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Canadian Intellectual Property Office

CA 2938229 C 2024/04/02

(11)(21) **2 938 229**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(22) Date de dépôt/Filing Date: 2016/08/04

(41) Mise à la disp. pub./Open to Public Insp.: 2017/02/14

(45) Date de délivrance/Issue Date: 2024/04/02

(30) Priorité/Priority: 2015/08/14 (US14/826,765)

(51) Cl.Int./Int.Cl. *C04B 41/89* (2006.01)

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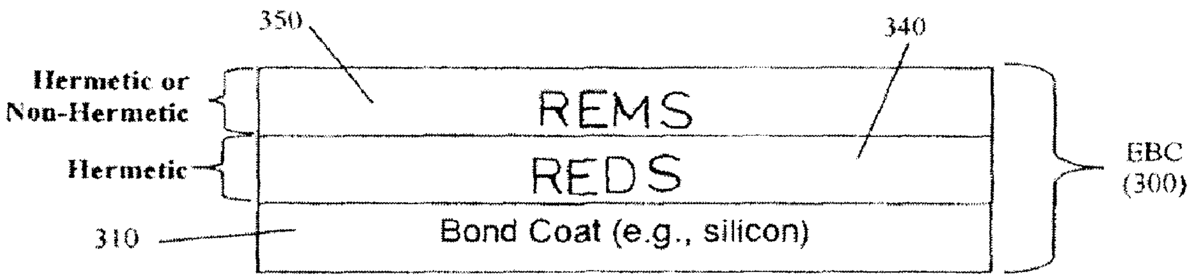
(54) Titre : REVETEMENTS PROTECTEURS ENVIRONNEMENTAUX RESISTANT AUX POUSSIERES CHAUDES
(54) Title: HOT DUST RESISTANT ENVIRONMENTAL BARRIER COATINGS



(57) Abrégé/Abstract:
An environmental barrier coating system for a component of a gas turbine includes at least one rare earth disilicate layer and at least one rare earth monosilicate layer. At least one of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer includes an alkaline earth oxide dopant.

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HOT DUST RESISTANT ENVIRONMENTAL BARRIER COATINGS

ABSTRACT

An environmental barrier coating system for a component of a gas turbine includes at least one rare earth disilicate layer and at least one rare earth monosilicate layer. At least one of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer includes an alkaline earth oxide dopant.

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HOT DUST RESISTANT ENVIRONMENTAL BARRIER COATINGS

BACKGROUND

[0001] The present technology relates to environmental barrier coatings, and more particularly to environmental barrier coatings that offer improved resistance to dust deposits.

[0002] Higher operating temperatures for gas turbine engines are continuously being sought in order to improve their efficiency. However, as operating temperatures increase, the high temperature durability of materials of manufacture of engine components must be maintained. Significant advances in high temperature capabilities of engine components have been achieved through improved formulation and processing of iron, nickel, and cobalt-based superalloys. While superalloys have found wide use for components in gas turbine engines, and especially in the higher temperature sections, alternative lighter-weight, higher-temperature component materials have been proposed.

[0003] Ceramic matrix composites (CMCs) are a class of materials that include a reinforcing material surrounded by a ceramic matrix phase. Such materials, along with certain monolithic ceramics (i.e. ceramic materials without a reinforcing material), are currently being used in a variety of high temperature applications. These ceramic materials are lightweight compared to superalloys, yet can still provide strength and durability to components made therefrom. Therefore, such materials are currently being considered for many gas turbine components used in higher temperature sections of gas turbine engines, such as airfoils (blades and vanes), combustor liners, shrouds and other similar components, that can benefit from the lighter-weight and higher temperature capability offered by these materials.

