Research Report

Light Emission Analysis of Trench Gate Oxides of Power Devices

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Abstract

This paper describes the analysis results of the trench oxide of power devices by means of light emission analysis. Localized electron injection was observed at the upper corners of the trench edges. In addition, it was found that the electron injection into the edge of trench oxide was consistently larger than that into the center of the trench oxide during the electrical stressing. From these results, we conclude that the oxide shape of the upper corner of the trench edge largely determines the reliability of the trench gate structure.

Keywords: Trench, Gate oxide, Reliability, Light emission, Power device, IGBT (Insulated Gate Bipolar Transistor),

1. Introduction

Insulated Gate Bipolar Transistors (IGBTs) have been widely used for a variety of power electronic applications, because they have excellent features such as low power loss and high power controllability by gate voltage. In particular, adoption of a trench gate enables a reduction in conduction loss.[1)]

The reliability of a gate oxide is important for all MOS-gate devices. A cross-sectional view of a trench gate structure is shown in **Fig. 1**. The electric field formed in a trench oxide layer is not uniform due to the nonuniformity of oxide thickness and the presence of trench corners. Thus, it is important to understand the relationship between the shape and the electrical properties of a trench oxide layer. If the electrical property distribution of the trench oxide can be observed, we can determine the portions that should be improved from the view of trench oxide reliability.

Trench oxide have been evaluated by measuring I-V characteristics and Time Dependent Dielectric Breakdown (TDDB) behavior, as reported in several papers.[2, 3)] It is however impossible to observe the distribution of trench oxide properties during electrical stressing by the methods above-mentioned.

In the present study, we have attempted to evaluate a trench oxide by means of light emission analysis because Fowler-Nordheim electron injection into an oxide layer was known to cause light emission from the oxide layer.[4)] We observed the electron injection distribution and the change in this distribution during electrical stressing. To understand the relationship between the shape and the electrical properties of trench gate oxide, device simulation was performed. We explained the change of the electron injection distribution by the behavior of trapped charges in the trench oxide layer.

2. Experiment

2. 1 Test sample

We fabricated a trench MOS capacitor with a poly-silicon gate. The structure of the trench capacitor is schematically shown in **Fig. 2**. The sample size was 12.3×9.3 mm^2. The thickness of the gate oxide on the wafer surface was 100nm. In this structure, the trench gates are interconnected at their trench edges extending in the longitudinal direction (y-axis). Hence, the poly-silicon gate touches the trench oxide layer at the upper corner of the trench edge.

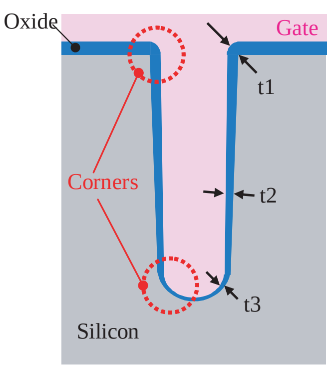

Fig. 1 Schematic cross-sectional view of a trench gate structure.

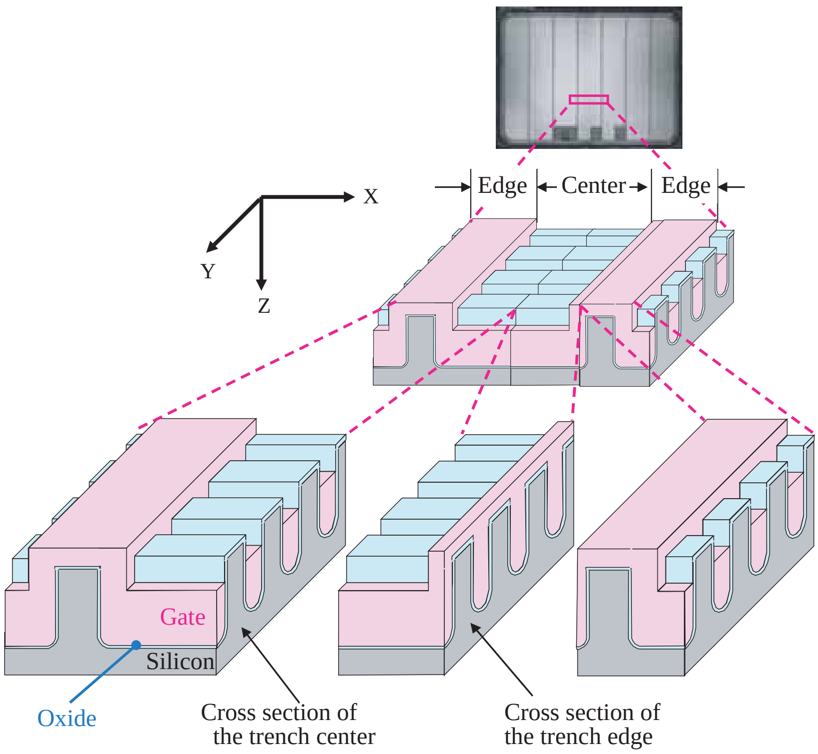

Fig. 2 Structure of test sample. The trench gate is interconnected at the trench edge in the longitudinal direction (y-axis). The trench gate touches the trench oxide layer at the upper corner of the trench edge.

