First Aero-Ukraine Workshop
"Bridging the Ukrainian Aeronautics Industry with the European Union"

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

EB-PVD technologies and equipment for deposition of graded protective coatings on gas turbine blades

Boris Movchan

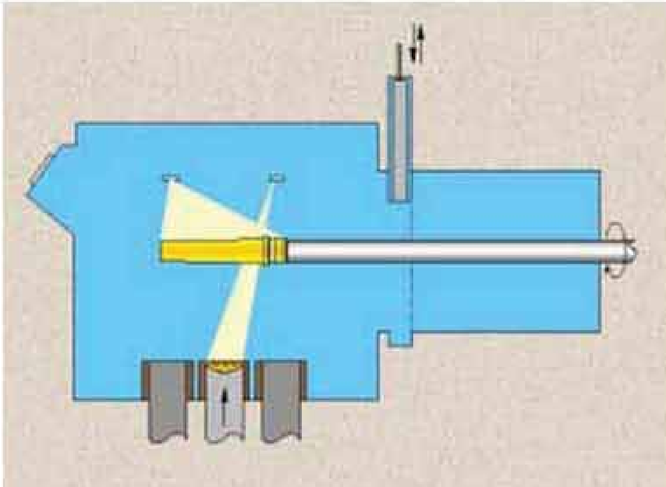
Kostyantyn Yakovchuk

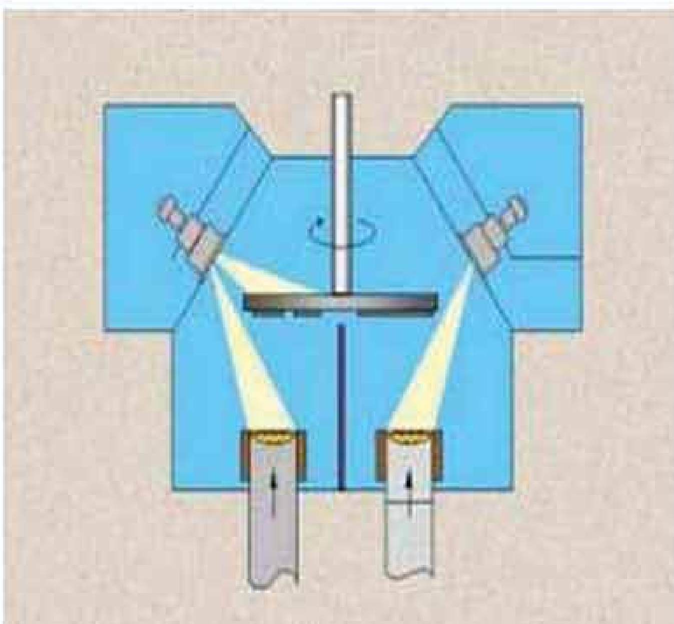
The International Center for Electron Beam Technologies
of E.O.Paton Electic Welding Institute, Kyiv, Ukraine

28-29 October, IPMS-NASU, Kiev

Electron Beam Physical Vapor Deposition (EB-PVD) is a modern process based on evaporation and condensation materials in vacuum.

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$





Electron Beam Physical Vapor Deposition (EB-PVD) technologies provide many opportunities for the melting, evaporation and deposition of various oxidation-resistant, and refractory metal alloys, ceramics and composites. EB-PVD provides protective and structural coatings that are widely used in modern technologies such as aeronautical and industrial gas turbines. In many cases unique EB-PVD is the only method available to manufacture microporous, microlaminated, graded, and nanostructured materials.

It's a perfect process for protective coating deposition.

