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Process for drying surfaces.

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Description

Background of the Invention

Field of the Invention

The present invention is directed to the drying of surfaces after fluid treatment or wet processing. More particularly, the invention relates to the manufacture of semiconductor components, and in particular to the preparation of semiconductor wafers prior to high temperature processing steps, such as diffusion, ion implantation, epitaxial growth, and chemical vapor deposition steps. Still more particularly, the invention relates to methods and apparatus for the drying of semiconductor wafers after prediffusion cleaning.

Brief Description of the Prior Art

In the fabrication of semiconductor wafers several process steps require contacting the wafers with fluids. Examples of such process steps include etching, photoresist stripping, and prediffusion cleaning. The equipment conventionally used for contacting semiconductor wafers generally consists of a series of tanks or sinks into which racks of semiconductor wafers are dipped. Wafer carriers are described, for example, in US-A-3,607,478, US-A-3,964,957 and US-A-3,777,926. Such conventional wet processing apparatus poses several difficulties.

Since the tanks are open to the atmosphere, airborne particulates can enter into the process solutions. Through surface tension these particles are easily transferred to the wafer surfaces as the wafers are dipped into and lifted out of the sinks. This particulate contamination is extremely detrimental to the microscopic circuits which the wafer fabrication process creates. It is especially important to minimize particulate contamination during prediffusion cleaning.

After fluid processing the wafers normally need to be dried. This can be a particularly challenging process because it is important that no contamination be created during the drying process. Evaporation is undesirable since it often leads to spotting or streaking. Even the evaporation of ultra high purity water can lead to problems because such water is very aggressive to the wafer surface and will dissolve traces of silicon and silicon dioxide during even short periods of water contact. Subsequent evaporation will leave residues of the solute material on the wafer surface. Contamination and other causes of semiconductor failure are discussed, for example, in J. Schadel, "Device Failure Mechanisms in Integrated Circuits," Solid State Devices 1983 Conf. Ser. No. 69 (Institute of Physics, London 1984) 105-120.

Conventionally, semiconductors are dried through centrifugal force in a spin-rinser-drier. Because these devices rely on centrifugal force to "throw" water off the wafer surfaces, their use results in several problems. First, there are mechanical stresses placed on the wafers which may result in wafer breakage, particularly with larger wafer sizes. Second, because there are many moving parts inside a spin-rinser-drier, contamination control becomes a difficult problem. Third, since the wafers conventionally travel at high velocity through dry nitrogen, static electric charges develop on the wafer surfaces. Since oppositely charged airborne particles are quickly drawn to the wafer surfaces when the spin-rinser-drier is opened, particle contamination results. Fourth, it is difficult to avoid evaporation of water from the surfaces of the wafers during the spin process with the attendant disadvantages discussed above.

More recently, methods and apparatus have been developed for steam or chemical drying of wafers, including the method and apparatus disclosed in our US-A-4,778,532. Chemical drying generally comprises two steps. First, the rinsing fluid, preferably water, is driven off the wafers and replaced by a nonaqueous drying fluid. Second, the nonaqueous drying fluid is evaporated using a predried gas, preferably an inert gas such as nitrogen at a low flow velocity.

Another chemical drying process currently used in Japan consists of sequentially immersing the wafer carrying vessel in tanks of deionized water, followed by suspending the wafers above a tank of boiling isopropanol. The wafer-carrying vessel is then slowly withdrawn from the isopropanol vapor to pull the water droplets off the wafer surfaces.

The most important feature for an effective wafer drying technology is that the wafers produced be ultraclean, i.e., with minimum particle contamination and minimum chemical residue. Because many drying solvents are flammable, safety is also a very important consideration. Other important design criteria include low chemical consumption, low waste generation, and automated handling with little or no operator exposure.

Brief Summary of the Invention

According to the present invention, a method for drying surfaces of objects is provided which are fully immersed in a rinsing fluid, said method comprising providing a drying vapor, replacing said rinsing fluid with said drying vapor by directly displacing said rinsing fluid from said surfaces with said vapor, characterized in that the rate at which said rinsing fluid is displaced by said vapor is chosen to be sufficiently slow so that substantially no liquid droplets are left on the surfaces after replacement of the rinsing fluid with drying vapor and substantially no rinsing fluid or drying vapor is removed by evaporating of liquid drop-
lets. Preferably, the drying vapor is provided from above the objects in a fully enclosed, hydraulically full (i.e., completely filled with process fluid) system, and the drying vapor pushes the rinsing liquid off the surfaces as the liquid level recedes downwardly.

In contrast to the teaching of US-A-4,778,532, the present invention requires that the rinsing fluid be replaced directly by the drying vapor so that no liquid droplets are left on the surface to be removed by evaporation or volatilization.

