

A Study of Charge Neutralization Method during High Current Ion Implantation for Ultra Thin Gate Dielectrics

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Abstract- Ultra thin gate oxide breakdown due to excess electrons supplied by charge neutralization system such as plasma flood system (PFS) is discussed. For the ultra thin gate oxide below 5nm, the oxide breakdown due to not only positive charge by ions but also negative charge by PFS becomes noticeable. The maximum energy of electrons from PFS dominates the oxide breakdown instead of total electron flux. For the 3.5nm gate oxide, maximum electron energy should not exceed 9eV to suppress the breakdown. For the ultra thin gate dielectrics, the energy control of electron is the most important to suppress the oxide breakdown by excess electrons from PFS.

I. INTRODUCTION

With increasing the device integration and reducing the design rule, the gate oxide thickness becomes thinner and thinner. For the 0.5 μ m CMOS devices, the gate oxide thickness was around 10nm. However, below 5nm gate oxide thickness is used for 0.25 μ m CMOS device and beyond. These thin gate oxides are extremely susceptible to charge build-up during wafer fabrication process such as high current ion implantation; plasma etching and plasma enhanced CVD. In particular, the charge build-up during high current ion implantation is the most important from the view point of thin gate oxide breakdown because the high dose implantation such as gate doping and source/drain formation is made through the gate electrodes [1][2].

In general, positive charge build-up due to ion beam is the dominant in ion implantation. For the gate electrode doping or/and source/drain formation, the positive charge build-up is remarkable as relatively high (>10mA) beam current is used. Usually a charge neutralization system has been used to compensate the positive charge by supplying the electrons to beam trajectory or wafer surface. This charge neutralization system is so called "Electron shower" or "Flood gun system" [3]. In past, as an electron shower had poor electron flux controllability, sometimes oxide breakdown was observed due to under or over compensation of positive charge. Recently, plasma floods system (PFS) has been used widely because the precise control of electron energy and flux is available [4][5][6].

Sufficient flux to compensate positive charge and relatively low energy electrons can be supplied by PFS, and it can be applicable down to 7.5nm gate oxide as virtually charge build-up free. In another word, down to 7.5nm gate oxide, no precise control of flooding electrons was not necessary. However, for the ultra thin gate oxide below 5nm, the oxide breakdown caused by charge build-up during ion implantation has been noticeable even the PFS is used. This oxide breakdown is due to negative charge build-up instead of positive charge build-up. Generally, the discussion of negative charge build-up due to excess electrons from PFS has been reported from the viewpoint of excess electron flux [7][8].

In this paper, we have investigated the charge build-up behavior of ultra thin gate oxide below 5nm during high current ion implantation. The relationship among oxide breakdown, electron energy and total electron flux from PFS is clarified by using

breakdown of antenna MOS capacitors with ultra thin gate oxide and by using electron energy and flux measurement for various PFS conditions.

II. EXPERIMENTAL

Charge Build-up Evaluation using Antenna MOS Capacitor

The gate oxide breakdown occurs when the total injected electrons exceed threshold charge to breakdown (Q_{bd}) of the oxide [7][9]. The breakdown sensitivity can be amplified by adding the large area charge-collecting electrode (antenna). In antenna MOS capacitor, the breakdown occurs when the following equation is satisfied.

$$Q_{inj} \times \text{Antenna ratio} > Q_{bd} \text{ -----(1)}$$

Where,

Q_{inj} : Total injected charge density (C/cm²)

Q_{bd} : Charge to breakdown of oxide (C/cm²)

Antenna ratio : (Antenna electrode area)/(Capacitor area)

Basically Q_{bd} has the stress polarity, stress current density and oxide thickness dependence. In this work, antenna MOS capacitors that have antenna ratio up to 1×10^6 with 3.5nm, 5nm and 10nm gate oxide were used. Both p-type and n-type substrates were used to detect the charge build-up polarity. The breakdown measurement was done by using ramp voltage method and a breakdown criterion was 100 μ A/cm².

