

## SPECIFICATION

**Title of the Invention:** Method for the Production of Water-Reactive Al Film and Constituent Member for Film-Forming Chamber

### Technical Field

[0001]

The present invention relates to a method for the production of a water-reactive Al film; and a constituent member for a film-forming chamber and in particular to a method for the production of a water-reactive Al film according to the flame spraying technique; and a constituent member for a film-forming chamber, which is covered with this Al film.

### Background Art

[0002]

In a film-forming apparatus for forming a thin film according to, for instance, the sputtering technique, the vacuum deposition technique, the ion-plating technique, or the CVD technique, a film of a metal or a metal compound, as a film-forming material, is inevitably adhered to a constituent member for a film-forming chamber, which is positioned within the film-forming apparatus during the film-forming process. As such constituent members for a film-forming chamber, there can be listed, for instance, an adhesion-preventive plate for inhibiting the adhesion of any film on the inner portions of a vacuum chamber other than a substrate, a shutter, a mask used for forming such a film only on the desired area on the substrate and a tray for conveying the substrate. A film having the same

composition as that of the intended thin film (a thin film to be formed on a substrate) is also deposited on or adhered to these members during the film-forming process. In this respect, it is the usual practice that these members are repeatedly used after the removal of the film adhered thereto.

[0003]

The film inevitably adhered to these constituent members for a film-forming chamber is thickened in proportion to the length of the working time of the film-forming process. Such an adhered film is peeled off, in the form of particles, from the constituent members for a film-forming chamber due to the action of the internal stress of the adhered film or the stress accumulated in the film through the repeated thermal hysteresis, and adhered to the substrate and this would accordingly result in the formation of a film having various defects. For this reason, it is the common practice that the constituent members for a film-forming chamber are subjected to the following cycle, at regular intervals; the removal or dismantlement thereof from the film-forming apparatus at a stage in which the adhered film is not yet peeled off, the washing thereof to remove the film adhered thereto, the subjection thereof to a surface-finishing treatment and the subsequent reuse thereof.

[0004]

When using a valuable metal such as Al, Mo, Co, W, Pd, Nd, In, Ti, Re, Ta, Au, Pt, Se and Ag, as a film-forming material, there has been desired for the establishment of a processing technique for the recovery of metals which do not take part in the formation of the film thereof on the surface of a substrate and are adhered to the constituent members other than

the substrate and for the development of a technique for making the members reusable.

[0005]

For instance, in the case of the adhesion-preventive plate used for inhibiting the adhesion of any film-forming material onto, for instance, the inner wall of the film-forming apparatus and the surface of a variety of such constituent members for a film-forming chamber, other than the surface of a substrate, the deposit formed during the film-forming process is, in the existing circumstances, peeled off from the foregoing members and/or the inner wall, for the reuse thereof. Currently used as such a method for the peeling off of this deposit include, for instance, the sandblasting technique, the wet etching technique which makes use of an acid or an alkali and the peeling technique which uses the hydrogen embrittlement by the action of, for instance, hydrogen peroxide and even the peeling method which makes use of the electrolysis thereof. In this case, when implementing the treatment for peeling off of the deposit, the adhesion-preventive plate is damaged in a treating liquid in no small quantities and therefore, the adhesion-preventive plate would be limited in the number of reusable times. For this reason, there has been desired for the development of a film-peeling technique which can reduce the occurrence of any damage of the adhesion-preventive plate as low as possible.

[0006]

In this respect, however, if the concentration of the peeled deposit present in the blasting waste generated during the foregoing sandblasting technique and in the waste liquor generated in the treatment with an agent such as an acid

treatment or an alkali treatment is low, the cost required for the recovery of the valuable metals is correspondingly quite high and accordingly, this method is not profitable. In such case, the deposit thus peeled off is accordingly handled as waste, under the present conditions.

[0007]

In the foregoing treatment with an agent, not only the cost for the agent per se is high, but also the cost required for the post-treatment of the used liquid containing such an agent is high and further the occurrence of any environmental pollution should be prevented. For this reason, there has been desired for the reduction of the amount of the foregoing agent to be used as low as possible. In addition, when carrying out the foregoing treatment with an agent, the film-forming material peeled off from the adhesion-preventive plate would be converted into other new chemical substances and therefore, the cost required for the recovery of only the film-forming material from the peeled deposit would further be piled up. Accordingly, the materials to be recovered are only the film-forming materials whose unit price is balanced with the recovery cost, in the existing circumstances.

[0008]

In addition to the method for peeling off of the deposit, as has been discussed above, there has been known a technique for recovering valuable metals which comprises the steps of implementing a film-forming process in an apparatus provided with constituent members covered with an Al film consisting of a water-reactive Al composite material having such characteristic properties that it can undergo a reaction in a moisture-containing atmosphere and can thus be converted

into substances soluble or active in water; peeling off and separating the film adhered to the Al film, during the film-forming process, through the reaction and/or dissolution of the Al film; and then recovering the valuable metals included in the film-forming material present in the adhered film thus peeled off (see, for instance, Patent Document 1 specified below). In this water-reactive Al composite material, the surface of a small or fine lump composed of Al crystalline grains is covered with a film of In and/or Si.

#### **Prior Art Literature**

##### **Patent Document**

[0009]

Patent Document 1: JP-A-2005-256063 (Claims).

#### **Disclosure of the Invention**

##### **Problems That the Invention is to Solve**

[0010]

Accordingly, it is an object, in a broad sense, of the present invention to solve the foregoing problems associated with the conventional techniques and more specifically to provide a method for the production of an Al film, which can be made soluble through the reaction with water in a moisture-containing atmosphere; and a constituent member for a film-forming chamber, which is covered with this Al film.

##### **Means for the Solution of the Problems**

[0011]

The method for the production of a water-reactive Al film according to the present invention is characterized in that

it comprises the steps of melting a material which comprises 4NAI or 5NAI as an Al raw material and added In in an amount ranging from 2 to 5% by mass on the basis of the mass of the Al raw material in such a manner that the composition of the material becomes uniform; thermally spraying the resulting molten material on the surface of a base material according to the flame spraying technique; and solidifying the sprayed molten material through quenching to thus form an Al film in which In is uniformly dispersed in Al crystalline grains.

[0012]

If the amount of the added In is less than 2% by mass, the reactivity of the resulting Al film with water is reduced, while if the amount of the added In is higher than 5% by mass, the reactivity of the resulting Al film with water becomes considerably high and the Al film may sometimes react with the moisture present in the atmosphere.

[0013]

The thermally sprayed Al film thus produced is in such a condition that In crystalline grains are highly uniformly dispersed in Al crystalline grains and therefore, the Al film can easily undergo a reaction with water in a moisture-containing atmosphere and can be dissolved in water while generating hydrogen gas.

[0014]

The method for the production of a water-reactive Al film according to the present invention is characterized in that it comprises the steps of melting a material which comprises 4NAI or 5NAI as an Al raw material, and added In in an amount ranging from 2 to 5% by mass and added Si, including the Si as an impurity of the Al raw material in a total amount ranging

from 0.04 to 0.6% by mass and preferably 0.04 to 0.2% by mass, on the basis of the mass of the Al raw material in such a manner that the resulting molten material has a uniform composition; thermally spraying the resulting molten material on the surface of a base material according to the flame spraying technique; and solidifying the sprayed molten material through quenching to thus form an Al film in which In is uniformly dispersed in Al crystalline grains.

[0015]

In this connection, if the amount of In is less than 2% by mass or if it exceeds 5% by mass, the problems described above would arise. On the other hand, if the total amount of Si is less than 0.04% by mass, the effect of controlling the reactivity, with water, of the resulting Al film is impaired, while if the total amount of Si exceeds 0.2% by mass, the reactivity of the resulting Al film with water begins to reduce and if the amount thereof exceeds 0.6% by mass, the reactivity, with water, of the Al film per se is reduced.

[0016]

The constituent member for a film-forming chamber of a film-forming apparatus according to the present invention is characterized in that the constituent member is provided, on the surface, with the foregoing water-reactive Al film.