Multilayered graded protective coatings

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

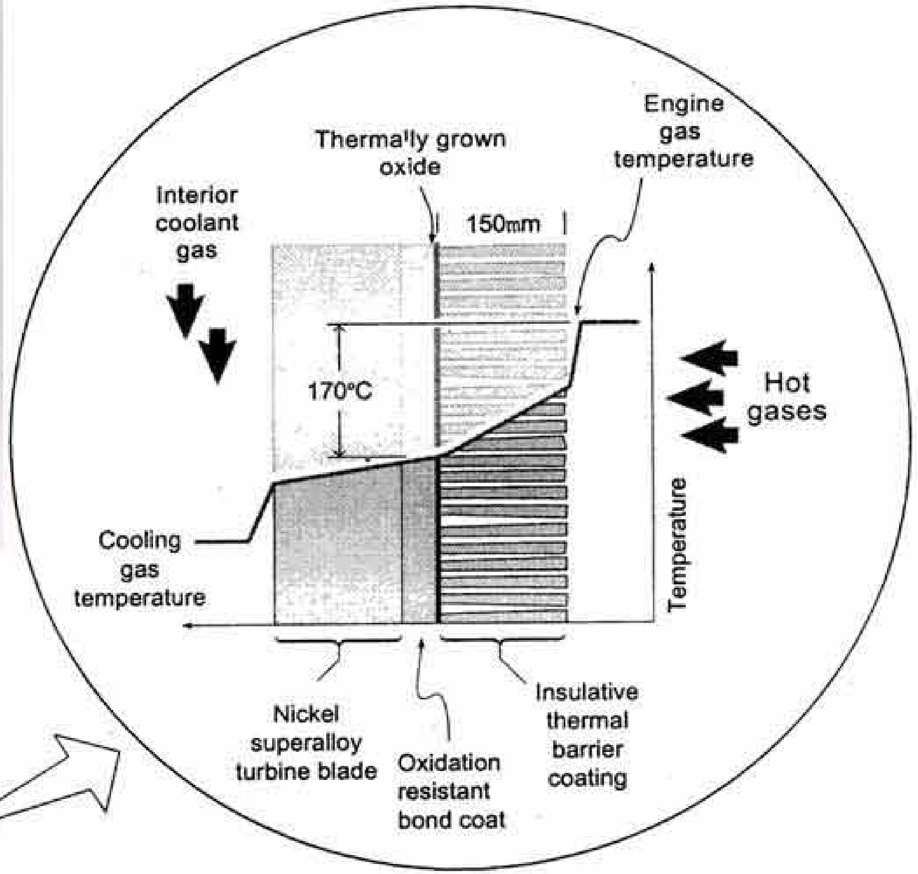
Requirements of modern industry:

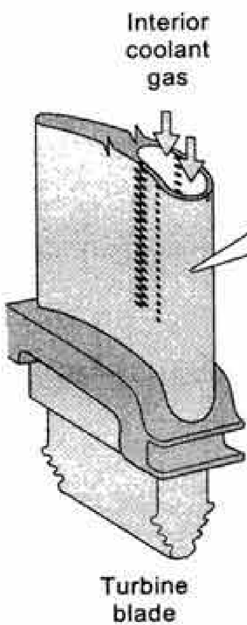
- new multilayered protective coatings (including TBC, vibration-damping and erosion-resistant) with higher level of key service properties;
- reducing of deposition time and cost of new multilayered coatings.

