

## Surface Charge Analysis (SCA) of 300 Angstrom Thermally Grown Oxides

Brian D. Handel  
Senior, Microelectronic Engineering  
Rochester Institute of Technology  
Rochester, N. Y. 14623  
May, 1996

### Abstract:

As the microelectronic industry progresses toward smaller devices, a decrease in the thickness of gate oxides accompanies them. High quality cannot be sacrificed as a result of this shrinkage. It is believed that oxide quality can be related to oxide charge density. Total oxide charge is related to a shift in  $V_t$  for transistors and believed to be related to oxide breakdown strength.

A surface charge analyzer on loan from the SemiTest Corp. was used to quantify oxide charge densities after thermal oxidation of 300 Å oxides under various processing conditions. Variations to the base process included the temperature at which wafers were pulled from the furnace, leaving the endcap of the furnace tube ajar, whether the wafers had been handled with tweezers or a vacuum wand, whether trichloroethane (TCA) had been included during the oxidation, and the type of wafer (P or N.)

The base process was as follows: 1) TCA cleaning of the furnace tube for 30 min. at 1100 C before processing 2) inserting the wafers at 900 C at 12 inches/min. with 5 LPM N<sub>2</sub> flowing 3) ramping up to 1000 C with 5 LPM dry O<sub>2</sub> 4) soaking for 18 min. with 5 LPM dry O<sub>2</sub> 5) ramping down to 750 C with 5 LPM N<sub>2</sub> 6) and pulling at 12 in/min with 5 LPM N<sub>2</sub>.

The resulting oxide thicknesses were measured using a Nanospec.

Early results indicated a strong dependence on wafer type. Generally P type wafers showed oxide charge densities ( $Q_{ox}$ ) an order of magnitude lower than N type wafers (E11 vs E12.) This proved to be a result of the measuring equipment and the problem was corrected.

Final results indicate no difference in  $Q_{ox}$  values for P vs. N type wafers, no difference in  $Q_{ox}$  due to handling procedures, differences related to pull temperature, and an ability to identify wafers that could be considered unfit for device fabrication.

### Introduction:

In the SCA (surface charge analysis) method, the electronic properties of a semiconductor surface are determined from measurements of the alternating current surface photopotential as a function of a dc electrical bias field, capacitively applied to the semiconductor-insulator structure. An insulated probe electrode is placed in intimate physical contact with the oxide layer. The probe capacitively couples a slowly varying dc bias voltage to the semiconductor oxide layer through the probe insulator. A beam of ac-modulated light passes through the transparent probe electrode onto the surface of the semiconductor, where it produces an induced ac photocurrent and a resulting ac photopotential. That potential is capacitively coupled to a measurement system that determines the photovoltage as a function of the applied dc bias voltage. At each bias value the SCA uses a ac-modulated low-intensity green light to determine the width of the surface depletion layer,  $W_d$ . From the set of  $W_d$  versus  $Q_{ind}$  data collected, the SCA computes values for the wafer type, p or n, the doping concentration,  $N_{sc}$ , the oxide charge,  $Q_{ox}$ , the density of interfaces states,  $D_{it}$ , and the minority carrier lifetime  $T_s$ . Figure 1 shows a typical output screen for the measurement of an N type wafer. Figure 2 is typical of a P type wafer.