[0017]

The constituent member for a film-forming chamber according to the present invention is further characterized in that the constituent member is an adhesion-preventive plate, a shutter or a mask.

## Effects of the Invention

[0018]

The thermally sprayed Al film produced by the flame spraying technique according to the present invention can easily be produced by a simple process while lowering the cost of production. Moreover, the Al film has such characteristic properties that it can be dissolved in water through the reaction with water in a moisture-containing atmosphere, even after the film experiences a thermal hysteresis phenomenon as a result of the film-forming process carried out at a temperature ranging from about 300 to 350°C.

[0019]

This thermally sprayed Al film can undergo a reaction with water in the presence of moisture and can effectively be dissolved in water while generating hydrogen gas. Accordingly, the following effects can be achieved by the Al composite film of the present invention: If the film-forming operation is carried out using a film-forming apparatus provided with constituent members for a film-forming chamber (for instance, an adhesion-preventive plate, a shutter and a mask), which are covered with the water-reactive Al film of the present invention, the inevitably adhered film consisting essentially of the film-forming material and adhered to the surface of, for instance, an adhesion-preventive plate during the film-forming process can be peeled off and/or separated from the surface of the constituent member for a film-forming chamber through the reaction and/or dissolution of this Al film and the valuable metals included in the film-forming material can be easily recovered from the adhered film peeled off from the surface of the constituent members and the constituent members can thus be reused over an increased number of times.

## Brief Description of Drawings

[0020]

Fig. 1 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Example 1.

Fig. 2 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Example 2.

Fig. 3 is a graph showing the effects of the gas flow rate, the wire feed rate and the heat-treatment temperature on the solubility of the thermally sprayed Al film, which is observed for the thermally sprayed Al film prepared in Example 2 and more specifically, Fig. 3(a) shows the relation between the wire feed rate ( $\text{cm}/\text{sec}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ) of the Al film; Fig. 3(b) shows the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ) of the Al film; and Fig. 3(c) shows the relation between the gas (air) flow rate ( $\text{L}/\text{min}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ) of the Al film.

Fig. 4 is a photograph showing the adhered film (deposited film) peeled off from the base material provided thereon with the thermally sprayed Al film prepared in Example 3.

Fig. 5 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Example 4.

Fig. 6 is a graph showing the relation between the

heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Reference Example 1.

Fig. 7 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), as a function of the temperature of water in which the thermally sprayed Al film is immersed, which is observed for the Al film prepared in Reference Example 1.

Fig. 8 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Reference Example 2.

Fig. 9 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Reference Example 4.

Fig. 10 is a graph showing the relation between the heat-treatment temperature ( $^{\circ}\text{C}$ ) and the reaction current density ( $\text{mA}/\text{cm}^2$ ), which is observed for the thermally sprayed Al film prepared in Reference Example 5.

#### **Mode for Carrying out the Invention**

[0021]

When producing a thin film in a film-forming apparatus according to a variety of film-forming techniques such as the sputtering technique, the interior of the film-forming chamber is subjected to the influence of repeated thermal hysteresis. For this reason, the surface of the constituent members such as an adhesion-preventive plate, which are positioned within the film-forming chamber and which are coated with the Al film

of the present invention, is also subjected to the influence of repeated thermal hysteresis. Accordingly, it would be necessary that the Al film, at the time of the film-formation through the thermal spraying technique before the film is subjected to the influence of the thermal hysteresis, is not only stable, but also easy to handle. At the same time, the thermally sprayed Al film provided thereon with adhered film inevitably attached thereto during the film-forming process should have such a solubility (or activity) that the Al film can easily be peeled off from the base material along with the adhered film and further should be stable, even after the Al film is influenced by the thermal hysteresis experienced in the film-forming process. In the case of the water-reactive Al film produced according to the present invention, such requirement for the solubility or activity would sufficiently be satisfied.

[0022]

The upper limit of the thermal hysteresis temperature within the foregoing film-forming chamber is on the order of about 300 to 350°C when the film is formed according to, for instance, the sputtering technique, the vacuum deposition technique, the ion-plating technique or the CVD technique. Therefore, it would in general be sufficient, from the practical standpoint, that the Al film has reactivity with water even after it is subjected to the influence of the thermal hysteresis up to a temperature of 300°C and it would be more suitable that the Al film preferably has reactivity with water even after the Al film experiences the thermal hysteresis up to a temperature of 350°C. In the case of the water-reactive Al film according to the present invention, such requirement

for the solubility would certainly be satisfied, as will be explained below more in detail.

[0023]

The foregoing solubility or activity of the Al composite film of the present invention is evaluated on the basis of the current density (in the present invention, also referred to as "reaction current density ( $\text{mA}/\text{cm}^2$ )") as determined by immersing a base material covered with the Al film in warm water maintained at a predetermined temperature (ranging from 40 to 130°C and preferably 80 to 100°C) and then determining the current density of the immersion liquid. This determination method is one which comprises the steps of determining the loss in weight observed for each sample before and after the immersion thereof in the treating liquid and then converting the result into the current density value while taking into consideration, for instance, the surface area of the sample and the immersion time of the same in the treating liquid. It can be said that the Al film provided thereon with adhered film inevitably attached thereto during the film-forming process has such a solubility (or activity) that the Al film can easily be peeled off from the base material along with the adhered film even after the Al film is subjected to the influence of thermal hysteresis experienced in the film-forming process, so long as the reaction current density as determined according to this method is not less than 50  $\text{mA}/\text{cm}^2$ .

[0024]

The present invention will hereunder be described with reference to the following embodiments.

[0025]

In the thermally sprayed Al film produced according to

the method for the production of the present invention, In is highly uniformly dispersed or distributed within the Al matrix and accordingly, the Al film can easily react with water within a moisture-containing atmosphere such as water, water vapor or an aqueous solution and as a result, it can thus be made soluble or active in water. Usable in the present invention as Al raw materials are, for instance, those having purities of 4N (99.99%) and 5N (99.999%). Each of them can be obtained by further treating an Al raw material having a low purity and prepared by the electrolytic process such as 2N (99%) Al or 3N (99.9%) Al according to the three layer electrolytic process or a method according to the partial solidification technique (the segregation technique) which makes use of the temperature difference between the solid and liquid phases upon the solidification. The principal impurities present in the 4NAl and 5NAl include Fe and Si and these Al raw materials further include, for instance, Cu, Ni and C as impurities other than the foregoing principal ones.

[0026]

In the Al-In system, the electrochemical potential difference between Al and In is in general quite high, but if the spontaneous oxide film of Al is present on the surface thereof, the ionization of Al is not advanced at all. However, when the spontaneous oxide film is once broken or removed and Al directly comes in close contact with In, the ionization of Al can be promoted very rapidly due to the potential difference between them. At this stage, In is, in the as-is status thereof, highly dispersed throughout the Al crystalline grains without causing any chemical change. In has a low melting point (157°C) and never forms any solid-solution with Al.

Accordingly, a desired Al film can be obtained by melting Al and In in such a manner that the composition thereof becomes uniform while taking care of the density difference between them and then thermally spraying the resulting molten material on the surface of a base material according to the flame spraying technique to thus give an Al film, as a result of the solidification of the deposited molten material through quenching as well as the compressive effect of the solidification.

[0027]

The added In is highly dispersed throughout the Al crystalline grains due to the action of the flame spraying process and it is maintained in the state in which it comes in direct contact with Al. The added In never forms a stable phase along with Al and therefore, the Al/In interface is maintained in its high energy state and can undergo a vigorous reaction with water within a moisture-containing atmosphere at the contact surface with water. In addition, In as an added element is in a highly dispersed condition and the H<sub>2</sub> gas bubbles generated during the reaction undergo expansion to thus generate a mechanical action. Therefore, the reaction products mainly comprising AlOOH are finely pulverized on the surface, due to the mechanical action, without forming any film thereon and dispersed in the liquid and the reaction or the dissolution reaction continuously and explosively proceeds at the successively renewed reaction boundary.