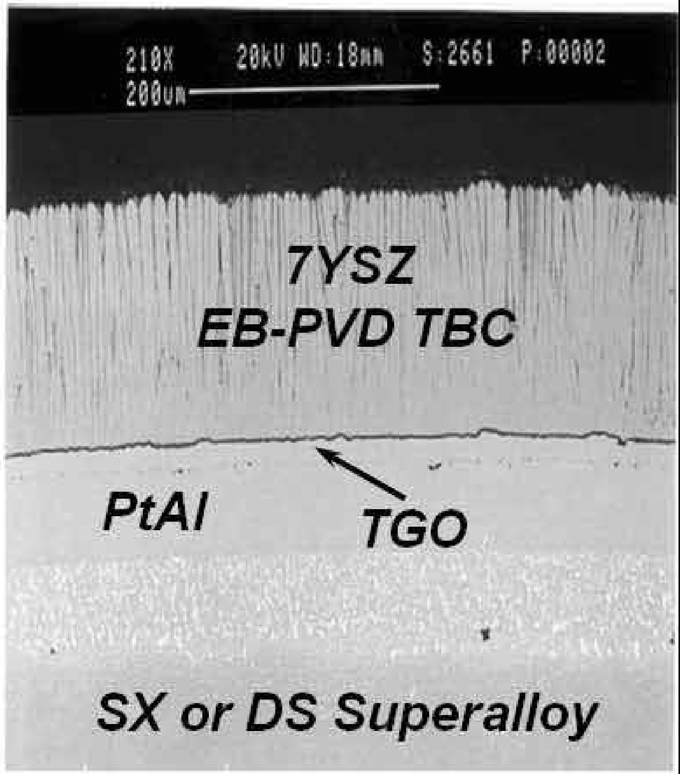
- This is solved by application of proposed one-stage EB-PVD technology and equipment for deposition of multilayered graded protective coatings that have improved key service properties due to producing metal and ceramic multilayers of graded composition and nanostructure with transition zones and two times lowering of the cost and time of the coating deposition due to using of one-stage technological process.

Traditional design and structure of thermal barrier coatings (TBC)

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$







In traditional thermal barrier coatings the ZrO_2-Y_2O_3 outer ceramic layer of 125-250 microns thick is deposited on the bond coat pre-deposited on the surface of the superalloy (substrate).