[0004] CMC's and monolithic ceramic components can be coated with environmental barrier coatings (EBCs) to protect them from the harsh environments of high temperature engine sections. EBCs can provide a dense, hermetic seal against the corrosive gases in the hot combustion environment, which can rapidly oxidize silicon-containing CMCs and monolithic ceramics. Additionally, silicon oxide is not stable in high temperature steam, but is converted to volatile (gaseous) silicon hydroxide species. Thus, EBCs can help prevent dimensional changes in the ceramic component due to such oxidation and volatilization processes.

[0005] Aircraft engines including CMC components are being operated in parts of the world where dust ingested with compressed air can deposit on the surfaces of hot stage CMC components and degrade the life of the EBCs. Hot gas path engine components can experience loss of performance resulting from intake and deposition of environmental particulate matter, especially during idling, takeoff, and landing. Accumulation of dust particles on the surfaces of gas turbine components can result in component overheating; in addition, molten dust deposits can react chemically with EBC's to cause EBC cracking and spallation, followed by undesirable exposure of the underlying CMC's to the engine environment. Dust deposition can thus reduce EBC durability and lead to premature degradation of CMC's and decreased component life. There is a requirement for improvements in composition and properties of EBC's to improve resistance to dust deposition.

SUMMARY

[0006] According to one example of the present technology, an environmental barrier coating system for a component of a gas turbine comprises at least one layer of rare earth disilicate and at least one layer of rare earth monosilicate. At least one of the at least one layer of rare earth disilicate or the at least one layer of rare earth monosilicate includes an alkaline earth oxide dopant.

[0007] According to another example of the present technology, a component of a gas turbine engine is coated with an environmental barrier coating system as described herein.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Examples of the present technology set forth herein will be better understood from the following description in conjunction with the accompanying figures, in which like reference numerals identify like elements, wherein:

[0009] FIG. 1 is a schematic cross sectional view of an environmental barrier coating system usable with the present technology;

[0010] FIG. 2 is a schematic cross sectional view of an article or component having an environmental barrier coating system according to the present technology; and

[0011] FIG. 3 is a schematic illustration of an example of rare earth oxide/silica/alkaline earth oxide compositional space, drawn for convenience on a ternary-style composition diagram of a type commonly used in the art, with certain compositions highlighted in accordance with examples of the present technology.

DETAILED DESCRIPTION

[0012] Referring to FIG. 1, an EBC system 300 may include a bond coat 310, a rare earth disilicate (REDS) layer 340 and a hermetic or non-hermetic rare earth monosilicate (REMS) layer 350. The REDS layer 340 should preferably be hermetic. As used herein, the term "rare earth monosilicate" refers to composition of the formula RE_2SiO_5, where RE is Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, or combinations thereof. As used herein, the term "rare earth disilicate" refers to a composition of the formula $RE_2Si_2O_7$, where RE is Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, or combinations thereof. As used herein, the term "rare earth silicate" refers to rare earth monosilicates and rare earth disilicates. As used herein the term "substantially hermetic" means that the layer or coating has a gas permeability that is below about $2x10^{-14}$ cm^2 (about $2x10^{-6}$ Darcy), the detection limit of commonly used measurement techniques. The EBC system 300 may include a bond coat 310 (e.g., silicon as disclosed in U.S. 6,299,988.

[0013] Referring to FIG. 2, a component 400 of a gas turbine engine may include an EBC system 300 as shown in FIG. 1. The component may be formed of, for example, monolithic ceramic or a ceramic matrix composite. As used herein, the term "ceramic matrix composite" refers to a material that includes a reinforcing material surrounded by a ceramic matrix phase.

[0014] The bond coat of the EBC systems disclosed herein may have a thickness of between about 10 μm and about 200 μm, for example from about 25-150 μm, or from about 50-125 μm. The rare earth disilicate-based layer may have a thickness of between about 10 μm and about 250 μm, for example from about 25-200 μm, or from about 50-150 μm. The rare earth monosilicate-based layer may have a thickness of between about 10 μm and about 100 μm, for example from about 10-75 μm, or from about 25-75 μm.

