

METHODS FOR IMPROVING SEMICONDUCTOR PROCESSING

CROSS REFERENCE TO RELATED PATENT APPLICATION

This application is a continuation-in-part of patent application serial number 08/229,450 filed on January 27, 1994, for "Methods for Improving Semiconductor Processing" by Frank R. Balma and Brent D. Elliot.

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to the field of semiconductor processing and more specifically, to a method for reducing moisture contamination during semiconductor processing.

2. DESCRIPTION OF RELEVANT ART

In order to obtain manufacturably acceptable yields, tight process control is essential in semiconductor manufacturing. Present processing techniques have a variety of shortcomings which effect process uniformity, reliability and throughput. One problem with present processing techniques is the inability to control moisture contamination. Another problem associated with present processing techniques is the inability to precisely control process gas temperatures, especially in those processes which utilize energy-dependent reactions.

Contamination has always been of paramount concern in the fabrication of integrated circuits. Scrupulously clean wafers and processes are critical to obtaining high yields in VLSI fabrication. As device dimensions shrink to well below the submicron range, wafer cleanliness is even more important than ever in fabrication of advanced semiconductor circuits. One of the largest sources of contamination in semiconductor processing is moisture contamination. Moisture contamination is present throughout the semiconductor fabrication process. For example, when wafers are transferred between various process modules they are exposed to moisture in the atmosphere. Moisture readily clings to outer semiconductor surfaces and materials formed thereon. Moisture is present even in the ultra-clean "clean rooms" normally associated with semiconductor processing. Not only is moisture adsorbed onto the surface of semiconductor wafers, but it also finds its way into process machinery. For example, load locks are well-known for being a source of moisture contamination.

Load locks are chambers used to move wafers to and from a process tool which is under vacuum. Figure 1 shows a typical cluster tool 100 used in semiconductor manufacturing. Cluster tool 100 comprises a transfer chamber 102, a plurality of process chambers 104a, 104b, and 104c, and a load lock chamber 106. When wafers are to be processed, (i.e., have materials deposited, materials etched, etc.) they are brought into cluster tool 100 through load lock 106. Load locks typically have two doors, a door 108b which opens to transfer chamber 102 and a door 108a which opens to the outside atmosphere. Door 108b remains closed when wafers are inserted from the atmosphere so that the process chambers 104 and transfer

chamber 102 can remain under vacuum and therefore contamination free. After wafers are placed in load lock 106, load lock 106 is pumped down to the same vacuum level as transfer chamber 102. When a common pressure is obtained, door 108b is opened and a robot arm in transfer chamber 102 removes a wafer and transfers it into a process chamber for the desired processing.

Because load lock 106 is open to atmosphere when wafers are transferred to and from the process tool 100, contaminants, mostly in the form of moisture, readily seep into load lock 106. Techniques such as spraying a curtain 110 of nitrogen (N_2) gas along the outer perimeter of door 108a when door 108a is open, have been used to help prevent moisture from seeping into the load lock. Such techniques, however, do not completely eliminate moisture seepage. Additionally, dirty gases and gas lines used to purge load lock 106 can also be a source of undesired moisture contamination. Still further, moisture adsorbed onto objects placed in load lock 106, such as a wafer carrier, can also be another source of moisture contamination in load lock chamber 106. Moisture found in load lock 106 will contaminate wafers placed therein.

It is to be appreciated that moisture contamination can affect the uniformity and reliability of semiconductor processing steps. For example, moisture can cause nonuniform doping profiles during ion implantation steps. Moisture can cause nonuniform etch rates during etching and patterning steps. Still further, moisture can cause corrosion of metal layers resulting in reliability problems including catastrophic failure. Moisture contamination is one of the biggest problems effecting process uniformity and reliability in today's advanced semiconductor manufacturing processes.

Another problem associated with many present semiconductor processing modules is the inability to accurately control gas temperatures. Many processes, for example, processes such as chemical vapor deposition (CVD), utilize chemical reactions which require high threshold energies in order to proceed. In a typical system, gases are fed into the process chamber at ambient temperature (i.e. room temperature). Once injected into the chamber, the gases are then heated with heating elements or plasmas in order to provide the gases with sufficient energy to allow the desired chemical reactions to occur. Because all machinery inherently acts differently, different pieces of the same machinery require different process times to allow gas to obtain the required temperature for reaction. This adds yet another variable to the process equation making overall process uniformity poor. Additionally, because of the large "ramp up" time necessary to heat the gases, wafer throughput suffers.

