APPLICATION NOTE

Advances in Optical Densitometry for Low Dose Measurements

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Abstract

The move to sub 130nm devices has driven the need to have a wafer level, high sensitivity low dose mapping capability for all species on large diameter silicon wafers. Sheet resistance mapping systems do not provide the feature sensitivity and matching capability required for precision 1E11 to 1E13 doses.

The new CorMap Optical Densitometry System uses a 595nm LED light source to measure the development of dye in a photo resist polymer. The Core Systems unit bounces the light off of a coated, standard silicon wafer. After the exposure to the ion beam, a very high definition wafer level map is produced in 1 – 2 minutes (for 200mm wafers). This paper will review the areas where the CorMap (Model 200) offers unique applications for process diagnostics and ion implant monitoring for dose, energy and energy/species. Dose and energy sensitivity over a wide range (inc. 2.5 MeV+) of lower doses will be shown and compared.

I. Introduction

Implanters manufactured for advanced MOS applications need to have a method for measurement of the dose and uniformity of lower dose implants. A few users may scale up their low dose implants to a dose where sheet resistance can be used but this is undesirable [1].

Low dose implants, < 1e13 ions/cm2 approximately, often require a move from sheet resistance measurement to some other dose measurement technique. Lower dose measurement techniques have historically had low to very low dose sensitivity or are subject to time consuming preparation or actual measurement time – especially when the user desires higher than normal resolution

High spatial resolution (the "visual acuity" of the measurement tool) becomes critical in cases where devices are getting smaller due to increased density and, as a consequence there are many more devices per unit area (chip to chip variation). On the other hand, improved resolution is also needed where integration is increasing the die size. This is also useful for CCD and CMOS imaging devices for example, where micro-striation problems become visibly defective [2]. The same applies to microprocessor die that now average between 1 and 2 cm2 (intra chip variation) [3, 4]. This is true for all doses and all energies – especially for low doses, where dose sensitivity has been lower than desired.

II. Reflective Optical Densitometry

CorMap is a new optical densitometry dose measurement system using a reflective technique through a special resist coating on a standard silicon wafer. Neither the wafer nor the coating is patterned for standard dose measurements but there are applications where patterned wafers with the user's own resist can be used for general in-line verification of implant condition. The coating does not require any other preparation such as an under-coat. The reflective technique on silicon wafers eliminates past problems with wafer charging or wafer handling, as was found with glass wafers using transmission optical densitometry. The coating is a form of PMMA resist and will not be sensitive to channeling. Therma-Wave is quite sensitive to channeling, so well that is can be used for rapid and accurate evaluation of beam parallelism [5]. Beam perpendicularity can be off by as much as 1.5 degrees or more – even though the beam might be "parallel". A tool such as Therma-Wave might be useful in detecting this condition.

For fast, low dose measurement the CorMap 200 is offered as an alternative technique for rapid, high-resolution mapping of dose in the 5E10 – 2E13 dose range – more or less depending upon specie and energy. The CorMap uses wafers with a tightly controlled copolymer coating that are pre-mapped and stored ready for use as an implant monitor for any implant species. The time for a measurement and map production for 37,700 points on a 200-mm wafer is just under 2 minutes with no other post process steps. A 300-mm wafer map reflects data from 86,700 data points and is mapped in ~ 3 minutes. In contrast, sheet resistivity mapping requires an anneal, followed by an extended measurement time for a resolution map of 625 points.

III. Experimental

A test to evaluate the CorMap dose and energy sensitivity for 10 – 200 keV was done using standard, mid current implanters located in Core's production bay. The implanters used were an Axcelis/Eaton 6200 series and a Varian CF3000 series. The implanter used for higher energies (500keV to over 6 MeV) was a custom instrument for 200mm wafers made by Diamond Semiconductor Group LLC. The test was designed around a similar test done earlier for low dose measurement evaluation [6]. The species used are B, P and As, and most of the doses are at energies between 10 and 190 keV. The higher energy implants were run with B or P at 400, 500, 750, 1000, 3000 and 6000 keV. The test matrix is listed in Table 1.