[0015] The various characteristics and embodiments of the rare earth silicate-based substantially hermetic layer as disclosed herein also relate to a thermal spray feedstock for producing a rare earth silicate-based substantially hermetic layer. For example, suitable rare earth silicates (RES) for use in the rare earth silicate-based hermetic layer produced by the thermal spray feedstock can include, without limitation, a rare earth element selected from the group consisting of ytterbium (Yb), yttrium (Y), scandium (Sc), lutetium (Lu), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), europium (Eu), gadolinium (Gd), terbium (Tb), promethium (Pm), and mixtures thereof.

[0016] Referring to FIG. 3, components comprising alkaline earth oxides, for example CaO, MgO, SrO, BaO, or combinations thereof, can be added to the EBC system without significantly changing (e.g. less than about 10%) the coefficients of thermal expansion of the EBC layers, thus improving the corrosion resistance of the EBC system layers 340 and/or 350 to solid or molten dust deposits while maintaining the integrity of the EBC system against cracking and spalling. Addition of alkaline earth oxides to the REDS layer 340, the REMS layer 350, or both, promotes the formation of an apatite phase in the EBC layers and increases the chemical activity of the alkaline earth oxide to a level that reduces the driving force for chemical reaction with dust deposits. FIG. 3 schematically illustrates an example of rare earth oxide/silica/alkaline earth oxide compositional space, drawn for convenience on a ternary-style composition diagram of a type commonly used in the art, in which the mole % of each composition is defined from 0-100% on its respective side of the compositional space. In the example of FIG. 3, the rare earth oxide is Y_2O_3 and the alkaline earth oxide is CaO. In some embodiments, the alkaline earth oxide dopant comprises CaO and the rare earth monosilicate layer contains Y_2O_3.

[0017] In one example, the composition of the REMS layer 350 is shown in region A, which is defined by the space encompassed by points 1-2-3, where point 1 is Y_2O_3, point 2 is $Ca_2Y_8Si_6O_{26}$, and point 3 is Y_2SiO_5. The mole % of the CaO dopant may be about 1-16%, for example about 10%. The amount of dopant added should not substantially change (i.e. increase or decrease) the coefficient of thermal expansion (CTE) of the REMS layer 350, for example the amount of dopant added should result in either a decrease or an increase in the CTE of the REMS layer 350 of less than about 10%. Larger decreases in the CTE of the REMS layer 350 are acceptable.

[0018] The composition of the REDS layer 340 is shown in region B, which is defined by the space encompassed by points 2-3-4, where point 4 is $Y_2Si_2O_7$. The mole % of the CaO dopant may be about 1-16%, for example about 10%. The amount of dopant added should not substantially change the coefficient of thermal expansion (CTE) of the REDS layer 340, for example the amount of dopant added should result in a change (i.e. an increase or decrease) of the CTE of the REDS layer 340 of less than about 10%. As another example, the amount of the dopant increases the coefficient of thermal expansion of the REDS layer 340 by no more than about 25%.

[0019] In another example, the composition of the REDS layer 340 is shown in Region C, which is defined by the space encompassed by points 2, 4, and 5. The mole % of dopant may be about 5-20%, for example about 10%. Again, the amount of dopant should not change the coefficient of the REDS layer 340 by more than about 10%.

[0020] Alkaline-earth-rare-earth-silicates may be added to the above phase regions for short-term protection. The alkaline-earth-rare-earth-silicates may be a composition of the formula AE·RE·S, where AE is Be, Mg, Ca, Sr, Ba, Ra, or combinations thereof, and RE is Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, or combinations thereof, and S is a compound containing an anionic silicon compound. For example calcium yttrium silicate (CaYS), including $Ca_3Y_2Si_6O_{18}$ (point 5), $Ca_2Y_2Si_2O_9$ (point 6) and/or $Ca_3Y_2Si_3O_{12}$ (point 7) may be added to the above phase regions for short-term protection. With time, some of these additions are expected to change the chemistry of the coating layers. Any compositions within the composition space defined by points 2-5-7 and/or 2-6-7 may be added to the phase regions A and/or B/and/or C for short-term protection. In such case, the amount of CaO dopant can be higher, exceeding 16%, but preferably remain below 25%. In some embodiments, the mole % of the dopant may be 1-25%.