Thus, what is needed are methods for improving uniformity, reliability, and throughput of semiconductor processes by reducing moisture contamination and by improving temperature control of gases used in temperature dependent reactions.

SUMMARY OF THE INVENTION

Methods for improving uniformity, reliability and throughput of semiconductor manufacturing processes are described. In one method moisture is removed from the surface of a semiconductor wafer prior to processing. In this method a wafer is placed into a chamber, such as a load lock. Next, the load lock chamber is evacuated to a pressure of approximately 100 mTorr with a standard vacuum pump. Next, a dry gas, such as nitrogen (N_2), heated to a temperature of between $150^{\circ}C$ - $800^{\circ}C$ is injected into the load lock. Heated gas is injected into the load lock until a pressure of approximately 15 psi is reached. The heated gas causes moisture clinging to the surface of the wafer to break away and evaporate into the heated gas. Next, the load lock is evacuated to a pressure of approximately 100 mTorr to thereby remove the heated gas and any moisture evaporated into the gas. The gas fill and evacuation steps can be repeated until the desired level of cleanliness is obtained. In a second method, gases used in semiconductor processes are heated to approximately reaction temperature prior to injection into a reaction chamber. This second method increases both process uniformity and process throughput.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of overhead view of a semiconductor processing apparatus capable of implementing the processes of the present invention.

Figure 2 is a flow chart illustrating process steps of the present invention.

Figure 3 is an illustration of a cross-sectional view of a first anhydrator which can be used to heat, dry and filter gases used in methods of the present invention.

Figure 4 is an illustration of a cross-sectional view of a second anhydrator which can be used to heat, dry and filter gases used in methods of the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

The present invention describes methods for improving semiconductor manufacturing processes. In the following description, numerous specific details, such as particular process parameters and equipment, have been described in detail in order to provide a thorough understanding of the present invention. However, it may be obvious to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well-known semiconductor processes and equipment, have not been set forth in particular detail in order not to unnecessarily obscure the present invention.

The present invention describes methods for improving the reliability, uniformity and quality of semiconductor processes used in the manufacture of modern high-density integrated circuits. One method of the present invention is used to remove moisture contamination from wafers and semiconductor equipment. In this method, wafers are placed in a sealed chamber. The chamber is then evacuated and refilled with a dry heated gas. The chamber is once again evacuated to remove the heated gas and any moisture desorbed from the wafers and/or chamber. In another method of the present invention, process gases are preheated to a process temperature prior to injection into a reaction chamber. Preheating the gases increases both process uniformity and throughput. The two methods of the present invention can be used together to provide a highly uniform, reliable process with good wafer throughput. It is to be appreciated that the term "wafer" is used throughout the present disclosure. Wafer is to be construed

to include unprocessed semiconductor substrates, including but not limited to silicon, gallium arsenide, and germanium, as well as semicomplete and complete integrated circuits or devices formed thereon. Additionally, the processes of the present invention are not intended to be limited to semiconductor processes but rather are generally applicable to other processes, such as those used in package manufacturing, circuit board manufacturing, etc., which are effected by moisture contamination and gas temperature control.

Many different process steps (approximately 25) are required to build the various layers needed to form modern ultra-large scale integrated circuits (ULSI). These steps include, among others, ion implantation used to form doped regions, oxide growth used to form field isolation regions, metal deposition and patterning used to form interconnections, and dielectric deposition used to isolate the various levels of metal interconnections. It is well-known that the reliability and uniformity of these processes are affected by moisture and particle contamination adsorbed onto the outer surface of the semiconductor wafer (or materials formed thereon). Moisture is readily adsorbed by wafers when they are exposed to the environment such as when they are transferred between various process modules. Additionally, process machinery itself can be a large source of moisture contamination of wafers.

