Thin Oxide Charging Current During Plasma Etching of Aluminum

H. Shin, C.-C. King, *Student Member, IEEE,* T. Horiuchi, and Chenming Hu, *Fellow, IEEE*

***Abstract*—*CV* measurement is shown to be a more sensitive technique for characterizing plasma-etching induced damage than oxide breakdown. Plasma charging current was deduced by reproducing the *CV* degradation by constant current stressing. The charging current is found to increase in proportion to the periphery rather than to the area of the "antenna."**

I. Introduction

The plasma-etching technique is widely used in VLSI manufacturing. In the plasma ambient, reactive ions generated in the discharge are accelerated by the self-bias voltage and collide with the surface of the wafer. This energetic bombardment achieves anisotropic etching, but also causes damage to the wafer. Degradation of gate oxides in MOS devices due to the plasma process has been observed and attributed to electrostatic charging during the process [1], [2].

Plasma etching of aluminum has been identified as one of the main processes which cause gate oxide damage [3], [4]. In the plasma ambient, charges are collected by aluminum pads, which serve as "antennas." The stress can cause trapped charges in the oxide as well as surface states at the SiO_2-Si interface, therefore decreasing the breakdown voltage and deforming the *CV* curve of the gate oxide. Breakdown voltage tests have been used in all previous studies to determine the amount of damage [1]–[5], but cannot give high resolution in a quantitative study. Changes in the breakdown voltage or charge to breakdown can be clearly measured only when the process-induced problem is very severe and when using large-area oxide samples (thus making it difficult to study large antenna-to-oxide ratios) and a large number of test devices. Even then it has not been possible to quantify the plasma charging current. In this study, we use *CV* to determine the amount of stress during the process. Accurate estimation of the amount of charge collection can be obtained by comparing the *CV* curves of MOS capacitors after plasma etching with control devices after electrical stress. Although it cannot be concluded with certainty that the deformation of *CV* curves is due to a constant current stress during plasma etching, *CV* is a good indicator of plasma-induced damage to oxide.

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H. Shin, C.-C. King, and C. Hu are with the Department of Electrical Engineering and Computer Sciences and the Electronics Research Laboratory, University of California, Berkeley, CA 94720.

T. Horiuchi is with the Department of Electrical Engineering and Computer Sciences and the Electronics Research Laboratory, University of California, Berkeley, CA 94720 on leave from NEC Corporation, Kanagawa, Japan.

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II. Experiment

The test structures used are polysilicon-gate MOS capacitors fabricated on an n-type (100) silicon substrate with 116-Å gate oxide grown in dry oxygen at 900°C. After gate definition, 5000-Å aluminum was deposited. Aluminum etching was done in a Lam Research Autoetch 690B system with a 50% overetch after the detection of endpoints for a total of 60 s. Control wafers receiving only wet etching were also fabricated.

Two types of test structures are studied. One consists of 1600-μm^2 capacitors with identical layout except for the sizes of the square aluminum pads, which range from 16 000 to 160 000 μm^2. The other group of capacitors has elongated aluminum "antennas" with the same area but different peripheral lengths. Quasi-static *CV* curves of capacitors were measured after aluminum etching.

III. Results and Discussions

Fig. 1 shows the quasi-static *CV* curves for MOS capacitors with different aluminum pad sizes after pad capacitances were subtracted. The *CV* curve for a wet-etched capacitor is also shown as curve *A*. Because a larger aluminum pad collects more charge during etching, the *CV* curves of capacitors with larger pads show a higher degree of degradation.

The differences in breakdown voltage and charge to breakdown between curves *A* and *E* are within the ranges of sample-to-sample random variations. Clearly, *CV* degradation is a more sensitive technique suitable for process monitor and for quantitative study of the charging process. The interface traps responsible for the *CV* shift can probably be passivated by a forming gas anneal, but are still undesirable because hot-electron stress may reverse the passivation process and increase the device degradation rate. Capacitors on wet-etched control wafers had identical *CV* (curve *A* in Fig. 1) independent of the Al geometry. They were stressed by passing different levels of constant current through the gate for 60 s, i.e., the same length as the plasma etching time, to generate a series of reference curves, as shown in Fig. 2. Also shown in the figure is the *CV* curve of a capacitor with a 16 000-μm^2 aluminum pad etched in plasma. This curve matches the reference curve of 10-nA stressing very well, indicating that the 16 000-μm^2 Al pad (curve *B* in Fig. 1) collected 10 nA (curve *C* in Fig. 2) of plasma charging

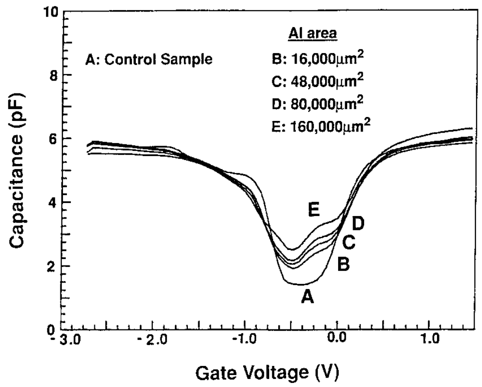

Fig. 1. 1600-μm^2, 116-Å oxide *CV* after 60-s plasma etching of Al. Curve *A* is the *CV* of wet-etched samples.