Since the rinsing fluid will usually be water in the liquid phase, it is preferred that the drying vapor be miscible with water and form a minimum boiling azeotrope with water, isopropanol being a particularly preferred drying vapor. Further, the drying vapor should be substantially pure and either saturated or preferably superheated, and the surfaces should be heated to a temperature near to but preferably below that of the drying vapor prior to contact. While this may result in some condensation of vapor on the surfaces, and too much condensation should be avoided, it has been found that preheating to above the temperature of the drying vapor yields poorer results.

A supply of dry, inert, non-condensable gas is provided to purge the drying vapor after replacement of the rinsing fluid, and a boiler and distillation column for concentrating the mixture of rinsing fluid and drying vapor after exit from the processing vessel.

In a preferred apparatus for carrying out the present invention, a vaporizer for producing the saturated drying vapor is provided with a lower boiler section and an upper holding section in which the drying vapor may be rapidly produced in the boiler section and held in the upper section at just the boiling point of the drying fluid. This may be accomplished by an insulating gasket to limit the amount of heat transfer from the boiler section to the holding section. The vaporizer is preferably totally enclosed and may be automatically replenished with fresh drying fluid by lowering the temperature of the fluid in the upper holding section to create a subatmospheric pressure which will draw fresh drying fluid into the vaporizer from a storage source which is preferably maintained below the temperature of the vaporizer. Saturated drying vapor with an appropriate latent heat curve (pressure-enthalpy diagram) is preferably superheated by means of a pressure drop valve and filtered between the vaporizer and the processing vessel.

**Brief Description of the Drawings**

The foregoing summary, as well as the following detailed description, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there is shown in the drawings an embodiment which is presently preferred, it being understood, however, that this invention is not limited to the precise arrangement and instrumentality shown in the drawings.

Figure 1 is a schematic flow diagram illustrating a preferred embodiment of an apparatus for carrying out the present invention.

Figure 2 is a slightly enlarged, more detailed, cross sectional view of the wafer vessel shown in Figure 1, and illustrating the gas-liquid-solid interface in the wafer vessel.

Figure 3 is a cross sectional view similar to Figure 2 but illustrating an alternate wafer vessel and carrier arrangement.

**Detailed Description of the Preferred Embodiment**

While the present invention is directed broadly to the drying of surfaces of solid objects, particularly planar objects, after various wet processing or fluid treatments, the invention will be described with particular reference to the drying of semiconductor wafers after prediffusion cleaning and rinsing, it being understood that the same general principles apply to the drying of other wet surfaces.

Further, while the drying system of the present invention may be used with a variety of cleaning, etching or other wafer processing methods and apparatus, the present system is specifically adapted for use in the process and apparatus for treating wafers with process fluids, as described and claimed in US-A-4,778,532. Thus, the present invention is an improvement which may be substituted for the steam or chemical drying systems described in that application.

Similarly, while various wafer carrying vessels may be used to suspend the semiconductor wafers in the rinsing and drying fluids as described herein, the wafer carrier described in our US-A-4,577,650 has been found to be particularly suitable for use in the method and apparatus of the present invention. Such carriers are shown in simplified form in Figure 2 of the present application for purposes of illustrating the present invention.

The apparatus for carrying out the present invention includes three primary pieces of equipment, namely a vaporizer 10 for producing drying vapor, a vessel 12 for holding the wafers for treatment with rinsing fluid and drying vapor, and a boiler 14 for concentrating used rinsing fluid and drying vapor for disposal and/or reuse. These three units with their associated piping, valves and other elements are shown schematically in Figure 1.

Referring first to Figure 2, a preferred vessel 12 for use in the present invention is illustrated. A plurality of semiconductor wafers 16 is shown (from a side view) suspended in two rows of parallel, vertically oriented wafers in upper and lower wafer carriers 18, 20, of the type described more fully in our US-A-4,577,650. While two such wafer carriers 18, 20 are illustrated in Figure 2 stacked one on top of the other,
it will be understood that vessel 12 could include only one such wafer carrier or more than two such carriers. In some instances vertical stacking may cause undesirable dripping onto lower carriers.

Wafer carriers 18, 20 are held in place by upper vessel clamp 22 connected to the fluid inlet 24 and lower vessel clamp 26 connected to fluid outlet 28. As shown in Figure 2 vessel 12 is partially filled with rinsing liquid 30 as drying vapor 32 fills the upper portion of vessel 12 and pushes the liquid-solid interface downward across wafers 16 in upper wafer carrier 18.

In Figure 3 a vessel 12' is shown which allows for a plurality of SEMI (Semiconductor Equipment and Materials Institute, Inc.) approved wafer carriers to be arranged side by side. In this embodiment upper vessel clamp 22' is in the form of a bell jar lid which is sealed over lower vessel clamp 26' by means of a gasket 25 and clamp fittings 27. Wafer vessels 18', 20', holding wafers 16', are supported on rods 21 in lower vessel clamp 28'. The vessel 12' is shown empty of rinsing fluid.