[0021] Although various examples have been depicted and described in detail herein, it will be apparent to those skilled in the relevant art that various modifications, additions, substitutions, and the like can be made and these are therefore considered to be within the scope of the claims which follow. For example, although the examples illustrated include a REMS layer and a REDS layer as shown, additional layers, including additional layers of REMS and REDS, may be provided, including layers between, below, and above the layers as shown, and dopant(s) may be provided to none, some, or all of the additional layers.

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WHAT IS CLAIMED IS:

1. An environmental barrier coating system for a component of a gas turbine, comprising:

   at least one rare earth disilicate layer; and

   at least one rare earth monosilicate layer,

   wherein at least one of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer includes an alkaline earth oxide dopant for promoting the formation of an apatite phase,

   wherein the at least one rare earth monosilicate layer is doped with the alkaline earth oxide dopant, and an amount of the alkaline earth oxide dopant is from 1 to 25 mole% of the at least one rare earth monosilicate layer,

   wherein the amount of the alkaline earth oxide dopant is limited such that the dopant reduces the coefficient of thermal expansion or increases the coefficient of thermal expansion of the at least one rare earth monosilicate layer by less than 10%.

2. The environmental barrier coating system according to claim 1, wherein the at least one rare earth disilicate layer is hermetic.

3. The environmental barrier coating system according to claim 1, wherein the at least one rare earth disilicate layer is doped with the alkaline earth oxide dopant and an amount of the alkaline earth oxide dopant is 1-25 mole % of the at least one rare earth disilicate layer.

4. The environmental barrier coating system according to claim 3, wherein the amount of the alkaline earth oxide dopant is 10 mole % of the at least one rare earth disilicate layer.

5. The environmental barrier coating system according to claim 3, wherein the amount of the alkaline earth oxide dopant increases the coefficient of thermal expansion of the at least one rare earth disilicate layer by no more than 25%.

6. The environmental barrier coating system according to claim 5, wherein the amount of the alkaline earth oxide dopant increases the coefficient of thermal expansion of the at least one rare earth disilicate layer by less than 10%.

7. The environmental barrier coating system according to claim 3, wherein the alkaline earth oxide dopant comprises CaO and the at least one rare earth disilicate layer contains Y_2O_3.

8. The environmental barrier coating system according to claim 7, wherein the at least one rare earth disilicate layer has a composition bounded by a region in the rare earth oxide/silica/alkaline earth oxide compositional space defined by a first composition point at $Ca_2Y_8Si_6O_{26}$, a second composition point at Y_2SiO_5, and a third composition point at $Y_2Si_2O_7$.

9. The environmental barrier coating system according to claim 7, wherein the at least one rare earth disilicate layer has a composition bounded by a region in the rare earth

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oxide/silica/alkaline earth oxide compositional space defined by a first composition point at $Ca_2Y_8Si_6O_{26}$, a second composition point at $Ca_3Y_2Si_6O_{18}$, and a third composition point at $Y_2Si_2O_7$.

10. The environmental barrier coating system according to claim 1, wherein the amount of the alkaline earth oxide dopant in the at least one rare earth monosilicate layer is 10 mole % of the layer.

11. The environmental barrier coating system according to claim 1, wherein the amount of the alkaline earth oxide dopant in the at least one rare earth monosilicate layer increases the coefficient of thermal expansion of the at least one rare earth monosilicate layer by less than 10%.

12. The environmental barrier coating system according to claim 1, wherein the alkaline earth oxide dopant comprises CaO and the at least one rare earth monosilicate layer contains Y_2O_3.

