Maximizing Productivity for Well Implantation

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Abstract. Until recently most semiconductor manufacturers have used high-energy ion implanters for deep well formation. This was partially driven by the fact that these well implants were beyond the productive operating range of conventional medium current implanters to achieve in a productive and cost effective fashion. Recently, VSEA has increased the energy range of the VIISta medium current implanter to 300keV, 600keV and 900keV for single charge, double charge and triple charge implantation, respectively. A combination of this new capability with a reduction in well implant energies due to device scaling, has brought most well implants in the regime of the VIISta 900XP system. This paper describes the superior process performance that is achieved and how this capability results in increased productivity and reduced cost of ownership.

Keywords: Ion Implantation, Productivity, Well Doping
PACS:

I. INTRODUCTION

Tight control of well implant parameters is key in manufacturing leading edge semiconductor devices [1, 2], due to increasing device packing density. Historically, sub-MeV well doping has been conducted on high energy implanters. With the device geometry scaling down, most of the well implant energies have been reduced to lower than 600keV. In addition, true zero degree well implants are required to avoid shadowing from the photo resist mask and encroachment. The effectiveness of zero well implants to control intra-well isolation has been reported [1, 2]. The new generation VIISta medium current implanters from Varian Semiconductor Equipment Associates (VSEA) has the capability of processing 300keV, 600keV and 900keV implants using single charge, double charge and triple charge ions, respectively. The VSEA single wafer architecture guarantees excellent implant angle accuracy. The VIISta 900XP medium current implanter satisfies all the process requirements of well doping, including dose uniformity and repeatability within wafer, wafer-to-wafer, and lot-to-lot, and beam incident angle accuracy. The system can also provide high productivity, comparing to high-energy implanters which significantly reduces the cost of ownership (CoO). In this paper, we will demonstrate the process performance of the VIISta 900XP, and its capability of maximizing productivity using a representative set of recipes with energy ranging from 30keV to 2.5MeV.

II. EXPERIMENTAL

In this paper, a B^+, 300keV, 3E13cm^{-2} recipe was chosen for process performance characterization. This implant is sensitive to small variations in ion channeling due to small incident angle differences and can easily be quantified by standard bare wafer techniques such as Secondary Ion Mass Spectroscopy (SIMS), thermawave, and sheet resistance. All wafers used were 300mm in diameter and were implanted on a VIISta 900XP ion implanter. After implant, wafers were annealed for 10 seconds at 1000°C in 10% oxygen atmosphere for dopant activation. Sheet resistance was measured by four-point probe with an edge exclusion of 3mm. As-implanted dopant profiles were characterized using SIMS. Thermawave was used for as-implanted dose uniformity characterization.

II1. PROCESS PERFORMANCE RESULTS

Dopant profiles obtained with SIMS from 5 points (center, left, right, top, and bottom) representative of three points each in the slow scan and fast scan direction for a 300keV, B^+, 3E13cm^{-2} at 0 degree tilt are shown in Figure 1. The top, bottom, left, and right points are obtained 5mm from the wafer edge. These dopant profiles consist of two peaks; the deeper peak at 1.15 micron consists of channeled ions while the peak at the lower depth of 0.75 micron consists of de-channeled ions. SIMS profiles obtained from different wafer locations overlay at both de-channeled and channeled regions. This behavior reflects the beam parallelism across the wafer. A 0.1^o un-parallelism in the beam across the wafer will show clearly on the overlay, since the Rp sensitivity per 0.1^o at 0° is about 43.2nm. With 0.1^o angle variation, the non-channeling portion will increase noticeably at the expense of channeling portion. In Figure 2, four dopant profiles taken from the center of four wafers implanted over a 20 day time period (including the center profile from Figure 1) are shown. The complete overlay of the four profiles indicates a well under 0.1^o variation dopant profile can be achieved repeatedly, demonstrating outstanding run-to-run repeatability of zero degree well implants on the VIISta 900XP implanter. The sheet resistance and Thermawave data from the four runs, as shown in Table I, confirms both within wafer dose uniformity and run-to-run dose repeatability of this channeled implant. Figure 3 contains the typical Thermawave and sheet resistance maps for this implant.

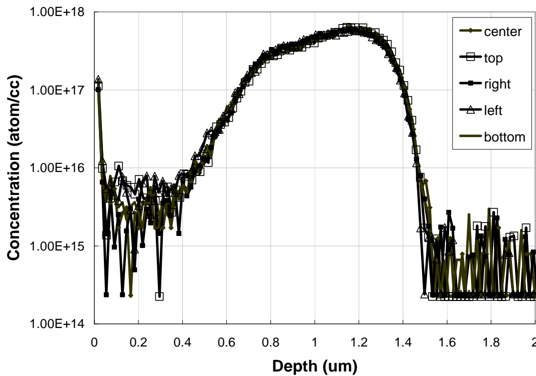

FIGURE 1. As-implanted dopant profiles from 5 locations of a wafer implanted with B^+, 300keV, 3E13cm^{-2}, $0^o/0^o$, with an edge exclusion of 5mm.

