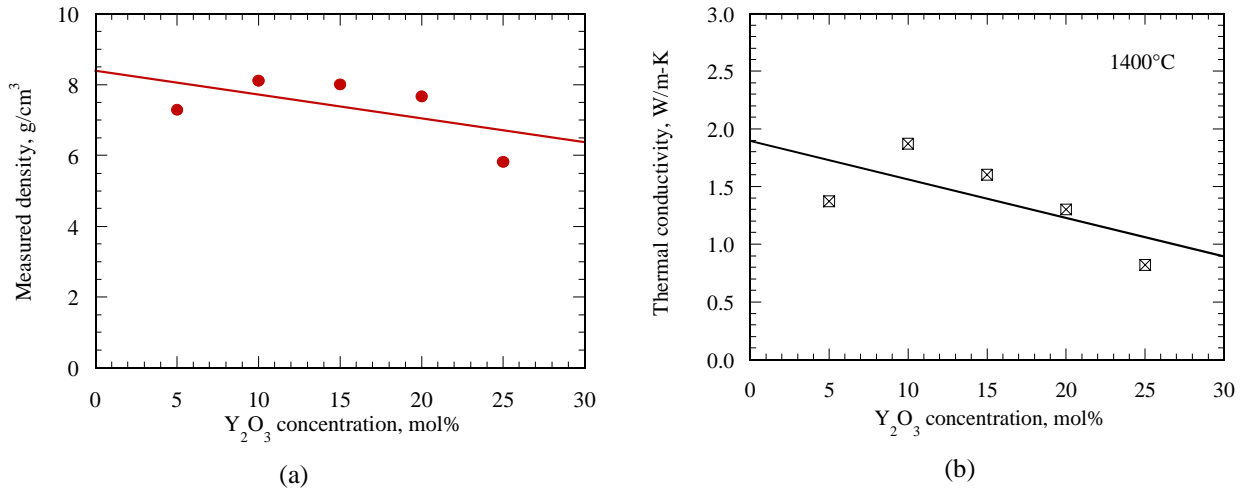


Figure 5.—The measured density (a) and thermal conductivity at 1400 °C (b) of the HfO₂ hot-pressed specimens as a function of Y₂O₃ concentration.

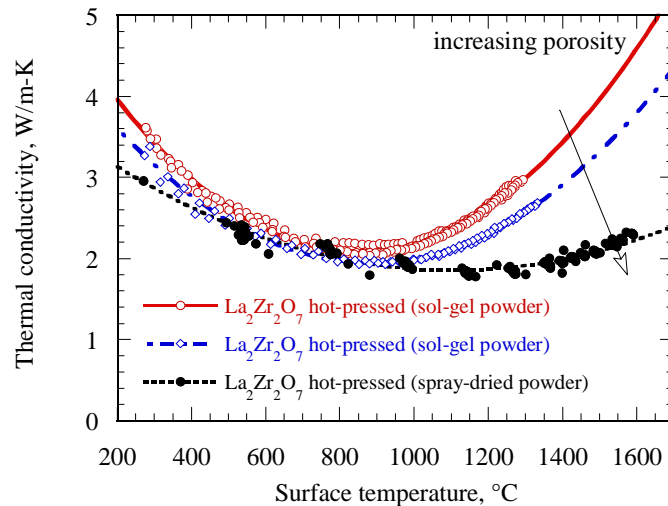


Figure 6.—Thermal conductivity of dense La₂Zr₂O₇ hot-pressed specimens as a function of surface test temperature. The conductivity can increase by more than 100% at high temperature for the very dense, sol-gel powder processed specimens because of the increased radiation heat-transfer under thermal gradient conditions.

Thermal conductivity of plasma-sprayed specimens HfO₂-based coatings

Figure 7 shows the thermal conductivity change kinetics of plasma-sprayed HfO₂-Y₂O₃ coatings as a function of temperature tested at 1650 °C with the pass-thru heat flux in the range of 95 to 100 W/cm². It can be seen that HfO₂-5mol% Y₂O₃ (5YSHf) had significant conductivity increase upon the 1650 °C thermal exposure even after a couple of hours testing. On the other hand, the HfO₂-15mol% Y₂O₃ (15YSHf) and HfO₂-25mol% Y₂O₃ (25YSHf) coatings showed lower initial and 20-hour sintered thermal conductivity, indicating the better temperature stability of the higher dopant coatings. The X-ray diffraction results showed that the as-sprayed 5YSHf coating initially had partially-stabilized tetragonal phase structure with a small amount of the monoclinic phase (2-3 mol%). The as-sprayed 15YSHf and 25YSHf had stabilized cubic structure. The monoclinic phase content in the 5YSHf coating increased to 10-12 mol% after the 1650 °C testing. Therefore, the conductivity increase for the 5YSHf coating is not only due to the significant sintering of the coating, but also due to the increased amount of the higher conductivity monoclinic phase in the coating.