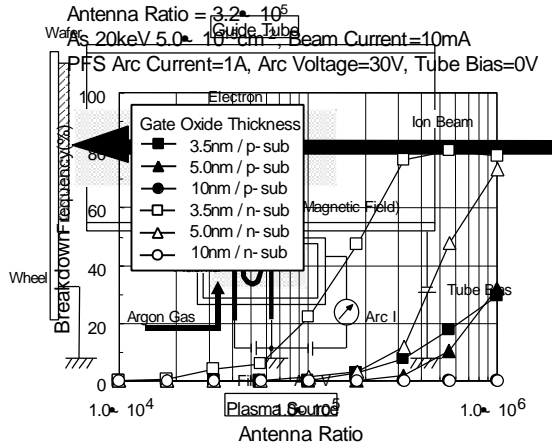


Fig.1 Schematic Drawing of Plasma Flood System (PFS)

Plasma Flood System on High Energy Ion Implanter

In this work, PI-9500xR (high current ion implanter system) and new plasma flood system (High Density Plasma Flood System; HD PFS) is used [10][11]. These systems are developed by Applied Materials.

Figure 1 shows the schematic drawing of plasma flood system used in this study [6][11][12][13]. The plasma is generated in the arc chamber with applying filament voltage, arc current and Argon (Ar) gas flow. The electrons are extracted to beam trajectory by applying magnetic field and differential pressure caused by Argon gas flow between arc chamber and guide tube. The electron is confined in guide tube by tube bias. And the electrons are flooded to wafer surface with certain energy by electric field made by ion beam and magnetic field in PFS. The charge build-up due to ion beam on wafer surface is compensated by flood electrons. The control parameters of PFS are arc voltage (Arc V), arc current (Arc I), and Ar gas flow and extraction voltage (Tube bias).

III. RESULTS AND DISCUSSION

Gate Oxide Thickness Dependence

Figure 2 show the antenna ratio dependence of oxide breakdown frequency of antenna MOS capacitor fabricated on p-type and n-type substrate by Arsenic (As) implantation as a parameter of gate oxide thickness. Arsenic implantation was made at 20keV with $5 \times 10^{15} \text{cm}^{-2}$ dosage. The beam current was 10mA. The PFS condition was Arc I=1A, Arc V=30V and Tube bias=0V.

For both p-type and n-type substrate, no breakdown is observed on antenna MOS capacitors with 10nm gate oxide. However, both 5nm and 3.5nm gate oxide breakdown when antenna ratio exceeds 1×10^5 . In particular, oxide breakdown is remarkable for n-type substrate.

These results suggest that the negative charge build-up was dominant because the breakdown percentage on n-type substrate was higher than that on p-type substrate [8]. This PFS condition is sufficient to suppress the breakdown for the 10nm gate oxide. However, the breakdown results of 5nm and 3.5nm gate oxides suggest that the excess electrons generate negative charge build-up under this PFS condition. To clarify the relationship between PFS parameters and oxide breakdown, we have investigated the arc current and tube bias dependence of oxide breakdown

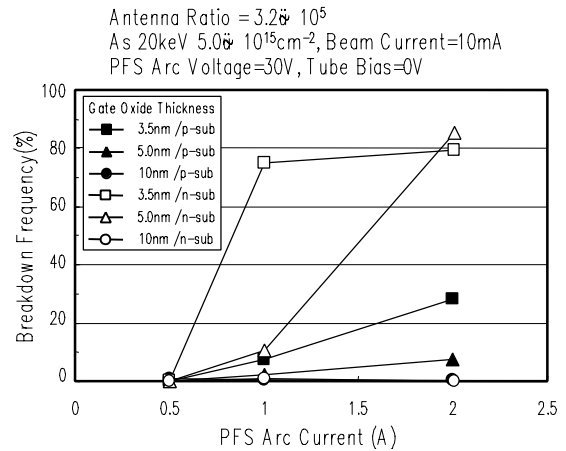
Fig.2 Antenna Ratio Dependence of Breakdown Frequency of Antenna MOS capacitors Fabricated

Arc Current Dependence of Oxide Breakdown

Arc current (Arc I) is defined as current flow between filament and arc chamber. Plasma density in arc chamber is strongly

depending on arc current. Generated electron flux and flooding electron flux are increased proportionally with increasing arc current.

