XII International Conference on Ion Implantation Technology, Kyoto, Japan, June 22-26, 1998.

Comparison of Implant Charging Results Obtained with QUANTOX® and CHARM®-2

Sonu Daryanani and Jeff Shields
Microchip Technology,
1200 S. 52nd St., Tempe, AZ 85283, USA

Abstract- A comparison of charging results obtained with Quantox® and CHARM®-2 is presented for the case of Arsenic implants at 80 KeV and 20 KeV, performed at doses of 5e14 /cm2 and 5e15 /cm2 at beam currents of 9 mA and 18 mA. The surface potential maps obtained by the Quantox are compared to the potentials and currents measured on the CHARM sensors, with the plasma charge control system on and off. The sensitivity of the Quantox system is compared for changes in the oxide thickness, the dose, and the beam density.

I. Introduction

An in-line wafer charging technique that provides little additional process burden to the fab and is quick to flag any charging problems can be of important practical benefit. This paper specifically addresses charge monitoring in ion-implantation. Some of the more commonly used techniques for this include oxide charge and voltage breakdown measurements on antenna capacitors [1], measurement of EEPROM device voltage shifts (e.g. the CHARM-2 devices made by Wafer Charging Monitors, Inc.) [2], and contact-less probing of charge build up on an oxide surface [3] (e.g. PDM wafer measurement by Semiconductor Diagnostics). The CHARM-2 devices mimic the response of integrated circuit devices by having small conductors on the surface of a silicon wafer that are connected to E^2PROM-based sensors. Both voltage and charge flux sensors are integrated onto the CHARM-2 wafers, enabling measurement of the floating charge-induced voltage, as well as the J-V plots of the beam plasma response for voltages below the floating potential. Since both sensors are bipolar, both the positive and the negative charging characteristics of the plasma can be measured.

A recently introduced tool by Keithley Instruments called the Quantox provides a non-contact probe measurement of oxide charge by use of an oscillating Kelvin probe that scans across the wafer surface and generates a map of the surface voltage. The measurement is quick and can thus be potentially used to provide real time data.

The purpose of this article is to compare charging data obtained with the CHARM wafers and the Quantox measurement, and examine the measurement sensitivity to changes in the implant dose and energy, beam currents, as well as the oxide thickness used for the Quantox monitor wafers.

II. Experimental

The Applied Materials 9500 xR implanter was used to implant the six inch CHARM-2 and Quantox monitor wafers. The CHARM-2 and the Quantox monitor wafers were implanted on the same wheel for particular implant conditions. The Quantox monitor wafers had either an 800 Å or a 900 Å thermally grown wet oxide in a horizontal furnace on n-type substrates. The implants used for this test were As^+ at energies of 20 KeV and 80 KeV. The projected range and straggle for the implants into oxide is:

80 KeV As: R_p = 450 Å, ΔR_p = 175 Å

20 KeV As: R_p = 100 Å, ΔR_p = 56 Å.

The two different doses used were 5e14 /cm^2 and 4.50e15 /cm^2. Beam currents of 9 mA and 18 mA were used for the implants done at 80 KeV, while 10 mA was used for the As implants done at 20 KeV. The 9500 implanter uses a Plasma Flood System (PFS) [4] charge control with a dense plasma flow generated near the wafer surface using Ar gas. All implants were done under conditions of both the PFS system off and on. The beam generated at 80 KeV used an extraction energy / post-analysis acceleration energy split of 40 KeV / 40 KeV, while the 20 KeV beam used only the extraction energy. No photoresist was used in any of the wafers, and hence outgassing effects on charging from different beam currents or different doses (number of scans) were minimized.

The PFS settings were kept constant for all implants done with the PFS on. These settings are: Arc V = 25 V, Arc I = 5.2 A, Guide tube V= -10 V and Ar flow = 2 sccm.

The Quantox surface voltage measurements were done with a sample spacing of 4 mm (approximately 1000 points measured per wafer).

