Surface Charge Profiling
– An advancement in Ion Implant Monitoring

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ABSTRACT ***As the industry gets on the new technology nodes of 65nm and 45nm devices, implant monitor becomes even more crucial for consistent device performance. Common practice has been the use of 4-point probe with sheet resistance and thermal wave technique with the implant damage. However, both techniques have limitations on sensitivity. With the need of monitoring smaller variations in the ion implantation process, there is a need for a new and better approach on implant monitoring.***

A new non contact method using SCP (Surface Charge Profiling) is gradually gaining ground in the industry as a control technique for ion implantation. In this work, the authors compare the responses on implanted wafers with thermal wave, sheet resistance and SCP. Comparisons are made to implants of low doses, high doses and low energies.

1. Introduction and theory of operation

The QCS-ICT 300$^{\text{TM}}$ is manufactured by QC-Solutions $^{\text{TM}}$ and uses a simple non-contact technique to measure the Surface Photo Voltage (SPV) or the surface recombination lifetime of a normal Silicon bulk wafer. Therefore the tool is equipped with two light sources with different wave lengths (Blue-Light (BL) and Ultra Light(UL)).

In principal the silicon surface is illuminated by a collimated beam of chopped light of photon energy greater than the silicon bandgap and the light is absorbed close to the surface. The acquisition of the resulting SPV (Surface Photo Voltage) signal is achieved by means of capacitive coupling though an air gap. The implanted dose and energy can be calculated by measuring the width of the surface depletion region and the surface recombination lifetime. It is possible to support the measurement of low dose implants with a positive or negative charged Corona. [1-2]

The resolution of the tool is adjustable between

high:	7671 (Diameter 150) points per Wafer
medium:	4418 (Diameter 75) points per Wafer
low:	1134 (Diameter 38) points per Wafer

2. Ion Implant Metrology

The measured surface photo-voltage is a result of the ion implant crystal damage and depends from several implant conditions like dose, energy, beam density and indecent angle. This effect is the difference to normal techniques in the common implant control philosophy.

Therefore the QCS-ICT 300 $^{\text{TM}}$ can be used to measure "as implanted" and "annealed" implant profiles.

The conditions of the measurement recipes are depending from these implant conditions and have several different settings. The authors used the experience from QC Solutions $^{\text{TM}}$ and created the following basic recipe groups divided by the implanted dose as the dominating factor[3]:

Boron_Less_5E13	(UL/BL, pos. Corona)
Phosph-Less_1E13	(UL/BL, neg. Corona)
Arsenic_Less_5E12	(UL/BL, neg. Corona)
Boron_5E13_and_more	(UL/BL, no Corona)
Phosph_1E13-and_more	(UL/BL, no Corona)
Arsenic_5E12_and_more	(UL/BL, no Corona)
LE-Boron_HD	(UL/BL, no Corona)
LE-Phosph_HD	(UL/BL, no Corona)
LE-Arsenic_HD	(UL/BL, no Corona)

Other recipe modifications were used as well.

Sensitivity

The sensitivity of the each recipe was measured on common implant qualification and production recipes. A nominal dose variation of ± 10% was used for each recipe. *Figure 1* is showing the very good sensitivity of the QCS-ICT 300 $^{\text{TM}}$ on a 5E13 Boron recipe with an energy < 10keV. With all the tested matrices, SCP showed up to 10 times more sensitive than the other techniques.

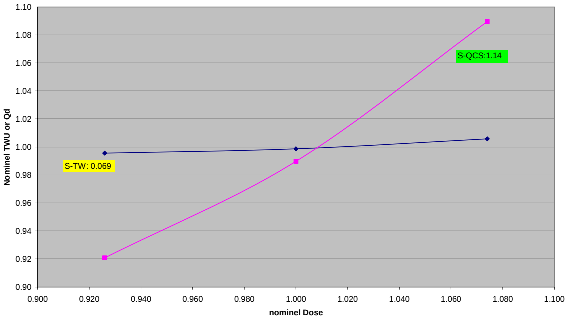

Figure 1: Sensitivity of QCS at ±10% Dose Variation

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In addition to the sensitivity, SCP also shows advantages in its high resolution mapping capability with good throughput. While other techniques give good wafer uniformity values, SCP reveals implant micro non-uniformity issues such as striping in the slow and fast scan direction of hybrid scanning, glitch recovery success rate and different test wafer surface conditions.

Figure 2 is showing a QCS map of a normal E13 Arsenic implant on a medium current tool with a common mechanical scan system in the slow scan direction (S) and an electrostatic beam scan in the fast scan direction (F).

