

ELECTRON BEAM PHYSICAL VAPOR DEPOSITION APPARATUS AND
CONTROL PANEL THEREFOR

This application claims benefit of Provisional
Patent Application No. 60/147,229, filed August 4, 1999.

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application is related to co-pending
United States patent application Serial No. [Attorney
Docket No. 13DV-13041], the contents of which are
incorporated herein by reference.

FIELD OF THE INVENTION

10 This invention generally relates to an electron
beam physical vapor deposition (EBPVD) coating apparatus.
More particularly, this invention is directed to such a
coating apparatus equipped with a control panel that
enables information regarding the operating status of an
EBPVD coating apparatus to be quickly and accurately
15 noted, and allows the operator to make appropriate manual
changes or adjustments to the apparatus and the coating
process.

BACKGROUND OF THE INVENTION

20 Thermal barrier coatings (TBC) have found wide
use for thermally insulating the exterior surfaces of
high-temperature gas turbine components in order to
minimize the service temperatures of such components.
Various ceramic materials have been employed as the TBC,
particularly zirconia (ZrO_2) stabilized by yttria (Y_2O_3),
magnesia (MgO) or other oxides. These particular
materials are widely employed in the art because they can
25 be readily deposited by plasma spray and vapor deposition
techniques. An example of the latter is electron beam
physical vapor deposition (EBPVD), which produces a

thermal barrier coating having a columnar grain structure that is able to expand with its underlying substrate without causing damaging stresses that lead to spallation, and therefore exhibits enhanced strain tolerance.

Processes for producing TBC by EBPVD generally entail preheating a component to an acceptable coating temperature, and then inserting the component into a heated coating chamber maintained at a low pressure, typically about 0.005 mbar. The component is supported in proximity to an ingot of the ceramic coating material (e.g., YSZ), and an electron beam is projected onto the ingot so as to melt the surface of the ingot and produce a vapor of the coating material that deposits onto the component. The temperature range within which EBPVD processes can be performed depends in part on the compositions of the component and the coating material. A minimum process temperature is generally established to ensure the coating material will suitably evaporate and deposit on the component, while a maximum process temperature is generally established to avoid microstructural damage to the article. Despite the use of fluid-cooled components, the temperature within the coating chamber continues to rise throughout the deposition process as a result of the intense heat from the electron beam and the molten pool of coating material. As a result, EBPVD coating processes are often initiated near the targeted minimum process temperature and then terminated when the coating chamber nears the maximum process temperature. Advanced EBPVD apparatuses enable coated components to be removed from the coating chamber and replaced with preheated uncoated components without shutting down the apparatus, so that a continuous operation is achieved. The continuous operation of the apparatus during this time can be termed a "campaign,"

with greater numbers of components successfully coated during the campaign corresponding to greater processing and economic efficiencies.

5 In view of the above, it can be seen that the proper operation of an EBPVD apparatus is complicated by the relatively narrow range of acceptable coating temperatures and low pressures, the complexity of moving extremely hot components into and out of evacuated chambers, and various other difficulties confronted when
10 operating and maintaining an advanced EBPVD apparatus. Accordingly, improved operation and control of EBPVD apparatuses are continuously sought.

BRIEF SUMMARY OF THE INVENTION

The present invention is an electron beam physical vapor deposition (EBPVD) apparatus for producing
15 a coating (e.g., a ceramic thermal barrier coating) on an article. The EBPVD apparatus of this invention generally includes a coating chamber that is operable at an elevated temperature (e.g., at least 800°C) and a subatmospheric pressure (e.g., between 10^{-3} mbar and 5×10^{-2}
20 mbar). An electron beam (EB) gun is used to project an electron beam into the coating chamber and onto a coating material within the chamber. The EB gun is operated to melt and evaporate the coating material.

According to the present invention, the
25 operation of the EBPVD apparatus can be enhanced through the use of a control panel by which certain components of the apparatus can be monitored and controlled. The control panel includes a schematic of at least a portion of the apparatus and its components, with indicia of the
30 components, visual indicators associated with the indicia for indicating the operating status of the components, and controls associated with the indicia and adjacent the

visual indicators for changing the operation of the corresponding component of the EBPVD apparatus. Examples of components that are preferably monitored and controlled with the panel include the EB gun and those components that determine the vacuum levels and coolant flows through the EBPVD apparatus. With the control panel, the operation of the EBPVD apparatus can be more closely monitored and controlled by an operator, thereby improving the overall coating process.

Other objects and advantages of this invention will be better appreciated from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 and 2 are schematic top and front views, respectively, of an electron beam physical vapor deposition apparatus.

Figure 3 shows a control panel for monitoring and controlling the operation of the apparatus of Figures 1 and 2.