2. 2 Measurement setup

To provide electrical stressing, a positive bias was applied to the gate electrode and the substrate was grounded. The light emission was monitored using a Hamamatsu-Photonics C3230 emission microscope at room temperature.

To measure the distribution change of the emission rate during electrical stressing, as shown in **Fig. 3**, we defined the following three window areas extending in the longitudinal direction (y-axis):

1) the edge of a trench gate,
2) the center of a trench gate, and
3) the in-active area.

The in-active area was used for monitoring the noise level. These three windows had the same area.

3. Results and discussion

3. 1 Localized electron injection into trench oxide

Figure 4 shows the light emission image of a test sample. The light emission at the trench edge is stronger than that at the trench center. This indicates that a large amount of electrons are injected into the interconnection portions of the trench oxide layer.

Figure 5 shows the transverse (x-axis) cross-sectional SEM photographs of the test sample. The upper part of the trench has convex corners, while the bottom part of the trench has concave corners. The curvature radius of the upper corner is smaller than that of the bottom corner. The oxide thickness of the upper corner is larger than that of the bottom. Thus, the intensively injected position could well be either the upper corner or the bottom corner.

In order to find the position of intensive injection in the depth direction (z-axis), we performed device simulation. **Figure 6** shows the dependence of the maximum electric field strength on the curvature radius. In Fig. 6, symbols ● and ▲ in the dotted circle indicate the data at the upper corner and bottom corner. The electric field at the upper corner is stronger than that at the bottom corner. In the simulation results, the amount of injected electrons at the upper corner is over one order of magnitude larger than that at the bottom corner. Therefore, we conclude that the localized electron injection occurred at the upper corner of the trench edge.

3. 2 Change of electron injection distribution

Figures 7 and **8** show the gate current and the light emission rate for the test sample as a function of

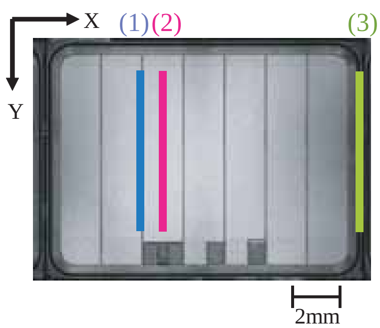

Fig. 3 Three windows for measuring light emission rate. These windows were used to obtain the distribution of electron injection: 1) the edge of a trench gate, 2) the center of a trench gate, 3) the in-active area, for monitoring the noise level.

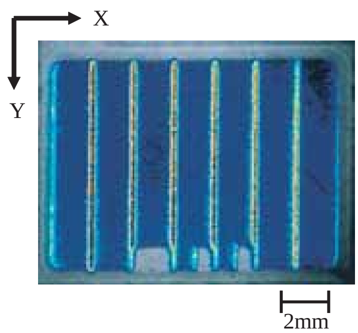

Fig. 4 Light emission image of test sample. Localized electron injection occurred at the trench edge in the longitudinal direction (y-axis).

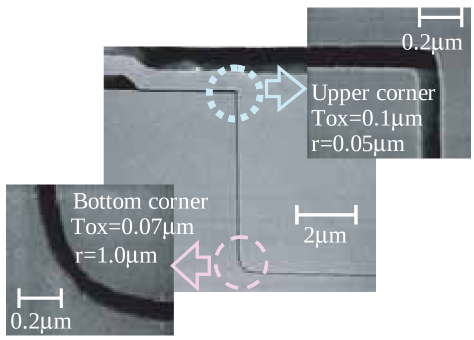

Fig. 5 Transverse (x-axis) cross-sectional SEM photographs of test sample.

elapsed time under a constant voltage stress (Vg=63V). By comparison between Figs. 7 and 8, it is found that the changes in these values over time may be divided into three phases.

In phase 1, localized electron injection occurs at the trench edge. The emission rate at the trench edge is over one order of magnitude larger than that at the trench center. In phase 2, the electron injection at the trench edge is decreased, whereas the electron injection at the trench center is increased. In phase 3, electrons are gradually injected into the whole of the trench oxide layer.

In this manner, the electrical stress progressively changes the spatial distribution of the electron injection. In addition, it is found that the electron injection into the edge of trench oxide is always larger than that into the center of the trench oxide during electrical stressing.

The gate current shift indicates the presence of trapped charges in the gate oxide layer. Under constant voltage stress, trapped electrons reduce the electric field at the Si/SiO_2 interface, causing a decrease in gate current. Trapped holes, on the other hand, increase the electric field at the Si/SiO_2 interface, causing an increase in gate current. These results indicate that holes were mainly trapped in phase 2 and that electrons were mainly trapped in phase 1 and 3.

To characterize the trench gate structure, a planar capacitor was also fabricated. The oxide of the planar capacitor was formed using the same process as the trench capacitor. **Figure 9** shows the gate current of the planar capacitor as a function of elapsed time under a constant voltage stress. In case of the planar oxide, holes are trapped in the initial stage and electrons are trapped in the second stage. The behavior of trapped charges in planar gate oxide has been reported in several papers.[5, 6] Those results agree with our experimental results.