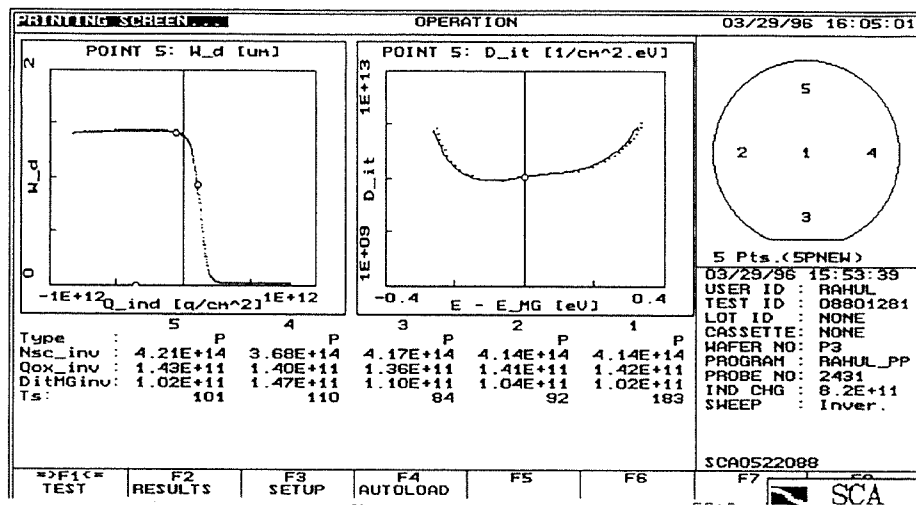


Figure 1

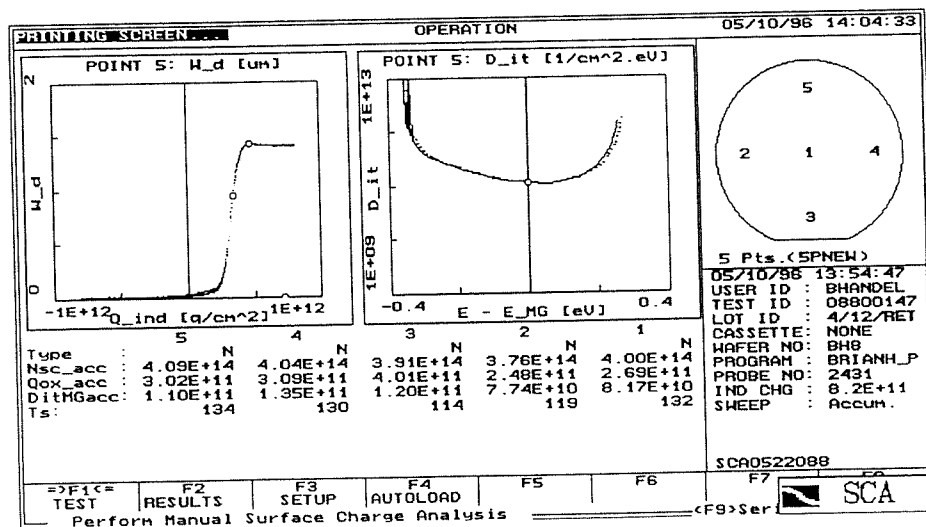


Figure 2

Although the SCA only gives one value for  $Q_{ox}$ , it is composed of four types of charges, interface trap charge, fixed oxide charge, mobile ionic charge and bulk oxide trapped charge. Interface trap charge is localized at the Si/SiO<sub>2</sub> interface on sites that may change their charge state by exchanging electrons or holes (charges) with the silicon. Fixed oxide charge is located within 35 angstroms of the Si/SiO<sub>2</sub> interface, in the transition region between the Si and SiO<sub>2</sub>. These charges do not change their state by exchange of mobile carriers with the silicon, thus the name fixed charge ( $Q_f$ ). The  $Q_f$  charge centers are predominately positive, although some negative compensating centers may also be present. The mobile ionic charge ( $Q_m$ ) is usually caused by sodium or potassium ions. These charges can be located either at the gate or the Si/SiO<sub>2</sub> interface because of their mobility which is a result of drifts under the presence of an applied positive field to the gate. The amount of mobile ionic charge incorporated into the SiO<sub>2</sub> is believed to be a result of the cleanliness of the oxidation process including such things as tube contamination, processing chemicals, and wafer handling procedures. The fourth type of charge is called oxide trapped charge ( $Q_{ot}$ ). Bulk oxide traps may be located at the gate/SiO<sub>2</sub> interface, the Si/SiO<sub>2</sub> interface as well as deep in the oxide. These traps are associated with defects in the SiO<sub>2</sub> such as impurities and broken bonds.

