Detecting Defects over the Whole Surface of Wafer by Non-destructive and Non-contact Pulse Photoconductivity Method (PPCM)

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ABSTRACT

Using conventional methods to inspect the condition of thin gate insulators reduces the yield of semiconductor devices due to sampling and destructive inspection. Since conventional methods use TEG (Test Element Group) for evaluation, it is difficult to know the condition of the whole gate insulator. In this study, the whole gate insulator of a 4-inch Si wafer and the gate insulator of a 12-inch Si wafer were evaluated by a non-destructive and non-contact pulse photoconductivity method. The electrical conductivity of different points of the two insulators was approximately 10^{-8} S/m.

Keywords: thin gate insulator, non-destructive method, electrical conductivity, inline process, pulse photoconductivity method

1 INTRODUCTION

With the miniaturization of CMOS, the gate insulator has extremely become thin until reaching the EOT (equivalent oxide thickness) of less than 1nm in order to keep maintaining high-speed performances of devices and low electric energy consumption. Since the gate insulator is so thin, leakage current increases and the gate dielectric breakdown can easily occur. This affects the reliability of semiconductor devices. To make good devices, it is necessary to use technologies for the evaluation of the gate insulator reliability.

TDDB (Time Dependent Dielectric Breakdown) has been one of the main methods for this evaluation. In this case, a wafer is destroyed in order to be evaluated, which makes this method inappropriate for inline processes.

This study proposes a new technique for the evaluation of the gate insulator which is a non-destructive and non-contact measurement method. The method is called Pulse Photoconductive Method (PPCM).The purpose of this study is to inspect the condition of the gate insulator over the whole surface of a 4-inch Silicon wafer and a 12-inch Silicon wafer using this method.

2 EXPERIMENTAL

In this experiment, two specimens were used: a 4-inch Si wafer with a 300nm-thick SiO_2 gate insulator and a 12-inch Si wafer with 5nm-thick SiO_2 gate insulator. Thermal oxidation was used to deposit oxide on that 4-inch Si wafer, and PECVD (Plasma Enhanced Chemical Vapor Deposition) was used to produce 5nm-thick oxide on the 12-inch Si wafer. To evaluate these specimens, the experiment setup of Fig.1a was employed. The equivalent circuit of this experimental setup is also shown in Fig.1b.

As shown in Fig.2, a voltage of ±180V is applied on a Si/SiO_2 specimen to the sample through the metal probe electrode close to the gate oxide on Si. At the time, internal electrical field $E_{in}(t)$ is generated and relaxed inside the oxide.

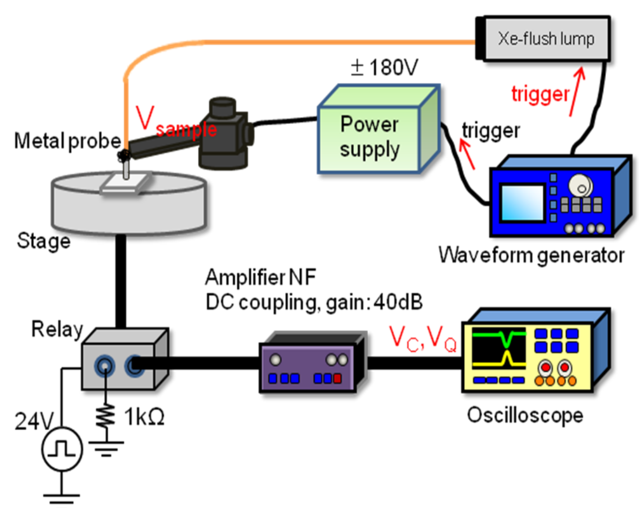

Fig.1a: The experimental setup for PPCM (Pulse Photoconductivity Method)

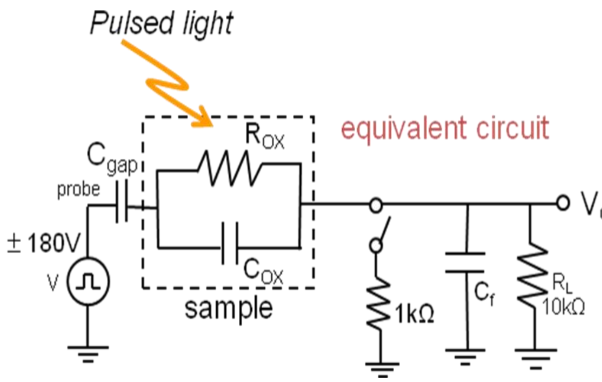

Fig.1b: The equuivalent circuit of the PPCM experimental setup

After it is charged, the specimen is irradiated by a xenon-flash-lamp in order to excite electrons inside the oxide SiO_2. The light wavelength of this lamp is shorter than 300nm.Since the energy of this pulsed light is beyond 4eV, electrons are emitted and move from the valence band of Si to SiO_2. It is possible to know the condition (the electrical conductivity) of the insulator (oxide) using this phenomenon.

