

Method and Apparatus for the Heat-Treatment
of a Plate-Like Member.

The present invention relates to a heat-treating technique, and more particularly to the heat treatment of a plate-like member such as a semiconductor wafer, and also to an apparatus for heat-treating such a member.

As is well known, when producing a semiconductor element, the semiconductor wafer is heat treated during crystal growth processing, impurity diffusion processing, crystal annealing processing, passivation film forming processing, dry etching processing and photoresist baking processing.

Heretofore, heating systems employing a heater, high-frequency heating etc. have been used to achieve such heat treatments. The heat-treating methods operate by supporting the semiconductor wafer on a jig or the like in a heating atmosphere so that the wafer is heated, or by putting the semiconductor wafer directly on a heating source such as a heating block. In any such method, the wafer lies in contact with its support.

In order to heat the wafer accurately with the above methods, the support (usually the jig, or heater block) must also be heated as accurately as the wafer itself. Simultaneously, the surrounding inner wall of the processing chamber containing

the wafer is heated. With the above methods, therefore, the heating efficiency is very poor, and the processing period is long. Another disadvantage is that, when the jig or the heater block is large, the heat-treating apparatus becomes large in size.

Similarly, when the heat treatment is accompanied by a reaction, parts other than the wafer, which do not take part in the reaction are heated. Therefore the reaction takes place on parts other than the wafer requiring no reaction, and an unnecessary product is formed on the supporting jig or the inner wall of the processing chamber. As a result, when manufacturing a semiconductor element by heat treatment accompanied by a reaction, the product of the reaction falls on the wafer in which the semiconductor element is formed, thereby degrading the quality of the manufactured semiconductor element.

Also, incidental operations such as the operation of clearing away the unnecessary product formed on the inner wall of the processing chamber must be performed.

The present invention seeks to provide a method of heat-treating a plate-like member in which the member may be heated without heating its surroundings. This is achieved by providing a method of heat-treating a plate-like member, comprising floating and rotating the plate-like member such that there is substantially no horizontal

movement of the plate-like member, and irradiating the plate-like member with electromagnetic radiation, so as to heat it.

In this way the plate-like member, which may be for example a silicon wafer, may be heated inductively
5 with little or no heat loss, as the surrounds may be made of materials which have low electromagnetic loss.

The plate-like member may be made to float by the action of a flow of a gas, which would cause the member to rotate, enabling uniform heating to be
10 achieved. The intensity of the electromagnetic radiation may be controlled in dependence upon the temperature of the member as this enables accurate determination temperature to which the member is to be heated.

15 By suitably focussing the electromagnetic radiation on a part of the member, that part may be selectively heated. This selective heating is not possible in the prior art arrangements.

Embodiments of the present invention will
20 now be described in detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a sectional view of parts of a heat-treating apparatus, being a first embodiment 1 of the present invention;

25 Figure 2 is an exterior view of a microwave baking apparatus being a second embodiment of the present invention;

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Figure 3 is a sectional view of parts of the microwave baking apparatus shown in Figure 2;

Figures 4A to 4D are sectional views of the processing steps involved in the photolithography of a semiconductor wafer; and

Figure 5 is a plan view of a jig of the second embodiment of the present invention.

Embodiment 1

Figure 1 is a sectional view which shows parts of a heat-treating apparatus according to a first embodiment of the present invention. It illustrates an apparatus in which a protective film is formed on a surface of a semiconductor wafer.

A processing chamber 1 in the form of a box-like enclosure is made of a material adapted to reflect microwaves (electrically conductive or low resistivity material, for example, metal), and defines a chamber for heating a semiconductor wafer 2. The metal forming the processing chamber 1 may be e.g. stainless steel or aluminium, and it is particularly advantageous to use the aluminium of low resistivity. In the central part of the processing chamber 1, is a funnel-shaped jig 3 (holding mechanism) having a Bernoulli chuck structure which causes the semiconductor wafer 2 to float in a gaseous medium so that it is not in contact with the jig 3 or parts of the processing chamber 1. The

jig 3 is formed of a material which passes microwaves and whose electromagnetic loss is low, for example, tetrafluoroethylene resin or quartz. The use of quartz permits treatment at temperatures in excess of 1000°C. In contrast, tetrafluoroethylene resin degrades and is unusable when it is exposed to a temperature of above about 350°C. To provide the medium in which the wafer 2 floats, a cleaned inert gas 4 or reaction gases 5, 6 are supplied to the jig through a gas supply pipe 7a from a gas supply controller 7.