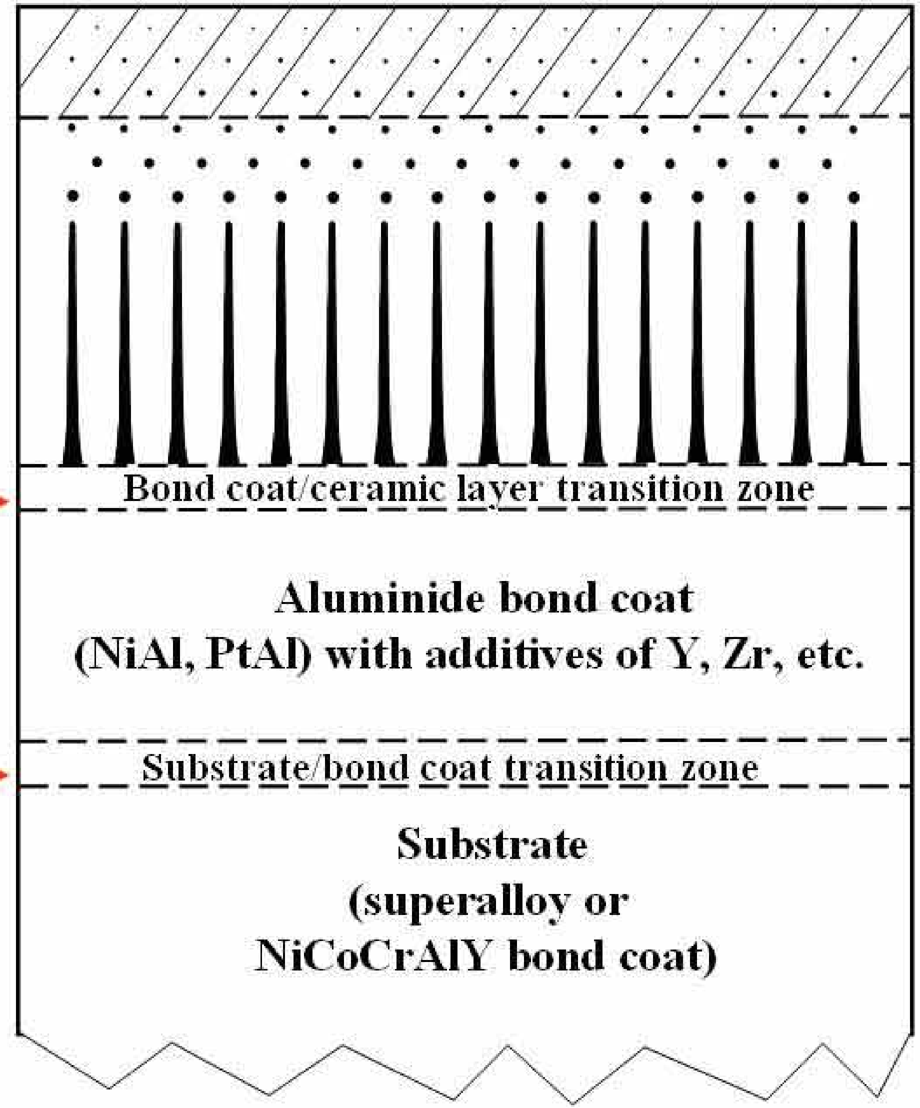
Optimal graded TBC design

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

stable thermal conductivity;
high sintering resistance;
high resistance to erosion/corrosion impact of an aggressive gas flow

Cermets (on Al_2O_3 or Cr_2O_3 base) with additives

Metals or alloys with additives (carbides, oxides, etc) deposited by organic compound evaporation



Graded outer ceramic layer

Graded bond coat

high oxidation resistance;
high level of adhesion and thermal stability due to the presence of the respective transition zone (diffusion barrier) on the boundary with the substrate.

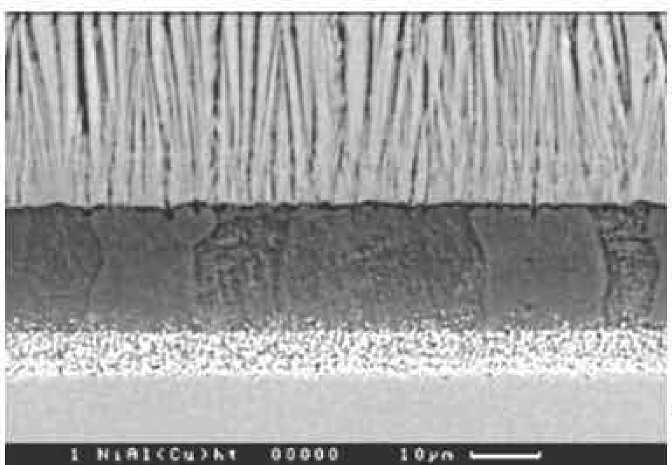
The transition zone on the metal bond coat/outer ceramic layer interface ensures formation of a scale film of optimum structure and composition in terms of minimum rate of this film growth at elevated temperature and high spallation resistance.

Technology features

$$D = {}^{2}\!/_{3}\,\frac{d}{f} \approx \Lambda$$

- Key elements of single-stage EB-PVD technology for deposition of graded protective coatings (TBC or vibration-damping and erosion-resistant coatings) are the composite ceramic ingot and carousel-type evaporator;

- Evaporation of a single composite ingot allows deposition of multilayered graded protective coating (bond coat, transition zones and top coat) per one process run in one EB-PVD coater.



← 8YSZ

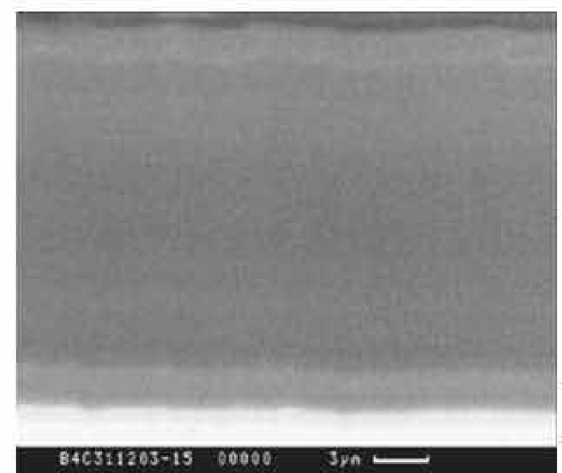
← Transition zone

← NiAl

← Transition zone

← Substrate Rene 142

Microstructure of multilayered graded TBC



← B_4C-based graded nanostructured top layer. H_m = up to 31GPa

← Bond coat

← Substrate

Microstructure of graded nanostructured vibration-damping&erosion-resistant coating

Advantages of single-step deposition process

$$D = 2/3 \frac{d}{f} \approx \Lambda$$

Traditional protective coating (multi-stages deposition technology)

First layer (bond coat) deposition (by diffusion saturation, electroplating, plasma spraying, EB-PVD, etc.)