[0028]

The higher the purity of an Al raw material, the more conspicuous the behavior of the Al-In system described above and, in other words, the behavior is particularly conspicuous

in the case of 4NA1 and 5NA1 as compared with 2NA1 and 3NA1.

[0029]

According to the present invention, the thermally sprayed Al film is produced by forming a film on the surface of a base material to be treated in a predetermined atmosphere according to the flame spraying technique while using a composite material consisting of an Al-In system. More specifically, 4NA1 as an Al raw material and In are prepared, In in an amount of 2 to 5% by mass on the basis of the mass of the Al raw material is incorporated into the Al raw material to thus uniformly disperse or dissolve In in Al, the resulting blend is formed into a rod-like article, the surface of a base material serving as a constituent member for a film-forming chamber of a film-forming apparatus such as an adhesion-preventive plate is covered with the Al composite material by thermally spraying the molten article as a thermal spraying material according to the flame spraying technique, while using Ar or N<sub>2</sub> gas as a spraying gas, and then solidifying the sprayed, molten article through quenching to thus give a base material provided thereon with a desired water-reactive thermally sprayed Al film. The thermally sprayed film thus produced is one in which In crystalline grains (having a particle size of not greater than 10 nm) are highly uniformly dispersed in Al crystalline grains.

[0030]

In this case, the flame spraying process is preferably carried out at a wire feed rate ranging from 1.5 to 3.5 cm/sec and a flow rate of the spraying gas (Ar or N<sub>2</sub> gas) ranging from 500 to 1120 L/min. In this respect, if the wire feed rate is low (a rate of less than 1.5 cm/sec), the droplets of the molten

composite material formed are small and are correspondingly quite susceptible to oxidation, while if the wire feed rate is high (a rate of higher than 3.5 cm/sec), the resulting droplets are large and are correspondingly less susceptible to oxidation, and the complete dissolution of the resulting thermally sprayed film becomes quite difficult. If the amount of the spraying gas is small (an amount of less than 500 L/min), the speed of the thermally sprayed particles is reduced and are thus quite susceptible to oxidation, while if the flow rate thereof is large (an amount of higher than 1120 L/min), the higher the temperature of the thermal hysteresis to which the thermally sprayed Al film is exposed, the lower the solubility, in water, of the film.

[0031]

The thermally sprayed Al film consisting essentially of the foregoing 4NaI-In composite material, which is formed through the flame spraying process, can be handled with great difficulty in the as-is state since it certainly shows high activity and the solubility thereof in water within a moisture-containing atmosphere is likewise too high. However, if a desired amount of Si is added to this material, the resulting thermally sprayed Al film is reduced in its activity and the handling of the film becomes easy. Contrary to this, the thermally sprayed Al film after it is subjected to the influence of the thermal hysteresis is improved in its activity and the film can thus show a high ability of dissolution (activity) in an atmosphere in which moisture is present. For this reason, the Al film may sometimes be converted into powder at ordinary temperature in the atmosphere depending on the compositional ratio of In and Si in the film. In such case,

the Al film is preferably stored in an atmosphere free of any moisture (a vacuum atmosphere may likewise be used) in order to avoid the occurrence of the reaction thereof with the moisture in the atmosphere.

[0032]

Now, the present invention will be described with reference to the water-reactive Al film consisting essentially of a 4NAl-In-Si, by way of example. The method for the production of water-reactive Al film by the flame spraying technique according to the present invention, as mentioned above, can be applied to the method for the production of the thermally sprayed Al film consisting of 4NAl-In-Si.

[0033]

The foregoing thermally sprayed Al film is, for instance, produced according to the method detailed below:

More specifically, the method for the preparation of the thermally sprayed Al film comprises the steps of preparing 4NAl, In and Si; combining the Al raw material with In, in an amount ranging from 2 to 5% by mass, and Si (inclusive of the Si present in the 4NAl) in a total amount ranging from 0.04 to 0.6% by mass and preferably 0.04 to 0.2% by mass, while taking into consideration the amount of Si present in the 4NAl as a contaminant to thus uniformly dissolve and disperse the both In and Si into Al; forming the resulting uniform mixture into a form of a rod or a wire to thus give a material for flame spray; then covering the surface of a base material, for instance, a constituent member for a film-forming chamber of a film-forming apparatus such as an adhesion-preventive plate used in the chamber by spraying the material in its molten state on the surface of the base material according to the flame

spraying technique, while using Ar gas or N<sub>2</sub> gas as a spraying gas; and subsequently quenching and solidifying the sprayed material to thus give a base material provided thereon with a desired water-reactive thermally sprayed Al film. The thermally sprayed film thus formed is one in which In is present in Al crystalline grains in its highly, uniformly dispersed state, as has been described above.

[0034]

As has been described above, in the case of the thermally sprayed Al film produced using a composite material obtained by adding a predetermined amount of Si to an Al-In system, the activity, i.e. the solubility, in water, of the thermally sprayed Al film can be controlled without subjecting the Al film to any post-treatment and this accordingly prevents the thermally sprayed film from the dissolution through the reaction with the moisture present in the atmosphere and this also makes the handling of the film easier. Moreover, if the upper limit of the temperature during the thermal hysteresis phenomenon taking place within the film-forming chamber is on the order of about 300°C, an Al film showing practically acceptable activity or solubility in water can be produced using an Al composite material which comprises Si, incorporated therein, in an amount ranging from 0.04 to 0.6% by mass and preferably 0.05 to 0.5% by mass, while if the upper limit of the temperature during the thermal hysteresis phenomenon is high on the order of about 350°C, a thermally sprayed Al film showing practically acceptable activity or solubility in water can be produced using an Al composite material which comprises Si, incorporated therein, in an amount ranging from 0.04 to 0.2% by mass and preferably 0.05

to 0.1% by mass.

[0035]

In addition, when Bi is added instead of In in the foregoing 4NaI-In system, the thermally sprayed Al film consisting of such a 4NaI-Bi composite material has a quite high activity in the state immediately after the formation thereof through the thermal spraying process and the solubility thereof in a moisture-containing atmosphere is too high to easily handle the same. Moreover, the reactivity (solubility) of the film after the latter experiences thermal hysteresis is only slightly lowered. If a predetermined amount of Si is added to the 4NaI-Bi composite material, however, the activity of the resulting thermally sprayed Al film is reduced and the handling thereof correspondingly becomes easy and the thermally sprayed film after it experiences thermal hysteresis becomes significantly active and shows a high solubility (activity) in a moisture-containing atmosphere.

[0036]

The aforementioned method for the preparation of a water-reactive Al film by the flame spraying technique in an Ar or N<sub>2</sub> gas atmosphere, according to the present invention can likewise be applied to the preparation of a thermally sprayed Al film consisting of such a 4NaI-Bi-Si system. The thermally sprayed film thus prepared is one in which Bi is highly uniformly dispersed in Al crystalline grains, as has already been discussed above.

[0037]

For instance, 4NaI as an Al raw material, Bi and Si are prepared, Bi and Si (including contaminant Si) are incorporated into the Al raw material in an amount ranging from

of 0.8 to 1.4% by mass and in a total amount ranging from 0.25 to 0.7% by mass, respectively, on the basis of the mass of the Al raw material, while taking account of the amount of Si present in the Al raw material as an impurity, to thus uniformly disperse or dissolve Bi and Si in the Al raw material, the resulting blend is formed into a rod-like or wire-like article, and the surface of a base material serving as a constituent member for a film-forming chamber of a film-forming apparatus such as an adhesion-preventive plate is covered with the Al composite material by thermally spraying the molten article as a thermal spraying material according to the flame spraying technique, while using Ar or N<sub>2</sub> gas as a spraying gas, and then solidifying the sprayed, molten article through quenching to thus give a base material provided thereon with a desired water-reactive thermally sprayed Al film. The thermally sprayed film thus produced is one in which Bi is highly uniformly dispersed in Al crystalline grains.