It will be understood that other vessel arrangements (not shown) can be used in carrying out the present invention. For example, another embodiment would allow for one or more wafer carriers to be placed in an overflow-type sink situated in a lower vessel clamp with an appropriate cover, such as a bell jar lid similar to upper vessel clamp 22' in Figure 3, to seal the system and provide for overflow and waste removal. Sealing the system is important to allow blanketing the vapor space around the wafers with drying vapor to prevent the introduction of foreign gases, e.g., nitrogen gas, during the direct displacement of the rinsing fluid with the drying fluid.

Referring to Figure 1, vaporizer 10 includes a lower boiler section 36 and an upper holding section 38, with the metal casings of the boiler and holding sections being separated by an insulating gasket 40 which limits the amount of heat transfer from the lower metal casing to the upper metal casing.

Boiler 36 is provided with heating bands 42 or other suitable heat transfer device to quickly heat the drying fluid above its boiling point. The boiler 36 should always be maintained full of liquid drying fluid so that the heat transfer surfaces are continually immersed. For this purpose a liquid level detector and switch (not shown) may be provided, as well as resistance temperature detectors (not shown) for measuring the heat of the drying liquid and monitoring the temperature of the heating bands.

The insulating gasket 40 may be of any suitable material which will withstand the heat of boiler section 36 and will resist corrosion by the drying fluid. For example, an envelope gasket which will fit between two ANSI flanges 44 of the boiler section 36 and holding section 38 will be suitable. The insulating gasket prevents troublesome temperature/pressure overshoot from rapid heatup of the metal casings without simultaneous heatup of the contained drying fluid. Thus, while the boiler may be very hot to quickly produce drying vapor, the holding section 38 should remain at just the temperature of the boiling drying fluid, which may be an elevated pressure boiling point.

The holding section 38 essentially holds the liquid capacity of the vaporizer, with the disengagement between liquid and vapor occurring at the very top, near flanges 48. A similar insulating gasket 48 may be placed between the flanges 48 to avoid unnecessary heat transfer from the top of holding section 38 near the liquid vapor interface. Holding section 38 may be provided with other associated devices (not shown), including a level detector and switch, heat tracing, and water cool-down jacket.

Drying liquid and vapor enter and leave holding section 38 through tubing 50 and cross connection 52. Fresh and/or recirculated liquid drying fluid enters vaporizer 10 through valve 54, preferably a bellows valve, and filter 56, preferably a submicrometer filter such as available under the trademark Millipore, in inlet line 58 which is connected to a source of fresh drying fluid (not shown) through 53 and/or to distillation column 54 and waste liquid receiver 95 which provide recirculated drying fluid as discussed below.

Saturated drying vapor flows to vessel 12 through valve 60, preferably also a bellows valve, and flash valve 62 in line 64. As will be described more fully below, the flash valve may be used to lower the pressure and thereby superheat the saturated drying vapor. After passing through flash valve 62 and 3-way selector valve 68, the drying vapor preferably also goes through a final 0.01 micrometer ceramic filter 69, such as a Model PGF-2 filter manufactured by Fastek division of Eastman Technology, Inc., because gases can be filtered to a higher degree than liquids.

Cross connection 52 is also provided with a pressure release valve 66 for emergency over pressurization of the vaporizer. The vaporizer may also be provided with a maintenance drain (not shown) at the bottom of the boiler 36.

Vessel 12 may be provided with other valves 70, 72, 74 and 76 for the control of various process fluids, such as etching, stripping, cleaning and/or rinsing fluids which may enter and exit the vessel 12 for treatment of wafers 16. The manner in which these fluids may be controlled for entry into and exit from vessel 12 is described in more detail, for example, in our US-A-4,778,532, but does not form a part of the present invention.

As drying fluid displaces rinsing fluid from wafers 16 at interface 34, the drying fluid mixes with the rinsing fluid and also forms a distinctive drying fluid layer on top of the rinsing fluid, reaching more than 1.3cm (one half inch) in thickness in some cases.

This final rinsing fluid and drying fluid layer exits
vessel 12 through valve 78 or metering pump 79 in line 80 which leads to boiler 14 for concentration and/or disposal of the used fluids. Preferably metering pump 79 is a variable rate pump to allow better control of the interface descent rate and to optimize drying time. Just preceding valve 78 and metering pump 79 in line 80 is a capacitance switch (limit switch) 82 which senses when vessel 12 has drained completely. At that point vapor line 64 is closed and a purging gas may be passed into vessel 12 through valves 71, 68 and 70 and filter 69.

Drying vapor and purging gas may also exit vessel 12 through valve 78 and pass into boiler 14. To achieve even better control of the descent rate of interface 34 and to optimize drying time, the rinsing liquid may be removed during at least part of the descent by a variable rate metering pump 79. The rinsing fluid is discarded to drain through valve 81. At the appropriate time, the layer of drying fluid and a layer of rinsing fluid immediately below it are diverted to boiler 14 through valve 83.