III. Results and Discussion

A. Arsenic, 20 KeV implants:

Figures 1a and 1b show the surface voltage maps measured on the Quantox for the wafers with 800 Å of oxide for the As^+, 20 KeV, 4.50e15 /cm^2 implants done with and without plasma flood assisted charge neutralization. The wafer with the PFS off reads a surface voltage with a mean value of 13.81 V, while the wafer with the PFS on reads an average voltage of -9.75 V.

The CHARM-2 voltage wafer maps for this implant with the PFS off are shown in Figure 2a and 2b. Both the positive and negative sensor results are shown. The positive voltage sensors, which record the response under the beam, are shown saturated at 15 V, while the negative sensors, which record the response outside the beam, read an average voltage of –7.2 V. The interesting thing to note here is that the

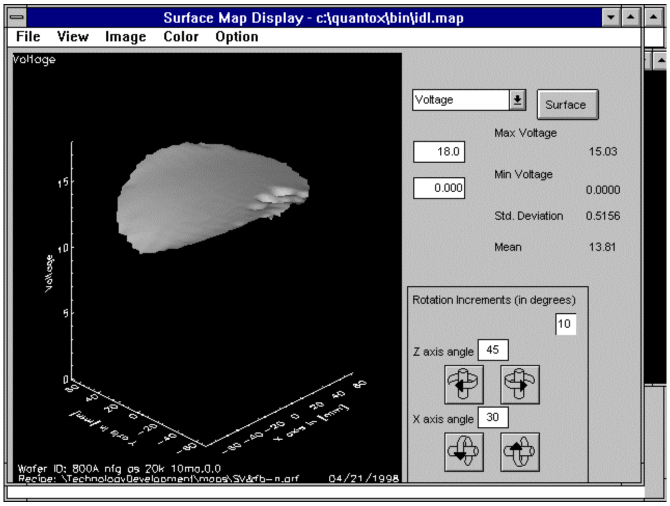

Figure 1a. Quantox wafer map for As^{+}, 20 KeV, 4.50e15 /cm^{2} implant with plasma flood off (80 nm oxide).

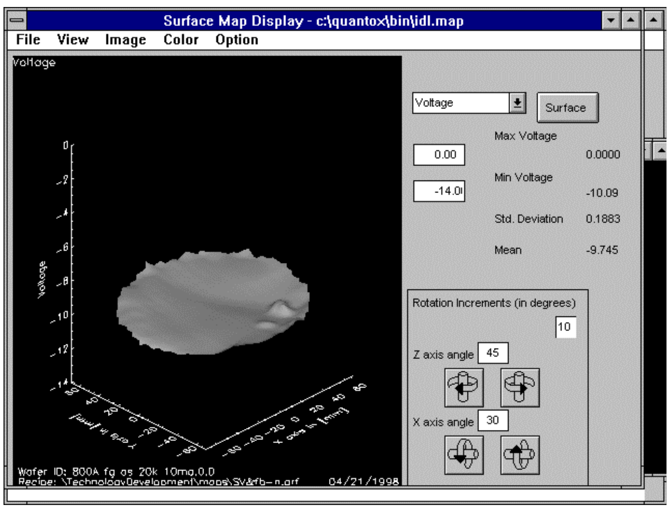

Figure 1b. Quantox wafer map for As^{+}, 20 KeV, 4.50e15 /cm^{2} implant with plasma flood on (80 nm oxide).

negative charge-flux sensors did not respond, as shown in Figure 3, indicating minimal negative charge density outside the beam. (The vertical line in Figure 3 is an asymptote indicating the voltage below which no response can be measured. As such, it is an artifact, indicating no response.)

The same wafer maps for the case of the PFS on are shown in Figures 4a and 4b. The positive sensors now read an average value of 5.1 V, while the negative sensors are saturated at an average value of –14.5 V, indicating a response to the additional electron flood from the PFS. This is also consistent with implant charging theory [5].