↓

Bond coat mechanical treatment and heat treatment/surface preparation

↓

Deposition of top layer (by plasma methods or EB-PVD, etc)

Current technologies use various equipment for deposition of individual coating layers:

-it does not allow producing graded coatings;

-high coating cost as result;

-difficulties with achieving a high repeatability of coating structure and properties.

Multilayered graded protective coating (single-stage EB-PVD technology)

Deposition of multilayered graded coating (all multilayers, including bond coat, transition zones and top coat) with nanostructure by one deposition process using evaporation of a single composite ceramic ingot

One EB-PVD unit and one process run are sufficient for deposition of a multilayered graded protective coatings

Technology benefits

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

This technology allows:

- producing multilayered nanostructured graded coatings with a higher level of key service properties (including reliability and durability) and lower cost, which is at least 2 times lower than that of the traditional coatings produced by the multistage technology, using various kinds of equipment;
- replacing the flat interface between layers by a graded transition zone and achieving a good adhesion of the coating to the substrate;
- achievement of a high degree of reproducibility of the composition and nanostructure of the multilayered graded protective coatings as compared with traditional multi-stage technologies of protective coatings deposition.

Graded TBC deposition by one-step EB-PVD technology

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

- a simple technological process of electron beam evaporation of a composite ingot can be sufficient for deposition of a graded TBC (metal bond coat, transition zones and outer ceramic layer are deposited in one EB-PVD unit in one cycle, <u>during one deposition run</u>);

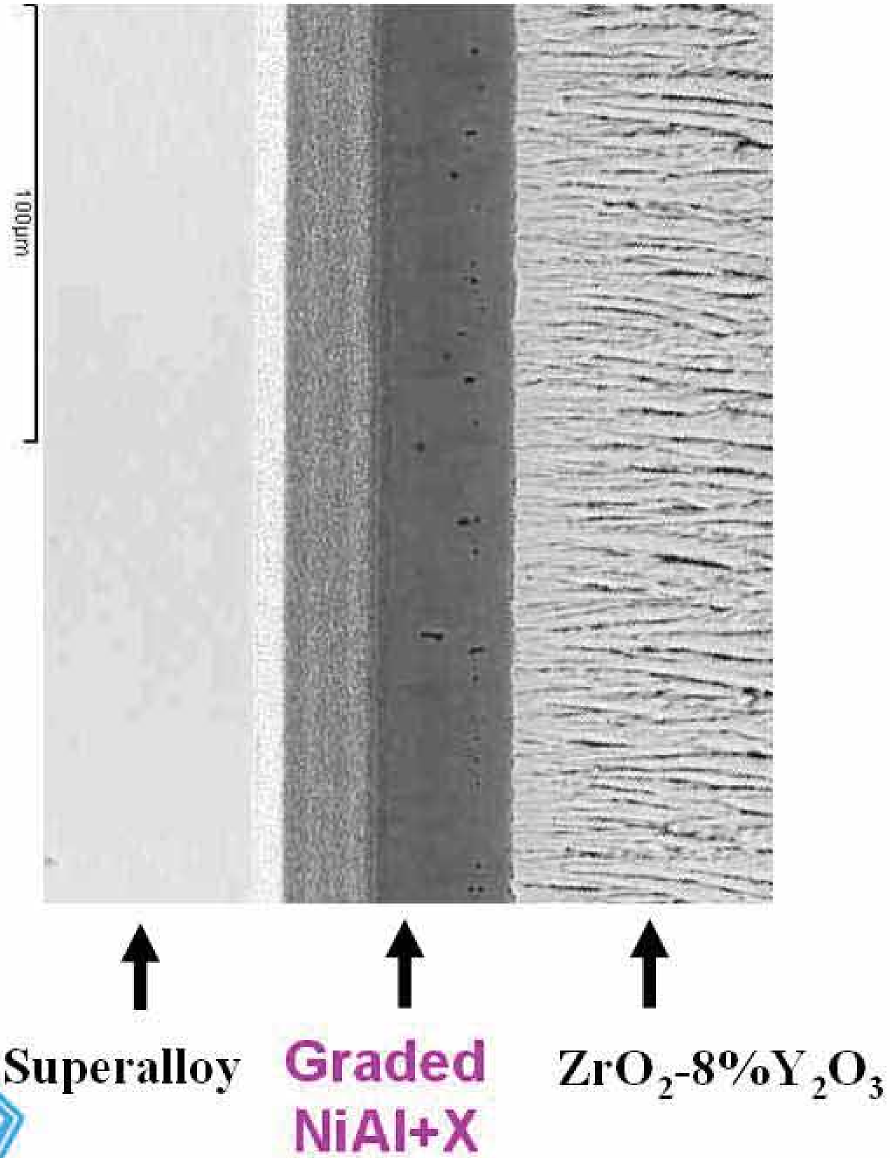
- composition, structure and thickness of layers and zones are programmed in the composite ingot in keeping with the requirements made of TBCs.