Boiler 14 is provided with band heaters 92 or immersion heaters to strip the drying fluid or an azetropes of the drying fluid and rinsing fluid from the waste water. The vapor goes through distillation column 94 for further concentration. A water-cooled condenser 96 condenses the drying vapor. Cool, non-condensable gas (e.g., purge gas) exits the condenser through vent 88, while a portion of the condensate exits through drain 90 into a waste liquid receiver 95 for recirculation to the feed line 58 for vaporizer 10.

Distillation column 94 may be a single column or a series of columns of generally conventional design, depending upon the degree of concentration of the drying fluid desired for recirculation or disposal of used fluid. The waste water from which the vapor has been stripped exits boiler 14 through overflow valve 96 as a new batch of used fluid enters boiler 14 from the next run. Fresh drying fluid may be added to the recycled fluid through valve 83.

In carrying out the method of the present invention, a drying fluid is selected which is miscible with the rinsing fluid and preferably forms a minimum-boiling azetropes with the rinsing fluid. Since water is the most convenient and commonly used rinsing fluid, a drying fluid which forms a minimum-boiling azetropes with water is especially preferred. Generally, the drying fluid should be an organic compound which is non-reactive with the surface to be dried and has a boiling point less than 140 degrees Centigrade at atmospheric pressure.

The chemical found most effective for drying is isopropyl alcohol (isopropanol). Isopropanol is economical, relatively safe (nontoxic) and forms a minimum-boiling azetropes with water. Also of importance, isopropanol has a low surface tension and has both hydrophobic and hydrophilic characteristics (i.e., it is miscible in both oil and water). Without wishing to be bound by any particular theory, it is believed that isopropanol has a tendency to break the harsh surface tension between the hydrophilic water and the relatively hydrophobic wafer surface. Since the solid phase at interface 34 is the wafer surface and the liquid phase is ultra pure water, the choice of gas phase properties can have a tremendous impact which isopropanol appears to satisfy best.

The method of the present invention will now be described in more detail with reference to the above described apparatus and the preferred rinsing fluid (water) and drying vapor (isopropanol), although it will be understood that the method can be carried out with other suitable apparatus, and the method will be similar for other rinsing and drying fluids.

In the wet processing of semiconductor wafers according to the method of our US-A-4,778,532, it is advantageous with some process fluids to have the fluid flow upward through the vessel 12 so that the fluid inlet 24 becomes an outlet and the fluid outlet 28 is the inlet. This is true of the rinsing fluid which normally circulates upwardly through vessel 12. However, according to the present invention, it has been found that the optimal configuration for wafer drying is downward.

Preferably, the last cycle of rinsing with ultra pure water is with hot water (e.g., 65-85 degrees Centigrade) in order to heat the wafers to approximately the boiling point of the isopropanol (82 degrees Centigrade). Alternatively, the wafers 16 may be heated by direct solid solid heat transfer through wafer carriers 18, 20 by means of heating bands or other heating devices applied to the carriers.

After the final rinsing cycle, vessel 12 is left hydraulically full with ultra pure hot water. Valve 78 may then be opened. However, the water will not leave vessel 12 because nothing has been allowed to enter at the top to replace it. Flash valve 62 and valve 70 are then opened to introduce a stream of pure, saturated isopropanol vapor to vessel 12 through inlet 24. As vapor enters the upper vessel 22, water flows out the bottom 26 through fluid outlet 28 and valve 78.

Alternatively, the rinsing water may be removed from vessel 12 by metering pump 79, with the flow rate being changed depending upon the phase of the removal cycle. For example, the metering pump 79 can be run at a very high rate until the interface 34 is just above the wafers, then slowed down as the interface descends past the wafers. Finally, after the interface has passed the last wafer surface 16, the bypass valve 78 around pump 79 may simply be opened and the remaining water and drying fluid may be blown from the vessel by purging gas.

It is important that the downward velocity of the gas-liquid-solid interface 34 be controlled at a relatively slow rate, although there is a compromise which must be taken into consideration. Thus, if the rinsing water exits vessel 12 too fast, liquid droplets will re-
main on the wafers and contamination will occur when these droplets are evaporated. Hence, the drying vapor must displace the rinsing fluid from the wafers at such a rate that substantially no liquid droplets are left on the wafer surfaces after replacement of the water with isopropanol. On the other hand, a faster descent of interface 34 would increase dryer productivity and minimizes chemical consumption.

Generally, interface descent rates (velocities) in the range of about 2.5-10 cm/minute (one to four inches per minute) have been found satisfactory. Descent rates much beyond 12.5 cm/minute (five inches per minute) yield poor results, whereas descent rates below 2.5 cm/minute (one inch per minute) are inefficient. It has also been found that warmer vessel temperatures of about 75 degrees Centigrade result in better drying performance by allowing a faster interface descent than a cooler vessel at about 60 degrees Centigrade.