For a complete description of the calculation methods involved the reader is referred to the *SCA-2000 Surface Charge Analyzer User Manual* available from SemiTest, Inc. 43 Manning Rd, Billerica, MA 01821 (508)-667-8783.

#### Early Problems:

While measuring the oxide charge densities during the first few runs under standard processing conditions it was common to measure  $Q_{ox}$  at the mid E11 to low E12 range. This, as mentioned earlier, was an order of magnitude higher than previous work in this field. It was originally believed to be caused by contamination in the furnace tube used for oxidation. Here at RIT, many students as well as faculty use equipment for varying processes and it is almost impossible to dedicate equipment for specific usage. A Hydrogen anneal (30 min, 5LPM H<sub>2</sub>N<sub>2</sub>, 450 C) of the first run showed an improvement in  $Q_{ox}$ . As a result, it was decided to remove the furnace tube and "clean" it. The manufacturer of the furnace was called and a solution of 50 percent HF and 50 percent HNO<sub>3</sub> was recommended. Unfortunately, no nitric acid was available at the time. Upon replacement of the tube and a subsequent run, no decrease in  $Q_{ox}$  was noted. The tube was again removed and cleaned, this time with HF/HNO<sub>3</sub> and then a 50/50 solution of HCL/DI water. Again no improvement was noted. These results are shown in Figure 3.

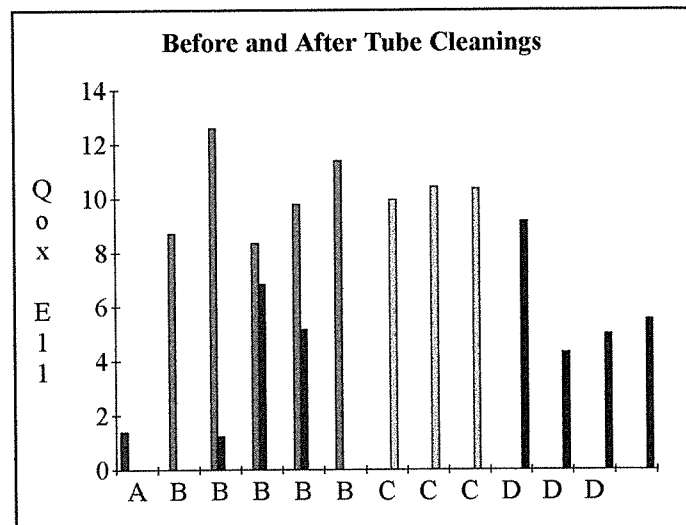


Figure 3

A represents a P type wafer processed before any tube cleanings, B are N type wafers before and after the hydrogen anneal, C are N type wafers after the first tube cleaning and D are N type wafers after the second tube cleaning.  $Q_{ox}$  values are  $1 \times E11$  scale.

It was noted that work being performed by other students had shown  $Q_{ox}$  values in the low E11 to high E10 range. A difference was noted as to the type of wafers being used by others and myself. This experiment had been using strictly N type wafers and others had been using P type. An investigation was begun into the possibility that wafer type had an effect on  $Q_{ox}$ . Two runs under standard conditions were made with noticeable differences of  $Q_{ox}$  depending on type (See figure 4).