In the fabrication of integrated circuits, semiconductor wafers are typically processed in a process tool such as cluster tool 100 shown in Figure 1. Cluster tool 100 comprises a plurality of process chambers 104a, 104b, and 104c. Process chambers are the locations where materials are deposited, ions are implanted, and/or materials etched, etc. Cluster tool 100

includes a central transfer chamber 102 for moving wafers between the various process chambers 104a, 104b, and 104c and load lock 106. A robot arm (not shown) is provided in transfer chamber 102 to facilitate the transfer of wafers between the various process chambers 104 and load lock 106. It is to be appreciated that process chamber 104a, 104b, and 104c and transfer chamber 102 are normally kept under vacuum to reduce their exposure to moisture and particle contamination. Load lock chamber 106 is the pathway between the outside world and cluster tool 100. Load lock chamber 106 has an outside door 108a which opens load lock 106 to the outside environment and an inside door 108b which opens load lock 106 to transfer chamber 102. Both door 108a and door 108b can be sealed in a manner that allows load lock chamber 106 to be pumped down to a pressure of less than 50 mTorr.

In reference to block 202 of Figure 2, the first step in processing wafers according to the present invention is to place a wafer or wafers into load lock 106. Load lock 106, if not presently at atmospheric pressure, is brought up to atmospheric pressure so that door 108a can be opened. A wafer or wafers are then placed inside load lock 106. Unfortunately, while door 108a is open to the atmosphere, moisture and other particle contamination from the environment find their way into load lock chamber 106. A curtain 110 of nitrogen (N_2) gas can be sprayed while door 108a is opened, to help reduce contamination of load lock 106. Once the wafers are placed inside load lock 106, door 108a is closed and sealed. It is to be appreciated, that at this point a significant amount of moisture is present in load lock 106. Some moisture came into load lock 106 from the atmosphere

when door 108a is opened. Additionally, some moisture came in on the wafer carrier, and some came in on the wafers themselves.

The next step according to the present invention is to remove or reduce substantially all the moisture present in load lock 106 so that a subsequent high quality processing can take place. In this regard, as detailed in block 204 of Figure 2, load lock 106 is evacuated to a pressure of less than 100 mTorr. A well-known vacuum pump (not shown) coupled to load lock chamber 106 can be used to evacuate load lock chamber 106. Once load lock chamber 106 is pumped down to the desired pressure, it is refilled with a dry, heated gas as detailed in block 206.

In the present invention, sealed load lock chamber 106 is refilled with a dry, heated gas at least until atmospheric pressure is reached, inside load lock chamber 106 and preferably until a pressure greater than 10 psi is reached. Gas injected into load lock 106 should be heated to a temperature of between approximately 150°C to 800°C, with a preferred temperature range between approximately 400°C to 600°C. In the preferred embodiment of the present invention, the gas is substantially pure nitrogen (N₂).

Nitrogen is preferred because it is dry, essentially inert to most materials formed on semiconductor wafers, and inexpensive since it is widely used and available in semiconductor manufacturing. It is to be appreciated, however, that other pure, dry, essentially inert gases such as, but not limited to Helium (He) and Argon (Ar), may also be used if desired. Helium, for example, is known to have a desirable high heat transfer coefficient. Additionally, it is to be appreciated that the heated gas injected into load lock 106 should have a moisture contamination level of less than 100 - 500 parts per billion.

The heated gas injected into load lock 106 breaks the bonds of moisture molecules clinging to the surface of the wafer. Once free from the wafer, the moisture molecules are evaporated into the heated gas ambient. Next, as detailed in block 208, load lock chamber 106 is once again evacuated to a pressure of less than 100 mTorr. This evacuation step removes from chamber 106 the heated gas ambient and any moisture evaporated into the ambient. It is important to evacuate load lock 106 as soon as possible after refilling chamber 106 with heated gas in order to insure that moisture is not readsorbed onto the wafers.

In the preferred embodiment of the present invention, steps 206 and 208 are repeated until the desired moisture contamination level is reached. Steps 206 and 208 in the preferred embodiment of the present invention are repeated between five to ten times. Five to ten refill and evacuation steps insure substantially complete removal of all moisture and particle contamination without detrimentally effecting wafer throughput. It is to be appreciated that the specific process in which the method of the present invention is used will dictate the necessary balance between wafer throughput and the moisture/particle contamination level.