Microwaves 8 are generated by a microwave generator 9 (assigned frequency for induction heating: 2.45 GHz, maximum power: 500 W), and are projected into the processing chamber 1 through a waveguide 10. The semiconductor wafer 2 is irradiated with the microwaves and is heated inductively. The temperature of the heated semiconductor wafer 2 is measured by a temperature sensor 12 through a window 11. The temperature measurement produced by the sensor 12 is processed by a temperature controller 13 which generates a temperature control signal which is transmitted to a sequence controller 14.

The sequence controller 14 selects the gas (the inert gas 4 or the reaction gases 5, 6) to be fed to the processing chamber 1 and controls the flow rate of that gas and controls the intensity of the

microwaves 8 produced by the microwave generator 9,
in accordance with the temperature control signal
generated by the temperature controller 13. In this
way the temperature of the semiconductor wafer 2
5 may be controlled to a constant value.

The reaction gases 5 and 6, having formed a
protective film 15 on the semiconductor wafer 2,
are emitted from the processing chamber 1 through
a discharge conduit 17 in the form of a discharge
10 gas flowing in the direction of arrow 16.

A method of forming the protective film 15
on a surface of the semiconductor wafer 2 by the
use of the apparatus discussed above will now be
described. The method is concerned to form a
15 Chemical Vapour Deposition (CVD):SiO₂ film on the
wafer surface. The wafer (diameter: 4 inches,
thickness: 240μm) which is to be heat-treated is
set on susceptors 1a and 1b adjacent the jig 3. The
susceptors 1a, 1b each have a needle-like structure,
20 and support the semiconductor wafer 2 at three or
four points. After the semiconductor wafer 2 has
been set on the susceptors 1a, 1b, the inert gas
4 is fed from the gas supply controller 7 in order
to cause the semiconductor wafer 2 to float. The
25 inert gas 4 is preferably nitrogen (N₂). A valve
of a conduit for the inert gas 4 is opened by the
sequence controller 14, and the inert gas passes

through the gas supply pipe 7a and is emitted from the gas emission ports 3a of the jig 3 toward the semiconductor wafer 2. This inert gas is emitted at approximately 15 litres/min. The semiconductor wafer 2 is moved vertically and floats and is rotated by the flows of inert gas within the jig 3. The principle on the basis of which the semiconductor wafer 2 floats within the jig 3 is generally known as the Bernoulli chuck. When the inert gas 4 is fed to the jig 3, a negative pressure occurs between the semiconductor wafer 2 and the jig 3, due to the flows caused by the blast of the inert gas 4, and the semiconductor wafer 2 floats within the jig 3 clear of the surface of the jig 3 while moving vertically and rotating.

With the semiconductor wafer 2 floating clear of jig 3, microwaves 8 are generated by the microwave generator 9 and are projected into the processing chamber 1 by the waveguide 10. The semiconductor wafer 2 is heated by the projected microwaves 8. Only the semiconductor wafer 2 is heated because parts other than the semiconductor wafer 2 are made of materials of low electromagnetic loss. The semiconductor wafer 2 is heated from the interior thereof by electromagnetic losses, such as resistance loss and dielectric loss, due to the semiconductor wafer 2 itself. The wafer 2 is heated without

touching the jig 3 etc. Therefore, it is heated efficiently and uniformly. The temperature of the semiconductor wafer 2 is measured by the temperature sensor 12. The intensity of the microwaves 8 is controlled on the basis of the result of the temperature measurement of the semiconductor wafer 2 by the temperature sensor 12, so that the semiconductor wafer 2 is held at the predetermined temperature necessary for the desired reaction. The optimum temperature for forming a CVD-SiO₂ film, as in the present embodiment, is 400°C. when the predetermined temperature required for the desired reaction has been reached, the reaction gases 5 and 6 (SiH₄-gas and O₂-gas) necessary for the formation of the protective film (SiO₂ film) 15 are fed from the gas supply controller 7 into the jig 3; the flow of the inert gas being maintained.

The SiH₄-gas is diluted to 5% with N₂ in advance, and the flow rate thereof is 1 litre/min. The flow rate of the O₂-gas is 0.5 litre/min. The SiH₄-gas and O₂-gas react on the front surface of the semiconductor wafer 2 heated to the predetermined temperature, and the SiO₂ film 15 is formed on the front surface of the semiconductor wafer 2. The inner wall of the processing chamber 1 and the surface of the jig 3 have a much lower temperature than the surface of the semiconductor

wafer 2, and are at temperatures at which no reaction with the reaction gas 5 takes place. Therefore, no unnecessary reaction product (for example, SiO_2) is formed.