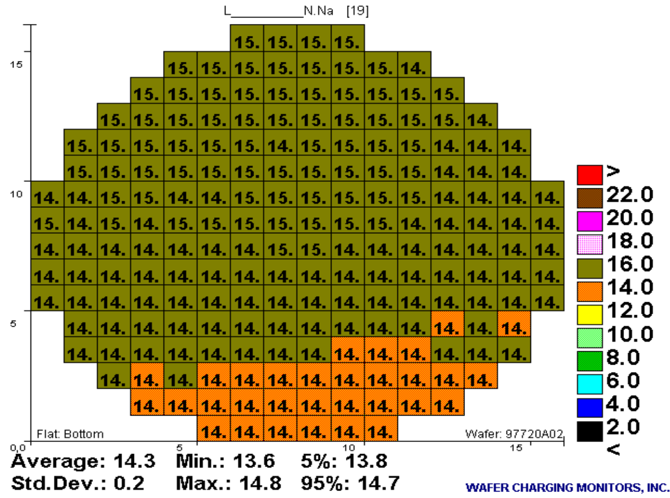

Figure 2a. CHARM-2 positive potentials for As^{+}, 20 KeV, 4.50e15 /cm^{2} implant with plasma flood off. (Note: sensors are saturated – actual values could be greater)

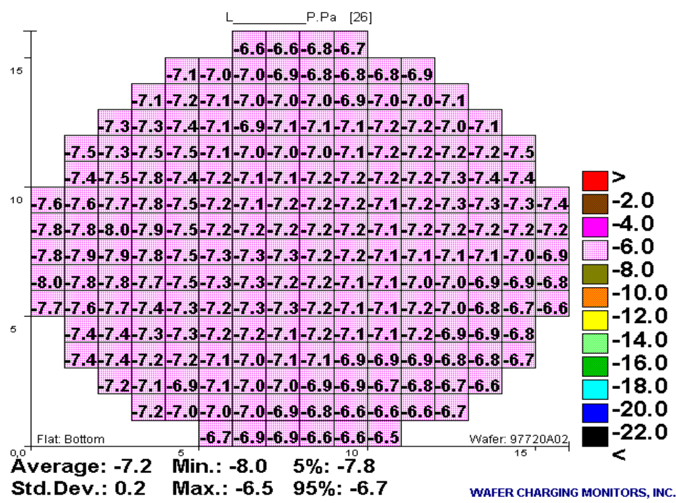

Figure 2b. CHARM-2 negative potentials for As^{+}, 20 KeV, 4.50e15 /cm^{2} implant with plasma flood off.

As^{+} implants were also done at 20 KeV at a dose of 5e14 /cm2, using the same beam current as the implants done at 4.5e15 /cm^{2}. The beam density in both cases is approximately the same, and the variable is the number of scans that the wafer sees. Previous experiments on CHARM-2 wafers have shown that CHARM-2 measurements are not sensitive to dose changes, as the EEPROM devices respond rapidly to changes in the surface charge on the wafer and the sensors are locked to that potential. The Quantox wafers, however, read significantly different positive and negative mean potentials compared to those measured at the higher dose.

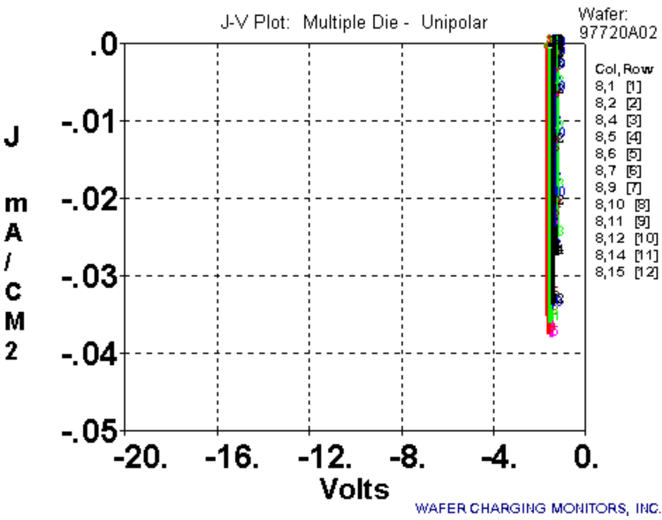

Figure 3. Negative J-V plots for the 4.5e15, 20 KeV, 10 mA implant with PFS off. (The vertical asymptote is an artifact, indicating that the charge-flux sensors did not respond.)