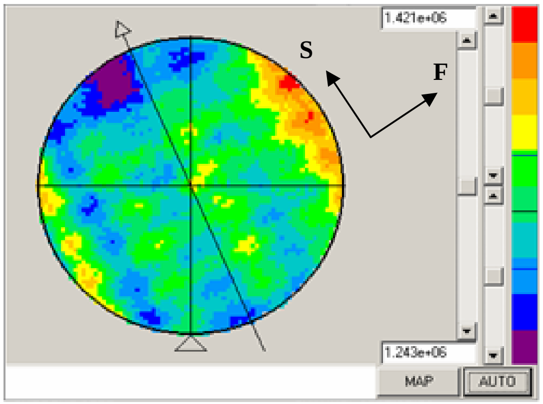

Figure 2: medium resolution map of a medium dose implant from an implanter with an electrostatic beam scan system

Figure 3a and *3b* are two cross section analyses in the slow and fast scan direction of the same wafer. The beam profile in the fast scan direction and the dose failure during surface outgasing in the slow scan direction is clearly visible in both cross sections.

Both analysis can be used to optimize the current implant regarding better beam profile, reduced edge effect, etc. and for failure analysis in general.

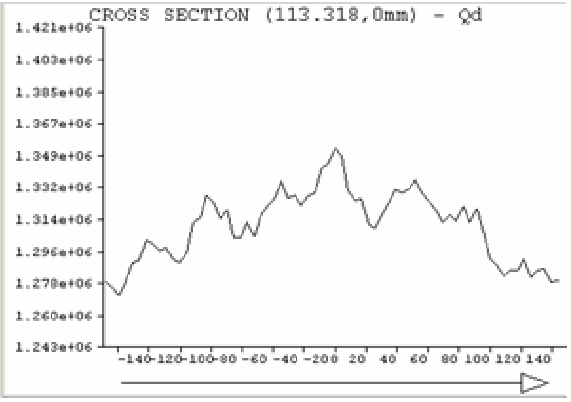

Figure 3a: Cross section in the slow scan direction

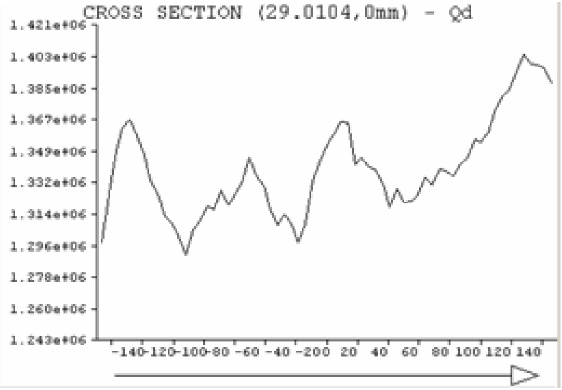

Figure 3b: Cross section in fast beam scan direction

Other typical implant tool finger prints were measured with the tool as well. *Figure 4a* is a typical map of an implanter with two mechanical beam scan systems. The implanted beam profile and the dose failure during outgasing are clearly detectable.

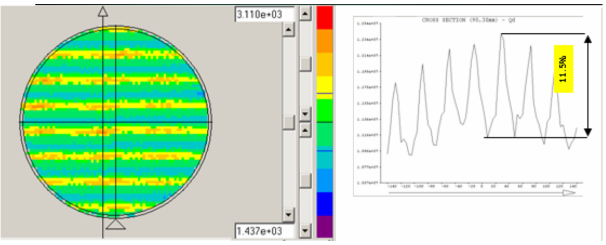

Figure 4a: medium resolution map of a high dose implant from an implanter with two mechanical scans

The micro-striping of the same wafer got reduced after a 1000°C/10sec anneal (*Figure 4b*) and is not detectable during the electrical transistor measurement of the wafer. This striping could become an important issue in Sub-45nm-Technologies again.

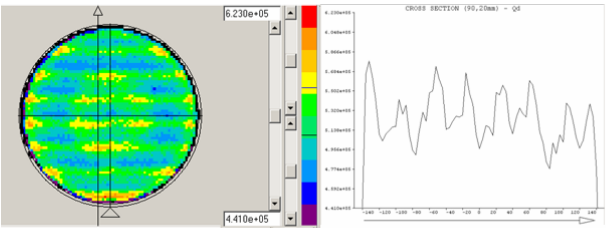

Figure 4b: same implant conditions as in 4a after annealing

Other typical implant effects become visible with this technique also.

Figure 5 clearly identifies two implant interruptions (Glitches) during a normal implant. Those non-uniformities got washed out during an annealing step and a high resolution sheet resistance map (>600points) is not able to detect these interruptions anymore.