5 Embodiment 2

Figure 2 is an exterior view of a third embodiment of the present invention, being a heat-treating apparatus for baking a photoresist (hereinafter referred to as a "microwave baking apparatus"), and Figure 3 is a sectional view of parts of this microwave baking apparatus.

The microwave baking apparatus shown in Figure 2 has a power source 31, an output controller 32 for controlling the power of the microwaves to an optimum
15 valve, a heat-treating chamber 33, a temperature monitor 34, a loader 35, an unloader 36, and a handler 37 for transporting a semiconductor wafer 38

into the heat-treating chamber 33. The semiconductor wafer 38 is transported from the loader 35 by a conveyor belt 39, and is stopped at the handler 37 by a stopper pin (not shown). This semiconductor wafer 38 is transported into the heat-treating chamber 33 by the handler 37. The heat-treated semiconductor wafer 38 is received in the unloader 36. The loader 35 and the unloader 36 may receive a plurality of semiconductor wafers, and move vertically.

Before describing the method of baking a photoresist using the microwave baking apparatus, the reason for baking the photoresist will be explained.

In manufacturing a semiconductor device, photolithography is indispensable. Figures 4A - 4D are sectional views of steps illustrating a process for selectively removing an SiO_2 film by photolithography.

First, as shown in Figure 4A, an SiO_2 film 101 formed on the front surface of a Si wafer 100 is coated with a photoresist (negative type photoresist) film 102. Subsequently, the photoresist is baked in a step usually called "prebaking" or "soft baking" prior to the exposure of the photoresist film 102 via a photo-mask. The prebaking step thermally volatilizes residual solvent in the applied photoresist film 102 (thickness: 8500 Å), thereby to

enhance the efficiency of the photochemical reaction of a sensitive resin by ultraviolet energy irradiation in the exposure and to stabilize the sensitive resin. The prebaking step requires a heating temperature of approximately 80°C, and is conducted in an N₂ atmosphere. The Si wafer 100 subjected to prebaking has a photo-mask of predetermined shape positioned thereto, and is irradiated with ultraviolet rays to cause a pattern to be printed on the photoresist 102. Thus exposure processing is achieved.

Next, developing is performed as shown in Figure 4B. The photoresist film 102, having absorbed the ultraviolet energy to change its chemical structure, has unnecessary parts dissolved by the developing process and thus forms a pattern. Thereafter, the photoresist is again baked in a step usually called "post-baking" or "hard baking". The post-baking is a heat treatment which volatilizes any organic solvent which has permeated the photoresist film during the developing process thereby enhancing the resistance of the photoresist film to chemicals and to strengthen the adhesion of the photoresist film to the Si wafer. The post-baking step is conducted at a heating temperature of approximately 150°C.

After the post-baking has ended, the Si wafer

100 bearing the photoresist film 102 formed with the pattern is immersed in an etchant, and the final pattern is obtained as shown in Figure 4C. An aqueous solution of $\text{HF} + \text{NH}_4\text{F}$ (volumetric ratio = 1:6) is used as the etchant.

When the unnecessary parts of the SiO_2 film 101 have been removed, the now unnecessary photoresist film 102 is removed as shown in Figure 4D.

Thus selective etching of the SiO_2 film is achieved by photolithography.

The prebaking and post-baking steps mentioned above may be carried out by the microwave baking apparatus illustrated in Figures 2 and 3. The method of baking the photoresist film will now be described in detail with reference to Figure 3.

The Si wafer 38 transported by the conveyor belt 39 is stopped on the handler 37 by the stopper pin (not shown). The handler 37 moves vertically and horizontally on a handler supporter 40 as indicated by arrows. The leading end of this handler 37 is structurally adapted to draw the Si wafer 38 by vacuum suction. The Si wafer 38 is drawn by vacuum suction and then transported into the heat-treating chamber 33 by means of the handler 37 until it is placed on jig 41 in position 38a. The jig 41 is provided with gas emission ports 41a and 41b. An inert gas such as N_2 -gas is blown through

the gas emission ports 41a, 41b, to cause the Si wafer 38a to float in a position 38b indicated by a dotted line. The floating Si wafer in position 38b rotates due to the flow of the inert gas. The rotation of the Si wafer in position 38b is achieved by providing four gas emission ports 41a, 41b, 41c and 41d extending in tangential directions as shown in Figure 5 and blowing the inert gas N_2 through these emission ports.

