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(54) **ENVIRONMENTAL BARRIER COATING**

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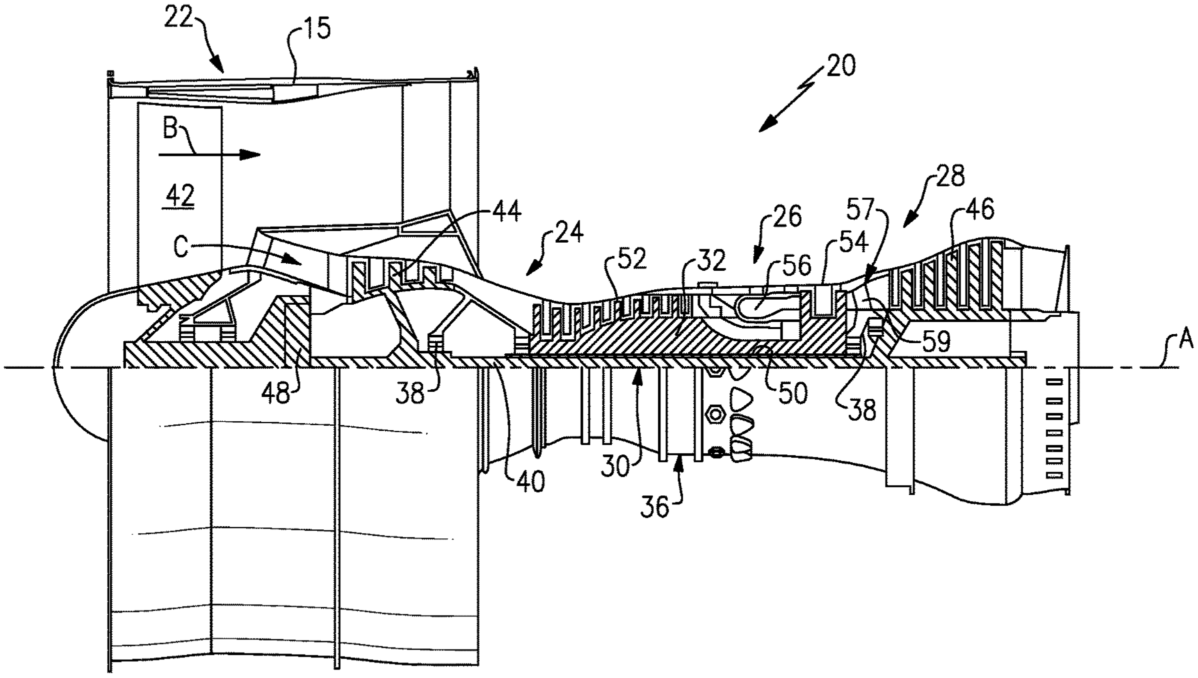
(57) **ABSTRACT**

An article according to an exemplary embodiment of this disclosure, among other possible things includes a substrate and a barrier layer on the substrate. The barrier layer includes a bond coat comprising a matrix, diffusive particles disposed in the matrix, and gettering particles disposed in the matrix; and a topcoat including a constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS). An article and a method applying a calcium-magnesium-alumino-silicate (CMAS)-resistant topcoat are also disclosed.