The pulsed light is applied 3 times with the time interval of 100μs to get 3 different photoconductive signals shown in Fig.3a. Photoconductive signals are amplified up to 100 times by a preamplifier before they are measured using a digital oscilloscope. The slope of these photoconductive signals' peaks is estimated, and then the electrical conductivity of a point on a wafer is calculated by the following expression:

$$\frac{\Delta \log E_{in}}{\Delta t} = \frac{-\dfrac{\sigma_{insulator}}{\varepsilon_{insulator}}}{\ln 10} \qquad (1)$$

$\varepsilon_{insulator}$ and $\sigma_{insulator}$ represent the permittivity of SiO_2 and the electrical conductivity of SiO_2, respectively.

3 RESULT AND DISCUSSION

Fig.3b shows the intensity of photoconductive signals in time for 37 regions on 4-inch wafer measured by PPCM. For each point, this intensity of photoconductive signal also becomes lower as the delay time becomes longer. Delay time is time between the charge of specimen and excitation of electrons inside Si wafer using the light. With three different delay times, three different photoconductive signals' peaks are obtained. Thus, one is able to estimate the slope of each point from an approximate line of these three photoconductive signals' peaks.

Fig.4 shows the electrical conductivities of a 4-inch wafer. These electrical conductivities were calculated according to the results obtained in Fig.3b using the relation (1) stated on the first page.

The electrical conductivities of the whole surface of a 12-inch Si wafer are indicated in Fig. 5. In this case, measurement was very difficult owing to a thin gate insulator SiO_2 (5nm) of this wafer.

Knowing that the intensity of the photoconductive signal can be calculated by the relation (2), the gap between the voltage applying probe and the wafer was extremely decreased in order to increase the intensity of the photoconductive signal.

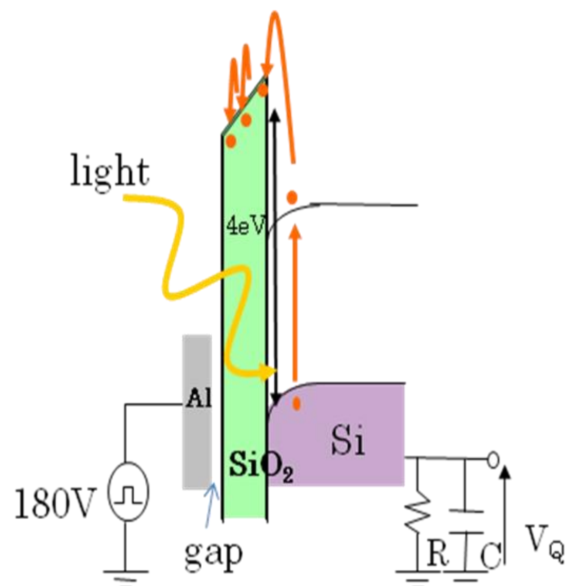

Fig.2: Pulse Photoconductivity Method (PPCM)

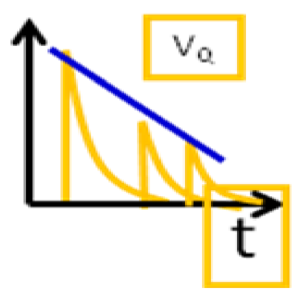

Fig.3a: Electrical signals measured on 1 point of the Si wafer

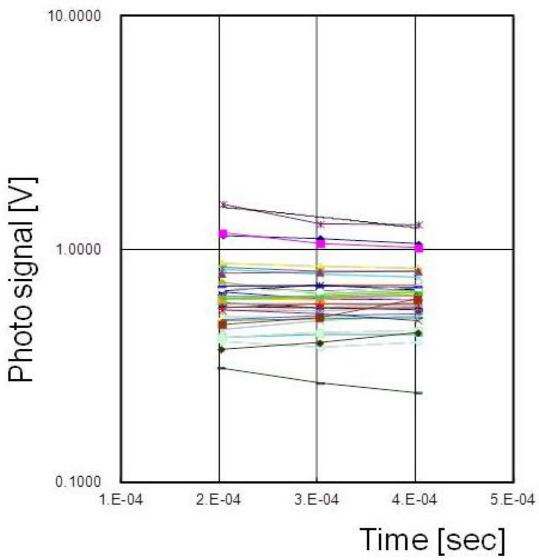

Fig.3b: Peaks of photoconductive signals

$$\Delta V(t_d) = \frac{kC_{gap}{}^2 V(t)}{C_f \left(C_{ox} + C_{gap}\right)^2} Q_{photo}(t_d) e^{-\frac{td}{\tau}} \qquad (2)$$

