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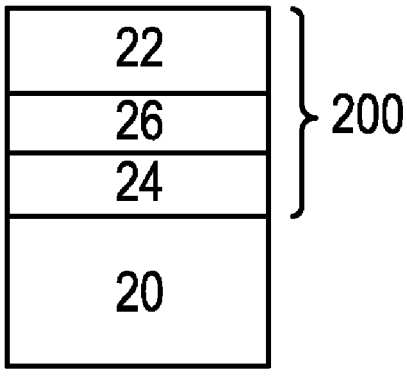
(54) Title: DURABILITY COATING FOR OXIDE FILMS FOR METAL FLUORIDE OPTICS

(57) Abstract: A coated metal fluoride optic is provided. The coated metal fluoride optic includes an alkaline earth metal fluoride substrate and a coating disposed on at least one surface of the substrate. The coating includes an adhesion layer comprising a fluoride-containing material, a non-densified intermediate layer deposited on the adhesion layer, and a densified capping layer deposited on the intermediate layer.

FIG. 2B



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DURABILITY COATING FOR OXIDE FILMS FOR METAL FLUORIDE OPTICS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 61/945,150 filed on February 27, 2014 the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure is directed to durable metal oxide films. In particular, the present disclosure is directed to metal oxide films having improved adhesion and reduced film stress when deposited on metal fluoride optics, and to a method for making such films.

BACKGROUND

[0003] Metal fluoride optics, such as calcium fluoride optics, frequently include a coating deposited on the surface of the optic. The coating serves as a protective layer that prevents fluorine loss that occurs when the optic is exposed to radiation in high fluence laser applications. The fluorine loss causes degradation of the optic which ultimately leads to the failure of the optic and the need to replace the failed optic.

[0004] During manufacture of the coated optics, and after they are used, the coated optics are frequently cleaned using a solvent wipe such as, for example, a methanol wipe. Wiping is a mechanical technique for removing particulate matter from the surface of the coating. However, removal of particulate matter using such technique causes particles to be dragged across the surface of the coating, which can damage the coating. The use of a solvent wipe to clean coated optics has been observed to cause blistering, crazing and delamination of the coating. As used herein, the term "blistering" refers to dome shaped projections in the coating and local losses of adhesion of the coating which causes lifting of the coating from the underlying optic surface. Additionally, as used herein, the term "crazing" refers to cracks that penetrate into the coating. Also as used herein, the term

"delamination" refers to loss of adhesion of the coating to the underlying optic surface, or to loss of adhesion between coating layers in coatings that include more than one layer.

[0005] Once damage such as blistering, crazing and/or delamination occurs, the coating's performance as a protective layer is reduced, and the adhesion of the coating to the surface of the optic is weakened. As a result, when the coating is damaged, fluorine loss in the optic, which the coating is meant to prevent, is observed during exposure to radiation in high fluence laser applications, and accelerated failure of the optic occurs.

SUMMARY

[0006] According to an embodiment of the present disclosure, a coated metal fluoride optic is provided. The coated metal fluoride optic includes an alkaline earth metal fluoride substrate and a coating disposed on at least one surface of the substrate. The coating includes an adhesion layer comprising a fluoride-containing material, a non-densified intermediate layer deposited on the adhesion layer, and a densified capping layer deposited on the intermediate layer.

[0007] According to another embodiment of the present disclosure, method for forming a coated metal fluoride optic is provided. The method includes depositing an adhesion layer comprising a fluoride-containing material onto at least one face of an alkaline earth metal fluoride substrate. The method further includes depositing an intermediate layer onto the adhesion layer without plasma ion assistance, and depositing a capping layer onto the intermediate layer with plasma ion assistance.

[0008] Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the embodiments as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0009] It is to be understood that both the foregoing general description and the following detailed description are merely exemplary, and are intended to provide an overview or framework to understanding the nature and character of the claims. The accompanying drawings are included to provide a further understanding, and are

incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiment(s), and together with the description serve to explain principles and operation of the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The disclosure will be understood more clearly from the following description and from the accompanying figures, given purely by way of non-limiting example, in which:

[0011] Figure 1 is an image of a coated calcium fluoride optic showing blistering, crazing and delamination of the coating;

[0012] Figure 2A illustrates a metal fluoride optic having a conventional coating;

[0013] Figure 2B illustrates a metal fluoride optic having a coating in accordance with the present disclosure;

[0014] Figure 3 illustrates an apparatus for coating a metal fluoride optic in accordance with the present disclosure;

[0015] Figure 4 shows high intensity scattered light images of five different coated metal fluoride optics (S1a, S2a, S3a, S4a, and S5a) in accordance with the present disclosure;

[0016] Figure 5 is an image of areas of crazing of optic S1a of Figure 3 captured using optical microscopy;

[0017] Figure 6 is an image of a micro-indented optic;

[0018] Figure 7 shows a comparison of images of five different coated metal fluoride optics (S1b, S2b, S3b, S4b, and S5b) after micro-indentation testing;

[0019] Figure 8 shows a comparison of images of a micro-indented optic before and after cleaning with a solvent wipe, wherein the optic has a conventional coating;

[0020] Figure 9 shows a comparison of images of micro-indented optic S1b before and after cleaning with a solvent wipe;

[0021] Figure 10 shows a comparison of images of micro-indented optic S2b before and after cleaning with a solvent wipe;

[0022] Figure 11 shows a comparison of images of micro-indented optic S3b before and after cleaning with a solvent wipe;

[0023] Figure 12 shows a comparison of images of micro-indented optic S4b before and after cleaning with a solvent wipe;

[0024] Figure 13 shows a comparison of images of micro-indented optic S5b before and after cleaning with a solvent wipe; and

[0025] Figure 14 is a graph showing % transmittance versus wavelength for coated metal fluoride optics in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0026] Reference will now be made in detail to the present embodiment(s), an example(s) of which is/are illustrated in the accompanying drawings. Whenever possible, the same reference numerals will be used throughout the drawings to refer to the same or like parts.