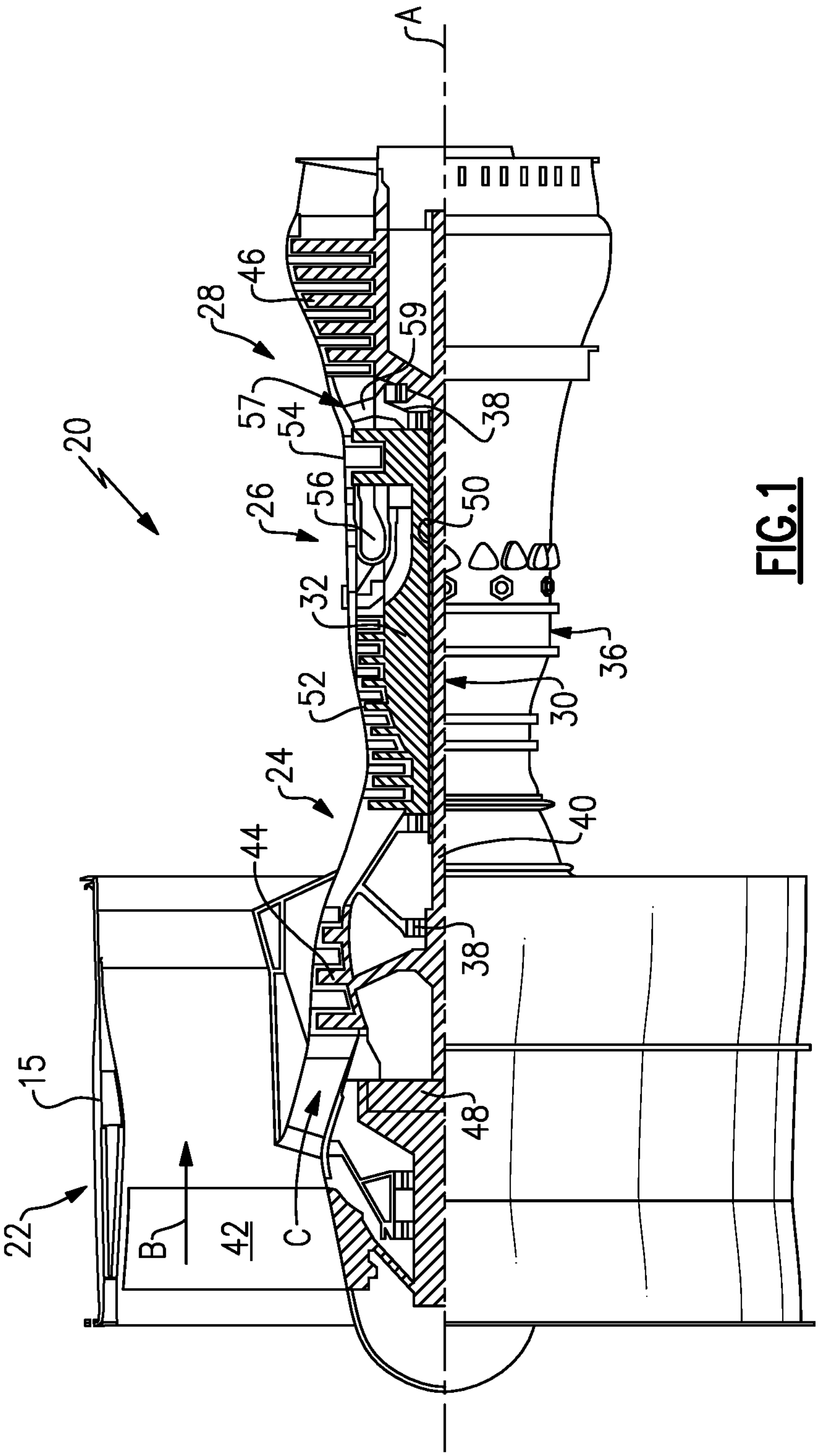


FIG.1

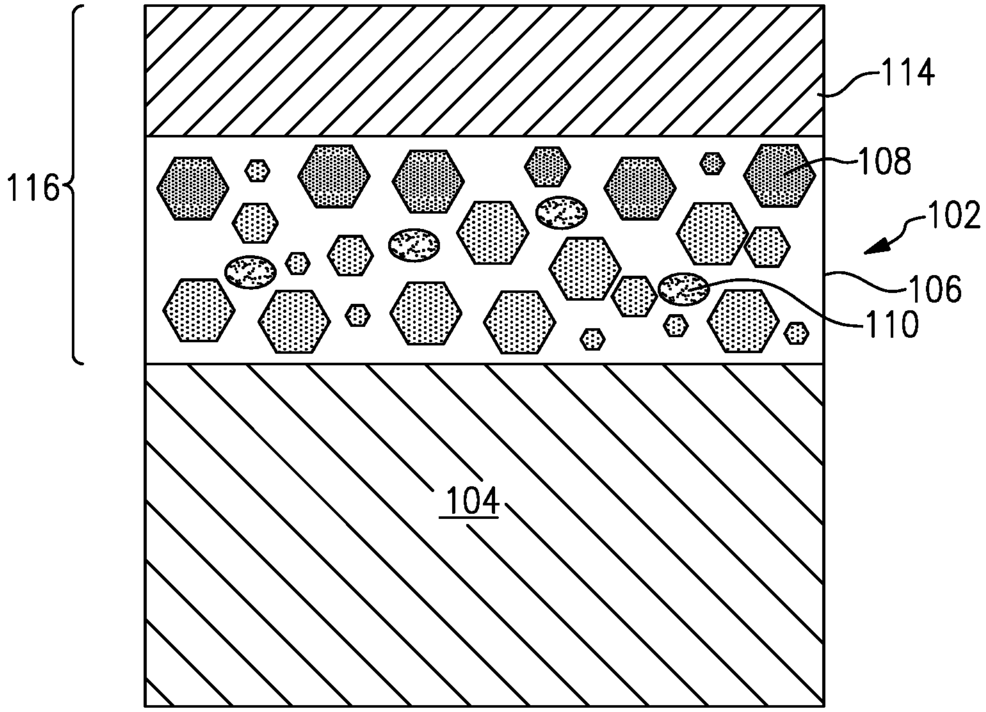


FIG.2

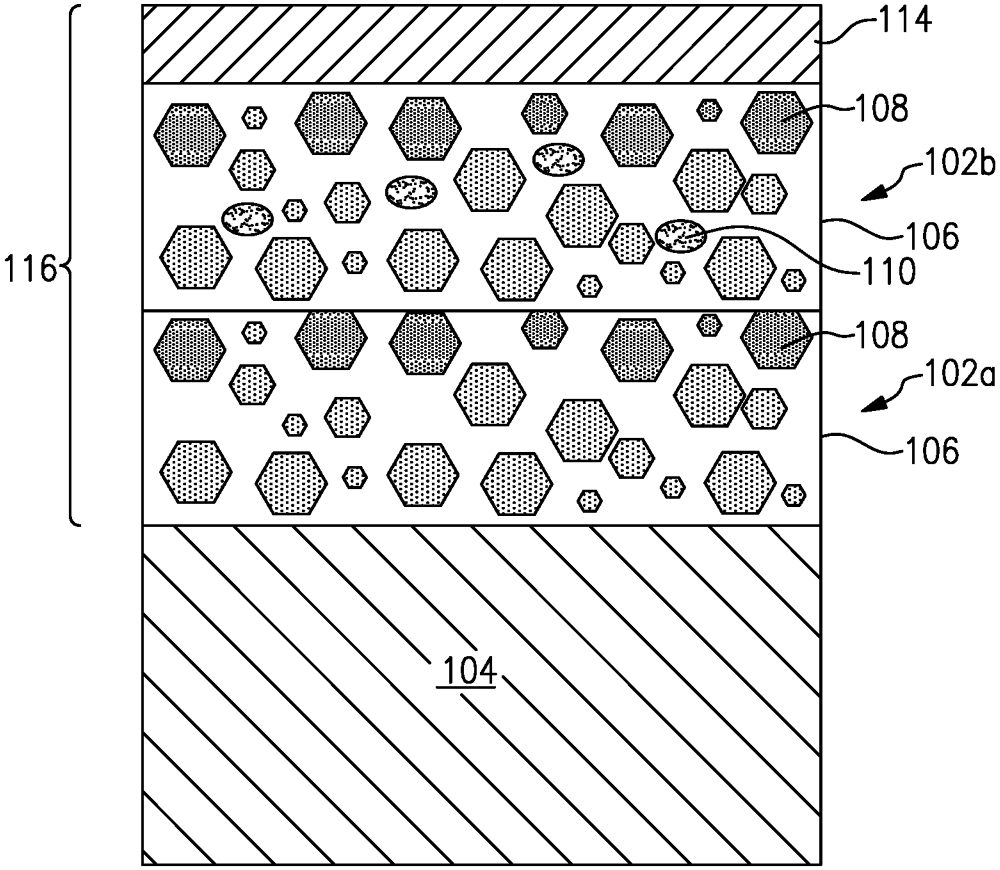


FIG.3

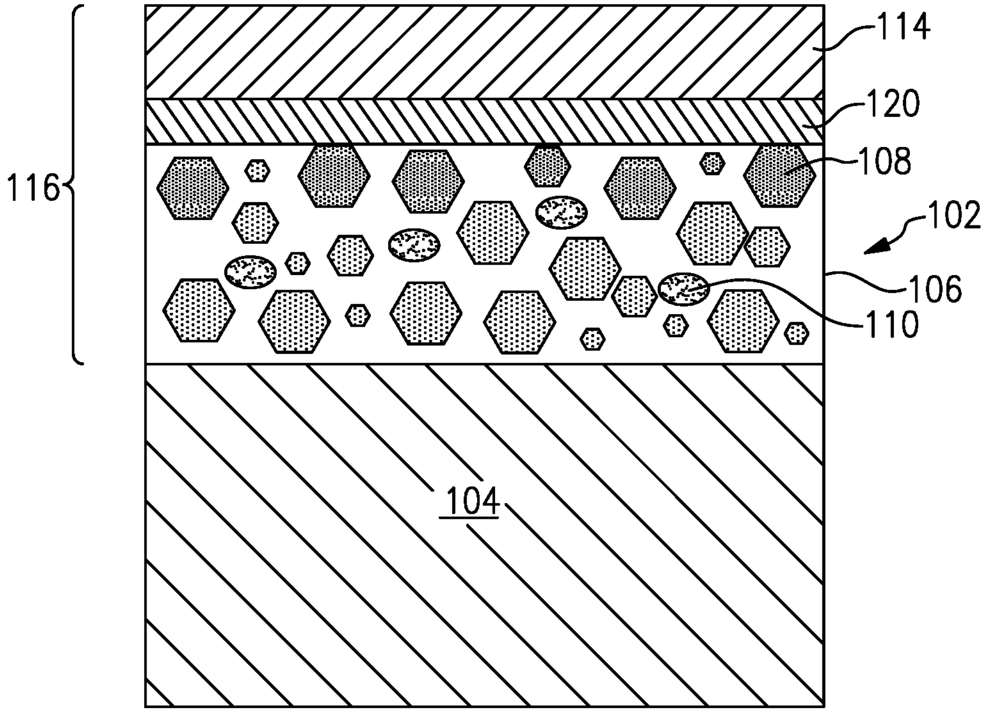


FIG.4

ENVIRONMENTAL BARRIER COATING

BACKGROUND

[0001] A gas turbine engine typically includes a fan section, a compressor section, a combustor section and a turbine section. Air entering the compressor section is compressed and delivered into the combustion section where it is mixed with fuel and ignited to generate a high-energy exhaust gas flow. The high-energy exhaust gas flow expands through the turbine section to drive the compressor and the fan section. The compressor section typically includes low and high pressure compressors, and the turbine section includes low and high pressure turbines.