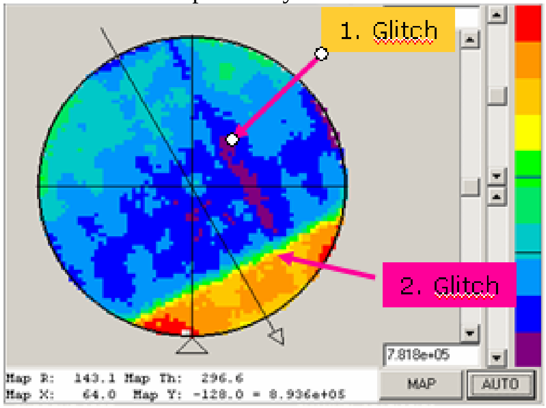

Figure 5: Two implant interruptions during a multi-twist implant

Statistical Process Control (SPC) and Stability

The QCS-ICT 300 ™ is easy to implement in the implant control loop. At AMD Fab36 it is used to measure the as-implanted conditions on daily implant qualification wafers. Several SPC-Charts were generated and indicating nearly every failure during the implant process now.

Some difficulties with Boron and with the substrate bulk material are discovered during this qualification process. The surface conditions and the silicon manufacturing process of each wafer can cause some different lifetime and SPV values. An implant qualification SPC-chart is shown in *Figure 6*. The usage of test-wafer material from an other silicon supplier generates Out-Of-Control (OOC) values in the QCS-SPC-chart suddenly while the sheet resistance chart seems to be more insensitive. It is not clear which surface conditions are generating these OOC-values, but the authors identified a much higher Oxygen level in these silicon wafers from that supplier.

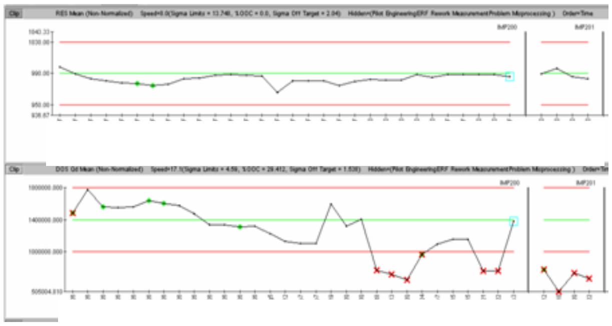

Figure 6: OOC QCS-signal change by silicon supplier change

Other usages

It is more and more important to control the implant tool prior the implant process and calibrate for instance the implant angle. Common techniques like the V-Curve-Method are used to adjust the 0°-Tilt-Position of each ion implanter. Several test wafer and implant processes at different tilt angles are necessary for this method. Normally the V-Curve got generated by 0°, ±1° and ±2° tilted implants at a certain dose and energy.

This is not necessary by using the QCS-ICT 300 ™.

The authors used one test wafer and switched the electrostatic scan on the ion implanter off. The center of the beam should hit exactly the middle of the wafer at 0° tilt and the normal beam divergence will generate different implant angles on the edge of the wafer. The horizontal diameter scan / cross section should show the exact centered V-Curve caused by different implant conditions in the center versus the edge of the wafer.

The results of this test with and tilt angle failure of < 0.5° are shown in *Figure 7*.

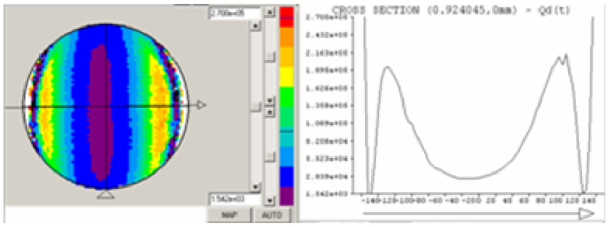

Figure 7: V-Curve measured with QCS on one test wafer

3. Summary

- QCS-ICT 300 can be used as an implant metrology tool
- The tool is able to measure „as implanted“ and annealed profiles with a high sensitivity
- Highest sensitivity is in the E12 – E14 dose region
- Beam glitches, beam non-uniformities, changes in the dose measuring system can be identified
- The tool is very sensitive regarding the conditions in the build up process
- Good repeatability results are observed

The authors believe SCP can be a good technique for ion implant statistical process control and implant trouble shooting.

References

(1) QC Solutions User Manual
(2) Edward Tsidilkovski, ed.al.: Ion Implant Process Monitoring with a Dynamic Surface Photo-Charge Technique
(3) QCS as-Implanted Conditions/Recipe Guide