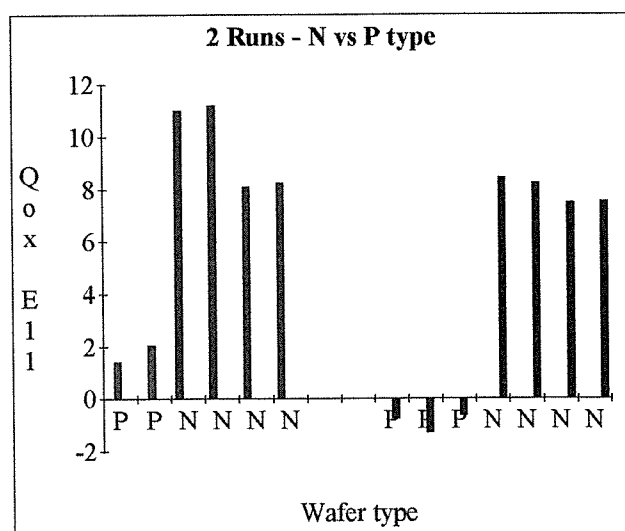
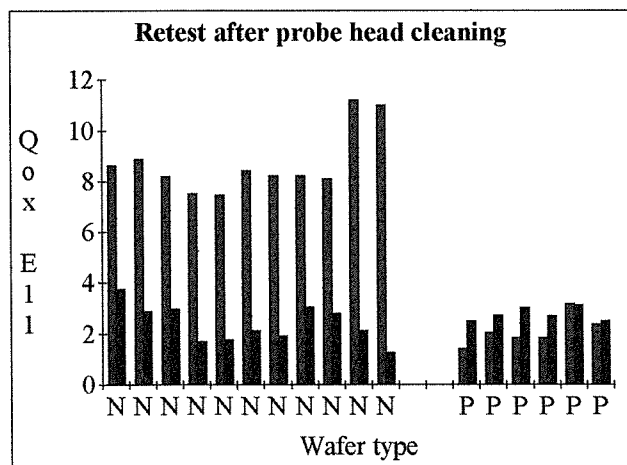


Figure 4

My advisor to this project, Dr. Michael Jackson, associate professor of microelectronic engineering at RIT, was convinced that wafer typing should not be a factor. A call was placed to the SemiTest Corp. and procedures for checking the calibration and operation of the SCA were obtained and implemented. One of these procedures included removing and cleaning the probe head assembly. Upon completion of this procedure a subsequent run measured Qox values in the low E11 range and failed to show any differences between wafer types.

#### Believable Results:

Upon completion of the probe head cleaning, wafers from earlier run were retested. The results are shown in figure 5. It appears as though the N wafers decreased in Qox while P wafers increased. This may be explainable by the fact that the N wafers did not measure correctly originally. It may be possible that both the N and P wafers show increases in Qox over time, it just is not noticeable here because of erroneous early testing.



Finally, intended processing variations were carried out. Pull temperatures of 750, 900 and 1000 C are compared in figure 6. The 750 C run also included wafers that had been handled with tweezers or a vacuum wand. A represents a pull temperature of 750 C, N type wafers, handled with tweezers, B are 750 C, N, vacuum wand, C are 750,P,tweezers, D are 705,P,vacuum, E are 900,P,vacuum, F are 1000,N,vacuum, G are 1000,P,vacuum and H are 750,P,vacuum with the endcap left ajar.

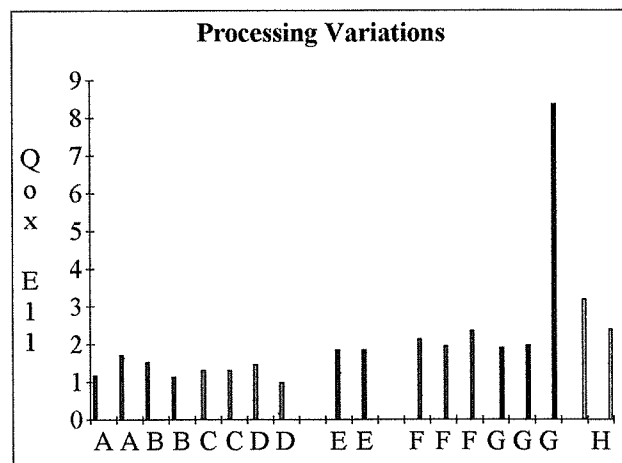


Figure 6

Because low Qox values that had been achieved by others while using TCA during oxidation, it was attempted here. Two runs were made using TCA, the first was identical to the standard procedure with the exception that 5 min. of the 18 min. soak time was replaced with TCA flowing. The second included 8 of the 18 min. soak time with TCA flowing. Qox values for both runs were the best (lowest) yet. See figure 7.