Figure 8 shows the initial and 20-hour sintering thermal conductivity of the HfO₂-Y₂O₃ coatings tested at 1650 °C as a function of the Y₂O₃ concentration. It can be seen that thermal conductivity decreases with increase in

Y₂O₃ dopant. HfO₂-5mol%Y₂O₃ (5YSHf) showed the highest conductivity and also conductivity increases after the 1650 °C testing. The more stable cubic HfO₂-15mol%Y₂O₃ (15YSHf) and HfO₂-25mol%Y₂O₃ (25YSHf) showed lower conductivity and less conductivity increase. Advanced multi-component HfO₂ coatings have achieved even lower thermal conductivity and better thermal stability.

Figure 9 shows the 1650 °C sintering and cyclic testing results of HfO₂ baseline coatings (HfO₂-5mol%Y₂O₃ or 5YSHf, and HfO₂-15mol%Y₂O₃ or 15YSHf), and a multi-component HfO₂ coating, coated on mullite EBC/Si on SiC substrates. The coatings were initially tested under the standard 20 hour steady-state 1650 °C sintering condition to assess the sintering behavior; the coatings were then thermal cyclically tested at 1650 °C to evaluate the cyclic durability. The two HfO₂ baseline coatings showed significant conductivity increases due to the extensive sintering, and later conductivity reductions due to coating cracking and delamination. The 5YSHf showed severe spallation after the testing partially due to the large amount of monoclinic phase formation (>25mol%) [3]. In contrast, the advanced multi-component HfO₂ coating had relatively low conductivity increase during the steady-state testing, indicating its good sintering resistance. The coating also showed essentially no conductivity reduction during thermal cycling, demonstrating its good cyclic durability.

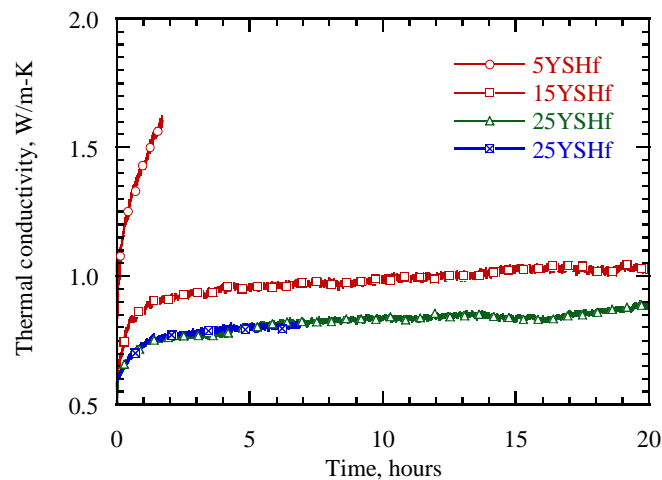


Figure 7.—Thermal conductivity of plasma-sprayed HfO₂-Y₂O₃ coatings tested at 1650 °C as a function of time (test pass-through heat flux 95-100 W/cm²).

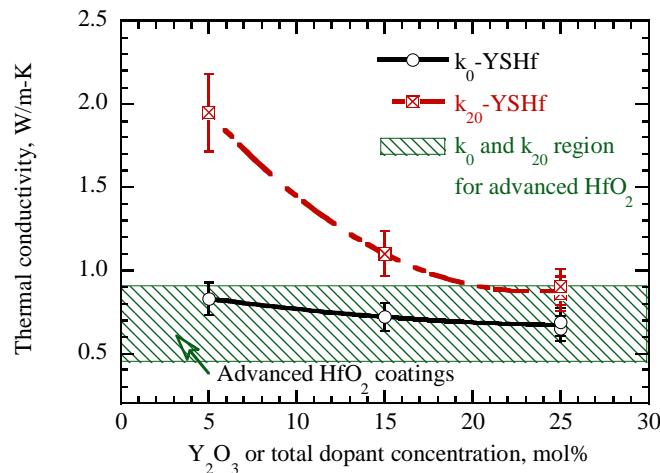


Figure 8.—The initial and 20-hour sintered thermal conductivity of plasma-sprayed HfO₂-Y₂O₃ coatings, tested at 1650 °C with the pass through heat flux 95-100 W/cm², as a function of the Y₂O₃ concentration. The k₀ and k₂₀ denote the initial and 20 hour sintered thermal conductivity of the HfO₂-Y₂O₃ system. As also indicated in the plot, advanced multi-component HfO₂ coatings have achieved even lower thermal conductivity and better thermal stability.