[0038]

As has been discussed above, in the case of a thermally sprayed Al film consisting of an Al composite material obtained by incorporating a desired amount of Si into an Al-Bi system, the solubility of the thermally sprayed film can be controlled while the film is in the condition just after the formation thereof by the thermal spraying technique and accordingly, the dissolution of the thermally sprayed film through the reaction thereof with the moisture present in the atmosphere can be prevented with certainty and the handling of the film becomes easy. Moreover, if this thermally sprayed Al film experiences thermal hysteresis, the activity and solubility thereof increase along with the increase in the amount of added Si and

the increase in the temperature due to thermal hysteresis. In particular, when the film experiences thermal hysteresis of not less than 250°C, the film is converted into powder simply by allowing it to stand in the atmosphere for 2 to 3 hours. In this respect, however, if Si is added in an amount of not less than 0.8% by mass, the resulting Al film loses its solubility in water.

[0039]

Moreover, the amount of Cu present in the Al raw material as an impurity may greatly affect the solubility of the thermally sprayed Al film after the film experiences thermal hysteresis. More specifically, if the Cu content is high or it exceeds 40 ppm, the thermally sprayed Al film after experiencing thermal hysteresis of a high temperature has an insufficient solubility in water and accordingly, the film can be peeled off, with great difficulty, from a base material even when the temperature of the water used for the film-peeling treatment is increased. In addition, if the Cu content ranges from 30 to 40 ppm, it is necessary to raise the temperature of the water used in the treatment for peeling off of any deposited film (for instance, the temperature should be increased to not less than 100°C), if the Cu content is not higher than 30 ppm, the Al film can satisfactorily be dissolved in water maintained at a low temperature (such as a temperature of lower than 80°C) and accordingly, it can easily be peeled off. Furthermore, if the Cu content is not higher than 10 ppm, the thermally sprayed Al film obtained after it experiences thermal hysteresis of a high temperature (on the order of about 300 to 350°C) shows further excellent solubility in water.

[0040]

The foregoing method of the present invention for the production of a water-reactive Al film according to the flame spraying technique can likewise be applied to the production of thermally sprayed Al films consisting of Al-In (and/or Bi) systems and Al-In (and/or Bi)-Si systems, which make use of 4NAl or 5NAl having a given contaminant Cu content as an Al raw material. These thermally sprayed Al films can be produced by, for instance, the method described below:

[0041]

In other words, an intended Al film can be produced by incorporating, into 4NAl or 5NAl, as an Al raw material, containing Cu present in the raw material as an impurity in an amount of not higher than 40 ppm, preferably not higher than 30 ppm and more preferably not higher than 10 ppm, at least one metal selected from In and Bi in amounts ranging from 2 to 5% by mass and 0.7 to 1.4% by mass, respectively, on the basis of the mass of the Al raw material; melting the resulting blend in such a manner that the resulting molten material has a uniform composition; forming the material into a rod-like or wire-like article to give a material used for thermal spraying; covering the surface of a base material serving as a constituent member for a film-forming chamber of a film-forming apparatus such as an adhesion-preventive plate by thermally spraying the molten material as a thermal spraying material according to the flame spraying technique, while using Ar or N<sub>2</sub> gas as a spraying gas; and then solidifying the sprayed, molten material through quenching to thus give a base material provided thereon with a desired water-reactive thermally sprayed Al film. The thermally sprayed film thus produced is one in which In (and/or Bi) is highly uniformly

dispersed in Al crystalline grains, as has been discussed above. In this case, it is also possible to use, as the material for thermal spraying, those obtained by adding 0.04 to 0.6% by mass of Si to the Al-In systems, or 0.25 to 0.7% by mass of Si to the Al-Bi systems. In this respect, the amount of Si is expressed in terms of the total amount thereof including the contaminant Si present in the Al raw material.

[0042]

If the respective added amounts of at least one metal selected from In and Bi are less than the corresponding lower limits, the resulting Al film is impaired in its reactivity with water, while if the amount thereof exceeds each corresponding upper limit, the resulting Al film shows extremely high reactivity with water and it may sometimes undergo a reaction with moisture present in the atmosphere. In addition, if the amount of Si is less than the lower limit thereof, the effect of controlling the reactivity, with water, of the resulting Al film is impaired, and if the amount thereof exceeds the upper limit thereof, the reactivity, with water, of the Al film per se is reduced.

[0043]

When immersing the base material covered with the thermally sprayed Al film in warm water or spraying water vapor on the base material, as has been discussed above, for instance, when immersing the same in warm water whose temperature is set at a predetermined level, the reaction of the film with water is initiated immediately after the immersion, which is accompanied by the generation of hydrogen gas, the water is blackened as the reaction further proceeds because of the presence of, for instance, deposited In, finally the thermally

sprayed film is completely dissolved and precipitates consisting of, for instance, Al and In remain in the warm water. This reaction vigorously proceeds with the increase in the temperature of the water.

[0044]

If using a base material, whose surface is covered with the foregoing water-reactive Al film, as a constituent member for a film-forming chamber such as an adhesion-preventive plate or a shutter which is positioned within the film-forming chamber of a film-forming apparatus, as has been discussed above, the film composed of the film-forming material inevitably adhered to the constituent member for a film-forming chamber can easily be peeled off from the constituent member after the completion of the film-forming process carried out over a predetermined number of times or cycles and accordingly, the valuable metals can be recovered from the peeled Al film provided thereon with the deposited film of the film-forming material, with ease.

[0045]

In this case, used as a liquid for peeling off of the Al composite film is not any chemical reagent, but is water such as pure water, water vapor or an aqueous solution. Accordingly, it is possible to prevent the occurrence of any damage of the constituent member for a film-forming chamber such as an adhesion-preventive plate due to the dissolution of the latter in the liquid and these constituent members can be reused over a substantially increased number of times, as compared with that observed for the case in which a chemical reagent is used as such a liquid for peeling. Moreover, any chemical reagent is not used in the present invention and therefore, this would

result in the considerable reduction of the cost required for the post-treatment and in the preservation of the environment. Furthermore, most of the film-forming materials adhered to the constituent members for a film-forming chamber such as an adhesion-preventive plate is never dissolved in water and accordingly, the present invention has such an advantage that a material can be recovered in the form of a solid having a composition and a shape substantially identical to those observed for the film-forming material. In addition, the present invention shows such an advantage that not only the recovery cost can be dramatically reduced, but also the process to be used for the recovery can be simplified and accordingly, wide variety of materials can be recovered according to the present invention. For instance, if the film-forming materials are expensive metals such as precious metals and rare metals, the use of a constituent member for a film-forming chamber such as an adhesion-preventive plate, which is provided, on the surface thereof, with a thermally sprayed film consisting of the water-reactive Al composite material of the present invention, would permit the removal or peeling off of the film inevitably adhered to the constituent member during the film-forming operations and consisting of the film-forming material, simply by immersing the member in water or spraying water vapor on the same. This in turn permits the recovery of precious metals and rare metals without being accompanied by any contamination. Thus, the recovery cost can be reduced and the film-forming material can likewise be recovered while they are still in their high quality conditions.

[0046]

The present invention will now be described in more detail

below with reference to the following Examples.

#### **Example 1**

[0047]

The following Al-In compositions were prepared and then inspected for the relation between the Al purity, the In concentrations and the solubility or activity of the resulting thermally sprayed films and the results thus obtained were investigated and compared with one another, while using 3NAl, 4NAl and 5NAl as the Al raw materials. In this connection, the added amount of In is expressed in terms of that relative to the mass (weight) of the Al raw material used.

[0048]

- 3NAl - 2% by mass (wt%) of In;
- 3NAl - 3% by mass of In;
- 3NAl - 4% by mass of In;
- 4NAl - 2% by mass of In;
- 4NAl - 3% by mass of In;
- 4NAl - 4% by mass of In;
- 5NAl - 1.5% by mass of In;
- 5NAl - 2.5% by mass of In;
- 5NAl - 3.5% by mass of In.