[0002] This disclosure relates to composite articles, such as those used in gas turbine engines, and methods of coating such articles. Components, such as gas turbine engine components, may be subjected to high temperatures, corrosive and oxidative conditions, and elevated stress levels. In order to improve the thermal and/or oxidative stability, the component may include a protective barrier coating.

SUMMARY

[0003] An article according to an exemplary embodiment of this disclosure, among other possible things includes a substrate and a barrier layer on the substrate. The barrier layer includes a bond coat comprising a matrix, diffusive particles disposed in the matrix, and gettering particles disposed in the matrix; and a topcoat including a constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

[0004] In a further example of the foregoing, the bond coat comprises a first bond coat layer adjacent the substrate and a second bond coat layer adjacent the top coat.

[0005] In a further example of any of the foregoing, each of the first and second layers include between about 5 and about 40 percent by volume matrix.

[0006] In a further example of any of the foregoing, the second layer includes between about 55 and 94 percent by volume gettering particles.

[0007] In a further example of any of the foregoing, the first layer includes between about 60 and about 95 percent by volume gettering particles.

[0008] In a further example of any of the foregoing, the second layer includes gettering particles having an average maximum dimension between about 1 and about 75 microns.

[0009] In a further example of any of the foregoing, the gettering particles in the second layer have a larger average diameter than the gettering particles in the first layer.

[0010] In a further example of any of the foregoing, the gettering particles are silicon carbide or silicon oxycarbide.

[0011] In a further example of any of the foregoing, the topcoat includes an interlayer adjacent the bondcoat that is free from the constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

[0012] In a further example of any of the foregoing, the constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS) includes titanium or cerium.

[0013] In a further example of any of the foregoing, the bond coat includes a sintering aid.

[0014] In a further example of any of the foregoing, the topcoat includes between about 2 and about 30 by weight constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

[0015] An article according to an exemplary embodiment of this disclosure, among other possible things includes a ceramic matrix composite substrate and a barrier layer on the substrate. The barrier layer includes a bond coat comprising a silicone dioxide matrix, diffusive particles disposed in the matrix, and silicon carbide or silicon oxycarbide gettering particles disposed in the matrix; and a topcoat including a constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

[0016] In a further example of the foregoing, the bond coat comprises a first bond coat layer adjacent the substrate and a second bond coat layer adjacent the top coat.

[0017] In a further example of any of the foregoing, the second layer includes gettering particles having an average maximum dimension between about 1 and about 75 microns. The gettering particles in the second layer have a larger average diameter than the gettering particles in the first layer.

[0018] In a further example of any of the foregoing, the constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS) includes titanium or cerium.

[0019] In a further example of any of the foregoing, the bond coat includes a sintering aid.

[0020] In a further example of any of the foregoing, the topcoat includes between about 2 and about 30 by weight constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

[0021] A method applying a calcium-magnesium-alumino-silicate (CMAS)-resistant topcoat according to an exemplary embodiment of this disclosure, among other possible things includes depositing a topcoat onto a bondcoat by thermal spray. A feedstock powder for the thermal spray includes between about 70 and 98% by weight topcoat material powder and the balance of CMAS-reactive constituent or precursor to CMAS-reactive constituent.

[0022] In a further example of the foregoing, the precursor to CMAS-reactive constituent is HfTiO4 or HfO2—CeO2.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. **1** is a schematic view of an example gas turbine engine.

[0024] FIG. **2** illustrates an article for the gas turbine engine with a coating.

[0025] FIG. **3** schematically illustrates another article for the gas turbine engine with another example coating.

[0026] FIG. **4** schematically illustrates another article for the gas turbine engine with another example coating.

DETAILED DESCRIPTION

[0027] FIG. **1** schematically illustrates a gas turbine engine **20**. The gas turbine engine **20** is disclosed herein as a two-spool turbofan that generally incorporates a fan section **22**, a compressor section **24**, a combustor section **26** and a turbine section **28**. The fan section **22** drives air along a bypass flow path B in a bypass duct defined within a housing **15** such as a fan case or nacelle, and also drives air along a core flow path C for compression and communication into the combustor section **26** then expansion through the turbine section **28**. Although depicted as a two-spool turbofan gas turbine engine in the disclosed non-limiting embodiment, it should be understood that the concepts described herein are not limited to use with two-spool turbofans as the teachings may be applied to other types of turbine engines including three-spool architectures.

