

Advanced Single Wafer High Current Beamline Architecture for Sub-65nm

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Abstract. Single wafer has been established as the preferred method for high current ion implant in next-generation semiconductor processing. To deliver the required gains in leading edge device fabrication, high current implanters must be capable of higher doses at lower energies, tight beam angle control, implant dose uniformity, charge and contamination control. The fundamental architecture of the implanter is critical to achieve the productivity and ion beam quality needed for sub-65nm device applications. The design elements of the VIISa HCP dual magnet ribbon beam high current implanter that enable increased low energy productivity, tight contamination control and interlocked ion beam quality are described here. We review implanter performance characteristics for productivity (beam current, tune times, wafer handling) and device yield (beam stability, beam angle and particle control). Finally we describe vMask™, a unique platform feature which significantly reduces device development costs.

Keywords: High current implanter, ion implantation, single wafer.

INTRODUCTION

High current ion implanters are used to create the conducting paths in the transistor such as the source and drain (S/D), source or drain extension (SDE) and gate doping. These device applications require higher implant doses and, as transistor scaling reduces critical device dimensions, lower implant energies for shallower junctions. Device scaling also drives lateral control requirements of implanted profiles. In fact, the need for diffusionless activation techniques such as flash or laser annealing has shifted the focus of high current implant to include not only junction depth control but also precise as-implanted dopant placement in the lateral dimension. The combined requirements of higher doses and precise as-implanted profiles drive the need for increased productivity at lower energies and precise implant beam control. A summary of typical high current implants is shown in Table 1.

Historically, high current implanters were configured as batch systems that relied on multiple wafer passes to ensure dose uniformity. Recent yield problems on batch systems from ballistic particles and the well-known cone angle effect have shifted the focus to single wafer high current architectures. Two approaches to single wafer high current implant have emerged: single magnet spot beam architectures with

two dimensional wafer scanning and the dual magnet ribbon beam architecture with one dimensional wafer scanning. Here we describe the design elements of Varian's fourth generation single wafer high current implanter, VIISa HCP, that provide increased productivity, precise dopant placement and low particle contamination.

TABLE 1. High Dose Implants

Implant	Dose Range (/cm ²)	Energy Range (eV)	Tilt
S/D	8E14-5E15	1-5k	No
SDE	5E14-5E15	200-5k	Low
Gate Doping	5E15-5E16	2k-5k	No
PAI	5E14-1E15	10-30k	No

SYSTEM DESCRIPTION

VIISa HCP, shown in Figure 1, is the latest generation single wafer high current system from Varian. The system builds on the production-proven reliability of VIISa HC. To address sub-65nm high current implant applications, innovative improvements have been incorporated into the ion beam injector optics, transport optics as well as the measurement and process control systems of VIISa HCP.

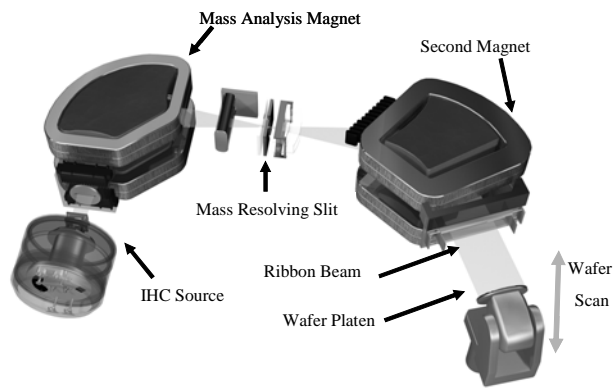


FIGURE 1. VIISa HCP

The VIISa HCP architecture incorporates high output long life injector optics, an indexed analysis magnet with focusing quadrupoles for horizontal and vertical beam control and a decel lens between the dual magnets that incorporates a state-of-the-art optics design for improved low energy, high perveance ion beam transport. A new 70° collimating second magnet design provides the uniformity and angle control required for ion beam optical precision. The system delivers angle control, ion beam symmetry and excellent contamination control. Electrostatic deceleration slit lens design enhancements after beam collimation provide high perveance space-charge compensation of the beam that result in improved low energy beam currents and active vertical and horizontal focus control. These changes specifically address low energy SDE gate over-lap implant precision requirements.

In addition, the low energy transport characteristics of the VIISa HCP low density ribbon beam have been optimized. Electro-static lenses in the beamline provide effective space-charge compensation and maintain excellent ion beam optical implant quality (ion beam/wafer incidence). The dual deceleration architecture enables ion beam transport of a low energy, normally high perveance beams at higher energy. The beam is decelerated prior to the second magnet and transported at 2-10x the final energy as a well neutralized low space-charge beam; it is then decelerated to the final energy.