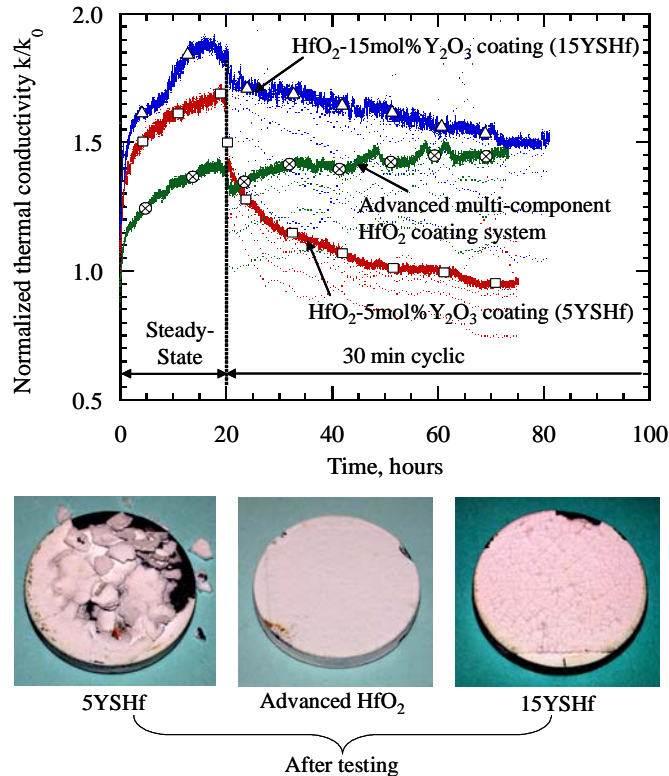


Figure 9.—Sintering and cyclic response of HfO₂ coating systems on mullite EBC/Si on SiC substrates tested at 1650 °C (3000 °F) with the pass-through heat flux of 95-100 W/cm². The advanced HfO₂ coating system showed excellent performance after the total 70 hours testing, with low sintering conductivity increase and essentially no delamination induced conductivity reductions.

La₂Zr₂O₇ coatings

Plasma-sprayed La₂Zr₂O₇ coatings were also tested under laser heat flux conditions. Fig. 10 shows thermal conductivity change kinetics of a plasma-sprayed La₂Zr₂O₇ tested at 1575 °C (with the pass-through heat flux of 80 W/cm²). The La₂Zr₂O₇ coating showed significant thermal conductivity increase (the conductivity increased from 0.55 W/m-K to 0.95 W/m-K in 20 hours), indicating the coating was undergoing substantial sintering at the test temperature. Fig. 11 shows the cyclic result of a La₂Zr₂O₇ TBC/mullite EBC/Si system on the SiC/SiC substrate at 1450 °C (pass-thru heat flux 50 W/cm²). The La₂Zr₂O₇ coating system demonstrated 150, 30 min hot-time cycles (or 75 hot hours) durability, and had the predominant coating sintering conductivity increase with only minor delamination related conductivity reduction. The coating had no visual damage after the testing. The plasma-sprayed La₂Zr₂O₇/mullite/Si system on the SiC/SiC substrate showed severe spallation upon heating under the higher heat flux (95-100 W/cm²), 1650 °C test conditions, as shown in Figure 12. The development of advanced pyrochlore coatings is also in progress to further improve the coating toughness, thermal stress resistance and overall performance.

CONCLUSIONS

In this study, a laser sintering-and-cyclic-durability test approach has been demonstrated for advanced 1650 °C (3000 °F) T/EBC development. The test results showed that HfO₂-Y₂O₃ and La₂Zr₂O₇ are promising candidate 1650 °C coating materials due to their low thermal conductivity and good sintering resistance. For the HfO₂-Y₂O₃ based coatings, the composition optimization can improve phase stability, and further reduce thermal conductivity. For the pyrochlore oxide coatings, further processing and coating composition modifications are needed in order to improve toughness for the 1650 °C application. The lattice and radiation conductivity of the advanced coating systems was also evaluated using the laser heat flux technique. The results showed that the radiation contribution can become significant at high temperature, especially for very dense materials. The phase stability, and sintering and thermal stress resistance are crucial for coating 1650 °C long-term cyclic durability.

