Water Cooled Plasma Flood Source for Intense Ion Beam Implantation

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***Abstract*—A plasma shower for ion beam and process wafer neutralization has been developed. A plasma is produced within an arc discharge chamber enclosed in a source housing with sufficient water cooling so that the housing temperature is close to room temperature. Arc discharge between a filament and the arc chamber ionizes the shower gas atoms or molecules in the arc chamber. The low energy electrons together with ions in the plasma drift out of the arc chamber and neutralize the ion beamsand the process wafers. The sufficiently cooled source housing prevents radiation to the process wafers and reduces vapor pressures of variety of elements in the arc chamber. Therefore, metal contaminations resulting from the shower operations are very low on the process wafers. The low temperature of the arc chamber reduces the gas leakage rate per unit area from the arc chamber by a factor of ~ 2. In this way, the beamline pressure can be kept low while more electrons can be extracted from the plasma source through the apertures with a larger area.**

I. Introduction

An ion implanter used for ion implantation purposes usually includes an ion source, ion beam transport optics, and a process chamber where the ion implantation occurs. An electron or plasma flood source is always an important component of an implanter. Not only can it help to reduce the charge buildup on target wafers during ion implantation processes, but also it can help to increase ion beam transportation efficiency to the target wafers, especially for low-energy ion beams.

It is well known during ion implantation that a charged ion beam will produce a buildup of charges on the surface of the semiconductor target. This charge buildup may not be removed from the surface of an insulating or semi-conductive wafer during or after the implantation. Also it may interfere with automatic wafer handling due to sticking, or break through layers of micro-circuitry and impact implant uniformity due to charged portions of the wafer surface deflecting the ion beam. The presence of such surface charges reduces yields in the production of integrated circuits.

One effective way to reduce the positive charge buildup on the wafer surface is to supply the same number of negative charges, specifically, electrons, on the wafer surface. Electron or plasma flood sources (i.e., electron or plasma shower sources) are usually used to supply these electrons and introduce them onto the wafer as the ion beam strikes the wafer's surface. As the requirement of implantation expands towards low energy ion beams with large currents for shallow junction formation, electron and plasma floods are also used to reduce ion beam space charge blow-up and to enhance the transportation of the low energy ion beams.

The plasma flood source commonly used in ion implantation is a hot cathode discharge plasma source. An ionizing gas, one of the inert gases, is introduced into an arc housing. The primary electrons are generated by thermionic emission from an electrically heated filament and accelerated to an energy that is determined by a negatively biased potential on the filament relative to the housing. The energetic primary electrons impact the gas atoms or molecules, knock off one or more electrons from each atom, and generate a plasma in which positive charges (ions) and negative charges (electrons) are almost equal. The kinetic energies of electrons inside the plasma depend on the plasma temperature, and are usually less than 5 eV with a narrow distribution. These low energy electrons and ions would drift out of the flood source through small hole(s) in the housing and reach the ion beam. These electrons and ions flood out of the housing, forming a plasma that has much lower density than the plasma inside the flood source, in the vicinity of the ion beam that passes by the plasma flood source.

The plasma floods have become the standard technique for controlling positive charging wafers damages. It is generally agreed that the presence of a relatively high density plasma near the wafer surface provides a reservoir of electrons that compensate for the positive charging associated with the ion beam [1]. Neutralization of an ion beam means equal densities of electrons and ions within the volume of the beam, some electrons of the plasma in the neighborhood of the ion beam are attracted by the positive beam potential and travel along with it. However, the efficiency of entrapment of electrons within the beam is a function of the plasma density as well as temperature that indicates an average electron kinetic energy of the plasma. The possibility for trapping electrons in the ion beam is inversely proportional to the electron velocities. Since the low energy electrons are dragged by the slowly moving heavy ions from the flood source, the electrons have more time to stay around the ion beam and are more easily trapped in the ion beam. When more electron are trapped inside the ion beam, the beam potential decreases, reducing its capability for trapping electrons. Therefore, this type of electron flood source can self-regulate the numbers of trapped electrons to avoid over or under compensating the positive beam currents. Since the electrons from the source have low energy, the wafer damage caused by high-energy electrons can be avoided. It is not necessary for the floods to be placed very close to the wafers and the electrons can flow to the positively charged surfaces via beam paths.