Specie	Energy (KeV)	Dose		
		E11	E12	E13
B	10, 20, 50, 100, 190	1, 1.1, 3, 5	1, 5	1, 2, 2.2
	500	1.5	1, 5	1
	750	-	1, 5	-
	1000	2	-	-
	3000	1.6, 2, 2.4	-	1
	6000	1.6, 2, 2.4	-	-
P	20, 50, 190	1, 1.1, 5	5	1, 2, 2.2
	400	-	1, 2	1, 2
As		1, 1.1, 3	5	1, 2, 2.2

Table 1. Species, Energies and Doses of Cormap 200 Tests

IV. Results and Discussion

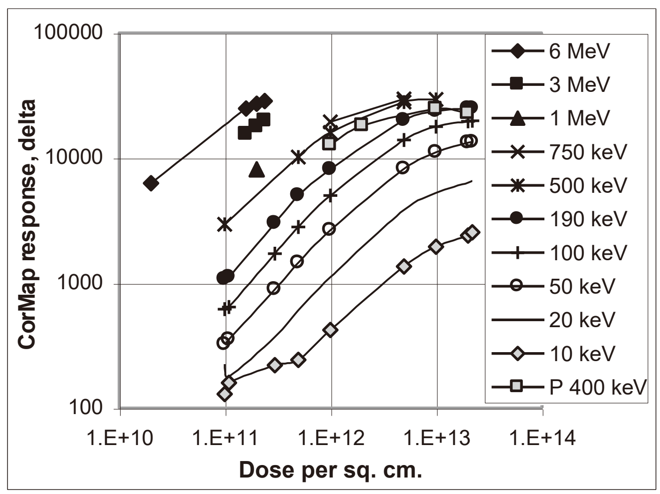

Figure 1. Measured response of CorMap wafers to boron by dose and energy. Note the inclusion of a single set of phosphorus points for comparison at 400 keV

From Figure 1 we can see that CorMap wafers have a useful response over a range that overlies the bulk of "parametric" implants and a number of other implant applications. The data available for phosphorus overlie those for the same dose and energy for boron at the lower doses within the resolution visible on paper, but at higher doses saturation occurs slightly earlier, presumably due to the reduced range. Only values for 400keV are plotted, to illustrate the trend. This fits with the principle of the CorMap response, in that it is measuring the breaking of bonds due to the deposition of energy by electronic stopping of the ions.

We have rejected four points from the 10 and 20 keV data which clearly break the overall trend, and re-plotted the remaining points on a scatter plot (Figure 2), where the abscissa is the CorMap signal, and the ordinate is Dose x Energy, i.e. the total energy implanted. The plot is log-log, and is given below. Most of the points lay tangent to a line with a slope of 0.85, which means the sensitivity is around 0.85 for dose or energy unless the particular point lies significantly below the trend line. The dose/energy combinations, above which the sensitivity drops significantly, are shown in Figure 3.

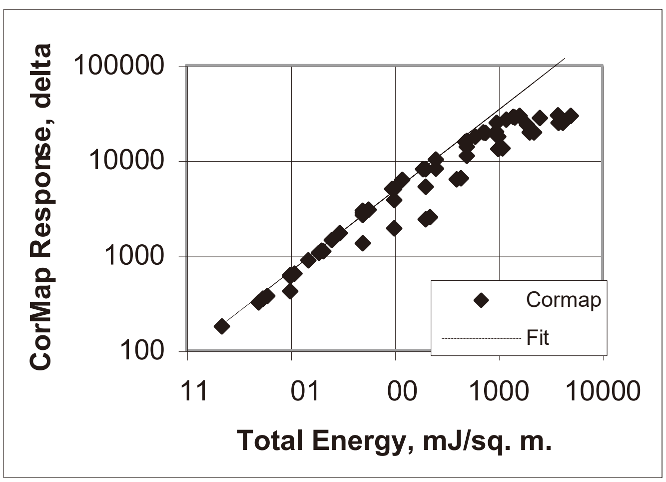

Figure 2. Log-log Plot of Boron Data Points, plotting the response against the total energy deposited by the implant

The total energy is proportional to dose x energy, and the CorMap response to this quantity is plotted. The points that lie below the line exhibit saturation. The shallower implants saturate at a lower dose x energy, presumably because the energy density is greater. The slope of the reference fit is 0.85, and this gives the sensitivity to small changes in dose or energy for those data points lying on the line.

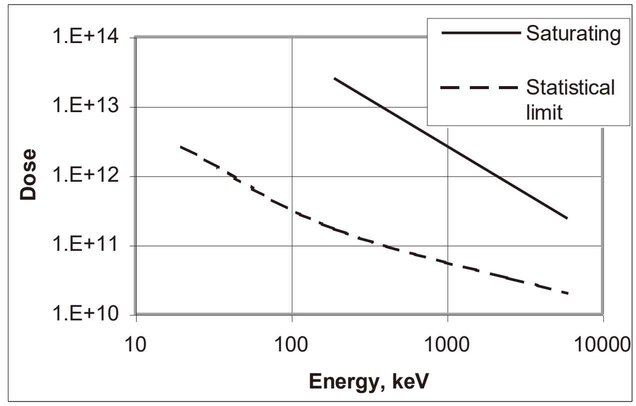

Figure 3. CorMap Region of Sensitivity (Boron). Sensitivity is best in the zone between the lines, but still useful with reduced precision outside these limits

The upper limit of usefulness is defined by the onset of saturation and the lower limit by the statistics of a small value of the digital CorMap response. Figure 3 defines the useful region for Boron, in terms of dose and energy. The sensitivity exceeds 0.7in most of the bounded region. The top line shows the useful quantitative limit defined by saturation and the lower limit by a CorMap delta of ~1000. Clearly useful but less precise data can be obtained outside these bounds.