[0027] The singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. The endpoints of all ranges reciting the same characteristic are independently combinable and inclusive of the recited endpoint. All references are incorporated herein by reference.

[0028] Embodiments of the present disclosure provide a coating for a calcium fluoride optic that may be used in applications such as, but without limitation, lenses, partially and fully reflective mirrors, and windows in high power, high repetition rate, laser systems.

[0029] Figure 1 is an image of a coated calcium fluoride optic showing areas of crazing 12, areas of blistering 14 and areas of delamination 16. Figure 2A illustrates a metal fluoride optic 20 having a conventional coating 100 which is similar to the coated metal fluoride of Figure 1. As shown, deposited on a metal fluoride optic 20 is a coating 100 having a capping layer 22, wherein the capping layer 22 may be, without limitation, silicon dioxide (SiO_2) or F-doped silicon dioxide (F-SiO_2). Metal fluorides, such as calcium fluoride, are crystalline materials. In contrast, materials used for metal fluoride coatings, such as silicon oxide, are amorphous materials. The two types of materials have different coefficients of thermal expansion (CTE). For example, calcium fluoride has a CTE of about 18 x 10^{-6}/K and silicon dioxide has a CTE of about 0.5 x 10^{-6}/K. This difference in CTE of the two types of materials induces a compressive stress in the coating after the deposited coating is cooled from deposition temperatures to ambient temperatures. Without wishing to be limited by any particular theory, it is believed that this compressive stress causes blistering, crazing and delamination of the coating from the underlying optic such as is shown in Figure 1.

[0030] Figure 2B illustrates a metal fluoride optic 20 having a coating 200 disposed on at least one surface of the optic 20 in accordance with the present disclosure. As shown, the coating 200 includes an adhesion layer 24 deposited on the surface of the metal fluoride optic 20, an intermediate layer 26 deposited on the adhesion layer 24, and a capping layer 22 deposited on the intermediate layer 26. The metal fluoride optic 20 may be made from single crystals of alkaline earth metal fluorides such as, but without limitation, MgF_2, CaF_2, BaF_2 and SrF_2, and mixtures thereof. The metal fluoride optic 20 may be made from, for example, single crystals of CaF_2 doped with between about 12 ppm and about 2500 ppm MgF_2.

[0031] The adhesion layer 24 may be a fluoride-containing material having a CTE that is less than the CTE of the metal fluoride material of the metal fluoride optic 20 and that is greater than the CTE of the material of the capping layer 22. The CTE of the fluoride-containing material of the adhesion layer 24 may be for example, but without limitation, between about 3.0 x 10^{-6}/K and about 12 x 10^{-6}/K, or about 5.0 x 10^{-6}/K. The fluoride-containing material of the adhesion layer 24 may also have a low refractive index,

for example, but without limitation, a refractive index of less than about 1.45, or even less than about 1.40. The fluoride-containing material may be for example, but without limitation, AlF_3, Na_3AlF_6, and MgF_2. The adhesion layer 24 may have a thickness of about 5.0 nm to about 70 nm. Alternatively, the thickness of the adhesion layer 24 may be between about 7.0 nm and about 50 nm.

[0032] The intermediate layer 26 is a non-densified layer deposited on the adhesion layer 24 without the use of plasma ion assistance. The intermediate layer 26 may be for example, but without limitation, SiO_2, F-SiO_2, Al_2O_3, F-Al_2O_3, SiON. The intermediate layer 26 may have a thickness of about 7.0 nm to about 20 nm. The capping layer 22 is a densified layer deposited on the intermediate layer 26. Similar to Figure 2A, the capping layer 22 may be, without limitation, SiO_2 or F-SiO_2. The capping layer 22 may have a thickness of about 40 nm to about 80 nm.

[0033] A method for forming a coated metal fluoride optic in accordance with the present disclosure is provided herein. The method may be performed using an apparatus such as is described in U.S. Patent No. 8,399,110 and U.S. Patent No. 7,465,681, the specifications of which are incorporated by reference in their entirety. Figure 3 illustrates a deposition system 120 having a vacuum chamber 111 in which is located a rotatable element holder 122 on which metal fluoride optics 112 to be coated are located. E-beam 116 that impinges on a target 117 to produce a vapor flux 115 that passes by the mask 114 for deposition on optics 112. The mask 114 may be a partial mask, as is shown in Figure 3, or may be a reverse mask. In addition there is a plasma source 118 that generates plasma 119. The rotatable element holder 122 can have openings through the holder element for placements of optics 112 so that only one side of the optical element is to be coated.