However, arc discharges inside the flood source can still generate metallic particles such as tungsten, aluminum, or molybdenum, depending on the building materials of the filament and the flood arc chamber. These metallic particles can drift out of the flood source with the plasmas and deposit onto the wafer surfaces. Increase of plasma densities that surround the ion beam can reduce the self-regulated ion beam potentials and improve low energy ion beam currents. Reducing the electron kinetic energy gives better wafer charging control. However, one has to drive the plasma flood source harder to increase low energy electron production inside the flood source and, consequently, more contaminant particles are generated. In ion implantation metal contaminations and wafer charging are two major factors that impact wafer yield. A design of the new plasma flood source in this paper can produce a higher density and lower temperature plasma with very low metal contamination.

II. Design considerations

To reduce space charge blow-up and charge buildup on wafers, electron floods are usually applied. Thermal electrons are extracted from the flood sources and flood onto the ion beams. These electrons travel along with the ion beams moving towards the wafers. They can increase the ion beam transmission from the ion source to the wafers and reduce wafer charging at the same time. However, almost all current electron flood sources used in ion implantation create some degree of metal contamination and wafer heating. The increase in densities of plasma requires higher intensities of plasmas inside the flood source housing. This results in higher levels of contamination and heating of the wafers. A newly improved design of a plasma flood source with xenon being an ionization gas is discussed here. The plasma flood source can overcome these problems by sufficient cooling of the flood source body. By significantly reducing the temperature of flood source body, the bleeding gas pressure inside the flood source body is also reduced. The flood source extraction aperture area can be increased to provide more electrons without affecting vacuum of the implanter. The new plasma flood source can produce a higher density and lower temperature plasma around an ion beam, minimize metal particles drifting from the arc housing, and eliminate radiation heating to wafers from the flood source.

A. Plasma density and electron energy

The plasma density surrounding the ion beam is regulated by the balance between the rate of plasmas drifting out of the flood source and the plasma diffusion towards to chamber walls that surround the ion beam. The plasmas in the vicinity of the ion beam can be treated as a weakly ionized gas because the plasma density is two orders in magnitude smaller than the residual gas density. Krall and Trivelpiece [2] pointed out that the effective plasma diffusion coefficient in the weakly ionized gas is approximately twice the free diffusion coefficient for ions. This is because electrons diffuse faster than the ions, but are inhibited by the space charge field they set up. This space charge field enhances the diffusion of ions, so the net effect is that both ions and electrons diffuse together. An effective diffusion coefficient is twice the diffusion coefficient of the ions. This diffusion is called ambipolar diffusion.

The ambipolar diffusion theory suggests a heavy ion specie is more preferable because the free diffusion coefficient is proportional to $1/M^{1/2}$ [3] (M is mass of ions). This is one of the reasons that xenon is widely used as an ionizing gas in plasma floods.

The rate at which the plasma drifts out from the plasma flood source is proportional to the plasma density inside the flood source and the sizes of the flood source extraction aperture(s). Xenon gas has a low ionization potential (12.1 eV) and much higher ionization cross section (6.2×10^{-16} cm^2) than argon (15.7 eV and 6.2×10^{-16} cm^2, respectively).[4] Moreover, xenon ions are ~ 2.5 times heavier than argon ions. The plasma density resulting from xenon discharges can be high in the flood source because of lower ambipolar diffusion rate and high ionization cross section. A stable xenon plasma can be produced at an arc voltage as low as 20 volts so that maximum electron energy can be reduced. Consequently, the problem of possible negative wafer charging due to energetic electrons can be minimized. Xenon, therefore, is a preferable gas to be used in the plasma flood source design because it can raise the plasma density in the vicinity of ion beams and reduce the electron energy.