This measurement technique can be used to confirm micro-uniformity specifications, since the resolved area (~ 0.8 mm2) in the standard, high-resolution maps is far smaller than the beams in commercial ion implanters. Micro-uniformity can only be checked on other techniques by performing a diameter scan, and this can easily miss the feature of interest. For example, a deliberate beam glitch was generated while implanting a 200mm wafer at high energy (6 MeV) on the aforementioned DSG MeV implanter. Scanning was resumed on a subsequent pass, and the CorMap data allows evaluation of the spliced implant. The wafer map is shown in Fig 4. The glitch, while representing a very small change in overall uniformity, is discriminated with the CorMap. The overall uniformity has a sigma of 0.05%, at a sensitivity of 0.3, so the sigma for the dose uniformity is 0.13%, even in the presence of the deliberate beam interruption. The CorMap technique had reserve resolution will below 0.01%.

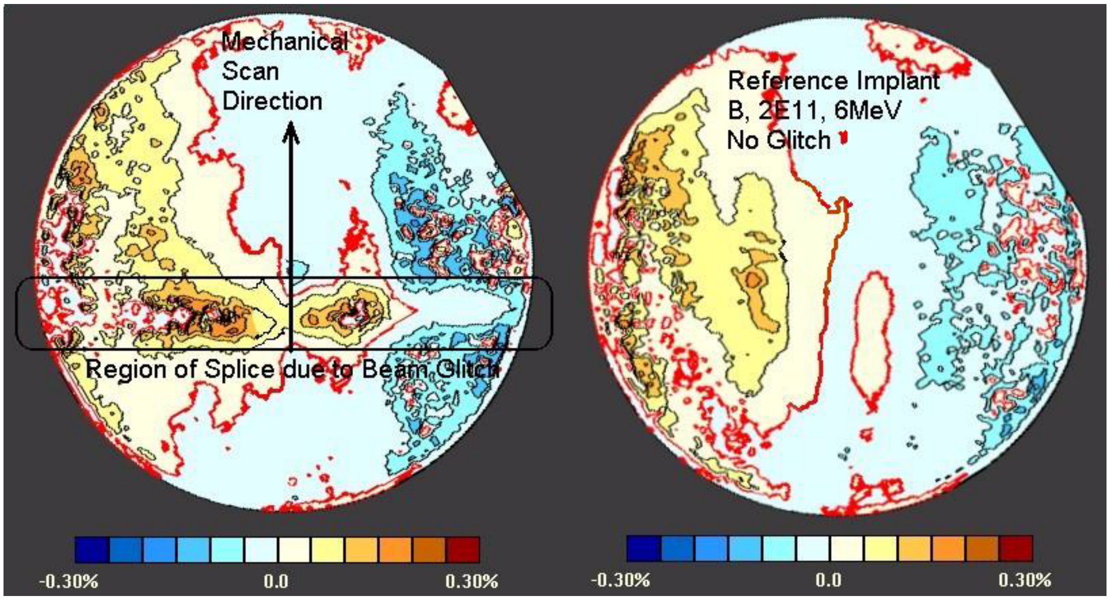

Figure 4. Fast-scan was horizontal, slow scan vertical in figure. The beam was deliberately interrupted and automatically spliced. The quality of the splice is clearly resolved. Boron, 6 MeV 2E11, 2 passes. Contour interval 0.2%, dose sensitivity 0.3 at this dose/energy.

Wafer #	Implant 2	Means	Range	SD%
1 & 2 (Ref)	none	4589 4577	12	0.31% 0.28%
3 & 4 (2.5%)	B, 40 keV, 1.9E11	4755 4746	9	0.24% 0.27%
5 & 6 (5.0%)	B, 40 keV, 3.8E11	4976 4980	4	0.26% 0.31%

Table 2. Energy Purity Check (Simulated Decel 40 to 20 Kv)

With the relatively high sensitivity for change in energy, we did a short test simulating decel implants to see what the measurement capability might be for energy purity where the “energy impurity” is deeper than the primary beam. A simulated decel was done using a common decel ratio of 2:1 [7]. We started by implanting six (6) wafers at 20 keV drift, retaining two as reference wafers. We then implanted two other wafers at an additional 2.5% dose at 40 keV and the other set at an additional 5.0% of the dose also at 40 keV. The results (shown in Table 2) show a clear 5% shift in CorMap mean for the 2.5% “impurity” and 10% shift in measurement value for the 5% “impurity”.