[0049]

There were combined Al and In with each other at the rates specified above to thus make In uniformly disperse or dissolve in Al, each of the resulting blends was formed into a rod-like article serving as a material for thermal spraying, and then the material for thermal spraying was molten and thermally sprayed on the surface of a base material made of aluminum according to the rod flame spraying technique (heat source:  $C_2H_2-O_2$  gas; temperature: about  $3,000^{\circ}C$ ; wire feed rate: 2

cm/sec), while using Ar gas as a spraying gas (flow rate of spraying gas: 800 L/min) to thus give the corresponding thermally sprayed Al films. Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to 350°C (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace) in place of subjecting the same to the influence of thermal hysteresis possibly encountered during the film-forming process. Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment (0°C) and the same base material used above and obtained after the heat-treatment each were immersed in 300 mL of pure water maintained at 80°C, followed by the determination of the current density of each immersion liquid to estimate the solubility of each thermally sprayed film and the subsequent investigation of the results thus obtained. The results thus obtained are plotted on Fig. 1. In Fig. 1, the heat-treatment temperature (°C) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) as ordinate.

[0050]

As will be clear from the data plotted on Fig. 1, when using the Al raw materials having purities of 4N and 5N, the resulting Al films show high solubilities in water as compared with that observed for the Al film prepared using 3NAl as the Al raw material and further there is observed such a tendency that the higher the In concentration (not less than 2% by mass), the higher the solubility of the resulting Al film, for each purity of the Al raw material. For this reason, in the case of the Al-In systems obtained using Al raw materials each having a purity of not less than 4N and having an In concentration

of not less than 2% by mass, the resulting thermally sprayed Al film shows excellent solubility in water. However, when using 5NAI, the resulting thermally sprayed film has an extremely high activity and therefore the handling ability thereof is rather low, although the solubility thereof is good.

#### **Example 2**

[0051]

The following Al-In compositions were prepared and then inspected for the relation between the kind of spraying gas used in the flame spraying process and the solubility, in water, of the resulting thermally sprayed film. In this connection, the added amount of In is expressed in terms of that relative to the mass (weight) of the Al raw material used.

[0052]

- 3NAI - 3% by mass of In (spraying gas: Ar gas);
- 3NAI - 3% by mass of In (spraying gas: N<sub>2</sub> gas);
- 3NAI - 3% by mass of In (spraying gas: air);
- 4NAI - 3% by mass of In (spraying gas: N<sub>2</sub> gas);
- 4NAI - 3% by mass of In (spraying gas: air).

[0053]

There were combined Al and In with each other at the rates specified above to thus make In uniformly disperse or dissolve in Al, the resulting blend was formed into a rod-like article serving as a material for thermal spraying, and then the material for thermal spraying was molten and thermally sprayed on the surface of a base material made of aluminum according to the rod flame spraying technique (heat source: C<sub>2</sub>H<sub>2</sub>-O<sub>2</sub> gas; temperature: about 3,000°C; wire feed rate: 1.5 to 3.5 cm/sec), while using a variety of gases (flow rate of spraying gas: 500 to 1120 L/min) as the spraying gases to thus give the

corresponding thermally sprayed Al films. Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to 350°C (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace) in place of subjecting the same to the influence of thermal hysteresis possibly encountered during the film-forming process. Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment (0°C) and the same base material used above and obtained after the heat-treatment each were immersed in 300 mL of pure water maintained at 60°C or 80°C, followed by the determination of the current density of each immersion liquid to evaluate the solubility of each thermally sprayed film and the subsequent investigation of the results thus obtained. The results thus obtained are plotted on Fig. 2. In Fig. 2, the heat-treatment temperature (°C) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate.

[0054]

As will be clear from the data plotted on Fig. 2, when comparing the thermally sprayed Al film prepared using 4NAl with that prepared using 3NAl, it was found that the Al film prepared using 4NAl shows a solubility higher than that observed for the film prepared using 3NAl for all of the spraying gases tested. When using Ar and N<sub>2</sub> as the spraying gases, the resulting Al films show almost the same solubility and when using a heat-treatment temperature ranging from 300 to 350°C, the resulting Al films show solubilities in water higher than that observed for the Al film prepared using the air as the spraying gas.

[0055]

Separately, there were investigated the effects of the foregoing gas flow rate, the wire feed rate and the temperature for heat-treating the thermally sprayed Al film on the solubility of the resulting thermally sprayed Al film. The results thus obtained are plotted on Figs. 3(a), (b) and (c). In Fig. 3(a), the wire feed rate (cm/sec) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate; in Fig. 3(b), the heat-treatment temperature (°C) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate; and in Fig. 3(c), the gas (air) flow rate (L/min) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate.

[0056]

It was found that when immersing, in warm water maintained at 80°C, the base material covered with a thermally sprayed film (4NAI-3% by mass of In; spraying gas: N<sub>2</sub>) having a good solubility in water and obtained after the foregoing heat-treatment, the reaction of the film with water is initiated immediately after the immersion, which is accompanied by the vigorous generation of hydrogen gas, the water is blackened as the reaction further proceeds because of the presence of, for instance, deposited In, finally the thermally sprayed film cannot maintain the state such that it is firmly adhered to the base material due to the reaction with water, and the film is to be peeled off from the base material with dissolution. In the case of immersing, in warm water maintained at 60°C, the base material covered with the thermally sprayed Al film as mentioned above, the solubility of the film in water was not good.

### Example 3

[0057]

Platinum (Pt) film-forming operations were repeated over 30 cycles using a sputtering apparatus provided with an adhesion-preventive plate whose surface had been covered with a thermally sprayed film (film thickness:  $200\mu\text{m}$ ) of the 4NAL - 3% by mass of In prepared in Example 1 (spraying gas:  $\text{N}_2$ ) and then the adhesion-preventive plate to which the Pt film had been adhered was disassembled from the sputtering apparatus and treated with warm water maintained at  $80^\circ\text{C}$ . As a result, it was found that the thermally sprayed film is completely dissolved within 30 minutes and that the adhered film of Pt is peeled off from the adhesion-preventive plate, as shown in Fig. 4. Thus, Pt as the film-forming material could easily be recovered. At this stage, it was found that In and  $\text{AlOOH}$  is precipitated in the warm water.

### Example 4

[0058]

An example will be given in this Example, in which Si is added for the control of the activity (solubility) of the resulting thermally sprayed Al film.

[0059]

Al-In-Si Compositions were prepared using 4NAL as the Al raw material and incorporating In and Si (including the contaminant Si present in the Al raw material) into the Al raw material, the resulting compositions were used for preparing thermally sprayed Al films and the latter was inspected for the relation between the purity of the Al raw material used in the composition, the added amount of Si and the solubility, in water, of the resulting thermally sprayed film. In this

connection, the added amounts of In and Si are expressed in terms of those calculated on the basis of the mass of the Al raw material.

[0060]

- 4NAI (contaminant Si: 100 ppm) - 3% by mass of In;
- 4NAI - 3% by mass of In - 0.05% by mass of Si (including the contaminant Si of 90 ppm);
- 4NAI - 3% by mass of In - 0.1% by mass of Si (including the contaminant Si of 100 ppm);
- 4NAI - 3% by mass of In - 0.2% by mass of Si (including the contaminant Si of 100 ppm);
- 4NAI - 2.6% by mass of In - 0.5% by mass of Si (including the contaminant Si of 100 ppm).

[0061]

There was combined Al with In and Si at each corresponding rate specified above to make In and Si uniformly disperse or dissolve in Al, the resulting blend was formed into a rod-like article for use as a thermal spraying material, and then the thermal spraying material was molten and thermally sprayed on the surface of a base material made of aluminum according to the rod flame spraying technique (heat source:  $C_2H_2-O_2$  gas; temperature: about  $3,000^{\circ}C$ ; wire feed rate: 2cm/sec), while using Ar gas as a spraying gas (flow rate of spraying gas: 800L/min) to thus give each corresponding thermally sprayed film. Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to  $400^{\circ}C$  (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace) in place of subjecting the same to the influence of thermal hysteresis possibly encountered during the film-forming process.

Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment ( $0^{\circ}\text{C}$ ) and the same base material used above and obtained after the heat-treatment (after experiencing the thermal hysteresis) each were immersed in 300 mL of pure water maintained at  $80^{\circ}\text{C}$ , followed by the determination of the current density of each immersion liquid to evaluate the solubility of each thermally sprayed film and the subsequent investigation of the results thus obtained. The results thus obtained are plotted on Fig. 5. In Fig. 5, the heat-treatment temperature ( $^{\circ}\text{C}$ ) is plotted as abscissa and the reaction current density ( $\text{mA}/\text{cm}^2$ ) as ordinate.

[0062]

The data plotted on Fig. 5 clearly indicate that the addition of a predetermined amount of Si permits the control of the activity and, in other words, the solubility of the thermally sprayed film prior to the heat-treatment while the film is in the condition just after the formation thereof by the thermal spraying technique. Accordingly, the dissolution of the thermally sprayed film through the reaction thereof with the moisture present in the atmosphere can be prevented with certainty. Moreover, if the upper limit of the temperature of the thermal hysteresis within the film-forming chamber is on the order of about  $300^{\circ}\text{C}$ , it was found that a thermally sprayed Al film can be produced using an Al composite material having an added Si content ranging from 0.04 to 0.6% by mass and preferably 0.05 to 0.5% by mass and the resulting Al film would have a practically acceptable activity or solubility in water. On the other hand, if the upper limit of the temperature of the thermal hysteresis is high on the order of about  $350^{\circ}\text{C}$ ,

it was found that a thermally sprayed Al film having a practically acceptable activity or solubility can be produced using an Al composite material having an added Si content ranging from 0.04 to 0.2% by mass and preferably 0.05 to 0.1% by mass.

[0063]

It was found that when immersing, in warm water maintained at 80°C, the base material covered with a thermally sprayed Al film (4NAl - 3% by mass of In - 0.1% by mass of Si) having a good solubility in water and obtained after the foregoing heat-treatment, the reaction of the film with water is initiated immediately after the immersion, which is accompanied by the vigorous generation of hydrogen gas, the water undergoes blackening as the reaction further proceeds because of the presence of, for instance, deposited In, finally the thermally sprayed film cannot maintain the state such that it is firmly adhered to the base material due to the reaction with water, and the film is peeled off from the base material with dissolution.

#### **Example 5**

[0064]

Al-In-Si Compositions were prepared using 4NAl and 5NAl as the Al raw materials and incorporating In and Si (including the contaminant Si present in the Al raw materials) into the Al raw material, the compositions were then used for the preparation of thermally sprayed Al films and the resulting Al films each were inspected for the relation between the purity of the Al raw material used in the composition, the added amount of Si and the solubility, in water, of the resulting thermally sprayed film. In this connection, the added amounts of In and

Si are expressed in terms of those calculated on the basis of the mass of the Al raw material.

[0065]

- 4NAI - 2% by mass of In - 0.05% by mass of Si (including 90 ppm of the contaminant Si);

- 4NAI - 3% by mass of In - 0.1% by mass of Si (including 100 ppm of the contaminant Si);

- 4NAI - 4% by mass of In - 0.5% by mass of Si (including 100 ppm of the contaminant Si);

- 5NAI - 1.5% by mass of In - 0.05% by mass of Si (including 100 ppm of the contaminant Si);

- 5NAI - 2.6% by mass of In - 0.1% by mass of Si (including 100 ppm of the contaminant Si);

- 5NAI - 3.5% by mass of In - 0.5% by mass of Si (including 100 ppm of the contaminant Si).

[0066]

There were combined Al, In and Si with each other at the rates specified above and the same procedures used in Example 4 were repeated to thus form each corresponding thermally sprayed film (spraying gas used: Ar gas). Each of the thermally sprayed films thus produced was subjected to a heat-treatment according to the same procedures used in Example 4 (the film was treated in the atmosphere for one hour and it was subsequently cooled within a furnace). Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment (0°C) and the same base material used above and obtained after the heat-treatment (the base material which experienced thermal hysteresis) each were immersed in 300 mL of pure water maintained at 80°C, followed by the determination of the current density of each immersion

liquid to estimate the solubility of each thermally sprayed film and the investigation of the results thus obtained.

[0067]

As a result, there was observed the same tendency as that observed in Example 4. It was thus found that the addition of a predetermined amount of Si permits the control of the activity and, in other words, the solubility of the thermally sprayed film prior to the heat-treatment, while the film was in the condition just after the formation thereof by the thermal spraying technique. Moreover, if the upper limit of the temperature of the heat-treatment is on the order of about 300°C, it was found that a thermally sprayed Al film can be produced using an Al composite material having an added In content of not less than 2% by mass and an added Si content ranging from 0.04 to 0.6% by mass and that the resulting Al film would have a practically acceptable activity or solubility in water. On the other hand, if the upper limit of the temperature of the heat-treatment is high on the order of about 350°C, it was found that a thermally sprayed Al film having a practically acceptable activity or solubility would be able to be produced using an Al composite material having an added In content of not less than 2% by mass and an added Si content ranging from 0.04 to 0.2% by mass.

#### **Example 6**

[0068]

The same film-forming process disclosed in Example 3 were repeated except for using a sputtering apparatus provided with an adhesion-preventive plate whose surface had been covered with a thermally sprayed film (film thickness: 200μm) of the 4NA1 - 3% by mass of In - 0.1% by mass of Si prepared in Example

4 and then the same deposited film-peeling test used in Example 3 were likewise repeated except for using the foregoing adhesion-preventive plate. As a result, it was found that the thermally sprayed film is completely dissolved and that the adhered film of Pt is peeled off from the adhesion-preventive plate, as in the case of Example 3.

[0069]

**(Reference Example 1)**

The Al-Bi composite materials each having the following composition were prepared using 2NAl and 4NAl as the Al raw materials, the resulting compositions were then used for the production of thermally sprayed films according to the flame spraying technique and the resulting Al films each were inspected for the relation between the purity of the Al raw material used in the compositions, the concentration of Bi and the solubility, in water, of the resulting thermally sprayed film and the results were compared with each other. In this connection, the added amount of Bi is expressed in terms of that calculated on the basis of the mass of the Al raw material.

[0070]

- 2NAl - 0.2% by mass of Bi;
- 2NAl - 0.5% by mass of Bi;
- 2NAl - 1% by mass of Bi;
- 4NAl - 0.2% by mass of Bi;
- 4NAl - 0.5% by mass of Bi;
- 4NAl - 1% by mass of Bi.

[0071]

There were combined Al and Bi with each other at the rates specified above to thus make Bi uniformly disperse or dissolve in Al, each of the resulting blends was formed into a rod-like

article serving as a material for thermal spraying, and then the material for thermal spraying was molten and thermally sprayed on the surface of a base material made of aluminum according to the rod flame spraying technique (heat source:  $C_2H_2-O_2$  gas; temperature: about  $3,000^\circ C$ ; wire feed rate: 2 cm/sec), while using Ar gas as a spraying gas (flow rate of spraying gas: 800 L/min) to thus give the corresponding thermally sprayed Al films. Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to  $400^\circ C$  (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace). Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment ( $0^\circ C$ ) and the same base material used above and obtained after the heat-treatment each were immersed in 300 mL of pure water maintained at  $80^\circ C$ , followed by the determination of the current density of each immersion liquid to estimate the solubility of each thermally sprayed film and the subsequent investigation of the results thus obtained. The results thus obtained are plotted on Fig. 6. In Fig. 6, the heat-treatment temperature ( $^\circ C$ ) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate.

[0072]

As will be clear from the data plotted on Fig. 6, when using 2NA1 as the Al raw material, the resulting thermally sprayed Al film scarcely showed any solubility in water, while when using 4NA1 as the Al raw material, the resulting thermally sprayed Al film was found to be very highly soluble or active in water. In this respect, there was observed such a tendency that the higher the concentration of Bi, the higher the

solubility of the resulting Al film, for each purity of the Al raw material used. For this reason, the use of the Al raw material having a purity of not less than 4N would permit the production of a thermally sprayed Al film having an excellent solubility in water. However, it was found that when using 4NAl, the activity of the resulting Al film is too high and the thermally sprayed Al film is accordingly converted into powder when allowing it to stand at ordinary temperature, in the atmospheric air over 2 to 3 hours. Accordingly, the thermally sprayed Al film after it experiences thermal hysteresis should be stored in an atmosphere free of any moisture (a vacuum atmosphere may likewise be used). For this reason, it is in fact necessary to control the activity (solubility) thereof to thus make the handling ability thereof easy.

[0073]

Separately, the thermally sprayed Al film consisting of the foregoing 4NAl - 1% by mass of Bi was inspected for the solubility in water, according to the same procedures used above, while the temperature of the immersion water was changed to 40°C, 60°C and 80°C. The results thus obtained are plotted on Fig. 7. In Fig. 7, the heat-treatment temperature (°C) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate.

[0074]

As will be seen from the data plotted on Fig. 7, it was found that the higher the heat-treatment temperature, the higher the solubility, in water, of the Al film and that the solubility of the Al film is scarcely reduced even after the film is subjected to a heat-treatment at a temperature of not

less than 300°C.

[0075]

**(Reference Example 2)**

In view of the results obtained in Reference Example 1, the inventors of this invention herein prepared Al-Bi-Si composite materials each having the composition specified below by adding, to 4NAl as an Al raw material, Bi and Si (including Si as an impurity present in the Al raw material), the resulting composite materials each were used for the production of thermally sprayed Al films and the resulting Al films were inspected for the interrelation between the added amount of Bi, the added amount of Si and the solubility of the resulting thermally sprayed film in water. In this connection, the added amounts of Bi and Si are expressed in terms of those calculated on the basis of the mass of the Al raw material.

[0076]

- 4NAl - 1% by mass of Bi (the amount of the contaminant Si: 90 ppm);
- 4NAl - 1% by mass of Bi - 0.25% by mass of Si (including 90 ppm of the contaminant Si);
- 4NAl - 1% by mass of Bi - 0.5% by mass of Si (including 100 ppm of the contaminant Si);
- 4NAl - 1.4% by mass of Bi - 0.7% by mass of Si (including 100 ppm of the contaminant Si);
- 4NAl - 1% by mass of Bi - 0.85% by mass of Si (including 100 ppm of the contaminant Si).

[0077]

Using a material for thermal spraying produced by combining Al, Bi and Si together at each rate specified above, uniformly dissolving or dispersing Bi and Si in Al and then

forming each of the resulting blends into a rod-like article, a thermally sprayed film was formed by melting the material formed into the rod-like article and then thermally spraying the resulting melt of the article on the surface of an aluminum base material according to the rod flame spraying technique (heat source:  $C_2H_2-O_2$  gas; temperature: about  $3,000^{\circ}C$ ; wire feed rate: 2 cm/sec), while using  $N_2$  as a spraying gas (flow rate of spraying gas: 800 L/min). Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to  $350^{\circ}C$  (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace). Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment ( $0^{\circ}C$ ) and the same base material used above and obtained after the heat-treatment (the base material after experiencing thermal hysteresis) each were immersed in 300 mL of pure water maintained at  $80^{\circ}C$ , followed by the determination of the current density of each immersion liquid to estimate the solubility of each thermally sprayed film and the subsequent investigation of the results thus obtained. The results thus obtained are plotted on Fig. 8. In Fig. 8, the heat-treatment temperature ( $^{\circ}C$ ) is plotted as abscissa and the reaction current density ( $mA/cm^2$ ) is plotted as ordinate.

[0078]

The data plotted on Fig. 8 clearly indicate that the addition of a predetermined amount (0.25 to 0.7% by mass) of Si permits the control of the activity and, in other words, the solubility of the thermally sprayed film prior to the heat-treatment while the film is in the condition just after the formation thereof by the thermal spraying technique.

Accordingly, the dissolution of the thermally sprayed film through the reaction thereof with the moisture present in the atmosphere can be prevented with certainty. Moreover, there is observed such a tendency that the thermally sprayed Al film prepared after the heat-treatment shows an increase in the activity and is improved in the solubility in water as the amount of the added Si and the heat-treatment temperature increase, but the addition of Si in an amount of 0.85% by mass results in the formation of an Al film scarcely showing any solubility in water. In this connection, in the case of a thermally sprayed Al film formed from a material for thermal spraying to which Si is added in an amount ranging from 0.25 to 0.7% by mass, it was found that the thermally sprayed Al film obtained after subjecting it to a heat-treatment of 250°C is converted into powder when allowing it to stand at ordinary temperature in the atmosphere for 2 to 3 hours.

[0079]

In the case of a thermally sprayed Al film consisting of an Al-Bi-Si composite material, there was observed such a tendency that the solubility of the Al film is not reduced, but it is increased even when the heat-treatment temperature exceeds 350°C.

[0080]

It was found that when immersing, in warm water maintained at 80°C, the base material covered with a thermally sprayed Al film (4NAl - 1% by mass of Bi - 0.5% by mass of Si) having a good solubility in water and obtained after the foregoing heat-treatment, the reaction of the film with water is initiated immediately after the immersion, which is accompanied by the vigorous generation of hydrogen gas, the

water undergoes blackening as the reaction further proceeds because of the presence of, for instance, deposited Bi, finally the thermally sprayed film cannot maintain the state such that it is firmly adhered to the base material due to the reaction with water, and the film is peeled off from the base material with dissolution.

[0081]

**(Reference Example 3)**

Platinum (Pt) film-forming operations were repeated over 30 cycles using a sputtering apparatus provided with an adhesion-preventive plate whose surface had been covered with a thermally sprayed film (film thickness: 200 $\mu$ m) of the 4NAl - 1% by mass of Bi - 0.5% by mass of Si prepared in Reference Example 2 and then the adhesion-preventive plate to which the Pt film had been adhered was disassembled from the sputtering apparatus and treated with warm water maintained at 80°C. As a result, it was found that the thermally sprayed film is completely dissolved within 20 minutes and that the adhered film of Pt is peeled off from the adhesion-preventive plate. Thus, Pt as the film-forming material could easily be recovered. At this stage, it was found that AlOOH is precipitated in the warm water, in addition to Bi.

[0082]

**(Reference Example 4)**

Al-In Compositions were prepared using 2NAl, 3NAl and 4NAl as the Al raw materials and incorporating In into each corresponding Al raw material, the resulting compositions were used for the preparation of thermally sprayed Al films and the resulting Al films were inspected for the relation between the purity of the Al raw material, the amount of contaminant Cu

present therein and the solubility, in water, of the resulting thermally sprayed film. In this connection, the added amount of In is expressed in terms of that calculated on the basis of the mass of the Al raw material.

[0083]

- 2NA1 (content of contaminant Cu: <400 ppm) - 3% by mass of In;
- 3NA1 (content of contaminant Cu: 70 ppm) - 3% by mass of In;
- 3NA1 (content of contaminant Cu: less than the detection limit) - 3% by mass of In;
- 4NA1 (content of contaminant Cu: less than the detection limit) - 3% by mass of In.