PRODUCTIVITY

One of the major challenges of device scaling is the requirement to maintain device manufacturability. Specifically, productivity levels for the key driver high dose implants shown in Table 1 must remain at

acceptable levels in order to be production worthy and cost effective. VIISa HCP leverages the ribbon beam architecture to deliver these levels of productivity today and the extendibility to continue to meet these needs beyond 45nm. Significant improvements in beamline optics and transport efficiency have resulted in a >150% productivity improvement over four generations of Varian’s single wafer high current implanter (Figure 2). Based on the VIISa common endstation with up to 500 wph wafer handling capability [1], the VIISa HCP is the industry benchmark for productivity.

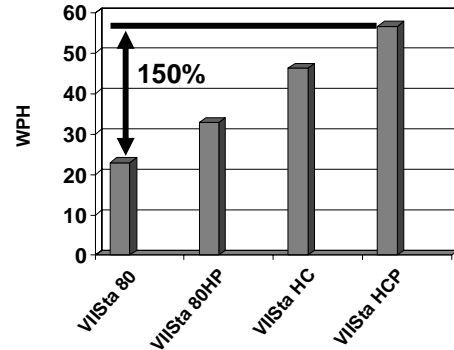


FIGURE 2. Productivity increase for four generations of VIISa single wafer high current tools. Aggregate throughput for an advanced logic recipe set.

Beam tuning performance is also key to productivity. The VIISa high current dual magnet architecture leverages the common Varian Control System (VCS) to deliver <4 minutes average tune time. Figure 3 shows tuning performance for typical applications.

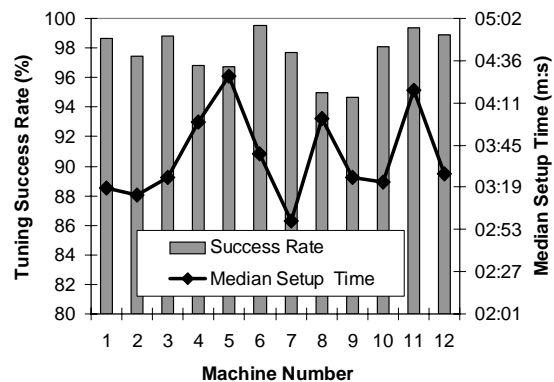


FIGURE 3. VIISa high current beam tuning success rate (%) and median beam setup time is shown for 5181 setups from 12 tools in production for a 30 day period. Overall success rate is 98% and median tune time for the entire population is 3:36.

PROCESS CONTROL

High current implant applications require control of implant dose, implant angle, particle contamination, metals, and wafer charging during implant. Detection of beam drop out during implant is a critical requirement for single wafer dose control. Beam instabilities must be detected and dose fill-in procedures designed for multiple, nested dose recovery events to assure dose integrity. Classic methods may not satisfy dose uniformity requirements when extreme beam drop-out occurs during a fill-in recovery. VIISa HCP incorporates advanced beam drop-out detection and dose fill-in capability that address all beam loss dose uniformity issues. Table 2 summarizes wafer test results from an extreme condition in which beam drop-out events are introduced in various degrees of severity on a sensitive monitor implant. Wafer #1 is the reference wafer with no glitches; wafer #2 has 2 glitches, with 1 introduced during normal recovery (requiring detection and fill-in recovery); wafers #3 - #5 have 3 to 5 glitches introduced to force execution of multiple fill-in areas during the implant. The beam drop-out detection and fill-in recovery results indicate identical process matching as the reference (no glitch wafer).

TABLE #2. Fill-in results - B 35keV 1.5E14 (7°/23°)

Wafer	Mean (ohm/sq)	% Std Dev
Wafer 1 Reference	512.8	0.62
Wafer 2: 2 glitches (1 fill-in)	513.5	0.69
Wafer 3: 3 glitches (2 fill-ins)	513	0.72
Wafer 4: 4 glitches (3 fill-ins)	513.1	0.74
Wafer 5: 5 glitches (4 fill-ins)	512.7	0.83

The angle control elements of VIISa HCP ensure the beam parallelism and beam steering are measured, controlled and interlocked prior to each implant. The ribbon beam provides a low divergence ion beam with typical measured values of $< 0.5^\circ$ [2]. The benefit of minimizing ion beam divergence for SDE implants in logic devices has been described in detail elsewhere [3]. The smaller beam divergence inherent in a ribbon beam enhances junction abruptness, minimizes overlap capacitance and results in faster devices. Furthermore, the VPS™ system on VIISa HCP ensures repeatable beam steering from wafer to wafer, minimizing skew of device parametrics such as I_{dsat} , I_{off} and V_t . Beam steering repeatability performance is $< 0.1^\circ$.