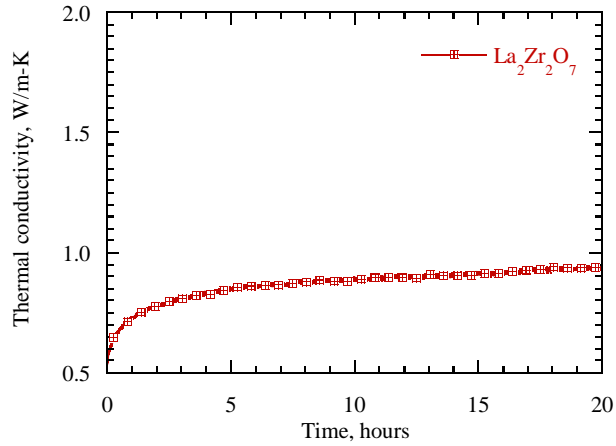


Figure 10.—Thermal conductivity change kinetics of a plasma-sprayed $\text{La}_2\text{Zr}_2\text{O}_7$ coating tested at $1575\text{ }^\circ\text{C}$ (with the pass-through heat flux of 80 W/cm^2).

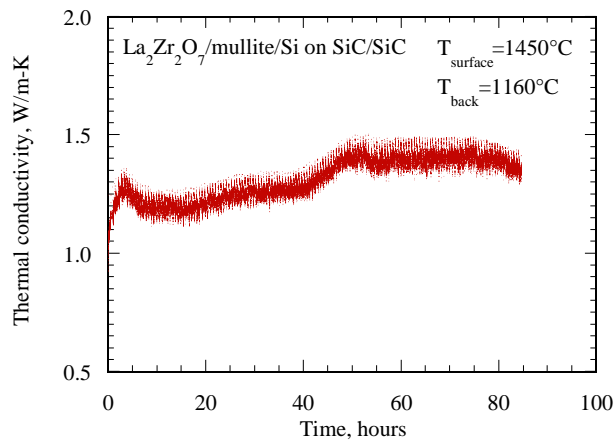


Figure 11.—The cyclic result of a $\text{La}_2\text{Zr}_2\text{O}_7$ TBC/mullite EBC/Si system on the SiC/SiC substrate at $1450\text{ }^\circ\text{C}$ (pass-thru heat flux 50 W/cm^2).

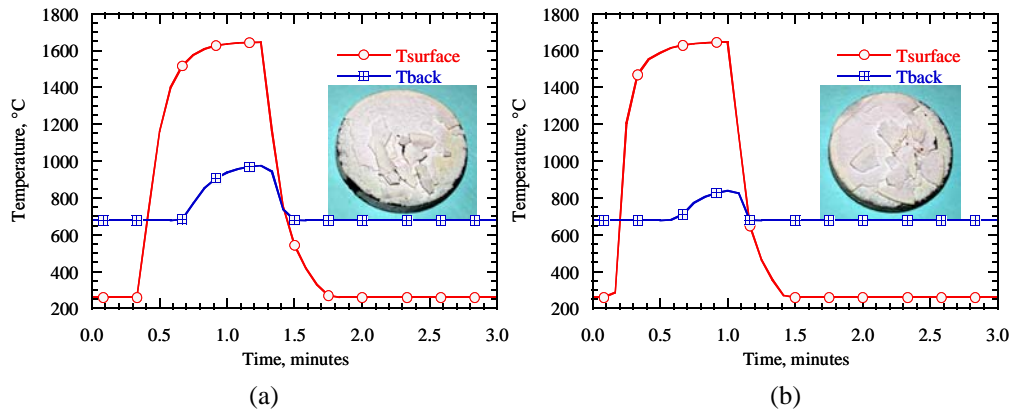


Figure 12.—The plasma-sprayed $\text{La}_2\text{Zr}_2\text{O}_7$ /mullite/Si coating system on the SiC substrates showed severe spallation upon heating under the heat flux of $95\text{--}100\text{ W/cm}^2$, $1650\text{ }^\circ\text{C}$ test conditions after the $1650\text{ }^\circ\text{C}$ exposure. (a) and (b) The temperature profiles and failure morphologies of two similarly processed $\text{La}_2\text{Zr}_2\text{O}_7$ coating specimens.