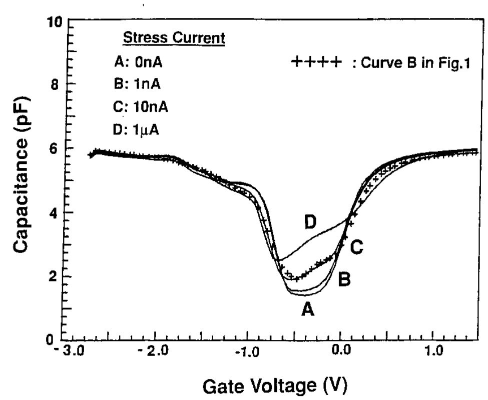

Fig. 2. Wet-etch Al and after constant current stress for 60 s at varying current levels. Plasma-etch induced damage can be closely reproduced with a constant-current stress.

current during the etching process. Note from Fig. 2 that this technique can infer a range of plasma charging current covering many orders of magnitude. By using the same method, the plasma charging current for each test capacitor can be extracted with a high resolution.

Fig. 3 shows the change in capacitance due to plasma etching at different locations across the wafer. There is a radial variation of stressing for devices from the wafer center to the edge. The after-stress *CV* curves of the wet-etched sample showed no position dependence.

Fig. 4 shows the plasma current as a function of aluminum pad areas. The curves in group *B* are for the devices near the edge of the wafer where the plasma density is found to be lower. Here, the plasma charging currents, i.e., the *CV* degradations, are independent of the pad sizes. However, the charging current for the devices in the center region (group *A*) shows obvious pad-size dependency, i.e., antenna effect, and the slope of all the lines is about 0.5. Clearly, the charging current does not increase in proportion to the Al area. Rather, it is roughly proportional to the peripheral length of the square Al pads.

Fig. 5 shows the plasma current for devices with the same pad area (80 000 μm^2) but different periphery lengths. In cases where charging is severe, i.e., long peripheral lengths

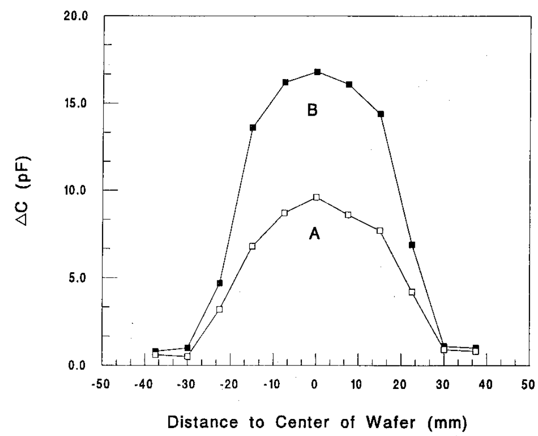

Fig. 3. The capacitance change (ΔC) measured at $V_G = -0.4$ V shows a clear radial variation. The peripheral lengths of Al pads are 3160 and 6820 μm for curves *A* and *B*, respectively.

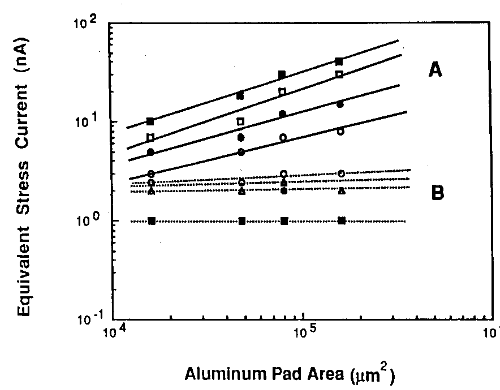

Fig. 4. When the deduced plasma charging current is large, it is approximately proportional to the square root of the square-shaped Al pad, i.e., proportional to the Al edge length.

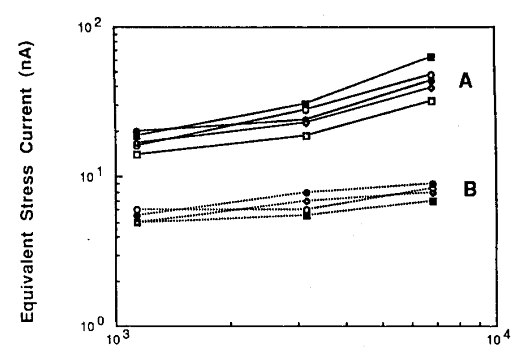

Fig. 5. When the plasma charging current is large, it is proportional to the peripheral lengths of elongated Al patterns with the same 80 000-μm^2 area.

in group A, the slope is found to be close to 1, reaffirming the proportionality to the peripheral length.

Figs. 4 and 5 suggest that there is a small component of plasma stressing that is independent of Al area and periphery length in addition to the component that increases linearly with the pheripheral length. The length-independent damage may be due to the charging stress before the Al film is completely etched through. All oxides under a continuous Al film are stressed at the same voltage. After the Al pads are formed, the overetch stress is then proportional to the peripheral length.

IV. Summary

Plasma etching of Al is shown to produce severe distortions in the oxide CV characteristics, from which one can easily deduce the plasma charging current over many orders of magnitude. A clear radial variation of stressing is found and the charging current increases in proportion to the Al peripheral length rather than the area. Using the measured 10-pA/μm value of the charging current, one should be able to predict the impact of this etch process on oxide integrity and interface stability for a given antenna geometry.

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