Increasing the flood source extraction aperture area is another way to raise the plasma density near ion beams. However, a high xenon gas flow rate is needed in order to maintain a similar gas pressure inside the flood source. This will increase background pressure in the beamline and in the process chamber. Too high a background gas pressure could cause a large numbers of beam ions to become energetic neutrals due to charge exchange interactions between beam ions and background gas molecules causing the implant dose can be erratic. Cooling the flood source body can greatly reduce the required gas flow rate. If the chamber wall temperature is reduced from 900 °C to 25 °C, then the gas flow rate can be twice as low while maintaining the same pressure inside the flood source.

B. Metal contamination

The plasma flood source is commonly placed next to the process wafers and can be a source of metal contamination. Any metallic particles resulting of the flood source operations are likely to land on the wafers. Most metallic particles are produced by evaporating processes inside the source since its filament is at very high temperature (> 2200 °C). The metal vapor drifts out of the plasma flood through the extraction holes. Therefore, reducing metal vapor pressures inside the source is the most effective way to minimize the metal contamination from a plasma flood source. A plasma flood source with the entire source walls cooled to room temperature, is the most distinguished feature of the design.

The low temperature environment allows the source walls to be made of aluminum which is a cost effective and friendly material to the semiconductor processes, eliminating the usage of other metals for the source components, such as molybdenum and graphite, except for the tungsten filament. The new plasma flood source confines the possible metal contaminations to only aluminum and tungsten from the plasma flood source. Moreover, the present design with the water-cooled source body eliminates aluminum vaporization rates and increases possibility of tungsten and aluminum depositions onto the cooled sources. The partial vapor pressures of tungsten and aluminum inside the flood source housing can be greatly reduced. The metal contaminations from the flood sources usually come from the metal vapor drifting out of the source from the flood source extraction aperture. Since the tungsten and aluminum vapor partial pressures are so low at room temperature that the metal contaminations on the wafers are negligible.

III. DESCRIPTIONS OF DESIGN

The new plasma flood source has a cold source housing. Fig. 1 is a functional block diagram for showing the plasma flood source. The plasma flood source includes a source housing with hollow walls, an arc plasma chamber in the upper part of the source housing, and a filament inside the arc plasma chamber. Cooling water flows from the water inlet into the water passway formed in the hollow walls of the source housing and comes out from the water outlet. This keeps the source housing at room temperature. Xenon gas is introduced into the arc chamber through the gas inlet. When a large current is running through the filament, thermal electrons emit from the filament surface into the arc chamber. The filament is electrically biased at a negative potential. As a result, the emitting electrons are accelerated by this potential and have sufficient kinetic energies to ionize the gas molecules inside the arc chamber and create an arc plasma. Electrons and ions in the plasma drift out of the flood source from extraction apertures (circular holes) move towards the ion beam to form a plasma flood. The low energy electrons in the flood are trapped in the positive ion beam and neutralize the beam. The trapped electrons flow with the ion beam to the processing wafers to keep them frim being charged up.

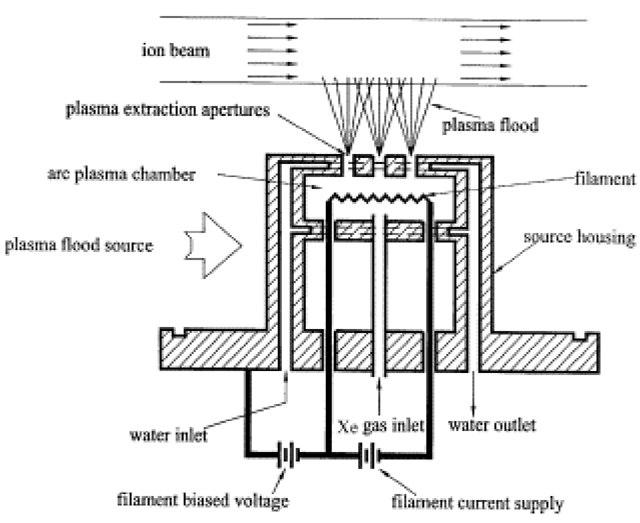

Figure 1. Functional block diagram of a plasma flood source.