DETAILED DESCRIPTION OF THE INVENTION

An EBPVD apparatus 10 in accordance with this invention is generally depicted in Figures 1 and 2. With the apparatus 10, a ceramic thermal barrier coating can be deposited on a metal component intended for operation within a thermally hostile environment. Notable examples of such components include the high and low pressure turbine nozzles and blades, shrouds, combustor liners and augmentor hardware of gas turbine engines.

For purposes of illustrating the invention, the EBPVD apparatus 10 is shown in Figures 1 and 2 as including a coating chamber 12, preheat chambers 14, and

two pairs of loading chambers 16 and 18, so that the apparatus 10 has a symmetrical configuration. The loading chambers 16 are shown as being aligned with their respective preheat chambers 14, with parts 20 originally loaded on rakes 22 within the chambers 16 having been transferred to the preheat chambers 14 and, as depicted in Figure 1, into the coating chamber 12. Ingots 26 of the desired coating material are shown as being loaded in channels 104 of a magazine 102, and then fed into the coating chamber 12 from beneath the coating chamber 12.

The loading chambers 16 and 18 are shown mounted on low-profile movable platforms 24, so that paired loading chambers 16 and 18 can be selectively aligned with the preheat chamber 14. For example, when the front lefthand loading chamber 16 is brought into alignment with the lefthand preheat chamber 14 to allow the parts 20 to be inserted into the coating chamber 12, the rear lefthand loading chamber 18 is set back from the lefthand preheat chamber 14, so that parts can be simultaneously loaded or unloaded from the rake 22 of the rear lefthand loading chamber 18. The platforms 24 are shown as being at least in part supported on roller bearings 44 mounted in the floor, though it is foreseeable that a variety of bearings could be used.

The loading chambers 16 and 18 are equipped with loading doors 40 through which parts are loaded onto the rakes 22. The loading chambers 16 and 18 are also equipped with access doors 42 to motion drives (schematically represented at 46 in Figure 1) that control the operation of the rakes 22. More particularly, the parts 20 supported on the rakes 22 are preferably rotated and/or oscillated within the coating chamber 12 in order to promote the desired coating distribution around the parts 20. The access doors 42

allow the operator of the apparatus 10 to quickly adjust or change the settings of the motion drives 46 without interfering with loading and unloading of parts from the loading chambers 16 and 18.

5 Coating is performed within the coating chamber 12 by melting and evaporating the ingots 26 with electron beams produced by electron beam (EB) guns 30 mounted on the coating chamber 12. Intense heating of the ceramic material by the electron beams causes the surface of each
10 ingot 26 to melt, forming molten ceramic pools from which molecules of the ceramic material evaporate, travel upwardly, and then deposit on the surfaces of the parts 20, producing the desired ceramic coating whose thickness will depend on the duration of the coating process.
15 Because the length of a coating campaign is limited in part by the maximum process temperature that can be withstood by parts 20 and those components of the apparatus 10 that form or are within the coating chamber 12, the walls and certain other components of the coating
20 chamber 12, including crucibles used to contain the molten coating material, are often fluid-cooled to minimize the rate at which the temperature within the coating chamber 12 rises during a coating campaign.

 The pressure within the coating chamber 12 is
25 controlled by the rate at which gases can be pumped from the chamber 12, and the flow rate into the chamber 12 of desired gases, such as oxygen and argon. In Figure 2, gases are shown as being introduced into the coating chamber 12 through a valve 58 located near the coating
30 chamber 12. The flow rates of the gases are individually controlled based on the targeted process pressure and oxygen partial pressure. After rough pumpdown with mechanical pumps 31, cryogenic and diffusion pumps 32 and 34 of types known in the art can be employed to evacuate

the coating chamber 12 prior to and during the deposition process. A pair of diffusion pumps 38 are shown as being employed to evacuate the preheat chambers 14. As shown in Figure 1, the diffusion pump 34 for the coating chamber 12 may be modified with a throttle valve 36 to regulate the operation of the pump 34 at relatively high pressures, e.g., above 0.010 mbar.

From the above, it can be appreciated that various parameters and equipment must be closely controlled during the operation of the apparatus 10. Shown in Figure 3 is a portion of a preferred control panel 118 for controlling and monitoring EBPVD apparatuses of the type shown in Figures 1 and 2. The control panel 118 is shown as including a schematic of a portion of the EBPVD apparatus 10 and its support systems, including indicia 120 for individual components and systems. In the schematic, visual readouts 122 are located adjacent the indicia 120 for indicating the operating status of the components represented by the indicia. In addition, controls 124 are included within the schematic by which the operation of the corresponding components can be adjusted based on the status indicated by the readouts 122.