[0034] In accordance with embodiments of the present disclosure, a fluoride-containing material having a low refractive index is deposited on at least one of the surfaces of the optics 112 in the vacuum chamber 111 to form an adhesion layer 24. To avoid fluoride depletion of the optics 112 and the adhesion layer 24, such deposition is performed without plasma ion assistance, i.e. plasma source plasma may be switched off

during the deposition of the fluoride-containing material. A non-densified intermediate layer 26 is then deposited on the adhesion layer 24. Such deposition is also performed without plasma ion assistance. A densified capping layer 22 is then deposited on the intermediate layer 26. In contrast to the previous deposition steps, the capping layer 22 is formed with ion plasma assistance. The use of Ar/O_2 plasma ensures adhesion of the capping layer 22 to the underlying intermediate layer 26 and also densifies the capping layer 22. As is further shown in Figure 3, the mask 114 forms zones α and β on the element holder 122. Use of the mask 114 limits deposition of the vapor flux 115 onto optics 112 in zone β. Similarly, where plasma ion assistance is utilized in the present method, only plasma ions reach the element holder 122 in zone α, whereas plasma ions interact with the vapor flux 115 in zone β. Deposition of the layers of the coating 200 as described herein may be performed at temperatures of between about 280°C and about 350°C. The deposition temperatures may be between about 290°C and about 325°C, or even between about 300°C and about 320°C.

[0035] As will become clearer in view of the Examples disclosed herein, embodiments of the present disclosure improve the adhesion of the capping layer 22 and provide a more robust protective layer for the metal fluoride optic 20. Without wishing to be bound by any particular theory, it is believed that the inclusion of the fluoride-containing material of the adhesion layer 24 forms a fluoride-to-fluoride bond with the metal fluoride of the underlying optic 20. It is also believed that the inclusion of the intermediate layer 26 deposited without the use of plasma ion assistance improves the adhesion of the capping layer 22 and protects the adhesion layer 24 from degradation by plasma containing oxygen such as is used in plasma ion assisted deposition. Furthermore, it is believed that the adhesion layer 24 and the intermediate layer 26 act as a mechanical buffer between the capping layer 22 and the metal fluoride optic 20, with the stack of the adhesion layer 24, the intermediate layer 26 and the capping layer 22 being less dense than the capping layer 22 of the conventional metal fluoride optic of Figure 2A. The less dense configuration is believed to provide a lower modulus of rupture that reduces propogation of damage in the coating. Additionally, the use of a fluoride-containing material having a CTE that is less than the CTE of the metal fluoride material of the metal fluoride optic 20 and that is greater than the CTE of the material of the capping layer 22 is believed to

reduce the compressive stress in the after the deposited coating is cooled from deposition temperatures to ambient temperatures, and in turn is believed to reduce blistering, crazing and delamination of the coating from the underlying optic.

EXAMPLES

[0036] Embodiments of the present disclosure are further described below with respect to certain exemplary and specific embodiments thereof, which are illustrative only and not intended to be limiting.

Example 1

[0037] Five groups (S1 to S5) of coated metal fluoride optics were formed in accordance with the data in Table I. The material of the intermediate layer and the capping layer of each of the coated metal fluoride optics was F-SiO_2 and the thicknesses of the intermediate layer and the capping layer were the same for all of the coated metal fluoride optics. Where formed, the adhesion layer and the intermediate layer of each coated metal fluoride optic was deposited without plasma ion assistance, while the capping layer of each coated metal fluoride optic was deposited using plasma ion assistance. The material of the adhesion layer and the thickness of the adhesion layer were different for each of the five groups of coated metal fluoride optics. The optics of group S1 were formed with no adhesion layer; the optics of group S2 were formed with an adhesion layer of AlF_3 having a thickness of 10nm; the optics of group S3 were formed with an adhesion layer of AlF_3 having a thickness of 30nm; the optics of group S4 were formed with an adhesion layer of MgF_3 having a thickness of 10nm; and the optics of group S5 were formed with an adhesion layer of MgF_3 having a thickness of 30nm. The deposition temperature for all layers was about 305°C.

TABLE I

OPTIC	ADHESION LAYER MATERIAL	ADHESION LAYER THICKNESS (nm)	INTERMEDIATE LAYER THICKNESS (nm)	CAPPING LAYER THICKNESS (nm)
S1a	None	0	10	52
S1b	None	0	10	52

S2a	AlF_3	10	10	52
S2b	AlF_3	10	10	52
S3a	AlF_3	30	10	52
S3b	AlF_3	30	10	52
S4a	MgF_2	10	10	52
S4b	MgF_2	10	10	52
S5a	MgF_2	30	10	52
S5b	MgF_2	30	10	52

Example 2

[0038] Five of the coated metal fluoride optics formed in Example 1 (S1a, S2a, S3a, S4a, and S5a) were cleaned using six cycles of a solvent wipe process. A cycle of the solvent wipe process included submerging the coated metal fluoride optic in deionized water and wiping the coated metal fluoride optic by hand for 5.0 seconds using a TX404 Absorbond™ Synthetic Wipe commercially available from ITW Texwipe, Kernersville, NC. A cycle of the solvent wipe process also included drying the coated metal fluoride optic in a spin rinse dryer.

[0039] Figure 4 shows high intensity scattered light images of the five coated metal fluoride optics (S1a, S2a, S3a, S4a, and S5a). The only differences observed in the images shown in Figure 4 are the visible scratches (shown by circles in images of coated metal fluoride optics S2a and S3a), which are the result of the wiping process. However, no blistering, crazing or delamination of the layers of the coatings was observed in the images. To analyze the coatings in more detail, images of the optics were captured using optical microscopy. Figure 5 shows the only instance of crazing that was observed for all of the five coated metal fluoride optics (S1a, S2a, S3a, S4a, and S5a). Crazing was observed on the coating of optic S1a, which was formed without an adhesion layer. Based on these results, the coatings of optics S2a to S5a, which included an adhesion layer, were determined to be more robust and better suited to withstand cleaning with a solvent wipe than coatings formed without an adhesion layer.

Example 3

[0040] Five of the coated metal fluoride optics formed in Example 1 (S1b, S2b, S3b, S4b, and S5b) were subjected to a micro-indentation process using an M1 Micro-indentation Tester commercially available from Nanovea, Inc., Irvine, CA. In the micro-indentation process, an indenter tip was driven into the coated metal fluoride optics by applying an increasing load up to a targeted value. After the targeted load was reached, the load was gradually decreased and the optics were examined for damage to the coatings.

[0041] Figure 6 is an image of a micro-indented optic and the different damage types induced by the indentation process. The optic of Figure 6 was formed in accordance with optics S1a and S1b. As shown in Figure 5, area 30 is the area of the optic covered by the indenter, with box 34 indicating the edge of the indenter. Delamination 32 of the coating from the surface of the optic is seen as dark areas. Blistering 38 of the coating, where the coating did not remain adhered to the optic but remained intact with other portions of the coating, is seen in lighter areas of the image. Radial cracks 36, which are channels in the layers of the coating, can be seen propagating from the edge of the indent.

[0042] Figure 7 shows a comparison of images of the five different coated metal fluoride optics (S1b, S2b, S3b, S4b, and S5b) after micro-indentation testing. As shown, less damage is observed for the coatings of optics S2b to S5b than for the coating of optic S1b. Based on these results, the coatings of optics of S2b to S5b, which included an adhesion layer, were determined to be more robust and better suited to withstand damage than optics formed without an adhesion layer.

Example 4

[0043] The five coated metal fluoride optics micro-indented in Example 3 (S1b, S2b, S3b, S4b, and S5b) were cleaned using the solvent wipe process discussed in Example 2. In addition, for purposes of comparison, a micro-indented coated metal fluoride optic having only an F-SiO_2 capping layer, such as the coated metal fluoride optic shown in Figure 2A, was cleaned using the solvent wipe process discussed in Example 2. Figure 8 shows a comparison of images of this micro-indented optic before and after cleaning with a solvent wipe. The similarities of the images of Figure 8 to the images of Figure 9, which shows a comparison of images of micro-indented optic S1b before and after cleaning with

a solvent wipe, indicates that optics S1a and S1b are can be treated as reasonable representations of a metal fluoride optics having conventional coatings.

[0044] Figures 9-13 show comparisons of images of the micro-indented optics, S1b-S5b respectfully, before and after cleaning with a solvent wipe. As shown, less blistering, crazing and delamination was observed for the coatings of the optics S2b to S5b than for the coating of the optic S1b after cleaning with a solvent wipe. Based on these results, the coatings of optics S2b to S5b, which included an adhesion layer, were determined to be more robust and better suited to withstand damage, in particular delamination as a result of cleaning with a solvent wipe, than optics formed without an adhesion layer.

Example 5

[0045] Three coated metal fluoride optics were formed in accordance with the data in Table II. Coated optic 40 was formed in accordance with the coated metal fluoride optic shown in Figure 2A, and coated optics 42 and 44 were formed in accordance with the coated metal fluoride optic shown in Figure 2B. For each of the coated optics the capping layer included a densified F-SiO_2. For coated optics 42 and 44, the adhesion layer included AlF_3 and the intermediate layer included non-densified F-SiO_2. Coated optic 40 was formed without an adhesion layer or an intermediate layer.

TABLE II

OPTIC	ADHESION LAYER THICKNESS (nm)	INTERMEDIATE LAYER THICKNESS (nm)	CAPPING LAYER THICKNESS (nm)
40	0	0	52
42	10	10	52
44	30	10	52

[0046] Spectral transmittance of each of the coated optics 42-44 was measured and Figure 14 is a graph showing % transmittance versus wavelength (nm) for the coated metal fluoride optics of Table II. As shown, coated optic 40 has a spectral transmittance of about 92% in the range of 190-196nm, coated optic 42 has a spectral transmittance of about 93%

in the range of 190-196nm, and coated optic 44 has a spectral transmittance of about 96% in the range of 190-196nm. It was determined that coatings including an adhesion layer in accordance with embodiments of the present disclosure provide improved transmittance over conventional coatings.

[0047] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

What Is Claimed Is:

1. A coated metal fluoride optic comprising:
an alkaline earth metal fluoride substrate; and
a coating disposed on at least one surface of the substrate, the coating comprising:
an adhesion layer comprising a fluoride-containing material;
a non-densified intermediate layer deposited on the adhesion layer; and
a densified capping layer deposited on the intermediate layer.

2. The coated metal fluoride optic of claim 1, wherein the alkaline earth metal substrate is a single crystal alkaline earth metal fluoride substrate selected from the group consisting of MgF_2, CaF_2, BaF_2, SrF_2, and mixtures thereof.

3. The coated metal fluoride optic of any of the preceding claims, wherein the alkaline earth metal substrate comprises a single crystal CaF_2 substrate doped with between about 12 ppm and about 2500 ppm MgF_2.

4. The coated metal fluoride optic of any of the preceding claims, wherein the fluoride-containing material of the adhesion layer is selected from the group consisting of AlF_3, Na_3AlF_6, and MgF_2.

5. The coated metal fluoride optic of any of the preceding claims, wherein the fluoride-containing material of the adhesion layer has a refractive index of less than about 1.45.

6. The coated metal fluoride optic of any of the preceding claims, wherein the fluoride-containing material of the adhesion layer has a CTE in the range of about 3.0×10^{-6}/K and about 12×10^{-6}/K.

7. The coated metal fluoride optic of any of the preceding claims, wherein the adhesion layer has a thickness of between about 5.0 nm and about 70 nm.

8. The coated metal fluoride optic of any of the preceding claims, wherein the intermediate layer comprises a material selected from the group consisting of SiO_2, F-SiO_2, Al_2O_3, F-Al_2O_3, and SiON.

9. The coated metal fluoride optic of any of the preceding claims, wherein the intermediate layer has a thickness of between about 7.0 nm and about 20 nm.

10. The coated metal fluoride optic of any of the preceding claims, wherein the capping layer comprises a material selected from the group consisting of SiO_2, F-SiO_2, Al_2O_3, F-Al_2O_3, and SiON.

11. The coated metal fluoride optic of any of the preceding claims, wherein the capping layer has a thickness of between about 40 nm and about 70 nm.

12. The coated metal fluoride optic of any of the preceding claims, wherein the adhesion layer has a thickness of at least about 10 nm, and wherein transmission of 190-196nm wavelength light through the metal fluoride optic is at least 93%.

13. The coated metal fluoride optic of any of the preceding claims, wherein the adhesion layer has a thickness of at least about 30 nm, and wherein transmission of 190-196nm wavelength light through the metal fluoride optic is at least 96%.

14. A method for forming a coated metal fluoride optic, the method comprising:

depositing an adhesion layer comprising a fluoride-containing material onto at least one face of an alkaline earth metal fluoride substrate;

depositing an intermediate layer onto the adhesion layer without plasma ion assistance; and

depositing a capping layer onto the intermediate layer with plasma ion assistance.

15. The method of claim 14, wherein the depositing steps comprise depositing at a temperature of between about 280°C and about 350°C.

16. The method of claim 15, wherein the depositing steps comprise depositing at a temperature of between about 300°C and about 325°C.

17. The method of any of claims 14-16, wherein the fluoride-containing material of the adhesion layer is selected from the group consisting of AlF_3, Na_3AlF_6, and MgF_2.

18. The method of any of claims 14-17, wherein the fluoride-containing material of the adhesion layer has a refractive index of less than about 1.45.

19. The method of any of claims 14-18, wherein the intermediate layer comprises a material selected from the group consisting of SiO_2, F-SiO_2, Al_2O_3, F-Al_2O_3, and SiON.

20. The method of any of claims 14-19, wherein the capping layer comprises a material selected from the group consisting of SiO_2, F-SiO_2, Al_2O_3, F-Al_2O_3, and SiON.

FIG. 1

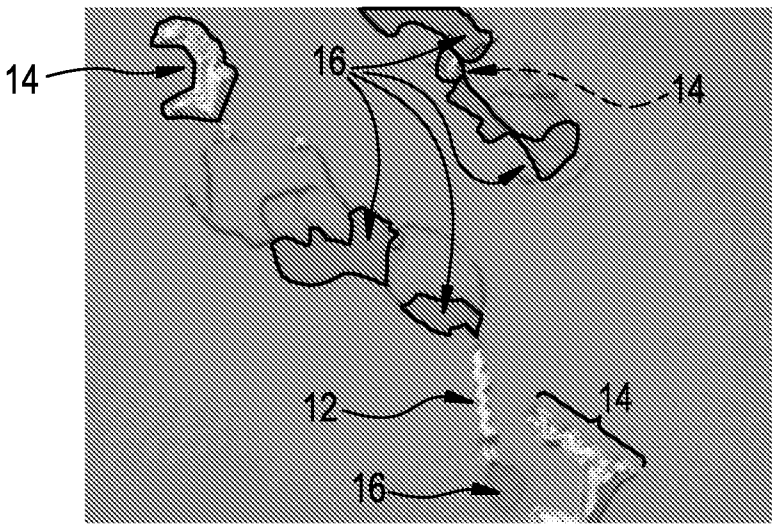


FIG. 2A

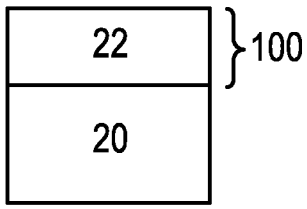


FIG. 2B

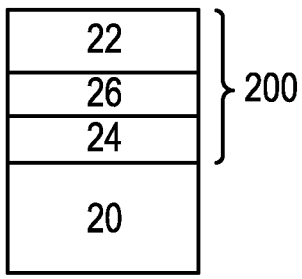


FIG. 3

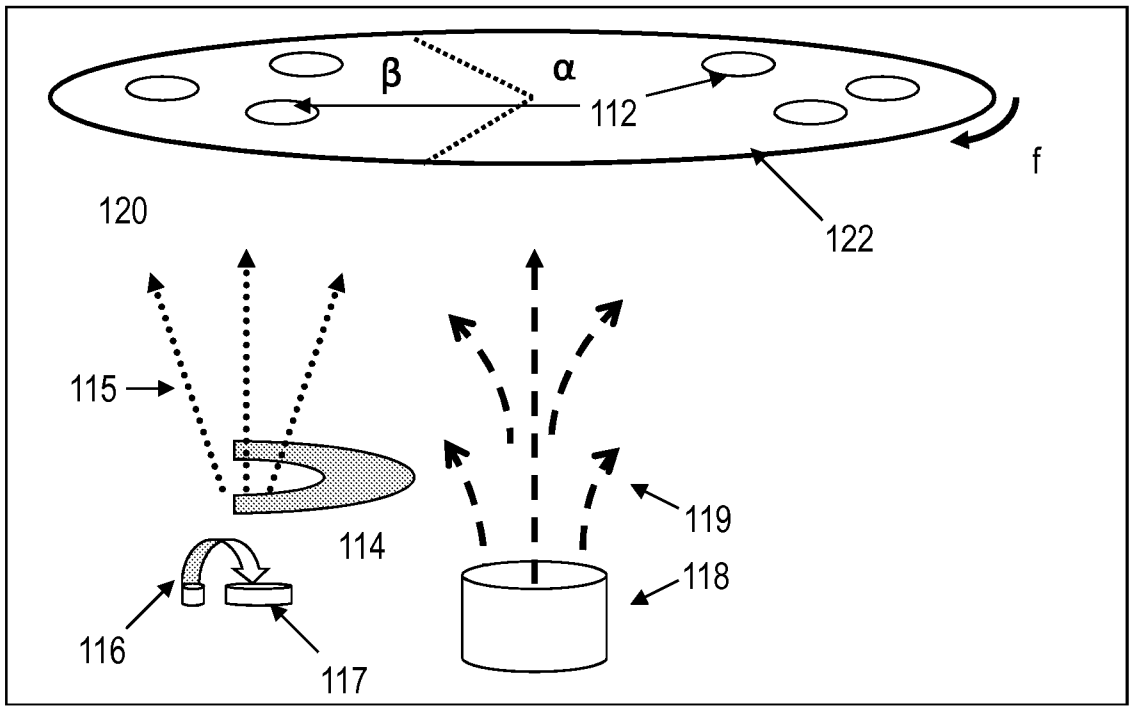


FIG. 4

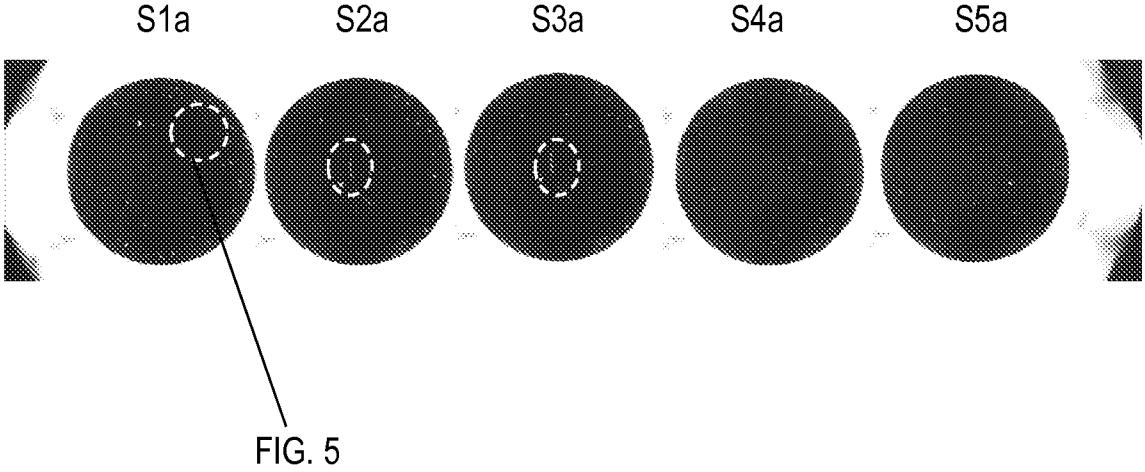


FIG. 5

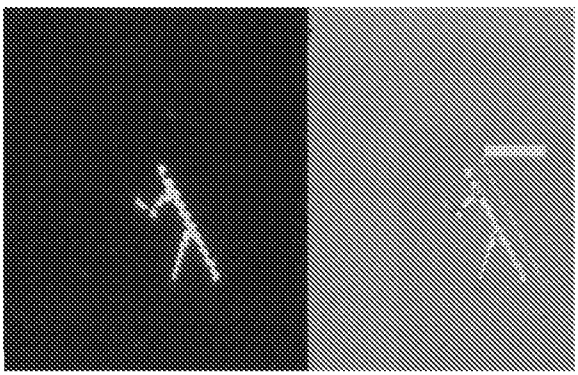


FIG. 6

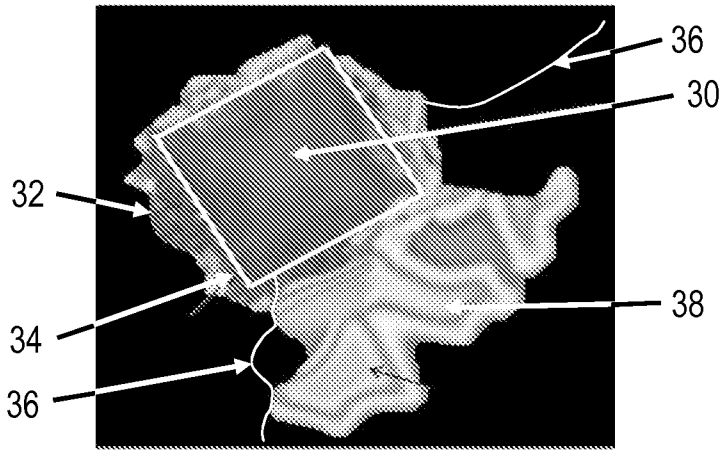


FIG. 7

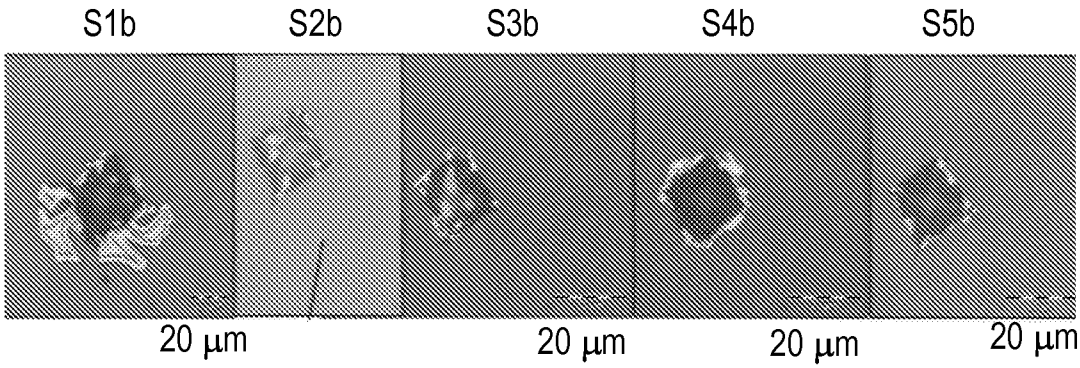


FIG. 8A

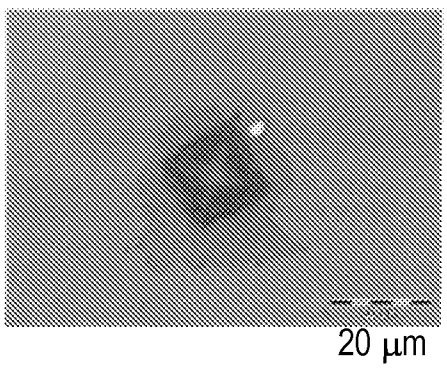


FIG. 8B

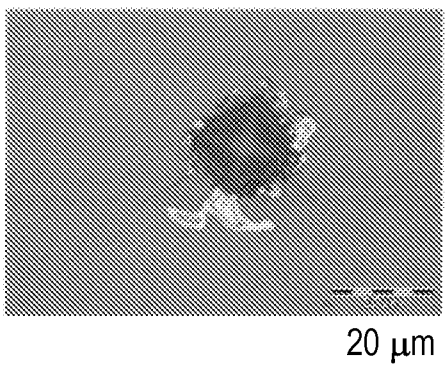


FIG. 9A

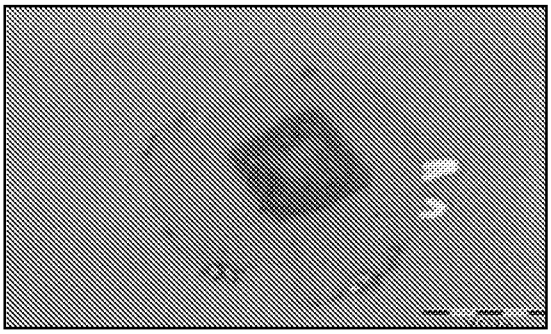


FIG. 9B

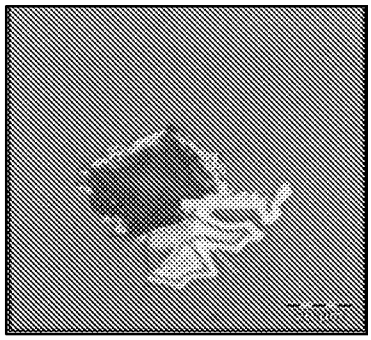


FIG. 10A

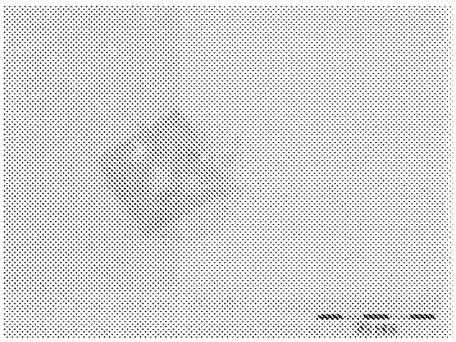


FIG. 10B

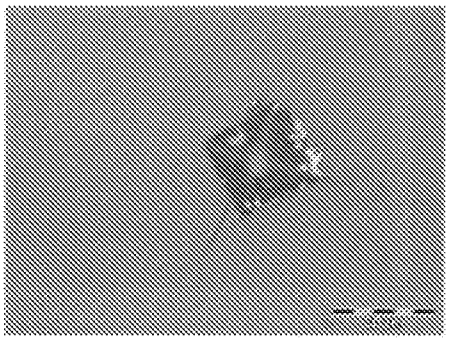


FIG. 11A

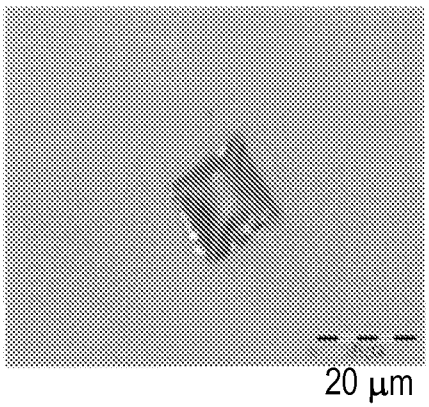