Fig. 2 shows a mechanical design of a plasma flood source with several plasma extraction apertures in the front source surface. The plasma flood source has an arc chamber size of 35 mm in diameter and 20 mm in depth. The flood source is fabricated of aluminum and operates at room temperature with active water-cooling. A 1 mm diameter filament passes through a ceramic base insulator and is heated to a thermionic emission temperature by a filament power supply. The filament current of 60 to 70 amperes is sufficient to provide the primary electrons to support the arc currents of 3 to 5 amperes. The filament can last several months in continuous operations. The arc voltage can be between 20 and 40 volts. The flood source is operated at very low xenon flow rate ~ 0.2 sccm even with such a large extraction area (3 times of a convention flood source).

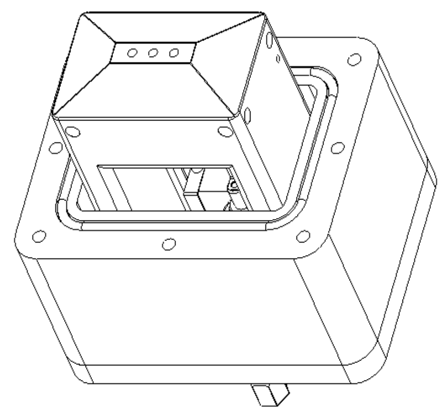

Figure 2. Three-dimensional mechanical design diagram of the plasma flood source.

Body temperature of a conventional plasma flood source without sufficient water-cooling can reach operation temperatures as high as 900 °C because of direct heating from arc discharges and radiation heating from the filament. Refractory metals or graphite is used to construct the arc chamber. Metallic particles from the filament and the chamber walls will not stick onto the hot walls. They will eventually leak out with the plasma flood, causing contaminations on the wafers. In the plasma flood source of the design discussed in the paper, the source housing is cooled to less than 25 °C, a factor of 4 lower than the conventional sources. The metallic particles inside the arc chamber have a higher possibility to deposit on the cool chamber walls and the metallic vapor pressures can be several orders of magnitude lower. The metal contaminations on the wafers in applying the plasma flood are therefore significantly reduced.

To sufficiently neutralize the ion beam, more flood plasmas need to be extracted out of the arc chamber, which requires one or multiple extraction apertures with a large total area. However, the large extraction area causes more xenon gases leaking into the beamline as well as wafer processing regions and increases the vacuum pressure in the regions. It is not desirable for the vacuum pressure near the wafers higher than 1E-5 torr. The vacuum pressures in the regions are proportional to the extraction aperture size and the gas pressure inside the arc chamber. The arc chamber pressure is reduced by a factor of 2 compare to the conventional source due to the active water-cooling. The extraction aperture area can be increased by a factor of 2 without changing the vacuum pressure. The larger extraction area can provide more electrons from the flood source and thus increase beam neutralization efficiency and reduce charge buildup on wafers.

The external flood source surfaces facing the wafers are at room temperature because of the sufficient water-cooling. The filament is installed in a position so that there is no filament exposure to the wafers through those apertures. Therefore there is no heat transfer between the flood source and the target wafers.

IV. CONCLUSIONS

This paper discusses the design of the plasma flood source with the entire source body being water-cooled to room temperature. The low operation temperature allows the flood source body to be made of aluminum that is a more friendly material to the wafers. Increase of the plasma density in the vicinity of an ion beam is critical for low energy beam space charge neutralization and wafer charging control during implants. Xenon plasmas are the best choice of the plasma flood and provide high plasma densities because of their low effective ambipolar diffusion coefficient. The water-cooled plasma flood source allows one to enlarge the flood extraction areas without increasing a xenon gas flow rate needed to sustain a stable plasma. The wafer heating from the flood source is eliminated in this design.

[1] D. L. Smatlak, M. E. Mack, and S. Metha, Nucl. Instr. And Math. **B** 96 (1995) pp22-29.

[2] N. A. Krall, and A. W. Trivelpiece, “Principles of Plasma Physics” McGraw-Hill Book Company, 1973, pp.321–324.

[3] F. F. Chen, “Introduction to Plasma Physics and Controlled Fusion: Plasma Physics”, Plenum Pub. Corp., Second edition, 1984.

[4] G. Dearnaley, J. H. Freeamn, R. S. Nelson, and J. Srephen, “Ion Implantation”, North-Holland Pub. Comp., 1973.