

METHOD FOR ENHANCING COATING PERFORMANCE USING APS THERMAL SPRAY COATING

FIELD OF THE INVENTION

5 [0001] The present invention generally relates to a method for creating thermal spray coatings, specifically to an Atmospheric Plasma Spraying (APS) method for creating high-performance coatings with enhanced quality, reliability, and durability for semiconductor components and other applications.

BACKGROUND

10

[0002] Atmospheric Plasma Spraying (APS) is a widely used thermal spray technique commonly applied in surface modification treatments for semiconductor components. Coatings made of yttrium fluoride (YF3), yttrium aluminum garnet (YAG), and other rare-earth oxides are frequently used as semiconductor chamber coating materials to reduce the production of
15 contaminating particles. These materials are known for their hardness, high wear resistance, dielectric strength, high corrosion resistance, and chemical stability, making them suitable for semiconductor industry applications.

[0003] Despite the fact that APS coating has high quality, reliability, and durability, good flexibility in application, and excellent control over characteristics such as thickness, porosity,
20 roughness, and hardness, it is not without drawbacks. Traditional APS coatings using single-component - yttrium fluoride (YF3), suffer from drawbacks such as the presence of unmelted powder particles, low hardness, and the tendency to develop longitudinal cracks in the YF3 coating cross section during the spraying process, particularly due to the uneven distribution and incomplete melting of raw powder particles during the spraying process. In addition,
25 traditional APC coating using single component- yttrium aluminum garnet (YAG) tends to develop many non-directional fine cracks, many coating defects and large pores.

[0004] These deficiencies negatively impact the durability, reliability, and overall performance of the coatings, especially under conditions that require high etch resistance and mechanical stability. To address the above issues, the present invention utilizes a mixed powder
30 of YF3 and YAG to create a low-porosity, high-hardness, and corrosion-resistant coating by APS for semiconductor chambers and other substrates like aluminum and ceramics.

SUMMARY

[0005] In one aspect, the present disclosure refers to a method of preparing a coating material for Atmospheric Plasma Spraying (APS), comprising preparing a hybrid powder by mixing yttrium fluoride (YF₃) and yttrium aluminum garnet (YAG) powders, wherein the mass fraction of YAG powder in the hybrid powder is 9-50%; wherein the YF₃ powder has a purity of $\geq 99.9\%$ and a particle size of 10-50 μm , and the YAG powder has a purity of $\geq 99.9\%$ and a particle size of 30-65 μm .

[0006] Advantageously, the method of the present disclosure prepares a low-porosity, high-hardness, and corrosion-resistant coating using a mixed powder of YF₃ and YAG through APS.

The mixed powder is characterized by improved homogeneity and enhanced coating properties, including increased dielectric strength, higher hardness, and reduced etching rates, making it suitable for various substrates such as aluminum and ceramics. The mixed powder's coating process provides superior resistance to plasma etching and better overall performance compared to traditional single-component coatings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

[0008] **Figure 1** is a picture taken by COXEM Desktop Scanning Electron Microscope of the coating obtained in Example 1.

[0009] **Figure 2** is a picture taken by COXEM Desktop Scanning Electron Microscope of the coating obtained in Example 2.

[0010] **Figure 3** is a picture taken by COXEM Desktop Scanning Electron Microscope of the coating obtained in Example 3.

[0011] **Figure 4** is a comparative picture taken by COXEM Desktop Scanning Electron Microscope of the single YF₃ coating obtained in Example 4 (control).

[0012] **Figure 5** is a comparative picture taken by COXEM Desktop Scanning Electron Microscope of the single YAG coating obtained in Example 4 (control).

DETAILED DESCRIPTION

[0013] The present invention introduces a method for producing APS thermal spray coatings using a hybrid powder composed of YF3 and YAG. This method results in coatings with significantly improved properties, including lower porosity, higher hardness, and enhanced etch resistance. The method is particularly suitable for creating coatings on substrates such as aluminum and ceramics.