[0028] The exemplary engine **20** generally includes a low speed spool **30** and a high speed spool **32** mounted for rotation about an engine central longitudinal axis A relative to an engine static structure **36** via several bearing systems **38**. It should be understood that various bearing systems **38** at various locations may alternatively or additionally be provided, and the location of bearing systems **38** may be varied as appropriate to the application.

[0029] The low speed spool **30** generally includes an inner shaft **40** that interconnects, a first (or low) pressure compressor **44** and a first (or low) pressure turbine **46**. The inner shaft **40** is connected to the fan **42** through a speed change mechanism, which in exemplary gas turbine engine **20** is illustrated as a geared architecture **48** to drive a fan **42** at a lower speed than the low speed spool **30**. The high speed spool **32** includes an outer shaft **50** that interconnects a second (or high) pressure compressor **52** and a second (or high) pressure turbine **54**. A combustor **56** is arranged in the exemplary gas turbine **20** between the high pressure compressor **52** and the high pressure turbine **54**. A mid-turbine frame **57** of the engine static structure **36** may be arranged generally between the high pressure turbine **54** and the low pressure turbine **46**. The mid-turbine frame **57** further supports bearing systems **38** in the turbine section **28**. The inner shaft **40** and the outer shaft **50** are concentric and rotate via bearing systems **38** about the engine central longitudinal axis A which is collinear with their longitudinal axes.

[0030] The core airflow is compressed by the low pressure compressor **44** then the high pressure compressor **52**, mixed and burned with fuel in the combustor **56**, then expanded through the high pressure turbine **54** and low pressure turbine **46**. The mid-turbine frame **57** includes airfoils **59** which are in the core airflow path C. The turbines **46**, **54** rotationally drive the respective low speed spool **30** and high speed spool **32** in response to the expansion. It will be appreciated that each of the positions of the fan section **22**, compressor section **24**, combustor section **26**, turbine section **28**, and fan drive gear system **48** may be varied. For example, gear system **48** may be located aft of the low pressure compressor, or aft of the combustor section **26** or even aft of turbine section **28**, and fan **42** may be positioned forward or aft of the location of gear system **48**.

[0031] The engine **20** in one example is a high-bypass geared aircraft engine. In a further example, the engine **20** bypass ratio is greater than about six (6), with an example embodiment being greater than about ten (10), and can be less than or equal to about 18.0, or more narrowly can be less than or equal to 16.0. The geared architecture **48** is an epicyclic gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3. The gear reduction ratio may be less than or equal to 4.0. The low pressure turbine **46** has a pressure ratio that is greater than about five. The low pressure turbine pressure ratio can be less than or equal to 13.0, or more narrowly less than or equal to 12.0. In one disclosed embodiment, the engine **20** bypass ratio is greater than about ten (10:1), the fan diameter is significantly larger than that of the low pressure compressor **44**, and the low pressure turbine **46** has a pressure ratio that is greater than about five 5:1. Low pressure turbine **46** pressure ratio is pressure measured prior to an inlet of low pressure turbine **46** as related to the pressure at the outlet of the low pressure turbine **46** prior to an exhaust nozzle. The geared architecture **48** may be an epicycle gear train, such as a planetary gear system or other gear system, with a gear reduction ratio of greater than about 2.3:1 and less than about 5:1. It should be understood, however, that the above parameters are only exemplary of one embodiment of a geared architecture engine and that the present invention is applicable to other gas turbine engines including direct drive turbofans.

[0032] A significant amount of thrust is provided by the bypass flow B due to the high bypass ratio. The fan section **22** of the engine **20** is designed for a particular flight condition—typically cruise at about 0.8 Mach and about 35,000 feet (10,668 meters). The flight condition of 0.8 Mach and 35,000 ft (10,668 meters), with the engine at its best fuel consumption—also known as "bucket cruise Thrust Specific Fuel Consumption ('TSFC')"—is the industry standard parameter of lbm of fuel being burned divided by lbf of thrust the engine produces at that minimum point. The engine parameters described above and those in this paragraph are measured at this condition unless otherwise specified. "Low fan pressure ratio" is the pressure ratio across the fan blade alone, without a Fan Exit Guide Vane ("FEGV") system. The low fan pressure ratio as disclosed herein according to one non-limiting embodiment is less than about 1.45, or more narrowly greater than or equal to 1.25. "Low corrected fan tip speed" is the actual fan tip speed in ft/sec divided by an industry standard temperature correction of $[(\text{Tram } ° \text{ R})/(518.7° \text{ R})]^{0.5}$. The "Low corrected fan tip speed" as disclosed herein according to one non-limiting embodiment is less than about 1150.0 ft/second (350.5 meters/second), and can be greater than or equal to 1000.0 ft/second (304.8 meters/second).