V. DOSE MATCHING – LOW DOSE

It is common to see implanters that are well matched at doses in the 1E13 – 1E15+ ranges with sheet resistance, be out of match at lower doses. Some fabs scale their low dose implants, i.e., run the same beam current and setup but for 10 - 20+ times longer in order to get into a sheet resistance reading regime. It is not uncommon to have a small, unnoticed error, Faraday leakage current for example, in the 1E13 – 1E15+ range. See Fig. 5 which shows a low dose implant (B, 100 keV, 5E12) measured on two implanters in the same fab – same time using CorMap.

These implanters had run implants from low E12 through 1E15 using sheet resistance as the monitor (B, 80 keV 5E14) for all doses for over several months. The two implanters were matched to within 0.5% with Rs and SIMS measurements. Low dose measurements over a few days on the two implanters show a clear difference of ~ 5%. It is possible that with sensitivities in the 0.08 – 0.15 regime, other metrology systems might indicate a dose match.VI. MEASUREMENT CAPABILITY

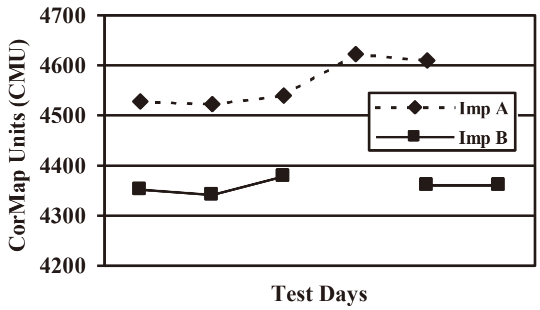

Figure 5. Two Implanters with Low Dose Implant (B, 100 keV, 5E12) after Long Term Dose Match with Rs at higher dose

The practical reproducibility of the maps from the test matrix seems to be a full range error of 73 using 36000 points, based on a reference wafer in the high-energy matrix. The resolution is about 0.006 % with a dose sensitivity of ~ 0.7, i.e. about 0.01% in true absolute dose, for a suitably selected implant in which the map data has 15000 counts mean value. This implies a gauge capability of 0.1%. Because the number of points is so large, the statistics of the mean dose are excellent, and one might argue that the gauge capability is better than this.

The repeatability of the CorMap was checked with two operators for two separate one-week tests on the same wafer. The wafer was unimplanted, and represents a reading close to the threshold of measurement for the CorMap (i.e. mid to high E10 dose). Measurements over 1 day (n = 10) and over 1 week (n = 15) showed a SD% of 0.036% and 0.041% respectively.

VII. Dose Rate and Dose Duty Cycle Measurements

A few short tests were done to see the effects, if any, of dose rate change and dose duty cycle change as seen in other measurement techniques [2]. Three implants were done on an implanter which is monitored daily with low dose on CorMap. The results (< 0.3% for the set) are shown in Table 3 and are well within the repeatability spec for the implanter.

Two wafers were implanted with Boron, 60 keV, 5.00E12 for a time = 7.5 seconds. Two other wafers were implanted at the same energy and dose but for 58 seconds. A third set was implanted with the 58-second setup but was interrupted at 33% and 66% complete for 5 – 6 seconds each time for a "relaxation" effect test. No difference was detected between a significant change in beam current or duty cycle. It is important to consider that these types of interruptions [2] during a quad mode implant monitor or after maintenance activities might cause initial HV trips during the first few implants. Low dose measurements where the dose sensitivity is low can compound the evaluation with these types of implants.

Implant Time (Sec)	Beam I (micro A)	CorMap Mean/SD	Notes
7.5	15	9864/21	
58	2	9914/18	
58 (A)	2	9894/16	(A) This implant had 5 to 6 second holds at 33 and 66% complete

Table 3. Dose Rate and Dose Duty Cycle Check (b, 60 kev, 5e12)

VIII. Summary

The useful range of CorMap signals, in terms of the delta between unimplanted and implanted spans approximately 100 to 28000 in CorMap units. There are saturation effects limiting the upper range, and the usefulness at the lower end is limited by statistics. In between is a large useful area providing very high resolution, very high precision mapping, with a good response to both dose and energy, and very little response to spurious factors. These factors will allow the user to easily and accurately match implanters at low dose within a fab. The CorMap is small and uses a simple optics package that allows it to be moved within the fab with little effort. The wafers are easily reused, providing a cost saving for large diameter wafers. The energy sensitivity – especially high energy, is useful for fast, in-line determination of energy and energy impurity. Work is ongoing with (i) on product wafer dose measurement and (ii) for lower energy capability (sub 5 keV Boron).

References

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