Similarly, consistent with the desire that liquids not be removed from the wafer surfaces by evaporation, it is preferred that the isopropanol be superheated in order to provide a drier vapor and avoid the risk of condensation of a vapor on the wafer surfaces. An advantage of an organic liquid such as isopropanol is that its latent heat curve in its pressure-enthalpy diagram slopes backwardly so that a pressure drop pushes the saturated vapor into the superheated region of the phase diagram. As a result, passing the saturated vapor produced by vaporizer 10 through a flash valve 62 results in a drier, superheated vapor being supplied to wafers 16 in vessel 12.

Holding section 38 of vaporizer 10 preferably holds enough liquid IPA so that vaporizer 10 may supply several loads of wafers without being replenished. When it is necessary to add fresh isopropanol to vaporizer 10, this may be done automatically by allowing the temperature of the boiling isopropanol in holding section 38 to drop below its boiling point (82 degrees Centigrade at atmospheric pressure). The temperature lowering may be assisted by use of a cooling jacket (not shown) on holding section 38. When the temperature drops below the boiling point, the vapor pressure in the vaporizer 10 becomes subatmospheric. When valve 54 is then opened, liquid isopropanol is drawn from storage by suction to the vaporizer. Because this liquid isopropanol is generally cooler than the vaporizer itself, the pressure in the vaporizer reduces further, enhancing the reflux operation.

As rinsing water leaves vessel 12 through valve 78 or metering pump 79 to drain 81 or valve 93, limit switch 82 senses when vessel 12 has drained completely of liquid. As soon as the vessel is completely empty, line 64 is closed and a stream of dry, inert, non-condensable gas, such as nitrogen, is admitted through valves 71, 68 and 70 to purge vessel 12 of isopropanol vapor. Since the nitrogen purge gas also goes through ceramic filter 69 between valves 68 and 70, the filter is inherently purged with nitrogen after the isopropanol. It is believed that this purge prevents isopropanol condensation and resultant binding problems inside the filter.

This purge quickly flushes all of the remaining vapor out of vessel 12 through drain valve 78. The nitrogen purge displaces isopropanol vapor out of the vessel and removes what appears to be a monolayer of isopropanol on the wafer surfaces. The monolayer is very volatile but the mechanism of removal appears different from evaporation.

Finally, the last of the used water and the isopropanol from vessel 12 enter boiler 14. The purpose of boiler 14 and distribution column 94 is to hold the isopropanol contaminated water mixture and reconcentrate the isopropanol into a smaller volume for recirculation or disposal. Once vessel 12 is emptied of liquid, the nitrogen purge begins. This nitrogen gas flows through and out of vessel 12 into boiler 14, exiting through condenser 86 and vent 88.

Since the isopropanol appears to be concentrated in a layer on top of the water as interface 34 descends in vessel 12, it is not necessary to strip all of the water which first exits vessel 12. Therefore, most of the water is allowed to flow through valve 81, and the last pint or so of liquid (i.e., the isopropanol layer and water immediately below it) is trapped in boiler 14 for processing. Since such a small amount of liquid is involved, and the isopropanol/water mixture may be boiled readily.

As band heaters 92 are energized, the water/isopropanol mixture is heated, and the azetropie isopropanol water mixture (boiling point 79 degrees Centigrade) vaporizes out of the waste water. This gaseous blend goes through distillation column 94 to condenser 86 where it is condensed and is either collected in a waste-liquid receiver 95 from drain 90 or is refluxed to distillation column 94. Waste water from which the azetropie and vapor have been removed overflows through valve 96 before used water from the next run enters boiler 14 from vessel 12.

Essentially, boiler 14 performs a crude separation, so that liquid sent to distillation column 94 from condenser 86 might be 50 weight percent water and 50 weight percent isopropanol. The distillation column will then separate the azetropie from the water to a 90 weight percent isopropanol/10 percent water azetropie. This azetropie may be reintroduced to vaporizer 10 on a batch basis, or continuously, as desired, through waste receiver 95 and appropriate mixing tanks and/or filters.

As indicated previously, if any water is left on the wafer surface after rinsing, streaking, spotting and particulate contamination will almost invariably occur. An advantage of using a minimum-boiling azetropie, such as isopropanol with water, is that any residual water film on the wafer surface, when combined with the isopropanol vapor will immediately flash into the
gas phase as the azeotrope.

While one theory holds that the efficiency of drying depends upon the thickness of the liquid isopropanol layer on the top of the receding rinsing water at interface 34, a thin isopropanol liquid layer or no layer at all is preferred due to fewer disposal problems, lower drying fluid cost, and fewer flammability problems. Regardless of the validity of this theory, it appears to be clear that streaking and spotting are minimized by decreasing the velocity of the receding water level (interface 34) and increasing the dryness of the vapor (superheat).

While the above description contemplates either recycling of isopropanol (closed loop system) or merely the stripping of the mixture to concentrate the organic liquid for disposal, purifying the isopropanol or other drying vapor for recovery and recycling is preferred because of environmental and economic considerations. The azeotrope mixture has a lower flash point and better heat transfer characteristics including heat capacity and heat transfer coefficient, apparently without sacrifice of particle performance (cleanliness) of the wafers compared to the use of fresh, pure isopropanol alone.