[0033] FIG. **2** schematically illustrates a representative portion of an example article **100** for the gas turbine engine **20** that includes a composite material bond coat **102** that acts as a barrier layer. The article **100** can be, for example, an airfoil in the compressor section **24** or turbine section **28**, a combustor liner panel in the combustor section **26**, a blade outer air seal, or other component that would benefit from the examples herein. In this example, the bond coat **102** is used as an environmental barrier layer to protect an underlying substrate **104** from environmental conditions, as well as thermal conditions. As will be appreciated, the bond coat **102** can be used as a stand-alone barrier layer, as an outermost/top coat with additional underlying layers, or in combination with other coating under- or over-layers, such as, but not limited to, ceramic-based topcoats.

[0034] The bond coat **102** includes a matrix **106**, a dispersion of "gettering" particles **108**, and a dispersion of diffusive particles **110**. The matrix **106** may be silicon dioxide (SiO_2), in one example. In one example, the gettering particles **108** are silicon oxycarbide particles (SiOC) or silicide particles such as molybdenum disilicide ($MoSi_2$) particles **108**, though other examples are contemplated. The gettering particles **108** could be, for instance, molybdenum disilicide particles, tungsten disilicide particles, vanadium disilicide particles, niobium disilicide particles, silicon oxycarbide particles, silicon carbide (SiC) particles, silicon nitride (Si_3N_4) particles, silicon oxycarbonitride (SiOCN) particles, silicon aluminum oxynitride (SiAlON) particles, silicon boron oxycarbonitride (SiBOCN) particles, or combinations thereof. The diffusive particles **110** could be, for instance, barium magnesium alumino-silicate (BMAS) particles, barium strontium aluminum silicate particles, magnesium silicate particles, calcium aluminosilicate particles (CAS), alkaline earth aluminum silicate particles, yttrium aluminum silicate particles, ytterbium aluminum silicate particles, other rare earth metal aluminum silicate particles, or combinations thereof.

[0035] The bond coat **102** protects the underlying substrate **104** from oxygen and moisture. For example, the substrate **104** can be a ceramic-based substrate, such as a silicon-containing ceramic material. One example is silicon carbide. Another non-limiting example is silicon nitride. Ceramic matrix composite (CMC) substrates **104** such as silicon carbide fibers in a silicon carbide matrix are also contemplated. These CMC substrates can be formed by melt infiltration, chemical vapor infiltration (CVI), polymer infiltration and pyrolysis (PIP), particulate infiltration, or any other known method.

[0036] The gettering particles **108** and the diffusive particles **110** function as an oxygen and moisture diffusion barrier to limit the exposure of the underlying substrate **104** to oxygen and/or moisture from the surrounding environment. Without being bound by any particular theory, the diffusive particles **110**, such as BMAS particles **110**, enhance oxidation and moisture protection by diffusing to the outer surface of the barrier layer opposite of the substrate **104** and forming a sealing layer that seals the underlying substrate **104** from oxygen/moisture exposure. Additionally, cationic metal species of the diffusive particles **110** (for instance, for BMAS particles, barium, magnesium, and aluminum) can diffuse into the gettering particles **108** to enhance oxidation stability of the gettering material. Further, the diffusion behavior of the diffusive particles **110** may operate to seal any microcracks that could form in the barrier layer. Sealing the micro-cracks could prevent oxygen from infiltrating the barrier layer, which further enhances the oxidation resistance of the barrier layer. The gettering particles **108** can react with oxidant species, such as oxygen or water that could diffuse into the bond coat **102**. In this way, the gettering particles **108** could reduce the likelihood of those oxidant species reaching and oxidizing the substrate **104**.

[0037] The bond coat **102** can be applied by any known method, such as a slurry coating method.

[0038] The bond coat **102** may include sintering aid such as silica, alkaline earth aluminosilicates, rare earth aluminosilicates, borosilicates, or combinations thereof.

[0039] A ceramic-based top coat **114** is interfaced directly with the bond coat **102**. As an example, the ceramic-based top coat **114** can include one or more layers of an oxide-based material. The oxide-based material can be, for instance, hafnium-based oxides, zirconium-based oxides, or yttrium-based oxides (such as hafnia, hafnium silicate, yttrium silicates, yttria stabilized zirconia or gadolinia stabilized zirconia), calcium aluminosilicates, mullite, barium strontium aluminosilicate, or combinations thereof, but is not limited to such oxides. The topcoat **114** can be applied by any known method such as thermal spray (like air plasma spray) methods or slurry application methods. The topcoat **114** can be between about 2 and about 8 mils (50.8 and 203.2 microns) thick, in some examples.

[0040] The top coat **114** and bond coat **102** together form a barrier coating **116** for the substrate **104**. The top coat **114** is the outermost layer of the barrier coating **116**, and is exposed to the elements when the article **100** is in use.