Figures 3 show PFS arc current dependence of breakdown frequency of antenna MOS capacitors fabricated on p and n-type substrate, respectively. For this measurement, 3.2×10^5 antenna ratio was used. With increasing the arc current the breakdown of 5nm and 3.5nm gate oxide becomes remarkable. However, no breakdown was observed for 10nm gate oxide. The breakdown at relatively high arc current is thought to be due to excess electron



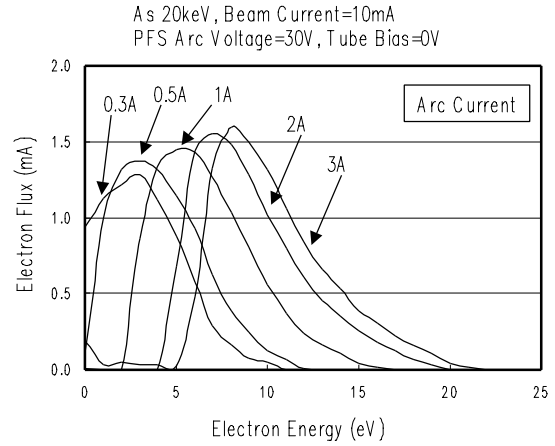
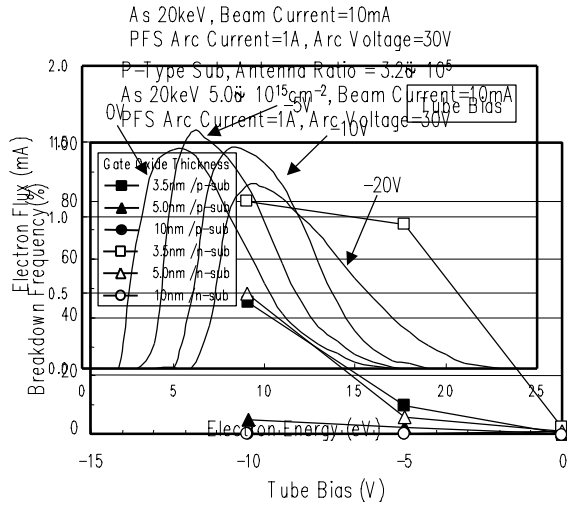
flux or high energy electrons.

Fig.3 Arc Current Dependence of Breakdown of Antenna MOS Capacitors Fabricated

Tube Bias Dependence of Oxide Breakdown

Tube bias is defined as the voltage between guide tube and ground. This tube bias acts as electron confining in guide tube. The flooding electron flux is increased with increasing tube bias. However, higher tube bias also gives higher electron energy distribution. Figures 4 show the tube bias dependence of breakdown frequency of antenna MOS capacitors fabricated on p and n-type substrate, respectively.

Usually, tube bias is set around -5V to enhance the flooding electron flux. However, the 5nm and 3.5nm gate oxide shows higher breakdown frequency at -5V tube bias. Only 10nm gate oxide shows no breakdown down to -10V tube bias. These results



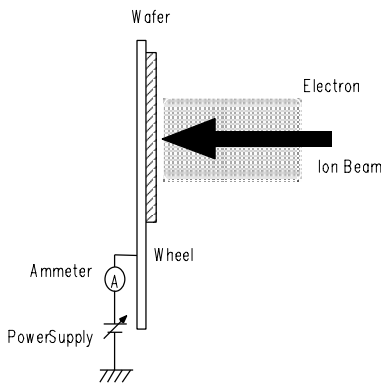
also suggest that the excess electron flux or high energy electrons impact oxide breakdown.

Fig.4 Tube Bias Dependence of Breakdown of Antenna MOS Capacitors Fabricated

Flooding Electron Property and PFS Parameter

To clarify the behavior of flooding electron energy and flux, flooding electron property is measured by using the measurement setup shown in Fig.5.

The variable voltage source and series ammeter are connected to wheel. During implantation sum of the current from ion beam and the PFS can be measured by ammeter. If bias voltage is applied to the wheel, the electrons that have lower energy than applied bias can not reach to the wheel. With varying the applied bias voltage, wheel current was measured. From these results, distribution of electron energy and flux can be calculated. In this



paper, we define the electron energy and flux by these methods.