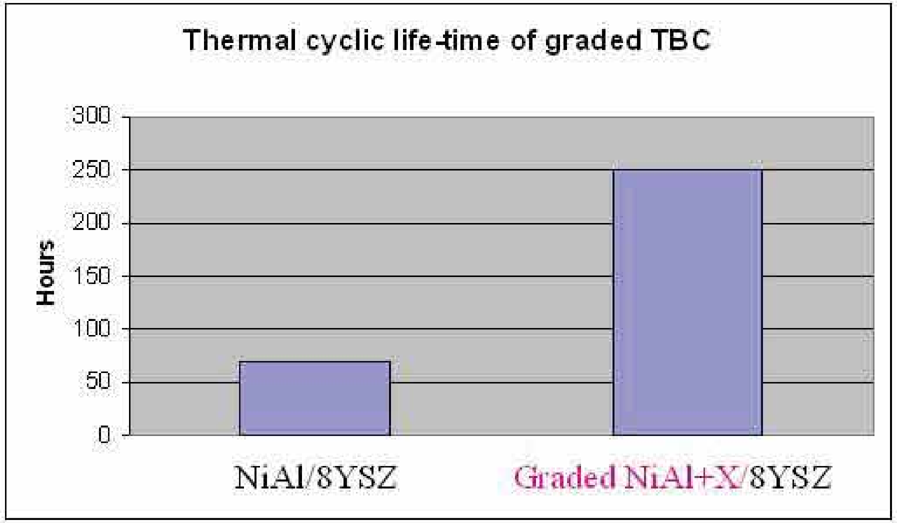
First sets of blades with graded TBC deposited by one-stage EB-PVD technology are in flight engine test now

Influence of reactive elements (X) additions on the NiAl bond coat performance

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

Microstructure of graded nanostructured NiAl+X / 8YSZ TBC on Ni-based superalloy sample





Reactive elements addition to NiAl bond coat allow to increase up to 4-5 times of thermal cyclic life-time of graded TBC at furnace cyclic test (Room temp ↔ 1190 ^{0}C, cycle= 3 h).

Approach for Vibration Damping/Erosion-Resistant coatings

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

<u>Key requirements:</u>

- Effective damping;
- Excellent erosion resistance;
- No detrimental effect on HCF strength;
- Smooth surface finish;
- Light weight.

Plasma Spray coatings will not meet requirements.

EB-PVD Technology offers best solution.