[0041] Components in engine **20** such as the article **100** can be susceptible to attack by silicate-based deposits such as calcium-magnesium-alumino-silicate (CMAS) that can deposit on the surface of the article **100**. During operation of the engine **20**, silicate-based debris (e.g., sand, ash, dirt, etc.) can melt to component surfaces and subsequently form CMAS. The CMAS deposits can be molten at times, and can react with and/or wick into the article **100** or coatings on the component, which can cause damage the article/coating. As will be discussed below, the durability of these engine **20** components can be increased by including coatings which have CMAS-resistant components that can reduce the activity of CMAS. For example, the CMAS-resistant components can include one or more constituents that are reactive with respect to CMAS to form a compound that seals the surface of the article/coating in a process known an "reactive crystallization."

[0042] Accordingly, the topcoat **114** is provided with constituents that are reactive with CMAS to induce reactive crystallization, thereby providing a CMAS-resistant topcoat **114**. Oxides containing cerium (Ce) (such as ceria (CeO_2)) and titanium (Ti) (such as titania (TiO_2)) are two example constituents that are reactive with CMAS. Any of the example topcoat **114** materials discussed above can be co-deposited with constituents that are reactive with CMAS or precursors to constituents that are reactive with CMAS. Co-deposition can be achieved by any known method. For instance, where the topcoat **114** is applied by a thermal spray method such as air plasma spray, the desired constituents of the topcoat **114** can be co-sprayed. Where the topcoat **114** is applied by a slurry method, the desired constituents can be added to the slurry and deposited by any known method.

[0043] In a particular example, titania (TiO_2) and/or ceria (CeO_2) are co-deposited with topcoat **114** material. During or after the deposition, the titania and/or ceria react with the topcoat **114** material to form titanate-silicates and/or cerate-silicates. For instance, where the topcoat **114** materials is hafnium silicate ($HfSiO_4$), the hafnium silicate is co-deposited with TiO_2 and/or CeO_2 which react to provide $HfTi_xSi_yO_4$/$HfCe_xSi_yO_4$, respectively, in the topcoat **114** during or after the deposition, where x=0 to 4 and y=0 to 4 and the sum of y and x is 4.

[0044] In another example, hafnium titanate ($HfTiO_4$) and/or hafnium cerate ($HfCeO_4$) are co-deposited with topcoat **114** material. During or after the deposition, the titania and/or ceria react with the topcoat **114** material to form titanate-silicates and/or cerate-silicates. For instance, where the topcoat **114** material is hafnium silicate ($HfSiO_4$), the hafnium silicate is co-deposited with $HfTiO_4$ and/or $HfCeO_4$ which react to provide $HfTi_xSi_yO_4$/$HfCe_xSi_yO_4$, respectively, in the topcoat **114** during or after the deposition, where x=0 to 4 and y=0 to 4 and the sum of y and x is 4.

[0045] In another example, hafnium titanate-silicate ($HfTi_xSi_yO_4$) and/or hafnium cerate-silicate ($HfCe_xSi_yO_4$), where x=0 to 4 and y=0 to 4 and the sum of y and x is 4, are co-deposited with topcoat **114** material. During or after the deposition, the titania and/or ceria react with the topcoat **114** material to form different titanate-silicates and/or cerate-silicates. For instance, where the topcoat **114** materials is hafnium silicate ($HfSiO_4$), the hafnium silicate is co-deposited with $HfTiO_4$ and/or $HfCeO_4$ which react to provide

$HfTi_wSi_zO_4$/$HfCe_wSi_zO_4$, respectively, in the topcoat **114** during or after the deposition, where w=0 to 4 and z=0 to 4 and the sum of w and z is 4.

[0046] In one particular example barrier layer **116** shown in FIG. **3**, the bond coat **102** comprises two layers **102***a*/**102***b*. The first layer **102***a* is disposed on the substrate **104** and the second layer **102***b* is disposed on the first layer. The topcoat **114** is disposed on the second layer **102***b*. In this example, both layers **102***a*/**102***b* include between about 5 and about 40 percent by volume matrix **106** such as silicon dioxide. The first layer **102***a* includes between about 60 and about 95 percent by volume gettering particles **108** such as silicon carbide or silicon oxycarbide which have an average diameter between about 1 and 75 microns (0.04 and 2.9 mils). The second layer **102***b* includes between about 55 and 94 percent by volume gettering particles **108** such as silicon carbide or silicon oxycarbide which have an average diameter that is between about 1 and 45 microns (0.04 and 1.77 mils), and the balance diffusive particles **110**.

[0047] In a particular example, the gettering particles **108** in the second layer **102***b* have an average diameter higher than the average diameter of the gettering particles **108** in the first layer **102***a*. In general, smaller particles conform better to the adjoining surface, increasing adhesion of the particles to the surface. Smaller particles also exhibit improved packing and therefore provide a coating layer with lower porosity. Additionally, smaller particles have higher surface area-to-volume ratio, meaning there is a higher likelihood that oxidant particles in the barrier coating **116** will react with the gettering particle **108** than the substrate **104**, providing an additional layer of protection near the substrate **104**. On the other hand, larger gettering particles **108** have a longer lifetime in the barrier coating **116** because they have more matter that is available to react with oxidants and provide environmental protection as discussed above. Therefore, providing smaller gettering particles **108** in the first layer **102***a* improves adhesion of the first layer **102***a* to the substrate **104** and provides a relatively low porosity layer **102***a*, while providing larger gettering particles **108** in the second layer **102***b* improves the environmental protection and lifetime of the layer **102***b*, which is exterior to the first layer **102***a* and therefore more likely to encounter oxidant particles.