Without wishing to be bound by any particular theory, it is believed that if interface 34 recedes at a sufficiently slow rate, the water/isopropanol interface will pull all of the water and azeotrope droplets off the wafers as the liquid level recedes. However, if the interface 34 recedes too quickly, the surface tension or affinity of water or other droplets for the wafer surface will exceed the surface tension of the receding liquid. Droplets will then be left on the wafer which will have to be evaporated, leaving streaks and contamination. Thus, it is believed that the method of the invention involves a physical pushing by the vapor or pulling by the liquid surface, resulting in direct displacement by vapor for liquid rather than an evaporation of liquid droplets.

It will be appreciated from the above description that the method and apparatus of the invention may be an enclosed, full flow system which is preferably hydraulically full (i.e. sealed) during both rinsing and drying steps, and requires no movement or handling of the wafers between rinsing and drying. The advantages of such systems are disclosed in our US-A-4,778,532.

The present invention results in improved drying efficiency of semiconductor wafers with less contamination of the wafer surfaces by dissolved particles and other contaminants which may be present in prior systems.

Claims

1. A method for drying surfaces of objects which are fully immersed in a rinsing fluid comprising pro-

viding a drying vapor, replacing said rinsing fluid with said drying vapor by directly displacing said rinsing fluid from said surfaces with said vapor, characterized in that the rate at which said rinsing fluid is displaced by said vapor is chosen to be sufficiently slow so that substantially no liquid droplets are left on the surfaces after replacement of the rinsing fluid with drying vapor and substantially no rinsing fluid or drying vapor is removed by evaporation of liquid droplets.

2. A method according to claim 1 wherein said rinsing fluid is water in the liquid phase.

3. A method according to claim 2 wherein said surfaces are heated to approximately the temperature of said drying vapor prior to being contacted by said vapor.

4. A method according to claim 3 wherein said heating is effected by said rinsing fluid as the heat transfer means.

5. A method according to claim 3 wherein said heating is effected by solid/solid heat transfer from a carrier which suspends said objects.

6. A method according to claim 1 wherein said rinsing fluid is pushed downwardly by said drying vapor.

7. A method according to claim 1 wherein said rinsing fluid is drawn away from said objects by external pumping means.

8. A method according to claim 1 wherein said drying vapor is purged from said surfaces by introducing a dry, inert, non-condensable gas after replacement of said rinsing fluid.

9. A method according to claim 8 wherein said gas is nitrogen.

10. A method according to claim 1 wherein said drying vapor is saturated.

11. A method according to claim 1 wherein said drying vapor is superheated.

12. A method according to claim 2 wherein said vapor is miscible with water.

13. A method according to claim 2 wherein said vapor forms a minimum-boiling azeotrope with water.

14. A method according to claim 13 wherein said vapor is isopropanol.
15. A method according to claim 1 wherein said vapor is an azeotrope.

16. A method according to claim 2 wherein said drying vapor is an isopropanol/water azeotrope.

17. A method according to claim 1 wherein said drying vapor is an organic compound non-reactive with said surfaces and having a boiling point less than 140 degrees Centigrade at atmospheric pressure.

18. A method according to claim 1 wherein there is no movement or handling of said surfaces between rinsing and drying steps.

19. A method according to claim 18 wherein said method is carried out in a vessel in which said objects are suspended and said vessel is completely filled with rinsing and/or drying vapor during said rinsing and drying steps.

20. A method according to claim 19 wherein said objects are blanket with drying vapor immediately after removal of the rinsing fluid.

21. A method according to claim 1 wherein said objects are semiconductor wafers.

22. A method according to claim 1 wherein said vapor is filtered in the vapor phase prior to contacting said surfaces.

23. A method according to claim 1 wherein said drying vapor is collected and recycled after drying said surfaces.

24. A method according to claim 23 wherein said vapor is recycled in the form of an azeotrope with said rinsing fluid.

25. A method according to claim 1 wherein said objects are semiconductor wafers, the rinsing fluid is hot water, and the drying vapor is isopropanol, the method comprising introducing isopropanol vapor from above the wafers to remove and replace the water as the water level recedes downwardly from the wafers at such a rate that no liquid droplets of water or isopropanol are left on the wafer surfaces, said wafers being at substantially the same temperature as said vapor when contacted by the vapor.

26. A method according to claim 1 wherein the vessel is fully enclosed and the drying vapor is introduced from above the objects to remove and replace the rinsing fluid in a full flow method such that the fluid level recedes downwardly from the object surfaces at such a rate that substantially no liquid droplets of rinsing fluid or drying vapor are left on the object surfaces after replacement of the rinsing fluid with the drying vapor.