We explain the change of the electron injection distribution into the trench oxide as follows. The behavior of the trench center in phases 2 and 3 corresponds to that of the planar capacitor. Phase 1 is a specific time phase observed only for the trench

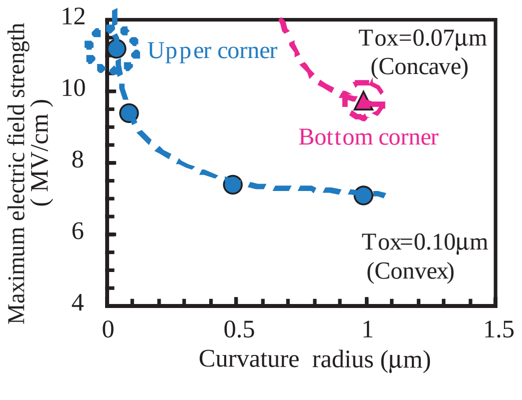

Fig. 6 Simulation results of maximum electrical field strength as a function of curvature radius. The symbol ● and ▲ in the dotted circles indicate the data at the upper corner and the bottom corner, respectively (see Fig. 5).

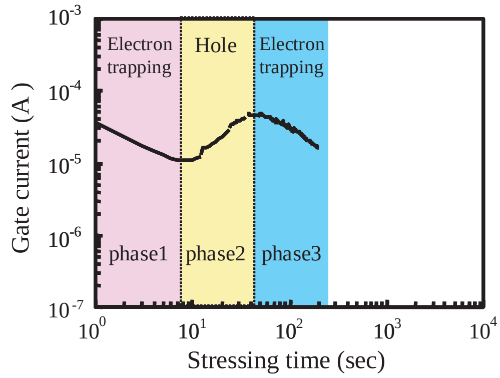

Fig. 7 Gate current of test sample as a function of stressing time under a constant voltage stress (Vg=63V).

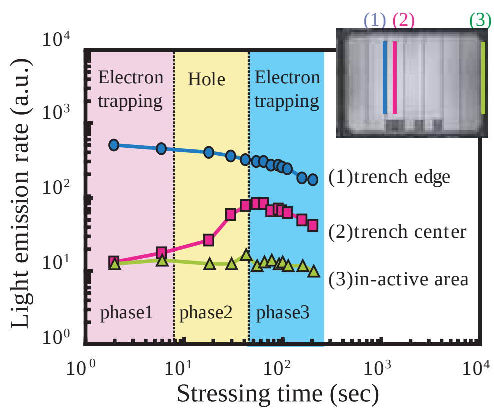

Fig. 8 Light emission rate of test sample as a function of stressing time under a constant voltage stress (Vg=63V).

oxide.

When the electric stress begins to be applied to the trench oxide, localized electron injection occurs at the upper corner of the trench edge because of the trench oxide shape. The emission rate of trench edge decreases due to the lowering of the electric field, which in turn is caused by the trapping of electrons there. At the beginning of phase 2, the electric field of the trench center is not negligible compared with that of the trench edge. Accordingly, electrons are injected into the trench center as well as into the trench edge at that time.

Nakamura et al. have investigated trench gate structures by means of a comparison between I-V characteristics and shape of the trench gate oxide.[2) It was found that the corner shape of the trench gate oxide largely determined the IV characteristics. They deduced that trapped electrons at the upper corner of the trench gate oxide reduce the electric field there. Their conception of carrier trapping agrees with our experimental results.

Therefore, we conclude that the oxide shape of the upper corner of the trench edge has a key influence on the reliability of the trench gate oxide.

4. Conclusion

We proposed a method for characterizing trench gate structures using light emission analysis. Using this method, we found that electron injection was localized at the upper corner of the trench edge. In addition, we observed that the electron injection into the edge of trench oxide was always larger than that into the center of the trench oxide during electrical stressing. Therefore, the oxide shape of the upper corner of the trench edge has a key influence on the reliability of the trench gate oxide.

Light emission analysis can clarify the relationship between the shape of the trench oxide and its electrical properties. This technique is effective in analyzing the trench oxide reliability and degradation mechanism of all MOS-gate devices.

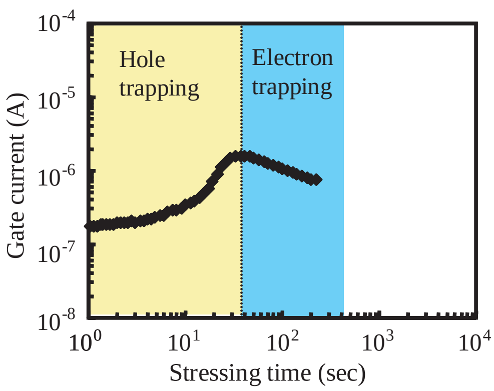

Fig. 9 Gate current of planar capacitor as a function of stressing time under a constant voltage stress.

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