13. The environmental barrier coating system according to claim 12, wherein the at least one rare earth monosilicate layer has a composition bounded by a region in the rare earth oxide/silica/alkaline earth oxide compositional space defined by a first composition point at Y_2O_3, a second composition point at $Ca_2Y_8Si_6O_{26}$, and a third composition point at Y_2SiO_5.

14. The environmental barrier coating system according to claim 1, wherein the amount of the alkaline earth oxide dopant either reduces the coefficient of thermal expansion of the at least one rare earth disilicate layer or increases the coefficient of thermal expansion of the at least one rare earth monosilicate layer by less than 10%.

15. The environmental barrier coating system according to claim 1, wherein at least one of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer further includes an alkaline-earth-rare-earth-silicate dopant of the formula AE·RE·S, where AE is Be, Mg, Ca, Sr, Ba, Ra, or combinations thereof, and RE is Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, or combinations thereof, and S is a compound containing an anionic silicon compound.

16. The environmental barrier coating system according to claim 15, wherein the alkaline-earth-rare-earth-silicate dopant is a magnesium-rare-earth-silicate dopant.

17. The environmental barrier coating system according to claim 15, wherein the alkaline-earth-rare-earth-silicate dopant is a calcium-rare-earth-silicate dopant.

18. The environmental barrier coating system according to claim 17, wherein the calcium-rare-earth silicate dopant is CaYS.

19. The environmental barrier coating system according to claim 18, wherein the layer including the alkaline-earth-rare-earth-silicate dopant has a composition including a composition point at $Ca_2Y_2Si_2O_9$ in the rare earth oxide/silica/alkaline earth oxide compositional space.

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20. The environmental barrier coating system according to claim 18, wherein the layer including the alkaline-earth-rare-earth-silicate dopant has a composition including a composition point at $Ca_3Y_2Si_3O_{12}$ in the rare earth oxide/silica/alkaline earth oxide compositional space.

21. The environmental barrier coating system according to claim 18, wherein the layer including the alkaline-earth-rare-earth-silicate dopant has a composition including a composition point at $Ca_3Y_2Si_6O_{18}$ in the rare earth oxide/silica/alkaline earth oxide compositional space.

22. The environmental barrier coating system according to claim 1, wherein the alkaline earth oxide dopant is CaO.

23. The environmental barrier coating system according to claim 22, wherein the amount of the CaO dopant is 1-25 mole % of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer.

24. The environmental barrier coating system according to claim 23, wherein the amount is 2-20 mole % of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer.

25. The environmental barrier coating system according to claim 24, wherein the amount is 2-10 mole % of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer.

26. The environmental barrier coating system according to claim 25, wherein the amount is 10 mole % of the at least one rare earth disilicate layer or the at least one rare earth monosilicate layer.

27. The environmental barrier coating system according to claim 1, wherein the alkaline earth oxide dopant is MgO.

28. The environmental barrier coating system according to claim 1, wherein the alkaline earth oxide dopant is SrO.

29. The environmental barrier coating system according to claim 1, wherein the at least one rare earth disilicate layer is a composition of the formula $RE_2Si_2O_7$, where RE is Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, or combinations thereof.

30. The environmental barrier coating system according to claim 1, wherein the at least one rare earth monosilicate layer is a composition of the formula RE_2SiO_5, where RE is Sc, Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, or combinations thereof.

31. The environmental barrier coating system according to claim 1, wherein both the at least one rare earth monosilicate layer and the at least one rare earth disilicate layer include an alkaline earth oxide dopant.

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32. The environmental barrier coating system according to claim 1, wherein the at least one rare earth disilicate layer comprises two rare earth disilicate layers, and at least one of the two rare earth disilicate layers includes an alkaline earth oxide dopant.

33. A component of a gas turbine engine, wherein the component is coated with the environmental barrier coating system as defined in claim 1.