**Patentansprüche**

1. Verfahren zum Trocknen von Oberflächen von Gegenständen, die vollständig in eine Spülfüssigkeit eingetaucht sind, umfassend das Bereitstellen eines Trockendampfes, Ersetzen der Spülfüssigkeit durch den Trockendampf, indem die Spülfüssigkeit von den Oberflächen direkt durch den Dampf verdrängt wird, dadurch gekennzeichnet, daß die Geschwindigkeit, mit der die Spülfüssigkeit durch den Dampf verdrängt wird, genügend langsam gewählt wird, so daß nach dem Ersatz der Spülfüssigkeit durch den Trockendampf im wesentlichen keine Flüssigkeitsröhren auf den Oberflächen zurückbleiben und im wesentlichen keine Spülfüssigkeit oder Trockendampf durch Verdampfung von Flüssigkeitsröhren entfernt wird.

2. Verfahren gemäß Anspruch 1, wobei die Spülfüssigkeit Wasser in flüssiger Phase ist.

3. Verfahren gemäß Anspruch 2, wobei die Oberflächen, bevor sie mit dem Dampf in Berührung gebracht werden, auf ungefähr die Temperatur des Trockendampfes erhitzt werden.

4. Verfahren gemäß Anspruch 3, wobei das Erhitzen durch die Spülfüssigkeit als Wärmeübertragungsmittel bewirkt wird.

5. Verfahren gemäß Anspruch 3, wobei das Erhitzen durch eine Wärmeübertragung in festen Körpern aus einem Träger bewirkt wird, welcher die Gegenstände trägt.

6. Verfahren gemäß Anspruch 1, wobei die Spülfüssigkeit durch den Trockendampf abwärts gedrückt wird.

7. Verfahren gemäß Anspruch 1, wobei die Spülfüssigkeit durch äußere Pumpmittel von den Gegenständen abgezogen wird.

8. Verfahren gemäß Anspruch 1, wobei der Trockendampf durch Einführen eines trockenen, inerten, nichtkondensierbaren Gases nach dem Ersatz der Spülfüssigkeit von den Oberflächen verdrängt wird.

9. Verfahren gemäß Anspruch 8, wobei das Gas Stickstoff ist.
10. Verfahren gemäß Anspruch 1, wobei der Trockendampf gesättigt ist.

11. Verfahren gemäß Anspruch 1, wobei der Trockendampf überhitzt ist.

12. Verfahren gemäß Anspruch 2, wobei der Dampf mit Wasser mischbar ist.

13. Verfahren gemäß Anspruch 2, wobei der Dampf ein am Minimum siedendes Azeotrop mit Wasser bildet.


15. Verfahren gemäß Anspruch 1, wobei der Dampf ein Azeotrop ist.


17. Verfahren gemäß Anspruch 1, wobei der Trockendampf eine mit den Oberflächen nicht reaktionsfähige organische Verbindung mit einem Siedepunkt bei Atmosphärendruck von weniger als 140 Grad Celsius ist.

18. Verfahren gemäß Anspruch 1, wobei zwischen den Spül- und Trockenschritten keine Bewegung oder Handhabung erfolgt.

19. Verfahren gemäß Anspruch 18, wobei das Verfahren in einem Gefäß durchgeführt wird, in welchem die Gegenstände während der Spül- und Trockenschritte gehalten werden und das Gefäß mit Spüll- und/oder Trockendampf vollständig gefüllt ist.

20. Verfahren gemäß Anspruch 19, wobei die Gegenstände unmittelbar nach dem Entfernen der Spülfüssigkeit mit Trockendampf überdeckt werden.

21. Verfahren gemäß Anspruch 1, wobei die Gegenstände Halbleiterwafer sind.

22. Verfahren gemäß Anspruch 1, wobei der Dampf in der Dampfphase filtriert wird, bevor er mit den Oberflächen in Berührung gelangt.

23. Verfahren gemäß Anspruch 1, wobei der Trockendampf nach dem Trocknen der Oberflächen aufgefangen und rückgeführt wird.

24. Verfahren gemäß Anspruch 23, wobei der Dampf in Form eines Azeotrops mit der Spülfüssigkeit zurückgeführt wird.


26. Verfahren gemäß Anspruch 1, wobei das Gefäß vollständig geschlossen ist und der Trockendampf über den Gegenständen unter Entfernen und Ersetzen der Spülfüssigkeit in einem Durchflußverfahren eingeführt wird, so daß der Flüssigkeitsspiegel von den Gegenständen mit einer solchen Geschwindigkeit absinkt, daß nach dem Ersatz der Spülfüssigkeit durch den Trockendampf im wesentlichen keine Flüssigkeitströpfchen der Spülfüssigkeit oder Trockendampf auf den Oberflächen der Gegenstände zurückbleibt.