ИЭС им. Е.О.ПАТОНА

IC EBT

Advanced Damping/Erosion-Resistant Coating

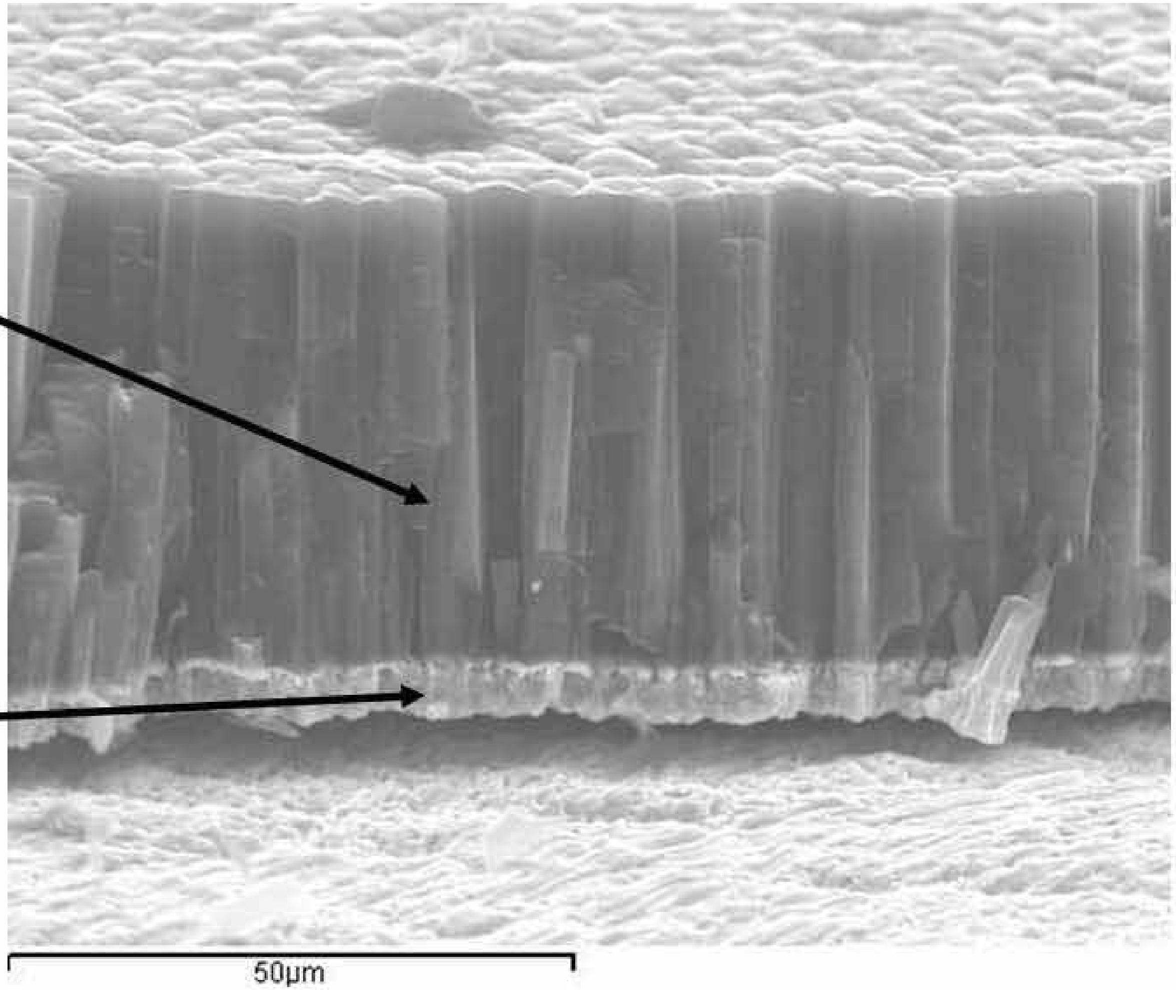
$$D = 2/3 \frac{d}{f} \approx \Lambda$$

Columnar B_4C-based damping/erosion-resistant layer:

- effective damping;
- excellent erosion-resistant;
- light weight.