This beam angle performance on the VIISta 900XP medium current ion implanter is controlled by the use of Varian Postioning System (VPS^{TM}), a closed loop angle control system integrated into all VIISta implanters [5]. With this system, both beam parallelism and beam steering angles are measured and corrected with each beam setup and at user selectable wafer intervals. This ensures accurate angle control, which is critical for 0° tilt well implants.

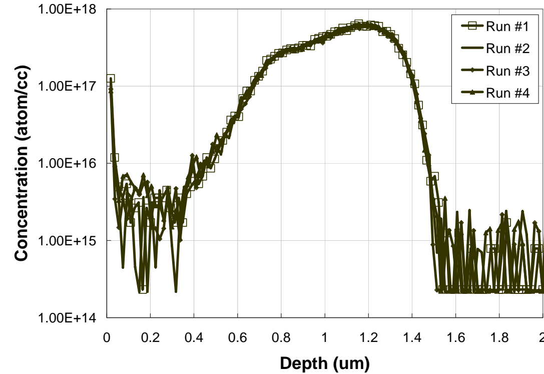

FIGURE 2. As-implanted dopant profiles from center of four wafers implanted with B^+, 300keV, 3E13cm^{-2}, $0^o/0^o$ over 20 days.

Table I. Sheet resistance and Thermawave data of B^+, 300keV, 3E13cm^{-2}, $0^o/0^o$ over 20 days

Implant Date	TW Unit	TW Unif. (%)	Rs (Ohm/sq.)	Rs Unif. (%)
Day 1	654.33	0.26	971.31	0.194
Day 4	654.11	0.33	974.89	0.266
Day 13	656.68	0.42	973.57	0.254
Day 20	655.92	0.39	978.44	0.261
Average	**655.26**	**0.35**	**974.55**	**0.24**
Repeat. (%)	**0.19**		**0.31**	

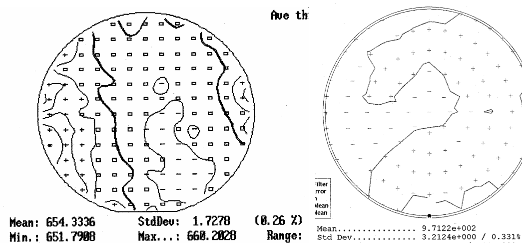

FIGURE 3. Typical Thermawave and sheet resistance maps of B^+, 300keV, 3E13cm^{-2}, $0^o/0^o$ implant.

A true 0° tilt implant has channeled doping profile, as shown in Figures 1 and 2, although the degree of channeling varies, depending on factors like substrate crystal orientation, beam energy, ion species, doping dose and implantation induced crystal damage, etc. [6, 7]. Figure 4 shows three doping profiles of B^+, 300keV, 3E13cm^{-2} implants with implant tilt angles at 0°, 0.5^o and 1°. It can be clearly seen that with the tilt angle changing from 0° to 0.5^o to 1.0^o, the extent of

channeling becomes less while the de-channeling portion becomes more dominant. In other words, the mean projected range of the ions (R_p) becomes smaller with implant tilt angle. The Thermawave data from these wafers, as summarized in Table II, are consistent with the conclusions drawn from the SIMS dopant profiles. The increase in thermawave unit with implant tilt angle shows that the 0° tilt implant has the most channeling. From these results it can be discerned that a variation 0.5 degree in implant angle will result in large variations in dopant profiles. This proves again that the VIISta 900XP can provide excellent beam parallelism and accurate beam incident angle control consistently, as shown in Figures 1 and 2. Surface concentrations of well implants are affected and have implications in definition of halo/well junctions, critical for transistor performance. Thus even a +/- 1 degree ion beam incident angle variation across the wafer, like that observed when using a relatively flat disc on a batch implanter, is not sufficient to enable small incident angle well implants.