With the panel 118 shown in Figure 3, information regarding the operating status of the EBPVD apparatus 10 can be quickly and accurately noted to allow the operator to make any appropriate adjustments to the apparatus 10 and the coating process. Examples of components that are of particular interest for monitoring and controlling with the panel 118 include the EB guns 30, those components that indicate and control the vacuum levels within the coating chamber 12, such as the pumps 32 and 34 and the gas valve 58, and those components that indicate and control the cooling flows through the EBPVD

apparatus. Readouts 122 in the form of actuation lights preferably indicate the operating status of the EB guns 30. The locations of the parts 20 within the chambers 12, 14 and 16 are also preferably indicated with
5 actuation lights to allow manual control with switches 124. Similarly, actuation lights and switches 124 are preferably provided to indicate and control the positions of the valves that set cooling flows and the positions of the valves that control evacuation of the chambers 12, 14
10 and 16 with the mechanical pumps, cryogenic pump 32, and diffusion pumps 34 and 38. By incorporating both the readouts 122 and controls 124 within the schematic, relatively novice operators are more readily able to identify that operating status of specific components,
15 and what if any adjustments should be made, based on a visual association between the apparatus 10 and the schematic representing the apparatus 10 on the panel 118.

While our invention has been described in terms of a preferred embodiment, it is apparent that other
20 forms could be adopted by one skilled in the art. Accordingly, the scope of our invention is to be limited only by the following claims.



WHAT IS CLAIMED IS:

1. An electron beam physical vapor deposition coating apparatus (10) having a control panel (118) for controlling and monitoring the electron beam physical vapor deposition coating apparatus (10), the control panel (118) comprising:

a schematic of at least a portion of the electron beam physical vapor deposition coating apparatus (10) and components thereof, the schematic including indicia (120) representing at least some of the components of the electron beam physical vapor deposition coating apparatus (10);

visual readouts (122) located on the schematic adjacent the indicia (120) of the components, each of the visual readouts (122) indicating the operating status of the component represented by the indicia (120) adjacent to the visual readout (122); and

controls (124) located on the schematic adjacent the indicia (120) of the components and adjacent the visual readouts (122), each of the controls (124) being operable to adjust the operation of the component represented by the indicia (120) adjacent to the control (124).

2. An electron beam physical vapor deposition coating apparatus (10) comprising:

a coating chamber (12) operable at an elevated temperature and a subatmospheric pressure;

an electron beam gun (30) for projecting an electron beam (28) into the coating chamber (12); and

a control panel (118) for controlling and monitoring the electron beam physical vapor deposition coating apparatus (10), the control panel (118) comprising:



a schematic of at least a portion of the electron beam physical vapor deposition coating apparatus (10) and components thereof, the schematic including indicia (120) of at least some of the components of the electron beam physical vapor deposition coating apparatus (10);

visual readouts (122) located on the schematic adjacent the indicia (120) of the components, each of the visual readouts (122) indicating the operating status of the component represented by the indicia (120) adjacent to the visual readout (122); and

controls (124) located on the schematic adjacent the indicia (120) of the components and adjacent the visual readouts (122), each of the controls (124) being operable to adjust the operation of the component represented by the indicia (120) adjacent to the control (124).

3. An electron beam physical vapor deposition coating apparatus (10) comprising:

a coating chamber (12) containing a coating material (26), the coating chamber (12) operating at an elevated temperature and a subatmospheric pressure;

an electron beam gun (30) projecting an electron beam (28) into the coating chamber (12) and onto the coating material (26), the electron beam gun (30) melting the coating material (26) and evaporating molten coating material (26);

support means (22) supporting an article (20) in the coating chamber (12) so that vapors of the coating material (26) deposit on the article (20);

means (34) for maintaining the subatmospheric pressure within the coating chamber (12);

means for determining the elevated temperature within the coating chamber (12); and



a control panel (118) for monitoring and controlling at least the electron beam gun (30), the maintaining means (34) and the determining means, the control panel (118) comprising:

5 a schematic of the electron beam physical vapor deposition coating apparatus (10) and components thereof, the schematic including indicia (120) of at least the electron beam gun (30), the maintaining means (34) and the determining means;

10 visual readouts (122) located on the schematic adjacent the indicia (120) of at least the electron beam gun (30), the maintaining means (34) and the determining means, the visual readouts (122) indicating the operating status of at least the electron
15 beam gun (30), the maintaining means (34) and the determining means represented by the indicia (120); and

controls (124) located on the schematic adjacent the indicia (120) and the visual readouts (122), the controls (124) being operable to adjust the operation
20 of at least the electron beam gun (30), the maintaining means (34) and the determining means represented by the indicia (120) adjacent to the control (124).