Graded bond coat:

- excellent bonding;
- ductility for HCF.



Aerodynamically smooth and thin coating produced in single step process using ICEBT EB-PVD equipment.

Expansion of EB-PVD technology

$$D = {}^{2}\!/_{3}\,\frac{d}{f} \approx \Lambda$$

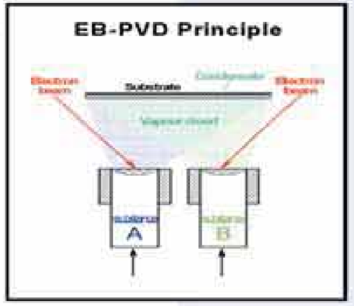
EB-PVD units of the last generation developed and manufactured at ICEBT are used in the USA, Canada, China, India.

USIC
United States Industry Coalition, Inc.

IPP
Initiatives for Proliferation Prevention
National Nuclear Security Administration

$$D = \frac{2}{3}\frac{d}{f} \approx \Lambda$$

Next Generation EB-PVD Apparatus



- Electron Beam Physical Vapor Deposition (EB-PVD) technologies provide wide possibilities for deposition of new materials as well as coatings of various heat resistant and refractory metal alloys, ceramics and composites with unique structures and properties
- EB-PVD is used across many industries:
  - Aeronautical & Industrial gas turbines
  - Fuel cells
  - X-ray systems
- Improved apparatus over commercially-available EB-PVD systems will be developed:
  - Innovative design features
  - Higher rates of deposition
  - Reduced time & operating costs
- Enable Ukrainian partner to compete in global market

General Electric Company
Niskayuna, NY

International Center for Electron Beam Technologies (ICEBT) of E.O. Paton Electric Welding Institute
Kyiv, Ukraine

"Impressive work is being accomplished in Ukraine (ICEBT) by GE Global Research to develop "Electron Beam Physical Vapor Deposition" hardware. Former Soviet defense experts are now low-cost producers of high-tech civilian industrial equipment built to Western standards".

Monte Mallin,

Director, Global Security Engagement and Cooperation, Office of Nonproliferation and International Security, National Nuclear Security Administration, USIC Meeting, March 7, 2006

IC EBT

International Center for Electron Beam Technologies (ICEBT) of E.O.Paton Electic Welding Institute, Kyiv, Ukraine

$$D = 2/3 \frac{d}{f} \approx \Lambda$$

Has over 40 years experience in EB-PVD for R&D as well as for the equipment design and manufacturing.

Our customers:

- Pratt & Whitney;
- General Electric;
- Rolls-Royce;
- Other USA, Russian, Canadian, Chinese and Indian universities, companies and laboratories.

Facilities

$$D = {}^{2}\!/_{3}\,\frac{d}{f} \approx \Lambda$$



- For express chemical analysis of all consumed materials, condensates and coatings: X-ray fluorescence unit "Philips-X-Unique II»;

- For the metallographic studies: Optical metallography: "PolyvarMet" (Austria) microscope/microhardness measurement; scanning and transmission electron microscopes (UK and Japan);

- For chemical element distribution analysis: microprobe: "Camebax" and "Link" (UK);

- For furnace cyclic test: automatic Rapid Temperature Furnace CM (USA) for test in temperature range from 20 to 1700 °C;

- For extended static oxidation test: automatic "Labotherm" (Germany) furnace with a maximum operating temperature of 1300 °C;

- For investigation of kinetic oxidation: "Perkin-Elmer" TGA-7 (USA) thermal-gravimetric.



$$D = 2/3 \frac{d}{f} \approx \Lambda$$

Thank you very much for your attention !

Please, you can find more detailed information: http://www.paton-icebt.kiev.ua

✉ 03150, Kyiv-150, Gorky str., 68 Phone/Fax (044) 287-3166
E-mail: yakovchuk@paton-icebt.kiev.ua