Apparatus 112 can be implemented with the anhydrator 360, shown in Figure 3. Anhydrator 360 can be used to supply a clean, dry, heated gas to load lock chamber 106. As shown in Figure 1, apparatus 112 is coupled between a gas supply 114 and load lock 106. As shown in Figure 3, anhydrator 360 comprises a gas inlet 312 and a gas outlet 314 having suitable fittings 316 and 318 for connection to gas distribution lines 151 coupled to gas supply 114, load lock 106, and process chambers 104. A housing 322 encloses a resistance heater 324 and a particle filter 326 for

the gas. The resistance heater 324 is connected to the gas inlet 312 and the particle filter 326 is connected between the resistance heater 324 and the gas outlet 314. The resistance heater 324 includes a sealed tube 327 defining a gas plenum 328. A resistance heater element enclosed in a cylindrical stainless steel alloy shell 330 is centrally disposed in sealed tube 327. A spiral ridge 332 winds around shell 330 to define a spiral path for gas flowing through the plenum 328 as indicated by arrows 334. The spiral ridge 332 has a narrower pitch near the gas inlet 312 and a wider pitch moving towards the filter 326 end of the plenum 328. This shape forces intimate contact between the gas and the heating element when the gas temperature difference compared to the heating element is greatest. An electrical power input 336 is connected to the resistance heater element through a rheostat control 338. A thermo-couple 340 is positioned against heater element 330 and is also connected to of the rheostat control 338. Filter 326 is implemented with a sintered stainless steel type filter element, obtainable from various suppliers. A control knob 342 is connected for adjustment of the rheostat control 338. A handle 344 is provided on housing 322 for transport. The housing 322 and sealed tube 327 are fabricated from a 316L or 304 type stainless steel.

Apparatus 112 is preferably implemented with the improved and presently preferred anhydrator 460 illustrated in Figure 4. Anhydrator 460 utilizes two thermo-couples 440 and 441 as opposed to a single thermo-couple in the anhydrator 360. Thermo-couple 441 is positioned near gas outlet 414 so that the temperature of the gas exiting anhydrator 460 is precisely monitored. Thermo-couple 441 is coupled to and provides temperature readings to rheostat 438 which in turn controls the temperature

of the gas with resistance heater 424. It is to be appreciated that the temperature of the gas decreases during the time it travels from resistance heater 424 to gas outlet 414. Thus, by positioning the gas temperature controlling thermo-couple 441 near gas outlet 414, the temperature of the exiting gas is accurately controlled with a high degree of precision in the present invention.

Anhydrator 460 includes a second thermo-couple 440 positioned against heating element 430 and coupled to rheostat 438. Thermo-couple 440 provides "over temperature" control. That is, for example, if no gas is flowing through anhydrator 460, the desired gas temperature will not be sensed by thermo-couple 441. Rheostat 438 will, therefore, continue to increase power to the heating element 430 in a fruitless attempt to obtain the desired gas temperature at thermo-couple 441. In such a situation heating element 430 will eventually burn out. Thermo-couple 440 is provided to prevent this problem. If no gas is present in resistance heater 424, thermo-couple 440 will sense the increase in temperature and relay this to rheostat 424 which in turn will turn off heating element 430 and prevent burn out.

As shown in Figure 4, anhydrator 460 also includes a gas inlet 412 and a gas outlet 414 having suitable fittings 416 and 418 for connection to gas distribution lines 151 coupled to gas supply 114, load lock 106, and process chambers 104. A housing 422 encloses a resistance heater 424 and a particle filter 426 for the gas. The resistance heater 424 is connected to the gas inlet 412 and the particle filter 426 is connected between the resistance heater 424 and the gas outlet 414. The resistance heater includes a sealed tube 427 defining a gas plenum 428. A resistance heater element enclosed in a cylindrical stainless steel alloy shell 430 is centrally

disposed in sealed tube 427. A spiral ridge 432 winds around shell 430 to define a spiral path for gas flowing through the plenum 428 as indicated by arrows 434. The spiral ridge 432 has a narrower pitch near the gas inlet 412 and a wider pitch moving towards the filter 426 end of the plenum 428. This shape forces intimate contact between the gas and the heating element when the gas temperature difference compared to the heating element is greatest. An electrical power input 436 is connected to the resistance heater element through a rheostat control 438. Filter 426 is implemented with a sintered stainless steel type filter element, obtainable from various suppliers. A digital control panel 442 is connected for adjustment of the rheostat control 438. The housing 422 and sealed tube 427 are fabricated from a 316L or 304 type stainless steel. It is to be appreciated that other well-known means can be used to supply a clean, dry, heated gas into load lock 106 if desired.