34. The component according to claim 33, wherein the component is formed of a ceramic matrix composite.

35. The component according to claim 34, wherein the environmental barrier coating system further comprises a bond coat that is between 10 to 200 μm thick.

36. The component according to claim 35, wherein the at least one rare earth monosilicate layer is between 10 to 100 μm thick.

37. The component according to claim 36, wherein the at least one rare earth disilicate layer is between 10 to 250 μm thick.

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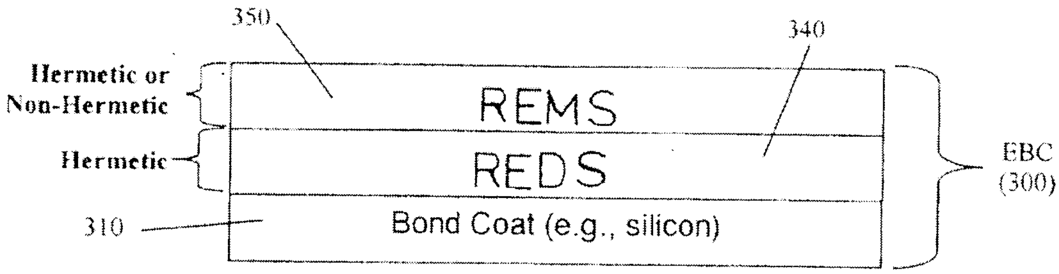

350
340
Hermetic or
Non-Hermetic
REMS
Hermetic
REDS
EBC
(300)
310
Bond Coat (e.g., silicon)

FIG. 1

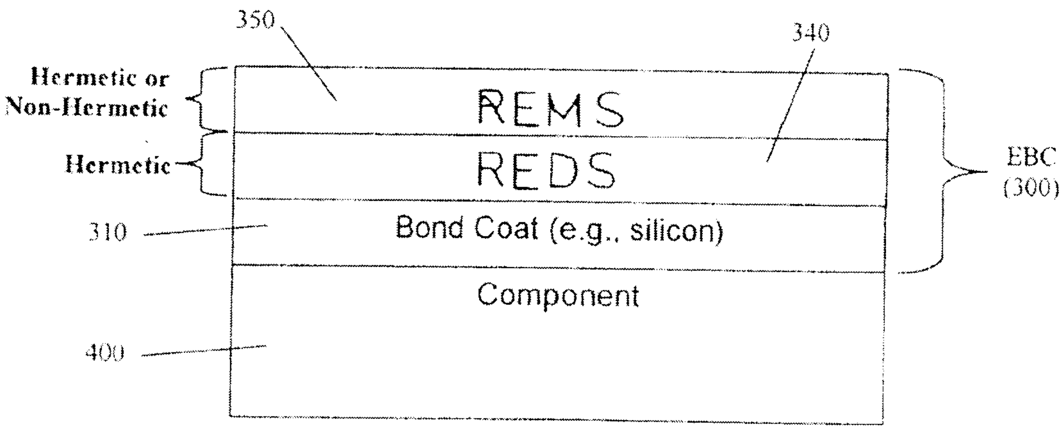

350
340
Hermetic or
Non-Hermetic
REMS
Hermetic
REDS
EBC
(300)
310
Bond Coat (e.g., silicon)
Component
400