[0014] Preparation of Coating Powders

[0015] In one aspect, the present disclosure refers to a method of preparing a coating material for Atmospheric Plasma Spraying (APS), comprising preparing a hybrid powder by mixing yttrium fluoride (YF3) and yttrium aluminum garnet (YAG) powders, wherein the mass fraction of YAG powder in the hybrid powder is 9-50%; wherein the YF3 powder has a purity of $\geq 99.9\%$ and a particle size of 10-50 μm , and the YAG powder has a purity of $\geq 99.9\%$ and a particle size of 30-65 μm .

[0016] The coating material/powders are prepared with the following specifications:

- YF3 Powder: Purity $\geq 99.9\%$, particle size 10-50 μm , preferably sieved to obtain 20-40 μm .
- YAG Powder: Purity $\geq 99.9\%$, particle size 30-65 μm , preferably sieved to obtain 40-60 μm .

[0017] In one example, the particle size of YF3 powder is 10-50 μm , 20-40 μm , 10-20 μm , 15-25 μm , 20-30 μm , 25-35 μm , 30-40 μm , 35-45 μm , 40-50 μm , about 10 μm , about 15 μm , about 20 μm , about 25 μm , about 30 μm , about 35 μm , about 40 μm , about 45 μm , or about 50 μm .

[0018] In another example, the particle size of YAG powder is 30-65 μm , 40-60 μm , 30-40 μm , 35-45 μm , 40-50 μm , 45-55 μm , 50-60 μm , 55-65 μm , about 30 μm , about 35 μm , about 40 μm , about 45 μm , about 50 μm , about 55 μm , about 60 μm , or about 65 μm .

[0019] In another example, the purity of the YF3 or the YAG powder need to be high, at least 99.9%. If the purity is not high, there tend to be black spots and impurities formed on the coated surface, which will affect the subsequent use.

[0020] The mixed powder consists of YF3 and YAG in a mass ratio ranging from 1:1 to 10:1. In one example, the mixed powder consists of YF3 and YAG in a mass ratio of about 1:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 1.5:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 2:1. In

another example, mixed powder consists of YF3 and YAG in a mass ratio of about 2.5:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 3:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 4:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 5:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 6:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 7:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 8:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 9:1. In another example, mixed powder consists of YF3 and YAG in a mass ratio of about 10:1.

[0021] In one example, the mass fraction of YAG powder in the hybrid powder is 9-50%. In another example, the mass fraction of YAG powder in the hybrid powder is about 9%, about 10%, about 12%, about 15%, about 20%, about 25%, about 30%, about 35%, about 40%, about 45%, about 50%, 9-15%, 10-20%, 15-25%, 25-50%, 25-35%, 30-40%, 35-45%, or 40-50%.

[0022] Preferably, the powders are dry-mixed and ball-milled with abrasive materials in a high-speed ball mill at a speed of 150-300 rpm for 24-48 hours to ensure a uniform mixture.

[0023] In one example, the powders are dry-mixed and ball-milled with abrasive materials in a high-speed ball mill at a speed of 150-300 rpm, 150-250 rpm, 200-300 rpm, about 150 rpm, about 200 rpm, about 250 rpm, or about 300 rpm, for a period of 24-48 h, 24-30 h, 30-36 h, 36-42 h, 42-48 h, about 24 h, about 30 h, about 36 h, or about 48 h.

[0024] In another example, the abrasive materials used in the ball mill are zirconia with a particle size of about 5 mm.

[0025] Before spraying, the mixed powders are dried. If the powder is wet, the porosity of the coating formed may be poor and there may be more raw powder in the coating. The drying can be done by a tool commonly used in the field, selected from the group consisting of oven, at a temperature of 50-70 °C, for 30 min-1 h.

[0026] **APS Coating Process**

[0027] The APS process parameters for spraying the mixed powder onto a substrate are as follows:

- Plasma Gas: Argon and hydrogen.
- Argon Flow Rate: 35-65 NLPM (main gas), 2-4.5 L/min (powder carrier gas). (NLPM stands for normal liters per minute, which is the same as L/min, and the two terms can be used interchangeably.)