REFERENCES

- [1] D. Zhu and R. A. Miller, "Thermal Conductivity Change Kinetics of Ceramic Thermal Barrier Coatings Determined by the Steady-State Laser Heat Flux Technique," in Research and Technology 1999, NASA Glenn Research Center, NASA/TM-209639, 29-31, March 2000.
- [2] D. Zhu and R. A. Miller, "Thermal Conductivity and Elastic Modulus Evolution of Thermal Barrier Coatings under High Heat Flux Conditions," *Journal of Thermal Spray Technology*, 9 (2000), 175-180.
- [3] D. Zhu and R. A. Miller, "Development of Advanced Thermal and Environmental Barrier Coatings Using A High-Heat-Flux Testing Approach," The 27th Annual International Conference on Advanced Ceramics and Composites, Cocoa Beach, Florida, January 26-31, 2003.
- [4] D. Zhu, N. P. Bansal, K. N. Lee and R. A. Miller, "Thermal Conductivity of Ceramic Coating Materials Determined by a Laser Heat Flux Technique," *High Temperature Ceramic Matrix Composites IV, Proc. 4th High Temperature Ceramic Matrix Composites Conference (HT-CMC 4)*, Munich, Germany, Oct. 1-3 (2001), Edited by W. Krenkel, R. Naslain, and H. Schneider, Wiley-VCH, Verlag GmbH, Germany, 2001, 262-267.
- [5] D. Zhu and R. A. Miller, "Thermal Barrier Coatings for Advanced Gas Turbines," *MRS Bulletin*, 25 (2000), 43-47.
- [6] D. Zhu, K. N. Lee and R. A. Miller, "Thermal Conductivity and Thermal Gradient Cyclic Behavior of Refractory Silicate Coatings on SiC/SiC Ceramic Matrix Composites," *Ceramic Eng. Sci. Proc.*, 22-4 (2001), 443-452.
- [7] D. Zhu and R. A. Miller, "Thermophysical and Thermomechanical Properties of Thermal Barrier Coating Systems," *Ceramic Eng. Sci. Proc.*, 21-4 (2000), 623-633.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY <i>(Leave blank)</i>	2. REPORT DATE November 2003	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Thermal Conductivity and Stability of HfO ₂ -Y ₂ O ₃ and La ₂ Zr ₂ O ₇ Evaluated for 1650 °C Thermal/Environmental Barrier Coating Applications		5. FUNDING NUMBERS WBS-22-714-04-30 1L161102AF20	
6. AUTHOR(S) Dongming Zhu, Narottam P. Bansal, and Robert A. Miller			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191		8. PERFORMING ORGANIZATION REPORT NUMBER E-14110	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001 and U.S. Army Research Laboratory Adelphi, Maryland 20783-1145		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-2003-212544 ARL-TR-3093	
11. SUPPLEMENTARY NOTES Prepared for the 105th Annual Meeting and Exposition sponsored by the American Ceramic Society, Nashville, Tennessee, April 27-30, 2003. Dongming Zhu, U.S. Army Research Laboratory, NASA Glenn Research Center; Narottam P. Bansal and Robert A. Miller, NASA Glenn Research Center. Responsible person, Dongming Zhu, organization code 5160, 216-433-5422.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Categories: 23, 24, and 27 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.		12b. DISTRIBUTION CODE Distribution: Nonstandard	
13. ABSTRACT <i>(Maximum 200 words)</i> HfO ₂ -Y ₂ O ₃ and La ₂ Zr ₂ O ₇ are candidate thermal and environmental barrier coating (T/EBC) materials for gas turbine ceramic matrix composite (CMC) combustor applications because of their relatively low thermal conductivity and high temperature capability. In this paper, thermal conductivity and high temperature stability of hot-pressed and plasma-sprayed specimens with representative partially-stabilized and fully-cubic HfO ₂ -Y ₂ O ₃ compositions and La ₂ Zr ₂ O ₇ were evaluated at temperatures up to 1700 °C using a steady-state laser heat-flux technique. Sintering behavior of the plasma-sprayed coatings was determined by monitoring the thermal conductivity increases during a 20-hour test period at various temperatures. Durability and failure mechanisms of the HfO ₂ -Y ₂ O ₃ and La ₂ Zr ₂ O ₇ coatings on mullite/SiC hexoloy or SiC/SiC CMC substrates were investigated at 1650 °C under thermal gradient cyclic conditions. Coating design and testing issues for the 1650 °C thermal/environmental barrier coating applications are also discussed.			
14. SUBJECT TERMS Thermal barrier coating; Environmental barrier coating; Thermal conductivity; Thermal stability; Ceramic matrix composites		15. NUMBER OF PAGES 15	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT