

DESCRIPTION

VACUUM DEPOSITION APPARATUS AND METHOD AND SOLAR CELL MATERIAL

Technical Field

The present invention relates to vacuum deposition apparatus and method and solar cell material.

Background Art

Known as vacuum deposition apparatuses for heating substrates to deposit thin films thereon are low pressure CVD and plasma CVD apparatuses and the like, using the technique of chemical vapor deposition (CVD), and vacuum evaporation, sputtering, ionization deposition apparatuses and the like, using the technique of physical vapor deposition (PVD).

In the CVD using apparatuses among these apparatuses, substrates heated to a predetermined temperature are retained in a deposition chamber kept at a vacuum, and source gas including elements which constitute film material is fed onto the substrates, whereby desired thin films are deposited on the substrates due to CVD by chemical reactions in the vapor phase and on the substrates. In such CVD, temperature of the substrates

for deposition often has closer relationship with film property than PVD and reactions in higher temperature tend to be required. Therefore, it is especially important in CVD to uniformly and quickly elevate temperature of the substrates.

Recently, in the plasma CVD among the CVD methods, to deposit films on a number of large-area substrates has increased importance in industrial applications. Above all, to deposit films on glass substrates has occupied an important position in applications. Glass substrates tend to be readily damaged when the substrates have uneven in-plane temperature distributions; to quickly and inexpensively elevate temperature of large-area substrates with such property involves technique with higher level of difficulty.

Thus, conventional vacuum deposition apparatuses are inefficient because of usually dealing with only one or two substrates at once; to concurrently treat with three or more substrates by such apparatuses would result in extreme increase in size of the apparatuses.

In a conventionally proposed vacuum deposition apparatus of this kind comprises, as shown for example in JP 2001-187332 A, a heating chamber for heating substrates above a deposition temperature, a load lock chamber and a deposition chamber for depositing thin films on the

substrates, the chambers being airtightly connected in the order named via gate valves, the substrates being heated by forced convection in the heating chamber, the gas passing through the heat source being fed in a circulating manner by an air blower, whereby hot gas is fed to the substrates to heat the same.

Furthermore, as shown in JP Patent 3211356, an inline-type plasma CVD apparatus may comprise an atmospheric heating furnace for preliminarily heating a substrate, a load chamber for heating in a vacuum the substrate introduced from the atmospheric furnace to a predetermined temperature, a reaction chamber for depositing film on the substrate and an unload chamber for cooling the substrate, the furnace and the chambers being arranged in series.

According to the above-mentioned JP 2001-187332 A, the plural large-area substrates can be concurrently dealt with without increasing the size of the apparatus, thereby substantially improving the productivity in the operation of depositing films on the substrates.

However, in said JP 2001-187332 A, it is difficult to heat the whole surfaces of the substrates to an uniform temperature in a short time. More specifically, in JP 2001-187332 A, heated hot gas is fluidized between the substrates to heat the substrates by forced convection,

the hot gas flowing in laminar flow in parallel with the surfaces of the substrates. Heating through such laminar flow may eventually obtain substantially uniform temperature in the direction of the surfaces when elevation in temperature of the substrates is completed; however, during the process of elevation in temperature, substantial nonuniformity in temperature tends to occur. During the process of elevation in temperature by heating with laminar flow and at an upstream side of the gas flow, heat of the gas flowing closer to the objects to be heated is transmitted to the objects, whereby the objects to be heated are heated and the gas is cooled. Thus cooled gas remains to be the laminar flow and flows downstream along the objects to be heated; during such movement, the gas robs heat from the hot gas flowing at positions away from the objects to be heated (that is, heat is replenished to the gas) and is heated again. Thus re-heated gas raises the temperature of the downstream objects to be heated. For these reasons, the temperature of the gas closer to the objects to be heated is gradually lowered as the gas flows downstream. To this end, the heating by the downstream laminar flow is slower in temperature elevation than that by the upstream one. Therefore, when the objects to be heated are made from material such as glass fragile to temperature gradient, they may be damaged

during temperature elevation due to thermal deformation.

As mentioned above, heat transfer from the gas at positions away from the objects to be heated to the gas closer thereto has a great role in the heating through the laminar flow. However, heat transfer in a direction perpendicular to the gas flow in the laminar flow is governed by diffusion and therefore is slow in velocity. As a result, the rate of temperature elevation downstream of the objects to be heated tends to be further lowered.

When the hot gas wide in width (or in the form of slit) is fluidized along the substrates to heat the same, deviation in gas flow rate in widthwise direction tends to occur, which disadvantageously prolongs the time period necessary for temperature elevation of the whole object to be heated to the required temperature; if the temperature gradient is remarkable during temperature elevation, thermal deformation may disadvantageously damage the objects to be heated.

In said JP Patent 3211356, the substrate is heated in the vacuum to the predetermined temperature through radiant heating using lamp heaters, so that it is insufficient in heating efficiency and takes much time for heating. Moreover, movement of the substrate is effected by a stainless chain conveyor so that concurrent heating of the plural substrates is difficult to carry out and

fundamentally it can be heated only one by one, leading to very poor productivity.

In said JP 2001-187332 A, the heating is effected at atmospheric pressure so that usable as heat source is city gas, kerosene or the like which has lower cost per unit calorific value and which has lower amount of carbon dioxide generated per unit calorific value; by contrast, JP Patent 3211356 has to use electric energy because of heating in the vacuum and therefore may be said to be a heating method with greater environmental burden.

In the heating by the lamp heaters shown in JP Patent 3211356, used is near infrared radiation with high energy density emitted from high-temperature heat source. When such heat source with high energy density is used and thermal capacity of the object to be heated differs largely and locally, there is a possibility of greater temperature nonuniformity in the direction of surface upon completion of temperature elevation. For example, when the thermal capacity of a holder holding the object to be heated is small and the object to be heated has larger thermal capacity, the temperature of the holder may be abnormally increased when the object to be heated is raised in temperature to a desired temperature. Moreover, as generally known, radiating and reflectance ratios to near infrared radiation substantially vary depending upon

kind of material and upon surface status. Therefore, when there is difference or change in surface status to infrared radiation within the surface of the object itself to be heated or between the object to be heated and the holder, uniform heating with good repeatability cannot be expected.

In view of the above, the invention has its object to carry out in a short period of time and with high efficiency heating of substrates as pretreatment of vacuum deposition formation thereon; uniform surface temperature is retained during thermal elevation and after completion of heating; moreover, the plural substrates are concurrently heated to enhance productivity of solar cell material or the like.

Summary of The Invention

The invention is directed to a vacuum deposition apparatus wherein substrates heated by a substrate heater are introduced to a deposition chamber for film deposition, said substrate heater comprising a heating chamber, flattened plate nozzles arranged in the heating chamber so as to be spaced apart from surfaces of the substrates introduced into said heating chamber by required spacing, each of said plate nozzles being provided with a gas intake, and a heating gas induction device for guiding

heating gas to the gas intakes of said plate nozzles, a face plate of each of said plate nozzles facing the corresponding substrate being formed with a plurality of gas spout holes so as to heat the substrate through impinging jet of the heating gas.

Thus, according to the invention, the heating gas is discharged through the gas spout holes on the plate nozzles so as to heat the substrates through the impinging jet, whereby heating efficiency is enhanced to shorten heating time for the substrates.

Generally speaking, when there is no target object for impingement, gas jet flow conditions may be classified, in the order of proximity to gas spout holes, into potential core, transition and developed regions. Depending upon to which region the substrate to be heated is located, heat transfer rate thereof may vary. By arranging the substrate up to the developed region near the transition region, higher heat transfer rate may be obtained. To the contrary, when the substrate is positioned far away from gas spout holes, no higher heat transfer rate may be obtained. The gas jet flow conditions may be also related with size of gas spout holes on the plate nozzle. The gas spout holes referred to herein are openings through which heating gas jets toward the substrate.

Shape of the gas spout holes such as square or circle may be selected depending upon design requirements; provided that a representative size of the spout holes is B , it is preferable that there is a relationship of $H/B < 20$ between this B and said required spacing H (the distance between the substrate and the plate nozzle). The representative size B is, for example, a side of a square when openings with square shape are selected; it is a diameter when round openings are selected. More generally, the representative size is a size employed when Reynolds number is determined which governs flow of the gas spout holes.

When the ratio H/B is less than 20, then a heating rate can be obtained which is industrially substantially higher.

In heating using impinging jet, effected is local heating around a stagnation point at a front of the gas spout hole. Local heat input is moderated by lateral heat transfer on the substrate, resulting in temperature increase of the substrate as a whole and thermal equalization of the substrate. With material such as glass which may be damaged due to steep local increase of temperature, great care is to be taken in this respect when heating is made through impinging jet. Provided that glass has enough thickness, then its in-plane heat

transfer is substantially great so that nonuniformity in glass in-plane temperature becomes smaller; alternatively, increasing number density of the gas spout holes may reduce nonuniformity.

In order to prevent the glass from being damaged, provided that the substrate is glass with thickness t and the distance between the respective gas spout holes to each other is r , then it is preferable to have the relationship $r/t < 20$.

Moreover, face plates on both sides of the plate nozzle may have gas spout parts, substrates being arranged to face the face plates on both sides of the plate nozzle. Furthermore, plate nozzles arranged oppositely to each other with the substrate between may have gas intakes at positions such that non-uniformity in gas spout amount due to pressure gradients in each of the plate nozzles may be balanced out. The plate nozzles may be comb-type nozzles which are arranged in plural in the form of comb with the substrates being arranged therebetween. The substrates may be introduced while supported by a carriage, the heating gas from the plate nozzles being introduced through said carriage into the heating gas induction device.

Since the plate nozzles are arranged oppositely to each other with the substrate between and are provided

with gas intakes at positions such that nonuniformity in gas spout amount generated in each of the plate nozzles due to pressure gradient may be balanced out, the substrate can be heated by more uniform surface temperature.

Since the heating gas is circulated through the carriage to the heating gas induction device after it have heated the substrate, stabilized are fluidization of the heating gas and heating of the substrate.

A further aspect of the invention is a vacuum deposition method which comprises arranging a substrate heater to be connected to a deposition chamber, introducing substrates into the substrate heater, injecting heating gas from gas spout holes on face plates of plate nozzles which are spaced apart from the substrates by required spacing, heating the substrates by jet heating, and introducing the substrates into the deposition chamber for film deposition after the substrates are heated to a uniform temperature.

The deposition method may be a plasma CVD method.

A still further aspect of the invention is solar cell material produced by the above.

Thus, according to the invention, the heating gas is introduced by the gas spout holes formed on the plate nozzles and the substrates are heated by the impinging jet,

so that heating efficiency can be enhanced to shorten heating time for the substrates.

Accordingly, solar cell material may be produced highly efficiently.

Brief Description of Drawings

Fig. 1 is a schematic plan view showing an overall layout of a vacuum deposition apparatus according to the invention;

Fig. 2 is a sectional front view showing an embodiment of a substrate heater in the vacuum deposition apparatus according to the invention;

Fig. 3 is a side view of a carriage;

Fig. 4 is a perspective view partly showing the carriage and rails;

Fig. 5 is an enlarged sectional view showing a part of a plate nozzle shown in Fig. 2;

Fig. 6 is a perspective view for explanation of gas spout holes formed on a face plate of the plate nozzle;

Fig. 7 is a partial sectional view showing a further embodiment of the plate nozzles for heating the substrates;

Fig. 8 is a partial sectional view showing a still further embodiment of the plate nozzles for heating the substrates;

Fig. 9 is a sectional plan view showing the plate nozzles which are arranged oppositely to each other with a substrate between and have gas intakes formed on opposite ends thereof; and

Fig. 10 is a diagram showing relationship of passage of time with change of temperature of substrate in a comparison between heating of substrate by impinging jet according to the invention and heating of substrate by conventional laminar flow.

Best Mode for Carrying Out the Invention

Embodiments of the invention will be described in conjunction with the drawings.

Fig. 1 is a schematic plan view showing an overall layout of a plasma CVD apparatus which is an embodiment of the vacuum deposition apparatus according to the invention. The plasma CVD apparatus comprises a substrate applied part 1, a substrate heater 3 with plate nozzles 33, a load lock chamber 6 with heat equalizers 4 and an evacuation device 5, a deposition chamber 11 with inductive coupling electrodes 7, an evacuation device 8, a source gas feeder 9 and a temperature controller 10, an unload lock chamber 13 with an ambient-air intake 2 and an evacuation device 12 and a substrate discharge part 14. Reference numerals 15a, 15b, 15c, 15d and 15e denote gate valves closable for

airtightness; and 16, a carriage adapted to be moved while vertically supporting a plurality of substrates 17.

A deposition operation on the substrates 17 supported by the carriage 16 is carried out in the following manner. The substrates 17 are vertically supported on the carriage 16 in the substrate applied part 1. In the embodiment shown in Fig. 1, six substrates 17 are supported on the carriage 16.

The carriage 16 with the substrates 17 supported is admitted into the heater 3 with the gate valve 15a being opened. Then, the gate valve 15a is closed and the substrates 17 are uniformly heated to a predetermined temperature by the action of the plate nozzles 33.

Then, the gate valve 15b is opened, and the carriage 16 is moved to the load lock chamber 6. Then, the gate valve 15b is closed, and the load lock chamber 6 is evacuated by the evacuation device 5 to a negative pressure same as that of the deposition chamber 11, the temperature of the substrates 17 being maintained to the above-mentioned predetermined temperature by the heat equalizer 4.

Thereafter, the gate valve 15c is opened and the substrates 17 are moved to the deposition chamber 11. Then, the gate valve 15c is closed and the source gas is supplied by the source gas feeder 9 to deposit silicon

films on the substrates 17 by the action of the inductive coupling electrodes 7, the predetermined negative pressure being maintained by the evacuation device 8 and the temperature of the substrates 17 being maintained to said predetermined temperature by the temperature controller 10.

After completion of the film deposition on the substrates 17, the gate valve 15d is opened and the substrates 17 are moved to the unload lock chamber 13 the interior of which has been evacuated by the evacuation device 12 to the negative pressure same as that of the deposition chamber 11. After the substrates 17 are discharged out to the unload lock chamber 13, the gate valve 15d is closed.

Then, the ambient-air intake 2 is opened to raise the pressure of the unload lock chamber 13 to the atmospheric pressure and the gate valve 15e is opened to guide the carriage 16 outside. The carriage 16 is moved to the substrate discharge part 14 and the substrates 17 with films deposited thereon and supported by the carriage 16 are taken out.

According to the vacuum deposition apparatus shown in Fig. 1, heating of the substrates 17 and silicon deposition on the heated substrates 17 can be conducted substantially in sequence, so that productivity can be enhanced and the plural substrates 17 supported on the

carriage 16 can be concurrently heated and deposited with silicon films, thereby attaining further enhanced productivity.

In the above-mentioned plasma CVD apparatus of Fig. 1, particulars of the substrate heater 3 will be described which heats the substrates 17 to a predetermined temperature in a short period of time and so as to have uniform surface temperature.

First of all, before referring to the substrate heater 3, the carriage 16 will be described. The carriage 16 comprises, as shown in Figs. 2-4, a rectangular support base 20 movable via wheels 19 on rails 18a and 18b arranged on an inner bottom of a heating chamber 23 which constitutes the substrate heater 3. Front and rear sides in the travel direction of the support base 20 have five support posts 21 and 21', respectively, spaced apart from each other by a required spacing in a lateral direction, the posts 21 and 21' extending vertically and being fixed oppositely to each other. The front and rear posts 21 and 21' leftmost in Fig. 4 and the posts 21 and 21' second-leftmost in Fig. 4 support at their right and left side surfaces, respectively, the substrates 17 via supports 22, the two substrates 17 being arranged oppositely. Similarly, the front and rear posts 21 and 21' third- and fourth-leftmost and the front and rear posts 21 and 21'

fifth- and sixth-leftmost have two of the substrates 17 in opposed relationship, respectively. Thus, on the carriage 16, the opposing three pairs of or six substrates 17 are arranged vertically.

The support base 20 has a longitudinally extending rack 24 on its lower surface, said rack 24 being in mesh with a pinion 25 carried by a shaft 26 which extends through the heating chamber 23 to be connected to an outer drive 27. Thus, the drive 27 is driven to rotate the pinion 25 which in turn can move the carriage 16 via the rack 24 along the rails 18a and 18b. Since the rails 18a and 18b are cut off for arrangement of the gate valves 15a, 15b, 15c, 15d and 15e, the drive 27 and pinion 25 are arranged for each of the chambers 6, 11 and 13 and the carriage 16 has the plural wheels 19 so as to run over the cuts of the rails 18a and 18b.

As shown in Fig. 2, the heating chamber 23 has in its interior an upper partition plate 28 which divides off the upper part of the carriage 16 and a side partition plate 29 which divides off one side (right side) in the travel direction of the carriage 16, the side partition plate 29 being fixed at its upper end to the upper partition plate 28 and extending at its lower end adjacent to the support base 20. The right rail 18b is in the form of laid-down ladder as shown in Fig. 4 so as to provide openings 30 for

gas distribution. The support base 20 of the carriage 16 which supports the substrates 17 is formed with gas passages 36 so as to allow the heating gas, which flows down between the substrates 17, to flow through downwardly. Thus, in the heating chamber 23, a gas circulation passage 31 is provided which communicates between the substrates 17 on the carriage 16, below the carriage 16, right-lower side of the side partition plate 29 and right-upper side of the upper partition plates 28 and which constitutes a part of a heating gas induction device 32.

Fixed to a bottom of the upper partition plate 28 at positions between the oppositely supported substrates 17 on the carriage 16 are upper ends of plate nozzles 33 each with a rectangular flat shape larger in area than each of the substrates 17 and in parallel with the substrates 17, the upper ends of the plate nozzles 33 constituting gas intakes 34 for communication between the gas circulation passage 31 above the upper partition plate 28 and interiors of the plate nozzles 33. Thus, the plate nozzles 33 are in the form of flat bags with the gas intakes 34 being provided at their tops. In Fig. 2, the three plate nozzles 33 are arranged in comb-like formation on the upper partition plate 28 so as to correspond to gaps each between each of the three pairs of opposing substrates 17.

Each face plate 33a of the flat bag-shaped plate nozzle 33 facing the corresponding substrate 17 is formed with, as shown in Figs. 2, 5 and 6, a plurality of gas spout holes 35 for injecting and impinging the heating gas vertically against a surface of the substrate 17, thereby providing a gas spout part A. Any arrangement of the gas spout holes 35 in this gas spout part A will do provided that temperature distribution of the substrates 17 becomes practically uniform; therefore, the gas spout holes may be regularly arranged to have for example rectangular or staggered arrangement; alternatively, they may be irregularly arranged to have constant area density.

The heating gas induction device 32 has a partition 37 intermediately of the gas circulation passage 31. The partition 37 is formed with an opening into which a circular fan 39 driven by a drive 38 extend. Furthermore, arranged between the partition 37 and the rail 18b with the openings 30 in the gas circulation passage 31 are gas heaters 40 for heating of the gas. Each of the gas heaters 40 shown in Fig. 2 comprises a heat transfer tube 41 arranged in the gas circulation passage 31 below the circulation fan 39, said heat transfer tube 41 being fed via a control valve 42 with hot fluid so as to heat the gas through heat exchange. In place of heating the gas through the heat transfer tubes 41, for example,

combustion cylinders may be arranged in the gas circulation passage 31 so as to heat the gas through combustion of fuel in the combustion cylinders; in this case, fuel flow rate is controlled by the control valve 42. Above the upper partition plate 28, there is provided a filter 43 for high-temperature.

A temperature detector 44 is arranged to sense gas temperature in the heating chamber 23 or preferably gas temperature just above the upper partition plate 28. Also arranged is a temperature controller 45 which receives input from the temperature detector 44 to control the control valve 42 so that the detected temperature may be maintained to a predetermined constant value, whereby heating of the gas by the gas heaters 40 may be controlled.

In Figs. 2 and 5, the face plates 33a on both sides of the plate nozzle 33 are formed with the gas spout parts A including the gas spout holes 35, and the substrates 17 are arranged to face the gas spout parts A, whereby only one surface of each of the substrates 17 may be heated; alternatively, as shown in Fig. 7, the gas spout part A is provided only one of the face plates 33a of the plate nozzle 33, whereby only one surface of each of the substrates 17 may be heated. Alternatively, as shown in Fig. 8, the gas spout part A is provided on the face plates 33a on both sides of the plate nozzle 33, whereby

the heating gas is injected from the gas spout holes 35 to concurrently heat both the surfaces of the substrate 17.

As shown in Fig. 9 which is the sectional plan view, in the plate nozzles 33 arranged oppositely to each other with the substrate 17 between and having the gas spout parts A at their surfaces facing the substrate 17, it is preferable that the plate nozzles 33 have gas intakes 34 at positions such that nonuniformity in gas spout amounts due to the pressure gradients in the respective plate nozzles 33 may be balanced out. More specifically, the plate nozzles 33 arranged oppositely to each other with the substrate 17 between may have the gas intakes 34 which are arranged at mutually (vertically or laterally) opposite ends. In Fig. 9, (left) one of the plate nozzles 33 has the gas intake 34 top on the paper or figure while the other (right) plate nozzle 33 has the gas intake 34 bottom on the paper or figure. Thus, the heat gas introduced from the one gas intake 34 into the one plate nozzle 33 and that introduced from the other gas intake 34 into the other plate nozzle 33 are mutually oppositely fluidized to be injected through the respective gas spout holes 35.

Mode of operation of the above embodiments will be described.

In the structure of Fig. 2, the circulation fan 39 is

driven by the drive 38 to fluidize the gas in the gas circulation passage 31 from below to above while hot fluid is fed to the heat transfer tubes 41 of the gas heaters 40 to heat the gas. The hot gas heated by the gas heaters 40 is fed by the circulation fan 39 to the filter 43 for purification, and then is introduced via the gas intakes 34 into the respective plate nozzles 33 where it is blown perpendicularly against the surfaces of the substrates 17 in an impinging manner via the plural gas spout holes 35 of the gas spouts A on the face plates 33a of the plate nozzles 33. Thus, the substrates 17 are heated.

The heating gas blown to the substrates 17 to heat the same flows down between the confronting substrates 17 and flows downstream through the gas passages 36 of the support base 20, and introduced again into the gas heater 40 via the openings 30 of the rail 18b.

The temperature controller 45 to which the detected temperature by the detector 44 above the upper partition plate 28 is inputted controls the flow rate of the hot fluid by the control valves 42, thereby controlling the temperature of the heating gas introduced into the plate nozzles 33 to be always to a predetermined constant value; thus, the substrates 17 are always and surely heated to the targeted or predetermined temperature. In place of controlling the flow rate of the hot fluid fed to the gas

heaters 40, the circulated amount of the heating gas through the circulation fan 39 may be controlled to control the heating temperature of the substrates 17.

As shown in Figs. 5, 7 and 8, the plate nozzles 33 blow the heating gas vertically against the surfaces of the substrates 17 in an impinging manner through the respective gas spout holes 35 of the gas spouts A, so that the substrates 17 are heated with high efficiency through the impinging jet produced by the impinge of the heating gas.

Fig. 10 shows relationship of passage of time with change in temperature of the substrate in a comparison between a case (solid line) where, as shown in Figs. 5, 7 and 8, the heating gas is vertically blown against the surface of the substrate 17 in an impinging manner to thereby heat the substrate through the impinging jet and a case (dotted line) where the substrate is heated by the heating gas in creeping or laminar flow in parallel with the substrate as in the prior art shown in said JP 2001-187332 A. In Fig. 10, temperature change of the substrate 17 is qualitatively shown when the substrate is heated to a target range, using the same heating gas flow rate.

As is clear from Fig. 10, in order to attain the target temperature range, the heating (dotted line) in the laminar flow will require longer time than the heating

(solid line) by the impinging jet according to the invention. Therefore, when the heating time is to be shortened in heating in the laminar flow, supply of the heating gas must be increased substantially, leading to increase in running cost. Moreover, flowing of such great amount of heating gas along the substrate 17 makes it further difficult to adjust uniform widthwise flow rate of the substrate 17, disadvantageously resulting in further tendency toward nonuniform surface temperature of the substrates 17.

As mentioned above, the gas spout holes 35 of the gas spout parts A on the face plates 33a of the plate nozzles 33 blow the heating gas perpendicularly against the surfaces of the substrates 17 in the impinging manner so that the substrates 17 are heated by the impinging jet, whereby the substrates 17 can be heated in a short time period and with high efficiency.

Moreover, the gas spout holes 35 of the gas spouts A on the face plates 33a are in an arrangement suitable for uniform heating of the substrate 17 in its surface direction so that the surface temperature of the substrates 17 can be uniformly controlled with high degree of accuracy.

In the embodiments of the invention, the gas spout holes 35 are round. Moreover, as main conditions of the

experiments, their diameter B was set to be 3 mm and the spacing H between the face plate 33a and the substrate 17 was set to 30 mm. While the diameter B was constant, the spacing H was changed in a range of 15 mm to 150 mm so as to measure the rate in temperature rise of the substrate 17. As a result, no substantial change was seen with the spacing of 15 mm to 20 mm. With the spacing of 15 mm to 30 mm, once the rate of temperature rise was increased to have a maximum value; then with the spacing of more than 30 mm, temperature rising rate was lowered. With the spacing of 60 mm, the temperature rising rate was lowered to 60% of the maximum. Similar experiments were carried out with the diameter of the gas spout holes 35 being 2 mm; then, with the spacing of more than 40 mm, temperature rising rate was violently lowered.

It is generally said that when heating is effected by impinging jet, heat transfer coefficient is complexly varied depending upon spacing H, diameter B, flow rate and the like so that heat transfer coefficient cannot be uniformly described. However, these experiments revealed that when industrially applicable conditions such as flow rate are added and the ratio H/B is retained below 20, then the substrates 17 can be speedily elevated in temperature.

Moreover, according to the present embodiments,

experiments were effected with the gas spout holes 35 having the pitch r of 35 mm and arranged in square arrangement, glass with thickness of 4 mm being used as substrates 17. Temperature difference was measured between the stagnation point at the front of the gas spout hole 35 and point farthest from the gas spout hole 35. When the heating was carried out with the main conditions of the experiments, the maximum temperature difference between the respective points became 30°C during temperature rising. It has been empirically known that glass substrate has higher probability of being damaged when in-plane temperature difference thereof exceeds 50°C . Thus, it was confirmed that there is substantially no probability of being damaged in the present embodiments. However, it was found out that when the pitch of the gas spout holes 35 is increased to more than 60 mm, then the glass substrates will be damaged due to glass in-plane temperature difference. Moreover, it was also deduced that when thickness of the glass substrate is reduced to less than 2 mm, then in-plane thermal transfer of the glass substrate slows, resulting in damage of the glass substrates.

With respect to the heating gas introduced into the plate nozzle from the gas intake 34 at the upper end of the bag-shaped plate nozzle 33, because of pressure

variation between the upper and lower parts, the heating gas amount injected from the lower gas spout holes 35 may be small relative to the heating gas amount from the upper gas spout holes 35; as a result, there may be a possibility of temperature rise deviation between the top and bottom of the substrate 17. However, in fact, it was found out that such temperature deviation can be substantially prevented. More specifically, in order to make substantially equal the gas spout amount of the upper gas spout holes 35 and that of the lower gas spout holes 35, it is effective to minimize pressure difference between upstream and downstream sides of the plate nozzle 33; to this end, by designing the plate nozzle 33 to have greater space volume, the gas spout amounts of the upstream and downstream sides are made substantially equal, thereby substantially removing the temperature deviation.

As shown in Fig. 9, when the plate nozzles 33 arranged oppositely to each other with the substrate 17 between have gas intakes 34 which are arranged mutually opposite ends thereof, the pressure gradients in the plate nozzles 33 are mutually reversely oriented and are balanced out, so that sum of the heating gas spout amounts from the left and right plate nozzles 33 arranged oppositely to each other with the substrate 17 between is uniform longitudinally (vertically in Fig. 9), whereby the

substrates can be heated to uniform temperature.

The substrates 17 heated to the predetermined and uniform surface temperature by the substrate heater 3 as mentioned above are introduced to the load lock chamber 6 in Fig. 1 where its temperature is maintained by the heat equalizer 4. Then, the substrates 17 are introduced into the deposition chamber 11 for deposition of silicon films while the substrates 17 are maintained to said predetermined temperature by the temperature controller 10 in the deposition chamber 11. Thus, the silicon films are deposited on the substrates 17 with their uniform surface temperature being maintained, so that silicon films of good quality are deposited on the substrates 17.

Thus, according to the above-mentioned vacuum deposition apparatus, solar cell material of good quality can be produced with high efficiency.

It is to be understood that the invention is not limited to the above embodiments and that various changes and modifications may be made without departing from the scope of the invention. For example, it may be applicable to any vacuum deposition apparatuses other than the plasma CVD apparatus such as sputtering apparatus, vacuum evaporation apparatus or ionization deposition apparatus which require heating of the substrates. Shape of the plate nozzles may be varied variously. Any heating gas

induction device other than that shown in the above-mentioned embodiment may be employed.

Industrial Applicability

Heating of substrates, which is effected as pretreatment of vacuum deposition treatment on the substrates, can be effected in a short time period and with high efficiency; during the temperature rising and after completion of heating, uniform surface temperature can be obtained; moreover, the plural substrates can be heated concurrently, whereby a product such as solar cell material of good quality can be produced with high efficiency.

CLAIMS

1. A vacuum deposition apparatus wherein substrates heated by a substrate heater are introduced into a deposition chamber for film deposition, characterized in that said substrate heater comprises a heating chamber, flattened plate nozzles arranged in the heating chamber so as to be spaced apart from surfaces of the substrates introduced into said heating chamber by required spacing, each of said plate nozzles being provided with a gas intake, and a heating gas induction device for guiding heating gas to the gas intakes of the plate nozzles, each of said plate nozzles having face plates facing said substrates, a face plate of each of said plate nozzles facing the corresponding substrate being formed with a plurality of gas spout holes so as to heat the substrates through impinging jet of the heating gas, said heating gas being circulated through the heating gas induction device after the heating gas injected from gas spout holes to heat the substrates.

2. The vacuum deposition apparatus as claimed in claim 1, characterized in that, provided that a representative size of said gas spout holes is B, there is a relationship of $H/B < 20$ between this B and said required spacing H.

3. The vacuum deposition apparatus as claimed in claim 1, characterized in that, provided that a typical size of said gas spout holes is B, there is a relationship of $H/B < 20$ between this B and said required spacing H and, provided that said substrates are made of glass with thickness t and mutual distance between said gas spout holes is r, then there is a relationship $r/t < 20$.

4. The vacuum deposition apparatus as claimed in claim 1, characterized in that each of said plate nozzles has opposite face plates each of which has gas spout holes, said substrates being arranged to face the opposite face plates of each of the plate nozzles.

5. The vacuum deposition apparatus as claimed in claim 1, characterized in that the plate nozzles arranged oppositely to each other with the substrate between have gas intakes at positions where nonuniformity in gas spout amounts due to pressure gradients in the respective plate nozzles may be balance out.

6. The vacuum deposition apparatus as claimed in claim 1, characterized in that said plate nozzles are comb-like nozzles arranged in comb formation between the substrates.

7. The vacuum deposition apparatus as claimed in claim 1, characterized in that said substrates are introduced while supported on the carriage, the heating gas injected from said plate nozzles being introduced into said heating gas induction device through said carriage.

8. A vacuum deposition method, characterized by arranging a substrate heater to be connected to a deposition chamber, introducing substrates into the substrate heater, injecting heating gas from gas spout holes on face plates of plate nozzles which are spaced apart from the substrates by required spacing, heating the substrates by impinging jet, circulating the heating gas through the heating gas induction device so as to be heated after the heating gas heats the substrates, supplying the heating gas to the plate nozzle, and introducing the substrates into the deposition chamber for film deposition after the substrates are heated to a uniform temperature.

9. The vacuum deposition method as claimed in claim 8, characterized in that said deposition method is a plasma CVD method.

10. Solar cell material produced by the vacuum deposition method as claimed in claim 8.

11. Solar cell material produced by the vacuum deposition method as claimed in claim 9.