- Hydrogen Flow Rate: 5-10 NLPM.
- Current: 500-700 A.
- Powder Feed Rate: 5-30 g/min.
- Spraying Distance: 100-300 mm.

5 [0028] In one example, the plasma gas for APS coating process is a mixture of argon and hydrogen. In another example, the argon in the plasma gas has at least 99.999% purity.

[0029] In one example, the main argon flow rate is 35-65 NLPM. In another example, the main argon flow rate is selected from the group consisting of 35-45 NLPM, 40-50 NLPM, 45-55 NLPM, 50-60 NLPM, 55-65 NLPM, about 35 NLPM, about 40 NLPM, about 45 NLPM,
10 about 50 NLPM, about 55 NLPM, about 60 NLPM, and about 65NLPM.

[0030] In one example, the powder feeding argon flow rate is 2-4.5 L/min. In another example, the powder feeding argon flow rate is selected from the group consisting of 2-3 L/min, 2.5-3.5 L/min, 3-4 L/min, 3.5-4.5 L/min, about 2 L/min, about 2.5 L/min, about 3 L/min, about 3.5 L/min, about 4 L/min, and about 4.5 L/min.

15 [0031] In one example, the hydrogen flow rate is 5-10 NLPM. In another example, the hydrogen flow rate is selected from the group consisting of 5-7 NLPM, 6-8 NLPM, 7-9 NLPM, 8-10 NLPM, about 5 NLPM, about 6 NLPM, about 7 NLPM, about 8 NLPM, about 9 NLPM, and about 10 NLPM.

[0032] In one example, the current used for APS coating process is 500-700 A. In another
20 example, the current used for APS coating process is selected from the group consisting of 500-600 A, 550-650 A, 600-700 A, about 500 A, about 550 A, about 600 A, about 650 A, and about 700 A.

[0033] In one example, the powder feed rate of 5-30 g/min. In another example, the powder feed rate is selected from the group consisting of 5-15 g/min, 10-20 g/min, 15-25 g/min, 20-30
25 g/min, about 5 g/min, about 10 g/min, about 15 g/min, about 20 g/min, about 25 g/min, and about 30 g/min.

[0034] In one example, the spraying distance for APS coating process is 100-300 mm. In another example, the spraying distance for APS coating process is 100-200 mm, 150-250 mm, 250-300 mm, about 100 mm, about 150 mm, about 200 mm, about 250 mm, and about 300
30 mm.

[0035] In one particular example, the APS process parameters for spraying the mixed powder onto a substrate are as follows: the main argon (purity of $\geq 99.999\%$) flow rate is about

35 L/min, the hydrogen flow rate is about 9 L/min, the current is about 550 A, the powder feeding argon flow rate is about 4 L/min, a turntable speed is 40-80 r/min (for example, about 60 r/min), and the spraying distance is about 140 mm.

[0036] For the substrate to be sprayed by the mixed powder as disclosed herein using the APS coating process, the substrate is selected from the group consisting of aluminum, ceramics coated with Y_2O_3 , and quartz coated with Y_2O_3 . Substrate surface roughness is controlled at 4-12 μm with plasma jet preheating. In one example, the substrate surface roughness is selected from the group consisting of 4-6 μm , 5-7 μm , 6-8 μm , 7-9 μm , 8-10 μm , 9-11 μm , 10-12 μm , about 4 μm , about 5 μm , about 6 μm , about 7 μm , about 8 μm , about 9 μm , about 10 μm , about 11 μm , and about 12 μm . In one particular example, the substrate surface roughness is 6-8 μm .

[0037] In one example, the substrate is pre-heated using plasma jet air spraying before APS spraying. Pre-heating will increase the bonding strength between the substrate and the coating.

[0038] The coating is applied to the substrate at a thickness of 100-300 μm , achieving a porosity of less than 2%, an adhesion strength greater than 12 MPa, a dielectric strength greater than 12 mm/KV, a hardness greater than 550 Hv, and an etch rate of less than 5 nm/min.