[0084]

Using a material for thermal spraying produced by combining Al and In together at each rate specified above, uniformly dissolving or dispersing In in Al and then forming each of the resulting blends into a rod-like article, a thermally sprayed film was formed by melting the material formed into the rod-like article and then thermally spraying the resulting melt of the article on the surface of an aluminum base material according to the rod flame spraying technique (heat source:  $C_2H_2-O_2$  gas; temperature: about  $3,000^{\circ}C$ ; wire feed rate: 2 cm/sec), while using Ar gas as a spraying gas (flow rate of spraying gas: 800 L/min). Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to  $350^{\circ}C$  (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace). Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment ( $0^{\circ}C$ ) and the same base material used above and obtained after

the heat-treatment (the base material obtained after the film experienced thermal hysteresis) each were immersed in 300 mL of pure water maintained at 80°C, followed by the determination of the current density of each immersion liquid to evaluate the solubility of each thermally sprayed film and the subsequent investigation of the results thus obtained. The results thus obtained are plotted on Fig. 9. In Fig. 9, the heat-treatment temperature (°C) is plotted as abscissa and the reaction current density (mA/cm<sup>2</sup>) is plotted as ordinate.

[0085]

The data plotted on Fig. 9 clearly indicate that the solubilities of the thermally sprayed Al films prepared using 2NA1 to 4NA1 as the Al raw materials fall within the range practically acceptable as preferred. The thermally sprayed Al film prepared using, as the Al raw material, 4NA1 whose contaminant Cu content is not higher than the detection limit has solubility, in water, higher than those observed for the Al films produced using 2NA1 and 3NA1. In addition, it was found that the thermally sprayed Al films prepared using 3NA1 and 4NA1 as the Al raw materials whose contaminant Cu content is less than the detection limit are soluble or active in water with certainty since the reaction current densities thereof are not less than 50 mA/cm<sup>2</sup> at a heat-treatment temperature of 350°C. However, it was found that the solubilities of the thermally sprayed Al films prepared using 2NA1 and 3NA1 as the Al raw materials whose contaminant Cu content is not less than 70 ppm are insufficient after subjecting them to a heat-treatment at a temperature of 350°C. In the latter case, the Al films could not be dissolved in water even when the temperature of the treating liquid was set at 100°C.

[0086]

**(Reference Example 5)**

In this Reference Example, the following Al-In compositions were prepared by incorporating In in 4NAl as an Al raw material, the resulting Al-In compositions were used for the production of thermally sprayed Al films and the resulting Al films each were inspected for the relation between the contaminant Cu content in the Al raw material and the solubility, in water, of the resulting thermally sprayed films and the results thus obtained were investigated and examined. In this connection, the added amount of In is expressed in terms of that relative to the mass of the Al raw material used.

[0087]

- 4NAl (the amount of contaminant Cu: less than the detection limit) - 3% by mass of In;
- 4NAl (the amount of the contaminant Cu: <10 ppm) - 3% by mass of In;
- 4NAl (the amount of the contaminant Cu: 40 ppm) - 2.5% by mass of In;
- 4NAl (the amount of the contaminant Cu: 40 ppm) - 3% by mass of In;
- 4NAl (the amount of the contaminant Cu: 10 ppm) - 3% by mass of In;
- 4NAl (the amount of the contaminant Cu: 20 ppm) - 3% by mass of In;
- 4NAl (the amount of the contaminant Cu: 30 ppm) - 2.5% by mass of In.

[0088]

There were combined Al and In with each other at the rates specified above to thus uniformly dissolve or disperse In in

the Al raw material and then each resulting blend was formed into a rod-like article and this article was used as a material for the thermal spraying process. Then a thermally sprayed film was formed by melting each of the rod-like article and then thermally spraying the resulting melt of the article on the surface of a base material made of aluminum according to the rod flame spraying technique (heat source:  $C_2H_2-O_2$  gas; temperature: about  $3,000^{\circ}C$ ; wire feed rate: 2 cm/sec), while using Ar gas as a spraying gas (flow rate of spraying gas: 800 L/min). Each of the thermally sprayed films thus produced was subjected to a heat-treatment at a temperature ranging from 0 to  $350^{\circ}C$  (the film was treated in the atmosphere for one hour and subsequently cooled within a furnace). Thereafter, the base material provided thereon with the thermally sprayed film prior to the heat-treatment ( $0^{\circ}C$ ) and the same base material used above and obtained after the heat-treatment (one obtained after it had experienced thermal hysteresis) each were immersed in 300 mL of pure water maintained at  $80^{\circ}C$ , followed by the determination of the current density of each immersion liquid to estimate the solubility of each thermally sprayed film and the results thus obtained were investigated. The results thus obtained are plotted on Fig. 10. In Fig. 10, the heat-treatment temperature ( $^{\circ}C$ ) is plotted as abscissa and the reaction current density ( $mA/cm^2$ ) is plotted as ordinate.

[0089]

The data plotted on Fig. 10 clearly indicate that the solubilities of the thermally sprayed Al films prepared using 4NA1 as the Al raw material certainly fall within the range practically acceptable since the reaction current density thereof is sufficiently high. If the Al raw material has a

contaminant Cu content of less than 40 ppm, the resulting thermally sprayed Al films each were found to be soluble in water since they show the reaction current density of not less than 50 mA/cm<sup>2</sup> for the heat-treatment temperature ranging from 300 to 350°C. Moreover, the thermally sprayed Al film prepared using an Al raw material having a contaminant Cu content of 40 ppm was found to be insufficiently soluble in water after the heat-treatment carried out at 350°C, while the same Al film obtained after the heat-treatment carried out at 300°C was found to be sufficiently soluble in water since the reaction current density thereof was found to be not less than 50 mA/cm<sup>2</sup>. Incidentally, when the temperature of the treating liquid was set at 100°C, the thermally sprayed Al film obtained after the heat-treatment of 350°C was found to be soluble.

### **Industrial Applicability**

[0090]

According to the present invention, the surface of constituent members for a film-forming chamber of a vacuum film-forming apparatus, which is used in forming a thin film of a metal or a metal compound according to the sputtering technique, the vacuum deposition technique, the ion-plating technique and the CVD technique, is covered with the water-reactive Al film. Accordingly, the film inevitably adhered, during the film-forming process, to the surface of such a constituent member for a film-forming chamber can be peeled off therefrom in a moisture-containing atmosphere and can easily be recovered. Therefore, the present invention can be used in the fields in which these film-forming apparatuses are employed, for instance, in the technical fields related

to semiconductor elements and electronics-related machinery and tools for the purpose of increasing the number of reuse times of the constituent members for a film-forming chamber of a film-forming apparatus and of recovering the film-forming materials which contains valuable metals.

## CLAIMS

1. A method for the production of a water-reactive Al film comprising the steps of

melting a material which contains 4NaAl or 5NaAl as an Al raw material and added In in an amount ranging from 2 to 5% by mass on the basis of the mass of the Al raw material in such a manner that the composition of the material becomes uniform;

thermally spraying the resulting molten material on the surface of a base material according to the flame spraying technique; and

solidifying the sprayed molten material through quenching to thus form an Al film in which In is uniformly dispersed in Al crystalline grains,

wherein even after the water-reactive Al film is subjected to an influence of a thermal hysteresis experienced in a film-forming process implemented within a film-forming apparatus in which an upper limit of a thermal hysteresis temperature is on an order of 300 to 350°C, reaction current density, as determined by immersing the base material covered with the Al film in warm water maintained at a temperature ranging from 40 to 130°C and dissolving the Al film in water, is not less than 50 mA/cm<sup>2</sup>.

2. A method for the production of a water-reactive Al film comprising the steps of

melting a material which contains 4NaAl or 5NaAl as an Al raw material, and added In in an amount ranging from 2 to 5% by mass and added Si, including the Si as an impurity of the Al raw material, in a total amount ranging from 0.04 to 0.6% by mass, on the basis of the mass of the Al raw material in such a manner that the resulting molten material has a uniform composition;

thermally spraying the resulting molten material on the surface of a base material according to the flame spraying technique; and

solidifying the sprayed molten material through quenching

to thus form an Al film in which In is uniformly dispersed in Al crystalline grains.

3. A constituent member for a film-forming chamber of a film-forming apparatus characterized in that it is provided, on a surface thereof, with a water-reactive Al film prepared according to the method as set forth in claim 1 or 2.

4. The constituent member for a film-forming chamber as set forth in claim 3, wherein the constituent member is an adhesion-preventive plate, a shutter or a mask.