Once the desired number of refill and evacuation cycles has been completed, the moisture removal process of the present invention is complete as detailed in block 212. At this point, load lock 106 and the wafer surface are substantially free of moisture contamination, allowing for a more uniform and reliable processing of the wafers. After load lock 106 has been evacuated for the last time, and transfer chamber 102 and load lock 106 are at the substantially same pressure, door 108b is opened. A wafer is then removed from load lock 108 and transferred by a robot arm or similar means into transfer chamber 102 and then into one of the process chambers 104. Subsequent processing of the wafer yields a very uniform and reliable process because substantially all of the moisture has been removed from the wafer prior to processing.

Once the wafer is transferred into a process chamber 104, the chamber door is shut and respective processing begun. A great majority of semiconductor process steps utilize energy dependent reactions. For example, chemical vapor deposition (CVD) processes require the chemical reaction of gases in order to proceed. In these processes, a second method of the present invention heats the gases to substantially process temperature prior to injection into the reaction vessel. Once the gases are injected into the reaction chamber, the reaction can occur immediately because the gases have the necessary reaction energy. Unlike the prior art, in the present invention no time is required to take the gas or gases from ambient temperature up to process temperature. This significantly increases wafer throughput and improves process uniformity. As shown in Figure 2, the process gases are preferably heated through the use of a plurality of apparatuses 112, such as anhydrator 460 described above, one for each gas. It is to be appreciated, however, that other well known means such as heating tape, lamps, etc. may be used to preheat the gases in the method of the present invention.

Thus, methods for improving uniformity, reliability, and throughput of semiconductor processes have been described. The processes can be used individually, or in combination, to improve results.

IN THE CLAIMS

We claim;

1. A method for removing moisture from a substrate prior to processing said substrate, said method comprising the steps of:
 - a. placing said substrate in a chamber;
 - b. evacuating said chamber;
 - c. filling said chamber with a heated gas; and
 - d. after filling said chamber with said heated gas, evacuating said chamber.
2. The method of claim 1, wherein said heated gas comprises a dry nitrogen gas.
3. The method of claim 1, wherein said heated gas has a temperature of between 150°C - 800°C.
4. The method of claim 3, wherein said heated gas has a temperature of between 400°C - 600°C.
5. The method of claim 1, wherein said steps (c) and (d) are repeated.
6. The method of claim 5, wherein said steps (c) and (d) are repeated at least five times.



7. The method of claim 1, wherein said chamber is filled with said heated gas to a pressure of greater than or equal to approximately 15 psi.
8. The method of claim 1, wherein after filling said chamber with said heated gas, said chamber is evacuated to a pressure of less than approximately 100 mTorr.
9. A method of removing moisture from a semiconductor wafer prior to processing said wafer, said method comprising the steps of:
 - a. placing said wafer in a load lock while said load lock is at approximately atmospheric pressure;
 - b. sealing said load lock;
 - c. pumping down said load lock to a pressure of approximately 100 mTorr;
 - d. filling said load lock to at least atmospheric pressure with a dry gas comprising nitrogen, said heated gas having a temperature of between 150°C - 800°C; and
 - e. after filling said load lock with said heated gas, pumping down said load lock to a pressure less than of approximately 100 mTorr.
10. The method of claim 9, wherein said temperature of said heated gas is between 400°C - 600°C.
11. The method of claim 9, wherein said steps (c), (d), and (e) are repeated at least five times.



12. In a semiconductor process which utilizes gases at elevated temperatures, a method for improving the uniformity and throughput of said process, said method comprising the steps of:

- providing a gas to a reaction chamber; and
- heating said gas to a predetermined temperature prior to providing said gas to said reaction chamber.

13. The semiconductor process of claim 12, wherein said gas is heated to substantially reaction temperature.

14. The semiconductor process of claim 12, wherein said gas is selected from the group consisting of nitrogen, helium, and argon.