[0039] In one example, the coating on the substrate as a thickness which is selected from the group consisting of 100-300 μm , 150-250 μm , 200-300 μm , about 100 μm , about 150 μm , about 200 μm , about 250 μm , and about 300 μm .

[0040] The advantages of the present invention are manifold:

(1) The composite powder prepared with YF3 and YAG as raw materials, and the composite coating obtained by APS spray coating are more uniform in structure and composition compared to the coating formed by single powder, and there are no channels such as grain boundaries and dislocations that can cause local rapid corrosion. In addition, the composite coating has extremely high strength and corrosion resistance.

(2) Under high-power plasma attack, the composite coating prepared with YF3 and YAG as disclosed herein has better plasma etching resistance than a single YF3 coating.

(3) The composite coating prepared with YF3 and YAG as raw materials solves the problem of the presence of a large number of unmelted particles generated by the plasma spraying process for preparing single YF3 coatings.

(4) The coating prepared by the method as disclosed herein contains YAG ($Y_3Al_5O_{12}$), which makes the bonding between the coating and the substrate stronger, thereby greatly reducing the risk of peeling of the coating in actual product production.

(5) The porosity of the composite coating prepared by the method as disclosed herein is less than 2%. Compared with the composite coating, the porosity of the conventional single YF3 coating is higher, so the composite coating is not prone to particle abnormality during operation.

5 [0041] As used in this application, the singular form “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise. For example, the term “a metal” includes a plurality of metals, including mixtures and combinations thereof.

[0042] As used herein, the term “comprising” means “including.” Variations of the word “comprising”, such as “comprise” and “comprises,” have correspondingly varied meanings.

10 Thus, for example, a composition “comprising” X may consist exclusively of X or may include one or more additional unrecited components.

[0043] As used herein, the term “about” in the context of concentration of a substance, size of a substance, length of time, or other stated values means +/- 5% of the stated value, or +/- 4% of the stated value, or +/- 3% of the stated value, or +/- 2% of the stated value, or +/- 1%
15 of the stated value, or +/- 0.5% of the stated value.

[0044] Throughout this disclosure, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically
20 disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

25 [0045] The disclosure illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms “comprising”, “including”, “containing”, etc. shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use
30 of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has

been specifically disclosed by preferred embodiments and optional features, modification and variation of the inventions embodied herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention.

5 [0046] The invention has been described broadly and generically herein. Each of the narrower species and subgeneric groupings falling within the generic disclosure also form part of the invention. This includes the generic description of the invention with a proviso or negative limitation removing any subject matter from the genus, regardless of whether or not the excised material is specifically recited herein.

10 [0047] Unless otherwise indicated, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which the invention belongs.

[0048] Other embodiments are within the following claims and non-limiting examples.

15 **EXAMPLES**

[0049] Non-limiting examples of the disclosure will be further described in greater detail by reference to specific Examples, which should not be construed as in any way limiting the scope of the disclosure.

[0050] **Example 1**

20 [0051] YF3 and YAG powders are sieved to obtain particle sizes of 20-40 μm and 40-60 μm , respectively. The powders are mixed in a **1:1** mass ratio and ball-milled at 200 rpm for 24-48 hours. The mixed powders are then dried and sprayed onto an aluminum test plate using APS coating, which has been cleaned, dried, sandblasted to a roughness of 6-8 μm , and blown clean. The APS parameters include main argon flow rate at 35 L/min, hydrogen flow rate at 9
25 L/min, current at 550 A, powder feeding argon flow rate at 4 L/min, a turntable speed is 60 r/min, and a spraying distance of 140 mm. The resulting coating has superior performance in terms of porosity, hardness, dielectric strength, and etch resistance compared to conventional YF3 coatings (Figure 1).