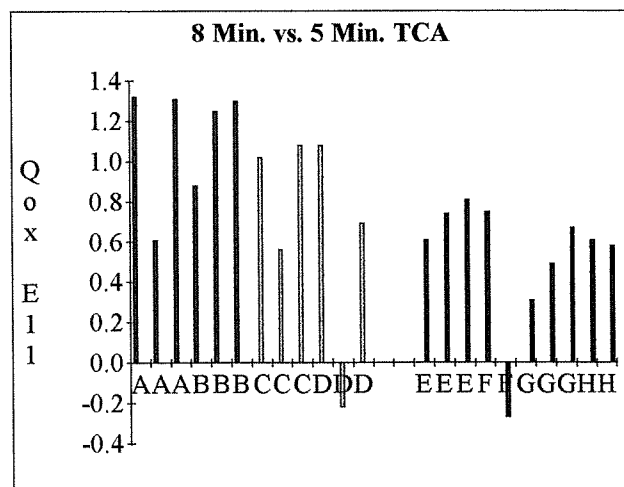


Figure 7

Note scale for Qox

A,E = N, tweezers  
B,F = N, vacuum  
C,G = P, tweezers  
D,H = P, vacuum

A-D are 8 min. TCA  
E-H are 5 min. TCA

Average values for a wafer (all wafers were measured at 5 points) were in the mid E10 to low E11 range.

Some individual measurements were achieved in the high E9 range. It was believed that increasing the amount of time that TCA was flowing would reduce Qox values. Results do not indicate this. One possible explanation is that a quartz wafer boat was found inside the furnace tube upon removal of the wafers from the 8 min. run. The boat is a possible contamination source. Another possibility is natural variation in the data collection procedure. Replication of results could not be attempted due to time constraints.

#### Overall Results:

Figure 8 shows the average values of Qox depending on run conditions as measured over time. Overall, measured Qox values declined during the course of this project. This was to be expected because of the results before and after probe head cleaning. Later results indicate no difference between whether a wafer had been handled with tweezers or a vacuum wand and no difference as a result of wafer type. Pull temperature variations do indicate a slight increase in Qox as pull temperature increases. This was to be expected. The largest values of Qox were obtained when the furnace endcap was left ajar, possibly allowing contaminants into the airflow of the furnace tube.

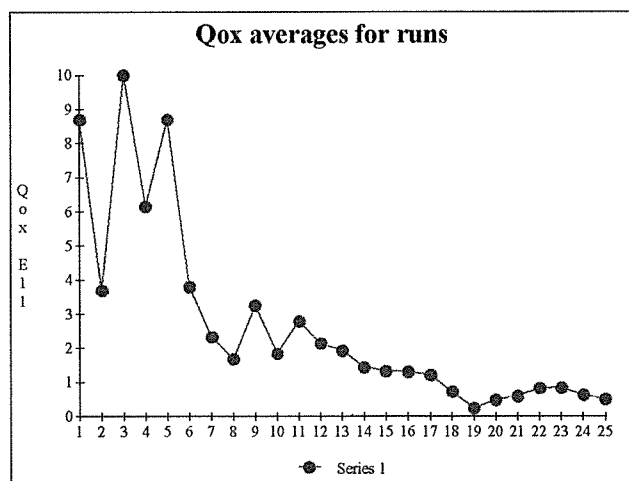


Figure 8

Run	Type	Process		
1	N	Standard	14	N Tweezers
2	N	H2 Anneal	15	N Vac. Wand
3	N	1st Tube Clean	16	P Tweezers
4	N	2nd Tube Clean	17	P Vac. Wand
5	N	Standard	18	N 5 TCA/Tweezers
6	P	Standard	19	N 5 TCA/Vacuum
7	N	Standard	20	P 5 TCA/Tweezers
8	P	Standard	21	P 5 TCA/Vacuum
9	N	Pull at 900 C	22	N 8 TCA/Tweezers
10	N	Pull at 900	23	N 8 TCA/Vacuum
11	P	Door Ajar	24	P 8 TCA/Tweezers
12	N	Pull at 1000 C	25	P 8 TCA/Vacuum
13	P	Pull at 1000 C		