FIG. 2

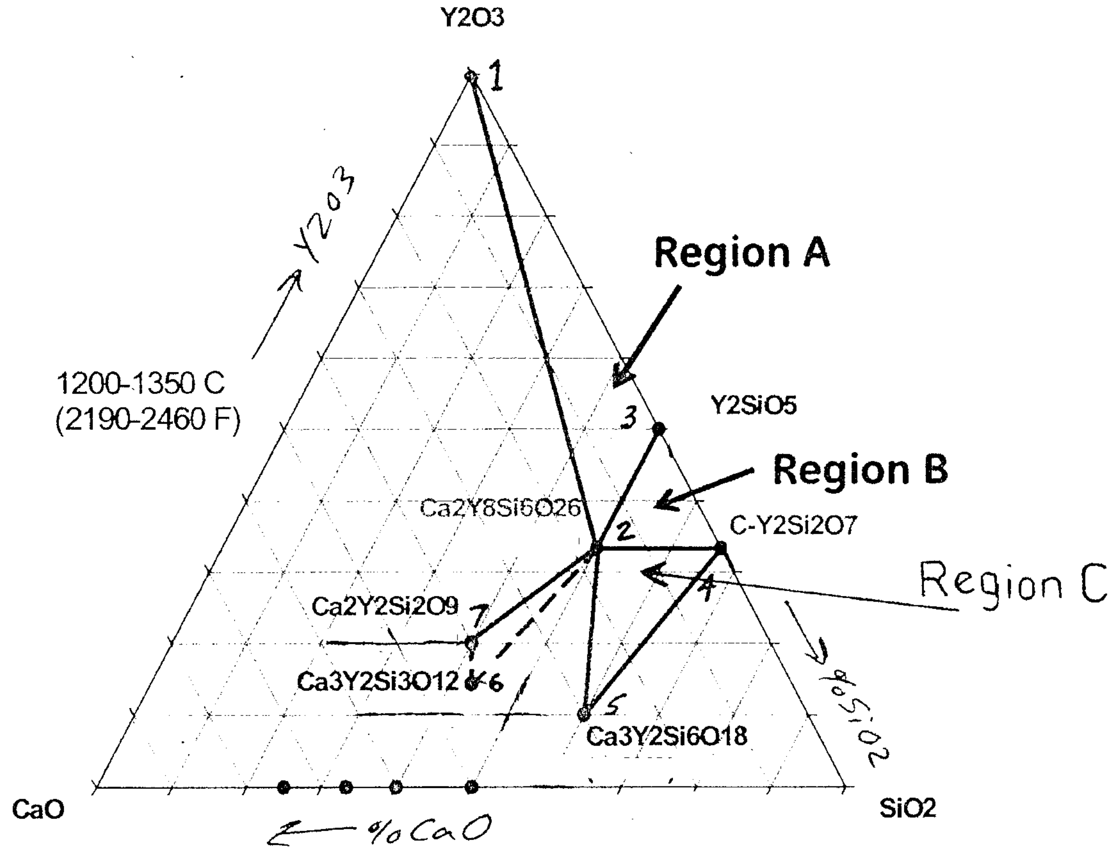
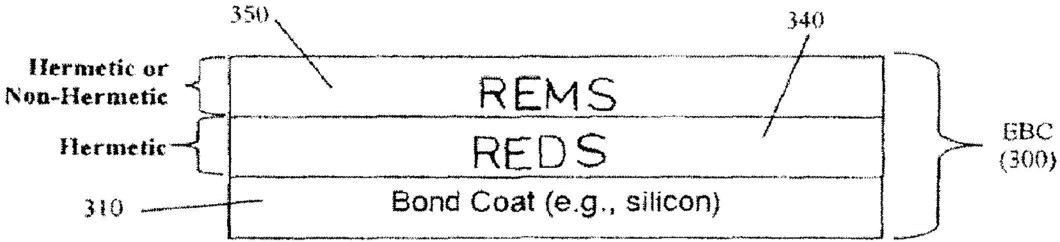

Y2O3
1
Y2O3
Region A
1200-1350 C
(2190-2460 F)
3
Y2SiO5
Region B
Ca2Y8Si6O26
2
C-Y2Si2O7
Region C
4
Ca2Y2Si2O9
7
Ca3Y2Si3O12
6
5
Ca3Y2Si6O18
%SiO2
CaO
SiO2
%CaO

FIG. 3


350
340
Hermetic or
Non-Hermetic
REMS
Hermetic
REDS
EBC
(300)
310
Bond Coat (e.g., silicon)