[0052] **Example 2**

30 [0053] A similar procedure is followed as in Example 1, but with a **2:1** mass ratio of YF3 to YAG powders. The mixed powders are sprayed under the same APS conditions. The resulting coating exhibits the best performance among all tested samples, with the lowest

porosity and highest dielectric strength (Figure 2). The coating in Example 2 has a porosity of less than 2%, an adhesion strength greater than 12 MPa, a dielectric strength greater than 12 mm/KV, a hardness greater than 550 Hv, and an etch rate of less than 5 nm/min.

[0054] **Example 3**

- 5 [0055] A 3:1 mass ratio of YF3 to YAG powders is used. The mixed powders are prepared and sprayed as described above. The coating performance (Figure 3) is slightly inferior to that of Example 2 but still superior to the traditional YF3 and YAG coatings used separately (Figure 4 and 5).

[0056] **Example 4 - Control**

- 10 [0057] Figure 4 shows coating obtained using single YF3 powder (purity $\geq 99.9\%$, particle size 10-50 μm) under the same APS coating conditions. Figure 5 shows coating obtained using single YAG powder (purity $\geq 99.9\%$, particle size 30-65 μm) under the same APS coating conditions. The performance of the coating with single powder is inferior compared to those obtained in Examples 1-3 (Table 1).

- 15 [0058] The performance in Table 1 is measured as follows: The cross section of the polished coated sample was scanned and photographed at an appropriate magnification using a COXEM desktop scanning electron microscope and the photo of the cross section of the coating was saved. The proportion of pores in the entire coating cross section image can be calculated using ImageJ software. Each group of samples was tested 5 times and the average value was taken.

- 20 [0059] The binding strength test was conducted in accordance with the international standard "GB/T 8642-2002". The sprayed $\Phi 25 \times 4 \text{ mm}$ disc sample was mixed with E-7 epoxy resin glue in a ratio of 9:1, and then the coating surface of the sample and the mold substrate surface were bonded and placed in an oven for curing at a curing temperature of 100 °C for more than 3 hours. After the cured sample was naturally cooled, the tensile binding strength
25 test was conducted on a microcomputer-controlled electronic universal testing machine of model XBD4504, and the tensile speed was set to 0.02 mm/min. The load value when the coating was peeled off was recorded, and the average value was taken after each group of samples was tested 5 times.

- [0060] The dielectric strength test was carried out using the Entai ET2671A withstand
30 voltage tester. The power supply was set to AC and the critical current was set to 0.5 mA. After measuring the breakdown voltage U value, the coating thickness h value of the test piece was

measured to obtain the dielectric strength $K=U/h$. Each group of samples was tested 5 times and the average value was taken.

[0061] The hardness of the coating cross section was directly detected using the Lai Shi Micro Vickers Hardness Tester (equipment model: HV-1000A). $F=1.96\text{ N}$ was selected as the test load and the holding time was 10 s. Each group of samples was tested 5 times and the average value was taken.

[0062] The etching rate is measured as follows: The polished coating surface was exposed to the fluorine-containing plasma of the three gases Ar: O_2 : CF_4 =45: 5: 40 at the set operating power of 250 W and the etching pressure of 20 Pa by the QX-400 plasma etcher for etching detection. All sample surfaces were partially shielded, that is, each sample had an etching area and a protection area. After the plasma etches the coating for a period of time t (10 h), the height difference h (etching depth) of the etched part of the sample relative to the protection zone is tested by a step profiler, and the etching rate $r=h/t$ can be obtained.

[0063] **Table 1: Coating performance test results**

	Coating cross-section porosity (%)	Binding strength (MPa)	Dielectric (kv/mm)	Hardness (HV)	Etching rate (nm/min)
Example 1	1.58	19.5	18.03	620.43	4.74
Example 2	1.46	20.25	18.51	654.75	4.18
Example 3	1.72	18.75	17.16	559.76	5.32
Control 1 (Single YF3 powder)	2.14	18.25	15.62	297.83	6.24
Control 2 (single YAG powder)	2.35	19.25	14.59	616.71	6.75

[0064] The present invention provides a method for producing high-performance APS thermal spray coatings with significantly improved properties, such as lower porosity, higher hardness, and enhanced etch resistance. The use of a YF3 and YAG hybrid powder offers a reliable solution to the challenges associated with traditional coatings, making it particularly suitable for use in the semiconductor industry.