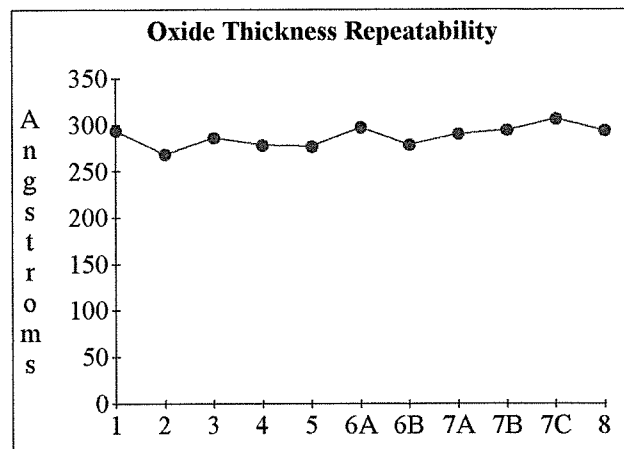


Figure 9

#### Run ID Process

1	Standard	6B	Door Ajar
2	Standard	7A	Pull at 1000 C
3	Standard	7B	Tweezers/Vac.
4	Standard	7C	5 Min. TCA
5	Standard	8	8 Min. TCA
6A	Pull at 900 C		

Oxide thickness repeatability from lot to lot is shown in figure 9. Oxide ranges were from about 260 angstroms to slightly over 300 angstroms. Within wafer variability was usually under 5 percent. Wafer to wafer variability was slightly higher around 10 to 15 percent. This may be attributed to the fact that no dummy wafers were used in the oxidation procedures to eliminate a possible source of contamination.

During SCA measurements other parameters were recorded but not analyzed for this study. They included doping concentration (Nsc), density of interface states (Dit), and minority carrier lifetime (Ts). A summary of the average values for each lot is included in Appendix B. Appendix C contains average values for each wafer that was SCA'd. Appendix D contains individual wafer measurements for Qox and oxide thickness.

#### Conclusions:

- 1) No difference can be attributed to wafer type
- 2) Decreasing pull temperature has a corresponding decrease in Qox values.
- 3) Qox differences due to wafer handling procedures for this experiment were insignificant.
- 4) Inaccurate results can easily be overlooked if the SCA is not calibrated correctly.

#### Future Studies:

- 1) Repeatability of experiment with expansion to other pull temperatures

- 2) Designed experiment to show interaction of tested factors
- 3) Manufacture of calibration wafers for correct SCA operation
- 4) Qox vs. Oxide breakdown studies

Acknowledgements:

Special Thanks to:

Dr. Santosh Kurinec, associate professor of microelectronic engineering RIT, for overseeing the entire project.

Dr. Michael Jackson, associate professor of microelectronic engineering RIT, for day to day advisement and critique.

Ms. Jill Tsakiris, Semitest Corp. for the loan of the SCA and the need for project results.

References:

1. S. Wolf, R.N. Tauber, *Silicon Processing for the VLSI Era*, vol 1, Lattice Press, 1986
2. *SCA-2000 Surface Charge Analyzer User Manual*, SemiTest Corp., Billerica MA, 1994
3. E.H. Nicollian, J. R. Brews, *MOS Physics and Technology*, chapter 12
4. Neamen, Donald A., *Semiconductor Physics and Devices*, Irwin, Homewood IL 60430, 1992