Revindicaciones

1. Procédé pour sécher des surfaces d’objets qui sont complètement immergés dans un fluide de rinçage, consistant à utiliser une vapeur de séchage, et à remplacer le fluide de rinçage par la vapeur de séchage en le déplaçant directement au moyen de la vapeur pour l’enlever des surfaces en question, caractérisé en ce que l’on choisit le taux de déplacement du fluide de rinçage par la vapeur de séchage pour que ce taux soit assez bas afin qu’il ne reste pratiquement plus de gouttelettes de liquide sur les surfaces après remplacement du fluide de rinçage par la vapeur de séchage, et qu’il n’y ait pratiquement aucun enlèvement de fluide de rinçage ou de vapeur de séchage par évaporation de gouttelettes de liquide.

2. Procédé selon la revendication 1, dans lequel le liquide de rinçage est de l’eau en phase liquide.

3. Procédé selon la revendication 2, dans lequel on chauffe les surfaces à traiter jusqu’à environ la température de la vapeur de séchage avant de les mettre en contact avec cette vapeur.

4. Procédé selon la revendication 3, dans lequel on effectue le chauffage en question en utilisant le fluide de rinçage comme fluide caloporteur.
5. Procédé selon la revendication 3, dans lequel on effectue le chauffage par un transfert thermique de solide à solide à partir d’un support auquel sont suspendus les objets à traiter.

6. Procédé selon la revendication 1, dans lequel le fluide de rinçage est repoussé vers le bas par la vapeur de séchage.

7. Procédé selon la revendication 1, dans lequel on enlève le fluide de rinçage des objets au moyen d’un système de pompage externe.

8. Procédé selon la revendication 1, dans lequel on enlève la vapeur de séchage des objets en introduisant un gaz sec, inerte, non condensable, après remplacement du fluide de rinçage.

9. Procédé selon la revendication 8, dans lequel le gaz est de l’azote.

10. Procédé selon la revendication 1, dans lequel la vapeur de séchage est saturée.

11. Procédé selon la revendication 1, dans lequel la vapeur de séchage est surchauffée.

12. Procédé selon la revendication 2, dans lequel la vapeur de séchage est miscible à l’eau.

13. Procédé selon la revendication 2, dans lequel la vapeur de séchage forme avec l’eau un mélange azéotrope à point d’ébullition minimum.

14. Procédé selon la revendication 13, dans lequel la vapeur de séchage est de l’isopropanol.

15. Procédé selon la revendication 1, dans lequel la vapeur de séchage est un azéotrope.

16. Procédé selon la revendication 2, dans lequel la vapeur de séchage est un azéotrope isopropanol/eau.

17. Procédé selon la revendication 1, dans lequel la vapeur de séchage est un composé organique non réactif avec les surfaces à traiter et qui a un point d’ébullition de moins de 140°C à la pression atmosphérique.

18. Procédé selon la revendication 1, dans lequel les surfaces à traiter ne subissent aucun mouvement ni aucune manipulation entre les phases de rinçage et de séchage.

19. Procédé selon la revendication 18, dans lequel on opère dans un récipient dans lequel les objets à traiter sont suspendus, ce récipient étant complètement rempli par le fluide de rinçage et/ou la vapeur de séchage pendant les phases de rinçage et de séchage.

20. Procédé selon la revendication 19, dans lequel on applique une couverture de vapeur de séchage sur les objets à traiter immédiatement après l’enlèvement du fluide de rinçage.

21. Procédé selon la revendication 1, dans lequel les objets à traiter sont des plaquettes de semiconducteurs.

22. Procédé selon la revendication 1, dans lequel on filtre la vapeur de séchage en phase vapeur avant de la mettre en contact avec les surfaces à traiter.

23. Procédé selon la revendication 1, dans lequel on recueille la vapeur de séchage pour la recycler après le séchage des surfaces à traiter.

24. Procédé selon la revendication 23, dans lequel on recycle la vapeur de séchage sous la forme d’un azéotrope avec le fluide de rinçage.

25. Procédé selon la revendication 1, dans lequel les objets à traiter sont des plaquettes de semiconducteurs, le fluide de rinçage étant de l’eau chaude et la vapeur de séchage de l’isopropanol, ce procédé consistant à introduire la vapeur d’isopropanol par le haut au-dessus des plaquettes pour repousser et remplacer l’eau au fur et à mesure de l’abaissement du niveau de l’eau qui abandonne les plaquettes en opérant à une allure telle qu’il ne reste aucune gouttelette d’eau ou d’isopropanol sur les surfaces des plaquettes, celles-ci étant sensiblement à la même température que la vapeur de séchage au moment où elles entrent en contact avec la vapeur.

26. Procédé selon la revendication 1, dans lequel on opère dans un récipient complètement fermé, en introduisant la vapeur de séchage par le haut au dessus des objets, pour repousser et remplacer le fluide de rinçage dans un processus d’écoulement continu, de telle manière que le niveau de fluide se retire vers le bas pour s’éloigner des objets à une allure telle qu’il ne reste sensiblement aucune gouttelette liquide du fluide de rinçage ou de la vapeur de séchage sur les objets après remplacement du fluide de rinçage par la vapeur de séchage.