Fig.5 Measurement Setup for Flooding Electron Energy and Flux Distribution

Fig.6 Electron Energy Distribution of PFS as a Parameter of Tube Bias with Ion Beam

Fig.7 Energy Distribution of the PFS as a Parameter of Arc Current with Ion Beam

Figure 6 shows the flooding electron energy distribution as a parameter of tube bias, and Fig.7 shows that as a parameter of arc current. Implantation condition was Arsenic 20keV with 10mA beam current. With increasing the tube bias, the peak energy and maximum energy distribution are shifted toward higher energy. The electron flux at peak energy shows the maximum value at tube bias -5V, however, total flux for each tube bias is very similar.

With increasing arc current, both electron energy and flux are increased. The influence of tube bias to electron energy and electron flux is similar to previous works. However, it has been thought that the arc current influenced to only total electron flux instead of electron energy.

This kind of result was reported in previous work. However, from Figs.6 and 7, the electron energy distribution is shifted toward higher energy caused by attracted high energy electrons due to electrostatic field formed by ion beam.

The parameters of the PFS have important role to control the electron flux and energy. Thus, careful adjustment of these parameters is very important to control the charge build-up.

Negative Charge Build-up and Flooding Electron

To clarify the origin of breakdown of 3.5nm gate oxide, we have investigated the relationship among oxide breakdown, electron flux and energy using n-type antenna MOS capacitors that is sensitive to negative charge build-up. Figure 8 shows the electron flux dependence of oxide breakdown for various antenna

ratios. The electron energy dependence of oxide breakdown for various antenna ratios is also shown in Fig.9. The total electron flux and electron energy is adjusted by changing the PFS arc current, tube bias and beam current during ion implantation

From Fig.8, the breakdown frequency becomes high with increasing the total electron flux. However, the correlation between total electron flux and breakdown frequency is not so strong. On the other hand, the relationship between flooding electron energy and breakdown frequency indicates strong correlation from Fig.9. Breakdown occurs when the flooding electron energy exceeds critical threshold value for all antenna ratio. The estimated breakdown threshold energy is around 9eV for 3.5nm gate oxide at antenna ratio 1×10^6 .

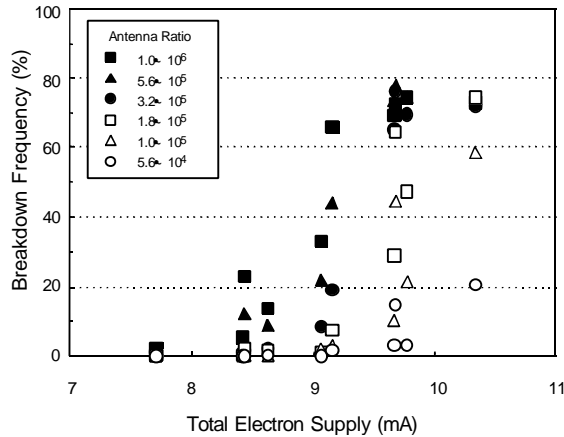


Fig.8 Total Electron Flux Dependence of 3.5nm Oxide Breakdown as a Parameter of Antenna Ratio

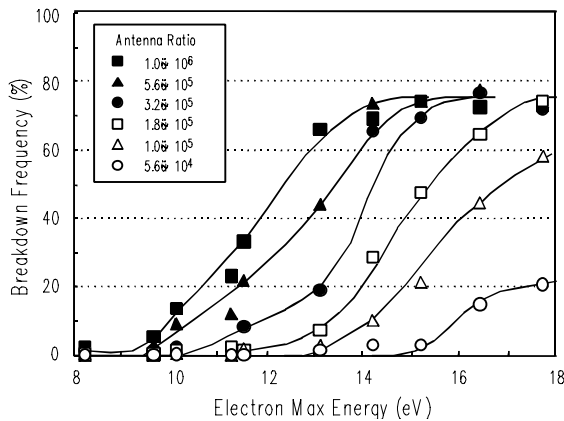


Fig.9 Electron Energy Dependence of 3.5nm Oxide Breakdown as a Parameter of Antenna Ratio

From these results, negative charge build-up caused by excess electrons from the PFS is dominated by maximum energy distribution of electrons instead of total electron flux.

