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14. ABSTRACT The objective of this research is the development of improved performance, more affordable thermal barrier coatings via electron beam - directed vapor deposition (EB-DVD), a high efficiency vapor deposition technology developed and patented by the principal investigator and graduate student in University of Virginia's Intelligent Processing of Materials Laboratory. During the research effort, experiments and modeling efforts were directed at development of coating structures with ultralow thermal conductivities. Yttria-stabilized zirconia layers with "zig-zag" morphologies and fine pore microstructures were produced with measured thermal conductivities of 0.8 W/mK. These coatings are of significant interest to industry engaged in production of naval aircraft and marine turbine engine applications, and specimens have been produced for their evaluation.

15. SUBJECT TERMS
Thermal barrier coatings, electron beam deposition, vapor deposition, thermal conductivity, aircraft and marine turbine engines.

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Electron Beam-Directed Vapor Deposition of Low Cost Thermal Barrier Coatings

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LONG TERM RESEARCH OBJECTIVE

Development of improved performance, more affordable thermal barrier coatings (TBC's) via electron beam-directed vapor deposition (EB-DVD). EB-DVD will be used to synthesize improved thermal barrier coatings microstructures tailored for the multifunctional requirements of the gas turbine engine environment.

SCIENCE AND TECHNOLOGY OBJECTIVES

A multilayer system is being investigated consisting of an yttria-stabilized zirconia top layer with engineered porosity optimized for both very low thermal conductivity and in-plane stiffness in order to both protect against the hot working gas and to reduce thermal mismatch stress.

APPROACH

In Year 1, the effort focused upon specific equipment upgrades to the EB-DVD system to optimize it for TBC deposition. Progress was measured based upon attainment of desirable phases and microstructures in the zirconia deposits produced utilizing the process enhancements. In Year 2, the effort focused on process modeling and further experimental enhancements. The process modeling aimed at establishing the envelope of processing conditions for optimized zirconia microstructural depositions. In Year 3, the effort was focused upon validation of the process models, leading to optimized deposition of zirconia coatings at high throughput efficiencies. Thermal barrier coatings with thermal conductivity as low as 0.8 w/mk were produced and measured.

SIGNIFICANT RESULTS

1) Experiments were performed on the effect of chamber pressure, substrate temperature and deposition rate on the morphology of yttria stabilized zirconia layers. The desired columnar microstructures could be achieved in these layers and column diameter, intercolumnar spacing and texture all varied greatly with processing conditions.

2) A Direct Simulation Monte Carlo (DSMC) approach was used to model vapor transport of zirconium under realistic processing conditions.

3) An initial theory explaining the observed morphologies was developed to explain experimental results observed under varying process conditions. This theory relates gas flow field properties (such as the mean free path and the velocity vectors of Zr atoms) observed in the DSMC modeling effort to observed layer morphologies.

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4) Deposition of reduced thermal conductivity YSZ layers with "zig-zag" morphologies were investigated by altering the "zig-zag" wavelength using various dwell times. The thermal conductivity of these samples were at 0.8 w/mk.
5) Reactive deposition of yttria stabilized zirconia was achieved using a two source crucible and advanced beam scanning techniques. Such approaches offer the possibility of in-situ compositional control.

NAVY RELEVANCE AND TECHNOLOGY TRANSFER

This effort is relevant to Navy needs for prime reliant coatings in air and marine gas turbine propulsion applications. Technology transfer is accomplished by frequent interactions with turbine engine companies and their suppliers of thermal barrier coatings. In particular, General Electric is interacting with the investigators to produce trial samples for GE's internal evaluation, as well as having discussions regarding licensing of EB-DVD technology from the University.

PLANNED RESEARCH

The research has been continued under the follow-on ONR Grant Number N00014-00-1-0147. Research will focus on the development of an atomistic level understanding of the growth processes during EB-DVD TBC deposition. Such an understanding will be critical in the development of highly engineered TBC layer which are optimized for low thermal conductivity, high spallation resistance and high thermal stability. Such research will add to the collective effort of developing prime reliant thermal barrier coatings for turbine applications. Once achieved, gas turbine engines can be designed to fully take advantage of TBC benefits leading to increased engine operating temperatures and improved engine efficiencies.

REFERENCES

Papers Published in Refereed Journals

Electron Beam-Directed Vapor Deposition of Thermal Barrier Coatings, D.D. Hass, H.N.G. Wadley, and P.A. Parrish, Journal of Vacuum science and Technology, December 1998.

Creep Expansion Of Porous Ti-6Al-4V Sandwich Structures, D.T. Queheillalt, B.W. Choi, D.S. Schwartz And H.N.G. Wadley, accepted Met. Trans. May 1999.

Presentations

Methods, Mechanisms and Models of EB-DVD, ONR Review, Woods Hole, MA, May 27, 1999.

Patents

D. D. Hass, H.N.G. Wadley and J. F. Groves "Apparatus and Method for Producing Thermal Barrier Coatings", June 16 1999.

(Disclosure filed) H.N.G. Wadley, J.F. Groves, and D.D. Hass, "Thin Film Combinatorial Synthesis via Electron Beam-Directed Vapor Deposition," submitted May 26, 1999.

Honors

1999 Virginia Space Grant.

STUDENTS SUPPORTED

Doctoral 2 Undergraduates 1
Females 0
Minorities 0

OTHER SPONSORED S&T

- Ultralight Metals (MURI), ONR through Harvard U, 9/1/96-8/31/01, $1,750,000

- Intelligent Processing of Materials for Design and Manufacturing, DARPA/NASA, 5/31/97-4/30/2000, $3,815,164
- Directed Vapor Deposition System for Atomically Engineered Surfaces (DURIP), ONR, $286,000.
- Plasma Assisted Electron Beam-Directed Vapor Deposition (DURIP), ONR, $92,500.