The mean positive voltage on the wafer that was implanted with the PFS off was 6.14 V (down from 13.81 V) and the mean negative voltage for the wafer implanted with the PFS on was –5.2 V (down from –9.75 V).

The 5e15, 20 KeV implant was also done on a wafer with 900 Å oxide. The mean positive voltage measured on the wafer with the PFS off decreased to 8.3 V, and there was a significant gradient across the wafer. A control wafer with the 900 Å oxide was also measured on the Quantox, and the resultant interface trap density (Dit) and oxide resistivity measured at 2e11 /cm^2 and 9.8e15 ohm-cm, showing that the oxide did not suffer from inherent leakage. The negative voltage measured on the wafer with the PFS on increased to -11.6 V. It would appear from these results that although the Quantox reads positive and negative voltages with the PFS off and on respectively, a change in the oxide thickness resulted in inconsistent results. I. e., if the measured charge resides on the surface of the wafer, both positive and negative potentials should increase with increasing oxide thickness. The above results are summarized in Table 1.

B. As, 80 KeV implants

Table 2 summarizes the results obtained with CHARM-2 and Quantox for the As^+ , 80 KeV implants at the different doses and beam currents used. The Quantox measurements were made on wafers with 800 Å of oxide.

Considering the data obtained by the Quantox for the case of the PFS on, the mean surface voltage again shows a dependence on the dose of the implant, for the same beam conditions, with the higher dose (higher number of scans) reading a high absolute value. Also, a reduction in the beam current for the same dose and the same PFS current gives a

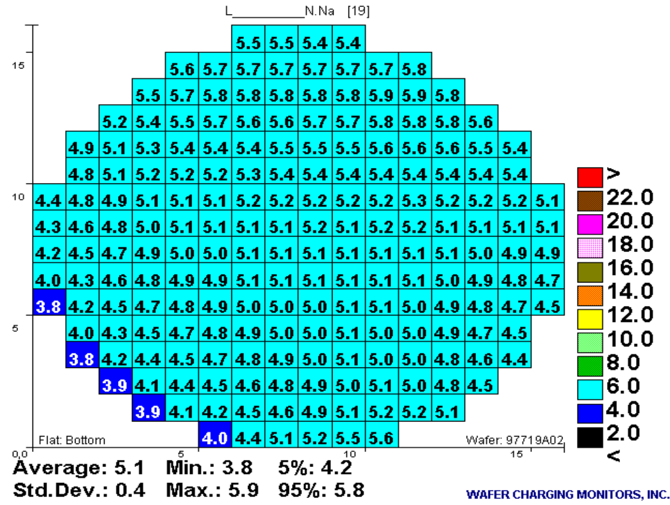

Figure 4a. CHARM-2 positive potentials for As^+, 20 KeV, 4.50e15 /cm^2 implant with plasma flood on.

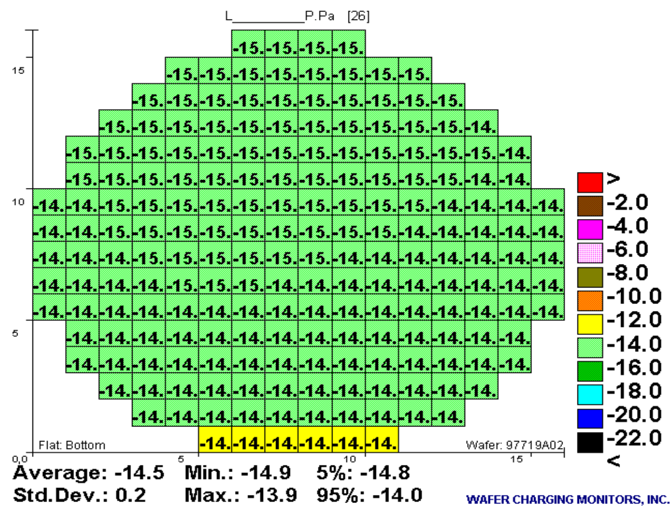

Figure 4b. CHARM-2 negative potentials for As^+, 20 KeV, 4.50e15 /cm^2 implant with plasma flood on. (Note: sensors are saturated – actual values could be greater)