Oxide Breakdown and Flooding Electron Energy

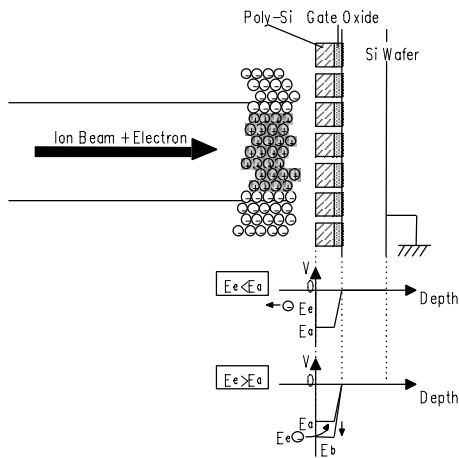
In this section, negative charge build-up model in ultra thin gate oxide by the PFS is discussed. Basically the oxide breakdown is occurred by injecting the current [1][2][8]. The origin of the injected current is thought to be excess electrons from the PFS in the case of negative charge build-up. If the actual injection current through gate oxide is dominated by total electron flux, the breakdown frequency should be increased by increasing total electron flux. However, as mentioned previous section, the breakdown frequency has strong correlation with flooding electron energy instead of total electron flux. To explain this phenomena,

we have assumed the new breakdown model shown in Fig.10.

The potential of gate electrode surface is defined as V_a by the sum of ion beam and flooding electrons from the PFS. The electric field E_a is established by V_a . Once electric field E_a is established on the surface of electrode, the flooding electrons can reach to the electrode if these electrons have higher energy than E_a . If there is no higher energy electron than E_a , the surface potential of electrode and electric field is sustained as V_a and E_a , respectively. The surface potential of electrode is shifted toward more negative (E_b) by incident electrons that have higher energy than E_a .

The injection current through the gate oxide is defined by electric field across the gate oxide. The higher electric field gives

higher injection current through the gate oxide. If the total electron flux is enough to flow the injection current defined by gate electric field E_b , higher current stress is applied to the gate oxide. Thus the higher energy electron becomes the trigger of the oxide breakdown.



The thin gate oxides have breakdown threshold electron energy. If the incident electron energy exceeds threshold value, the oxide breakdown frequency is suddenly increased. Form Fig.13; the breakdown threshold electron energy is around 9eV for 3.5nm gate oxide. For example, for 5nm and 7.5nm gate oxides this breakdown threshold electron energy is around 12eV and 15eV, respectively. This threshold electron energy is experimentally expressed by following equation.

$$E_{th} = 2.5 \times T_{ox} \text{ (eV)} \text{ -----(2)}$$

Where,
 E_{th} : Threshold electron energy (eV)
 T_{ox} : Gate oxide thickness (nm)

Of course, the oxide breakdown depends on not only total charge build-up but also specific Qbd of oxide film. As mentioned in introduction, when we discuss the oxide breakdown quantitatively, total understanding of the behavior of Qbd is indispensable.

Fig.10 Schematic Model of Relationship between Potential of Wafer Surface and Flooding Electron Energy

IV.SUMMARY

The negative charge build-up behavior caused by flooding electrons from the PFS on ultra thin gate oxide below 5nm has been investigated by using the antenna MOS capacitors.

The relationship among the electron energy distribution, total electron flux and physical parameters of the PFS is investigated. The electron energy is influenced by not only tube bias but also arc current, and total electron flux can be controlled by arc current.

Negative charge build-up strongly depends on the maximum electron energy instead of total electron flux. If the electron energy exceeds threshold value, the breakdown frequency is suddenly increased. This threshold electron energy has a specific value correspond to the gate oxide thickness. The obtained threshold electron energy that results oxide breakdown is 9eV, 12eV and 15eV for 3.5nm, 5nm and 7.5nm, respectively.

A newly designed electron flood system, HD PFS, has been thus developed for Applied Materials xR series ion implanters and has demonstrated a successful suppression of gate oxide breakdown during high current ion implantation for ultra-thin gate oxide regime down to 3.5nm.

To suppress the charge build-up on ultra thin gate oxide, the PFS that can supply sufficient electron flux with relatively low energy is very effective. The relationship between negative charge build-up and electron energy can be successfully identified. To clarify the relationship among stress current, Qbd of oxide and electron energy, further investigation is strongly expected.

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