FIG. 11B

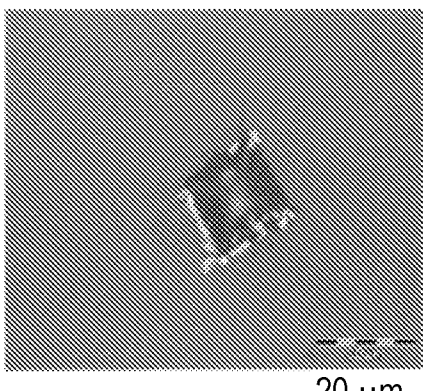


FIG. 12A

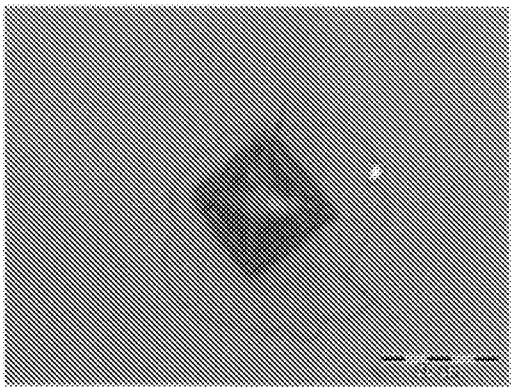


FIG. 12B

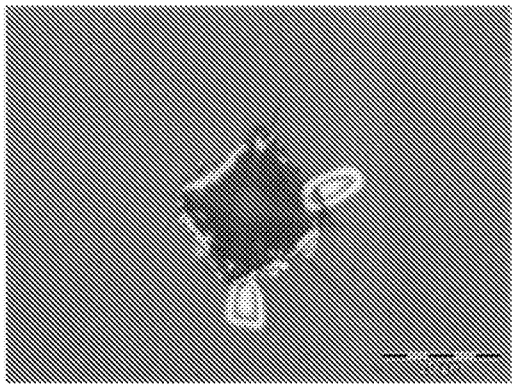


FIG. 13A

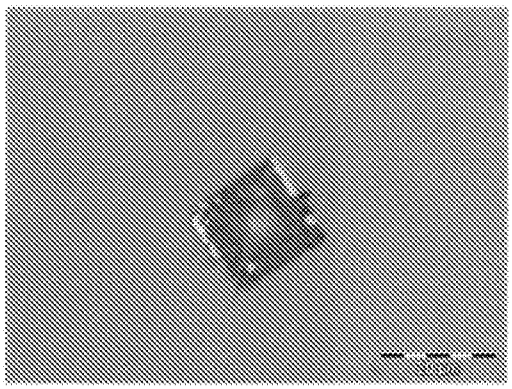


FIG. 13B

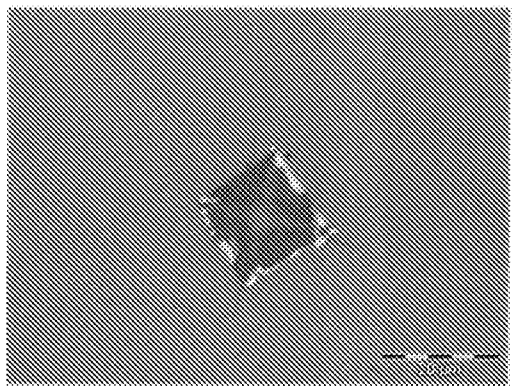
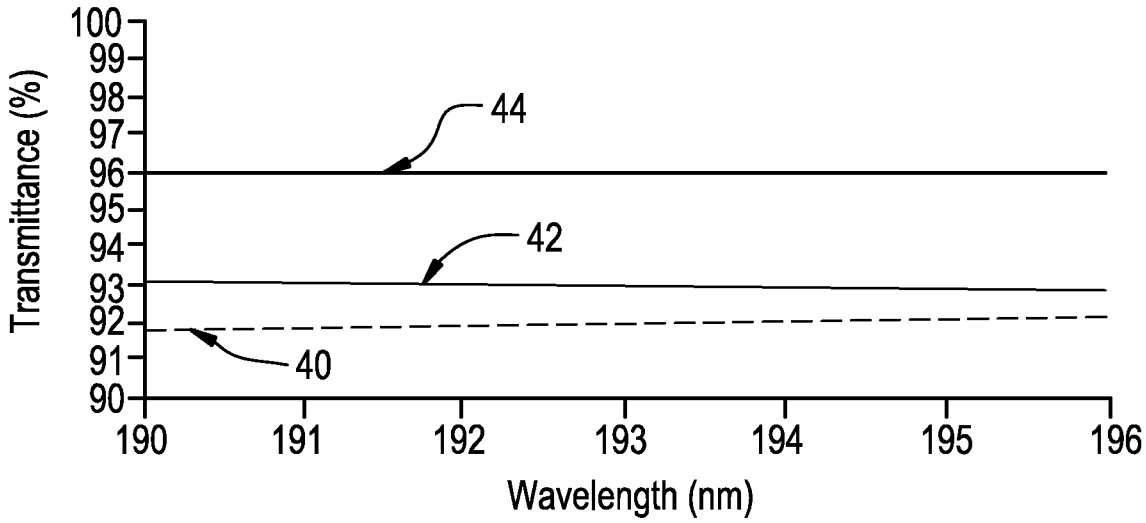


FIG. 14


100
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95
94
93
92
91
90
Transmittance (%)
44
42
40
190
191
192
193
194
195
196
Wavelength (nm)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/017199

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B1/115 C23C14/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B C23C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2013/181175 A1 (CORNING INC [US]; CANGEMI MICHAEL JEROME [US]; DEWA PAUL GERARD [US];) 5 December 2013 (2013-12-05) paragraphs [0023] - [0025]	1-20
X	WO 2009/070227 A1 (CORNING INC [US]; CANGEMI MICHAEL J [US]; SCHREIBER HORST [US]; WANG J) 4 June 2009 (2009-06-04) paragraphs [0006], [0009], [0034], [0035]; figures 9,10	1-20
A	US 8 399 110 B2 (CANGEMI MICHAEL J [US] ET AL) 19 March 2013 (2013-03-19) cited in the application column 3, lines 22-59	1,14

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 May 2015	28/05/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Mollenhauer, Ralf

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/017199

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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PCT/US2015/017199

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