[0065] **Industrial Applicability**

[0066] Various other modifications and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such modifications and adaptations come

5 within the scope of the appended claims.

Claims

1. A method of preparing a coating material for Atmospheric Plasma Spraying (APS), comprising preparing a hybrid powder by mixing yttrium fluoride (YF3) and yttrium aluminum garnet (YAG) powders,
 5 wherein the mass fraction of YAG powder in the hybrid powder is 9-50%;
 wherein the YF3 powder has a purity of $\geq 99.9\%$ and a particle size of 10-50 μm , and the YAG powder has a purity of $\geq 99.9\%$ and a particle size of 30-65 μm .
2. The method of claim 1, wherein the YF3 powder has a particle size of 20-40 μm , and the YAG powder has a particle size of 40-60 μm .
- 10 3. The method of claim 2, wherein the YF3 powder is sieved to obtain powder with a particle size of 20-40 μm , and the YAG powder is sieved to obtain powder with a particle size of 40-60 μm .
4. The method of claim 1, wherein the YF3 powder and the YAG powder is mixed in a mass ratio ranging from 1:1 to 10:1.
- 15 5. The method of claim 4, wherein the YF3 powder and the YAG powder is mixed in a mass ratio of 1:1 to 3:1, and the mass fraction of YAG powder in the hybrid powder is 25%-50%.
6. The method of claim 1, further comprising APS spraying the hybrid powder onto a substrate under APS spraying conditions to obtain a coating.
- 20 7. The method of claim 6, wherein the APS spraying conditions comprise a current of 500-700 A, a powder feed rate of 5-30 g/min, and a spraying distance of 100-300 mm.
8. The method of claim 7, wherein a plasma gas mixture of argon and hydrogen is used in APS, and main gas is argon; wherein a main argon flow rate is 35-65 NLPM, a powder feeding argon flow rate is 2-4.5 L/min, and a hydrogen flow rate is 5-10 NLPM.
- 25 9. The method of claim 8, wherein the main argon flow rate is about 35 L/min, the hydrogen flow rate is about 9 L/min, the current is about 550 A, the powder feeding argon flow rate is about 4 L/min, a turntable speed is 60 r/min, and the spraying distance is 140 mm.
10. The method of claim 8, wherein the argon has a purity of $\geq 99.999\%$.
11. The method of claim 9, wherein the YF3 powder and the YAG powder is mixed in a mass
 30 ratio of 2:1.
12. The method according to claim 6, wherein the APS spraying conditions further comprise a turntable speed of 40-80 r/min.

13. The method of claim 12, wherein the APS spraying conditions further comprise a turntable speed of about 60 r/min.
14. The method of claim 1, wherein the hybrid powder is prepared by ball-milling the mixed powders of YF3 and YAG in a high-speed ball mill with abrasive materials for 24-48 hours.
15. The method of claim 14, wherein the ball-milling is done at 150-300 rpm.
16. The method of claim 14, wherein the abrasive materials are zirconia with a particle size of about 5 mm.
17. The method of claim 6, further comprising drying the hybrid powder before APS spraying;
18. The method of claim 17, wherein the drying is done by oven at a temperature of 50-70 °C, for 30 min-1 h.
19. The method of claim 6, wherein the substrate is selected from the group consisting of aluminum, ceramics coated with Y₂O₃, and quartz coated with Y₂O₃.
20. The method of claim 19, wherein the substrate surface roughness is controlled between 4-12 μm before APS spraying.
21. The method of claim 20, wherein the subject is pre-heated using plasma jet air spraying before APS spraying.
22. The method of claim 6, wherein the coating has a porosity of less than 2%, an adhesion strength greater than 12 MPa, a dielectric strength greater than 12 mm/KV, a hardness greater than 550 Hv, and an etch rate of less than 5 nm/min.
23. The method of claim 22, wherein the coating has a thickness of 100-300 μm.