With the Si wafer held in the floating state in position 38b within the jig 41, microwaves 42 are generated by a microwave generator 43 and projected from a waveguide 44 into the heat-treating chamber 33. The Si wafer in position 38b is heated by the projected microwaves 42. Only the Si wafer is heated because parts other than the Si wafer, are made of the material of low electromagnetic loss. The Si wafer is heated from the interior thereof by electromagnetic losses, such as the resistance loss and the dielectric loss, of the Si wafer itself, and it is heated without touching the jig 41 etc., so that it is heated efficiently and uniformly. The temperature to which the Si wafer is heated is measured by the temperature monitor 34, and the output controller 32 controls the output of the microwave generator 43 on the basis of the measured result. Consequently, the Si wafer is held at a

predetermined temperature necessary for the baking treatment of the photoresist film. In this way, baking treatment (prebaking, post-baking) of the photoresist film may be achieved. In particular, since the baking treatment of the photoresist film is intended to volatilize the solvent in the photoresist film as described before, the microwave heating as in the present embodiment is particularly advantageous because the photoresist film is heated from the interior thereof, so the surface of the film is not hardened, and it is easy to volatilize the solvent.

The following advantages may be obtained:

(1) According to the present invention, a plate-like member is heat-treated by heating the electromagnetic radiation such as microwaves. Heating with electromagnetic radiation such as microwave generates heat by electromagnetic losses, such as resistance loss and dielectric loss, which are developed within the member. This gives excellent heating efficiency due to the heat generation within the member. In this manner, according to the present invention, only the member is directly heat-treated, and the holding mechanism for holding the member is not heated. The capacity of members can therefore be minimized, so that the power of the heating source can be minimized.

(2) The member is held in a floating state, and lies out of contact with the holding mechanism. Therefore, uniform heating of the member can be maintained, and heating at high precision becomes possible. Since the member is in the floating state, it cannot be kept stationary, but the uniform heat treatment is possible owing to the microwave heating.

(3) Since it is difficult for heat to be lost from the member, surplus heating becomes unnecessary, and the power of the heating source need not be large.

(4) Since the dissipation of heat from the member can be reduced, the member can be efficiently heated in a short time.

(5) Since the surroundings of the member are desirable are an atmosphere of low temperature, no unnecessary product is deposited on the interior of a processing chamber containing the member.

(6) Since the semiconductor wafers are heat-treated sequentially in Embodiments 1 and 2, the apparatuses for the heat treatment may be simplified in structure and reduced in size, and also automatic

processing and continuous processing may be achieved. In addition the wafers can be processed irrespective of the magnitudes of the diameters thereof.

5 (7) In the baking treatments of Embodiment 2, the baking time of both the prebaking and the post-baking steps is 2 min. As compared with the prior-art heat treatment employing a heater (baking time: 10 min.), the embodiment can treat the wafers in a
10 shorter time and can enhance the throughput.

In the above description, two embodiments of the present invention have been discussed. The present invention is not restricted to these
embodiments, however. For example, microwaves may
15 be projected at the same time as a magnetic field is applied to a reaction substance. In this way activation of a reaction phenomenon may also be achieved. In this case, enhancement in the reaction efficiency adds to the effects of permitting a
20 reaction of good quality and a shortened processing time.

The heat-treatment of the present invention may be carried out in a high pressure atmosphere, a normal pressure atmosphere, a low pressure atmosphere,
25 in vacuum, or in a substance adapted to transmit the microwave. In all these cases, effects similar to those of the embodiments discussed above may be

attained.

The present invention has been described in the context of the formation of a protective film on a semiconductor wafer surface, an annealing treatment and a photoresist baking treatment in the manufacture of a semiconductor device. However, the present invention is not restricted thereto, but it is also applicable to, e.g., vapor growth, impurity diffusion processing, crystal annealing processing or dry etching processing. The present invention is also applicable to the sintering of a circuit board made of ceramics.

CLAIMS:

1. A method of heat-treating a plate-like member, comprising floating and rotating the plate-like member such that there is substantially no horizontal movement
5 of the plate-like member, and irradiating the plate-like member with electromagnetic radiation, so as to heat it.
2. A method according to claim 1, wherein the plate-like member is a semiconductor wafer with a photoresist
10 film deposited on its surface.
3. A method according to claim 1 wherein a reaction substance reacts on the member, during the heating of the member.
4. A method according to any one of claims 1 to 3,
15 wherein the intensity of the electromagnetic radiation is controlled on the basis of measurement of the temperature of the member.
5. A method according to any one of the preceding claims, wherein the floating of the plate-like member is achieved
20 by flow of a gas around the member.
6. A method of heat-treating a plate-like member substantially as any one herein described with reference to the accompanying drawings.



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