Where $\Delta V(t_d)$ indicates the photoconductive signal, V(t) is the voltage applied on the wafer, and C_{gap},C_{ox} are the capacitance of the gap and of SiO_2, respectively.

Cox >> Cgap

According to the equation (3), the capacitance of the 5nm-thick SiO_2 is 60 times bigger than the 300nm-thick SiO_2, therefore the photoconductive is extremely small which makes it more difficult to measure that photoconductive signal.

$$C_{ox} = \varepsilon \frac{S}{d} \qquad (3)$$

As shown in Fig.5, points of SiO_2 with higher electrical conductivity are found at the wafer edge region, whereas points with lower electrical conductivity were seen at inner side.

4 SUMMARY AND CONCLUSION

In this study, the condition (electrical conductivity) of the whole surface of two different thin gate insulators was examined using a non-destructive and non-contact pulse photoconductive (PPCM) method.The electrical conductivities was about 10^{-8}S/m for many measured points. Region of the gate insulator with defect has higher leak current, and therefore its electrical conductivity is bigger.

The gate insulators employed in this paper were a 300nm-thick and a 5nm-thick insulator.
A high precision gate insulator's condition inspection is possible owing to PPCM's high accuracy of positioning.
For the defect detection at in-line measurement in next generation mass-production with high throughput, we are now developed an PPCM equipment with multi-probe instead of a single probe measurement used in this study. With this equipment, one is able to measure the electrical conductivity of one million points of a 12-inch wafer in one minute.

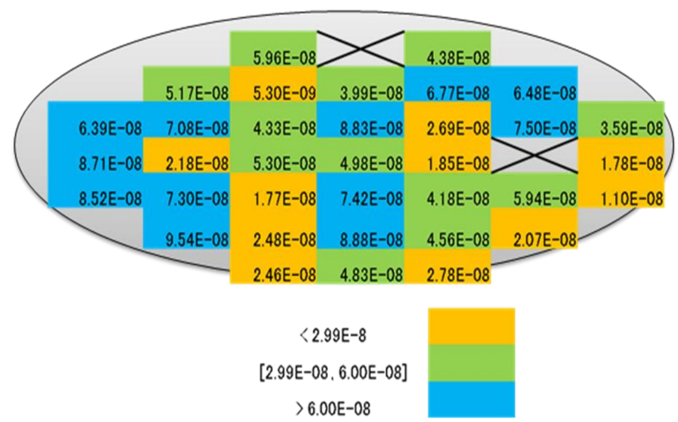

Fig.4: Electrical conductivity σ(S. m^{-1})of 37 regions on a 4-inch wafer

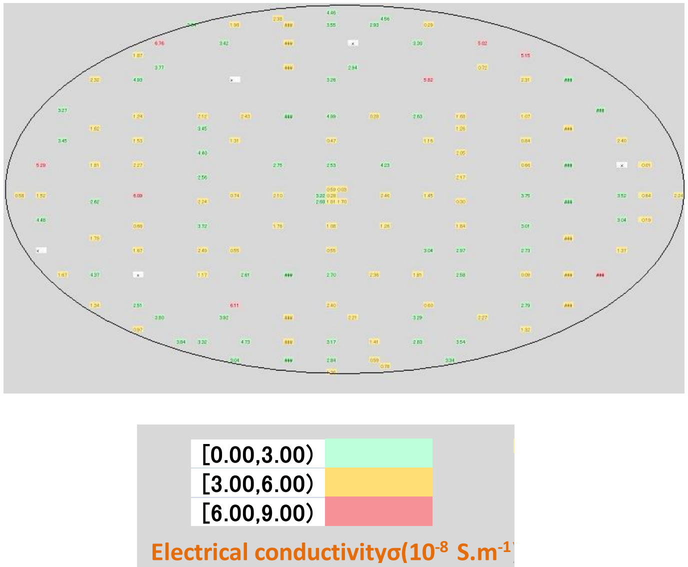

Fig.5: The electrical conductivities of the whole surface of a 12-inch Si wafer

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