Table II. Thermawave data from B^+, 300keV, 3E13cm^{-2}, with various implant angles

Implant Angle (deg)	TW Unit
0	654.33
0.5	674.43
1.0	717.63

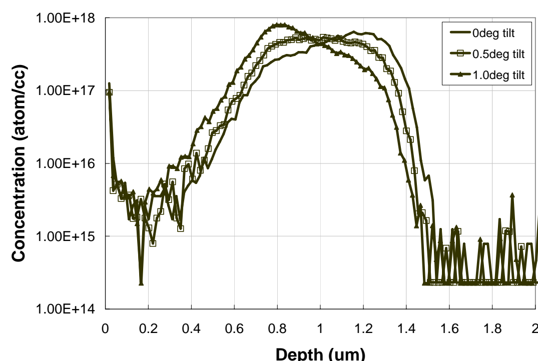

FIGURE 4 As-implanted dopant profiles of B^+, 300keV, 3E13cm^{-2}, implant with various implant angles.

III. PRODUCTIVITY IMPROVEMENT

To illustrate the productivity improvement by transferring sub-MeV well implants from high energy tools to medium tools with 300keV and 600keV capability, a representative recipe set, including implant energy from 30keV to 2.5MeV, as summarized in Table III, is used for modeling. The productivity simulation that follows has the following assumptions:

1. 90% of specification beam current
2. 70% of tool utilization rate
3. 300mm wafers, 100 wafer lot

The following two scenarios are simulated, based on the above assumptions.

1. High energy implanter and a medium current implanter without increased beam energy capability, where implants 3, 4, 5, 12, 13, 26 and 27 are dedicated to high energy implanter, and the rest to a medium current implanter
2. High energy implanter and medium current implanter with increased beam energy capability combination, where implants 4, 5, 26 and 27 are assigned to high energy implanter, and the rest to medium current tool with increased beam energy capability.

The simulation results are shown in Figure 5. All data are presented in percentage, after being normalized to scenario 1.

When a medium current tool without increased beam energy capability is used, seven out of the twenty seven recipes are dedicated to the high-energy tool. With the increased beam energy capability, only four of the twenty seven recipes are dedicated to the high energy implanter for maximizing productivity. As a results, the number of total tools required decreases by 25% to 40% for wafer start per month (WSPM) ranging from 10k to 50k as compared to scenario 1. These advantages will continue to occur with the addition of other medium current recipes. For customers who do not have recipes with energy higher than 900keV, all the implants can be carried out on medium current implanter with 300keV and 600keV capability. With fewer types of implanters in the bay, the operation overhead, such as maintenance will be reduced, resulting in reduced CoO.

This capability of optimizing the tool requirements as a function of wafer utilization is enabled by the seamless process transfer between the VIISta 900XP medium current and VIISta 3000HP high energy ion implanters [1]. More over, the commonality between these tools allow transparency of their use as well as optimized utilization in a dynamic environment with varying product mixes

Table III, recipe set for bay capacity simulation

Implant Name	Species	Energy (keV)	Dose
1	B	200	3.50E+13
2	B	250	9.00E+12
3	B	300	5.00E+13
4	B	400	2.00E+13
5	B	600	2.00E+12
6	P	200	1.00E+13
7	P	250	4.00E+12
8	P	400	1.00E+13
9	P	400	2.00E+13
10	P	400	3.00E+13
11	P	500	3.00E+13
12	P	600	3.00E+13
13	P	600	8.00E+13
14	As	180	8.00E+12
15	B	70	9.00E+12
16	B	70	1.00E+13
17	B	30	6.00E+12
18	As	30	1.00E+13
19	P	50	1.00E+13
20	B	30	2.00E+13
21	P	30	1.00E+13
22	P	40	1.20E+14
23	B	250	1.00E+13
24	B	120	8.00E+12
25	B	120	6.00E+12
26	P	1000	3.00E+13
27	P	2500	2.00E+13

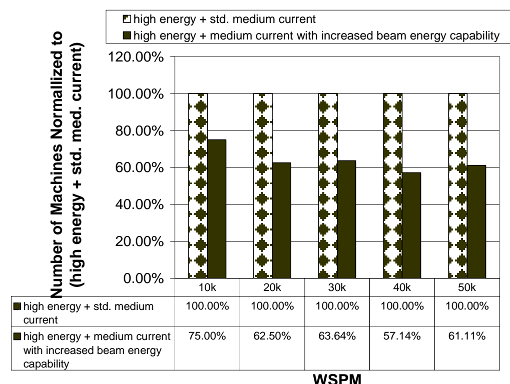

FIGURE 5 Calculated implanter requirement for various wafer start per month, all data are normalized to scenario 1 and are presented in percentage

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IV. CONCLUSIONS

The expanded energy range of the VIISta 900XP enables the transfer of most high-energy well implant applications to the VIISta 900XP medium current implanter. If manufacturers do not have any implants with energy higher than 900keV, they can select either VIISta 900XP only or combining it with VIISta high energy tool, depending on the recipe set. All of these can be accomplished without any compromise to process performance, due to the tight process control capabilities on VIISta 900XP and VIISta 3000HP implanters.

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