[0048] The topcoat **114** includes between about 2 and about 30% by weight CMAS-reactive constituent such as titania, ceria, hafnium titanates, hafnium cerates, hafnium titanate-silicates, and/or hafnium cerate-silicates.

[0049] In some examples, shown in FIG. **4**, the topcoat **114** includes a thin interlayer **120** of topcoat **114** material which is free from the CMAS-reactive constituent adjacent the bond coat **102**. CMAS may have similar chemical characteristics as the diffusive particles **110** and therefore the CMAS-reactive constituent may be reactive with the diffusive particles **110**. The interlayer **120** serves to minimize or prevent such reactions. In other examples, the topcoat **114** has a graded composition through its depth such that the CMAS-reactive constituent is concentrated at the exterior surface of the topcoat **114**.

[0050] In a particular example, the topcoat **114** is applied by thermal spray such as air plasma spray with a feedstock powder that includes between about 70 and about 98% by weight topcoat **114** material powder such as hafnium silicate powder. The feedstock also includes the balance of CMAS-reactive constituent or precursor to CMAS-reactive constituent such as $HfTiO_4$ and/or HfO2-CeO_2.

[0051] As used herein, the term “about” has the typical meaning in the art, however in a particular example “about” can mean deviations of up to 10% of the values described herein.

[0052] Although the different examples are illustrated as having specific components, the examples of this disclosure are not limited to those particular combinations. It is possible to use some of the components or features from any of the embodiments in combination with features or components from any of the other embodiments.

[0053] The foregoing description shall be interpreted as illustrative and not in any limiting sense. A worker of ordinary skill in the art would understand that certain modifications could come within the scope of this disclosure. For these reasons, the following claims should be studied to determine the true scope and content of this disclosure.

What is claimed is:

1. An article, comprising:

a substrate; and

a barrier layer on the substrate, the barrier layer including

a bond coat comprising a matrix, diffusive particles disposed in the matrix, and gettering particles disposed in the matrix, and

a topcoat including a constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

2. The article of claim **1**, wherein the bond coat comprises a first bond coat layer adjacent the substrate and a second bond coat layer adjacent the top coat.

3. The article of claim **2**, wherein each of the first and second layers include between about 5 and about 40 percent by volume matrix.

4. The article of claim **3**, wherein the second layer includes between about 55 and 94 percent by volume gettering particles.

5. The article of claim **3**, wherein the first layer includes between about 60 and about 95 percent by volume gettering particles.

6. The article of claim **2**, wherein the second layer includes gettering particles having an average maximum dimension between about 1 and about 75 microns.

7. The article of claim **6**, wherein the gettering particles in the second layer have a larger average diameter than the gettering particles in the first layer.

8. The article of claim **1**, wherein the gettering particles are silicon carbide or silicon oxycarbide.

9. The article of claim **1**, wherein the topcoat includes an interlayer adjacent the bondcoat that is free from the constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

10. The article of claim **1**, wherein the constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS) includes titanium or cerium.

11. The article of claim **1**, wherein the bond coat includes a sintering aid.

12. The article of claim **1**, wherein the topcoat includes between about 2 and about 30 by weight constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

13. An article, comprising:

a ceramic matrix composite substrate; and

a barrier layer on the substrate, the barrier layer including

a bond coat comprising a silicone dioxide matrix, diffusive particles disposed in the matrix, and silicon carbide or silicon oxycarbide gettering particles disposed in the matrix, and

a topcoat including a constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

14. The article of claim **13** wherein the bond coat comprises a first bond coat layer adjacent the substrate and a second bond coat layer adjacent the top coat.

15. The article of claim **14**, wherein the second layer includes gettering particles having an average maximum dimension between about 1 and about 75 microns, and wherein the gettering particles in the second layer have a larger average diameter than the gettering particles in the first layer.

16. The article of claim **13**, wherein the constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS) includes titanium or cerium.

17. The article of claim **13**, wherein the bond coat includes a sintering aid.

18. The article of claim **13**, wherein the topcoat includes between about 2 and about 30 by weight constituent that is reactive with calcium-magnesium-alumino-silicate (CMAS).

19. A method of applying a calcium-magnesium-alumino-silicate (CMAS)-resistant topcoat, comprising:

depositing a topcoat onto a bondcoat by thermal spray, wherein a feedstock powder for the thermal spray includes between about 70 and 98% by weight topcoat material powder and the balance of CMAS-reactive constituent or precursor to CMAS-reactive constituent.

20. The method of claim **19**, wherein the precursor to CMAS-reactive constituent is $HfTiO_4$ or HfO_2—CeO_2.

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