more negative value, indicating the more negative nature of the beam with fewer positive beam ions. The Quantox was, however, unable to measure any positive voltages when the PFS is turned off. This could be a result of two possible factors. The higher energy of these implants could be causing enough physical damage to the oxide, so as to render it leaky and hence read a voltage that corresponds to the damage generated trap charges in the oxide and the Si-SiO_2 interface. The other mechanism is that under these implant conditions, even with the PFS off, the wafer still sees a negative charge halo around the ion beam, which is non-zero unlike for the 20 KeV implants. This negative charge under conditions of the PFS off is measured by the CHARM-2 negative J-V sensors. Representative plots for the 4.5e15, 18 mA beam are shown

TABLE 1

20 KeV IMPLANT	PFS	CHARM-2		QUANTOX
Dose, I_{beam}		V(+)	V(-)	Vsurface
				800 A oxide
4.5e15, 10 mA	off	14.3*	-7.2	13.8
	on	5.1	-14.5*	-9.75
5.0e14, 10 mA	off	As above[1]		6.14
	on	As above[1]		-5.2
				900 A oxide
4.5e15, 10 mA	off	As above		8.3
	on	As above		-11.6

* some or all the potential sensors are saturated - actual values may be greater

[1] CHARM-2 is not dose sensitive, as determined in previous experiments.

TABLE 2

80 KeV IMPLANT	PFS	CHARM-2		QUANTOX
Dose, I_{beam}		V(+)	V(-)	Vsurface
4.5e15, 18 mA	off	14.8*	-9.9	-1.5
	on	8.3	-15*	-5.3
5.0e14, 18 mA	off	As above[1]		-2.4
	on	As above[1]		-4.6
4.5e15, 10 mA	off	14.5*	-6.9	-2.5
	on	4.9	-14.6*	-9.2
5.0e14, 9 mA	off	As above[1]		-2.1
	on	As above[1]		-7.3

* some or all the potential sensors are saturated - actual values may be greater

in Figure 5. The Quantox wafer integrates this negative charge, and since the halo of the beam is the last charge that the wafer sees, it will in effect record this negative charge and overwrite the positive potential generated by the ion beam. Further tests are needed to confirm this hypothesis.

IV. Conclusions

A comparison has been carried out between the Quantox tool and the CHARM-2 wafer charge measurement system. Although the Quantox does provide the potential for quick, in line charge measurements and flag potential deviations in the charge control, an understanding of the limitations placed by the implant beam and energy conditions must be made. A calibration to a known tool such as the CHARM-2 system is essential to get a complete picture of both the positive and negative charge densities that the wafer experiences.

Acknowledgements

The authors would like to acknowledge the entire Technology Development group at Microchip Technology for supporting this study. The authors also acknowledge the assistance of Dr. Wes Lukaszek of Wafer Charging Monitors for assistance in interpretation of the CHARM-2 data.

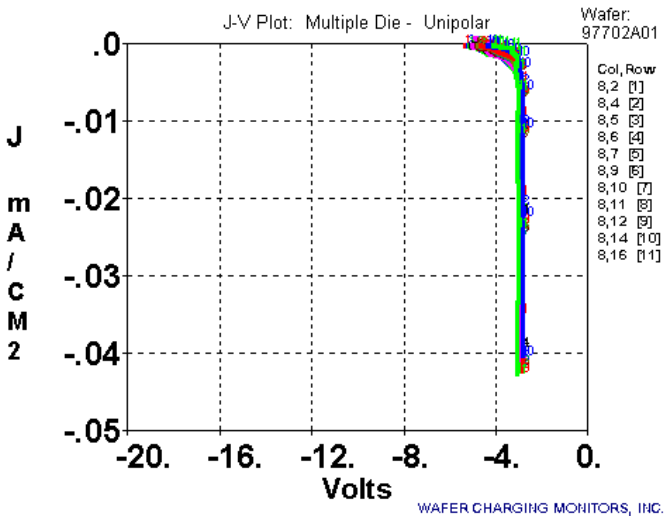

Figure 5. Negative J-V plots for the 4.5e15, 80 KeV, 18 mA implant with PFS off. (The vertical asymptote is an artifact, and should be disregarded.)

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