The main motivation to shift to single wafer high current systems from traditional batch tools was yield loss due to ballistic particles [4]. There are two main contributions to particles in high current ion implant: mechanical adders from wafer handling and beam-borne adders from the beamline. VIISa HCP relies on

a simple wafer scan technique that minimizes mechanical adders and the system uses a dual magnet beamline that isolates the wafer from sources of particles with a second magnet. The VIISa HCP has been recognized as one of the cleanest wafer processing systems in the fab. Particle performance is shown in Figure 4. The same design criteria also deliver metals performance to better than the specification of $2E10 \text{ cm}^{-2}$ for heavy metals and $2E11 \text{ cm}^{-2}$ for aluminum.

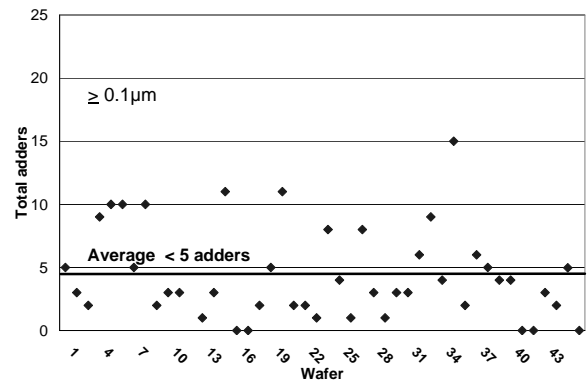


FIGURE 4. Particle adders on VIISa HCP in logic production. Particle size $\geq 0.1\mu\text{m}$ over approximately 6 weeks of data collection.

A new plasma flood gun technology [5] has been incorporated into VIISa HCP. This provides both improved charge control and reduced metals contamination. It is an RF-based plasma system that provides an abundant supply of low energy electrons for charge control and eliminates tungsten as a major source of metals contamination. Lifetime has also been increased to twice that of traditional plasma flood systems.

COST ADVANTAGE

During the development of new technology nodes, ion implant is among the biggest users of test wafers. Given the dramatic increase in multiple implants to control diffusion and damage profiles combined with the lack of good TCAD predictability, the number of full flow device wafers is rising. This increase in expensive full-flow wafers along with the pressure to improve R&D efficiency has led Varian to release a new feature on its high current implanters that reduces development wafer costs by up to 75%. vMask™ is a carbon implant proximity mask that enables up to four implant splits per wafer and has been integrated into Varian's common endstation. The vMask™ feature reduces the number of split lot wafers for development of a new process, limits the effect of split lot variability and shortens time to market for new device

designs. A typical split lot process result is shown in Figure 5.

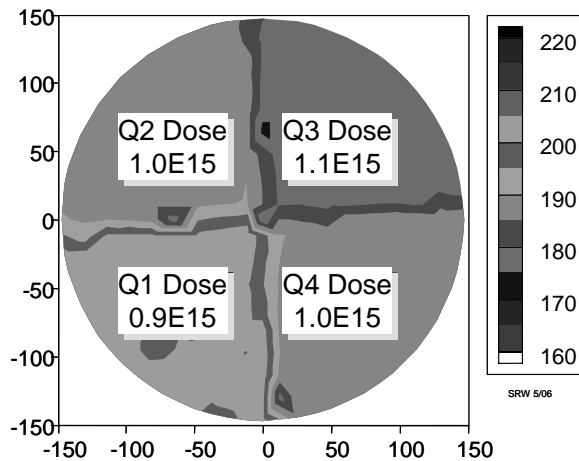


FIGURE 5. vMask process result for 5keV B implant with dose splits of $9E14 \text{ cm}^{-2}$ to $1.1E15 \text{ cm}^{-2}$.

CONCLUSION

VIISa HCP provides a significant increase in productivity for all high current implant applications. Design changes have been incorporated into this fourth generation system to increase beam current delivered to the wafer. Together with average demonstrated tune times of < 4 minutes and the VIISa common endstation for high speed wafer handling, the VIISa HCP continues the track record of highest overall productivity for logic, memory and foundry applications. Improvements have also been made to the process capability of the tool, particularly in the area of dose integrity, angle performance and charge control. Finally, vMask™ enables multiple implants per wafer, significantly reducing wafer usage and development costs.

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