

# Optimized Autotuning for Single Wafer High-Current and Medium-Current Implanters

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**Abstract.** As semiconductor lot sizes decrease the impact of autotuning performance on productivity is increased. The dual magnet architecture of the VIISta series of single wafer ion implanters provides unparalleled defect prevention and beam control while presenting unique challenges for autotuning. We present data from field installations of high-current and medium-current VIISta implanters demonstrating excellent autotuning performance in terms of tuning speed and success rate.

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## INTRODUCTION

Over the past several years semiconductor fabrication facilities have been transitioning from batch ion implanters to single wafer systems. In batch tools the beam enters the process chamber where wafers are rotated at high speed through the beam, while the rotation mechanism is translated back and forth through the beam. An advantage of the batch system is the ability to provide a uniform dopant dose by mechanical means. This eliminates the need to adjust the beam shape to provide a uniform implant. However, several disadvantages of this technique, including mechanical stress and ballistic particle damage of semiconductor device features, and cone angle effects have led to the increasing use of single wafer systems. [1]

Single wafer implanters can be divided into categories. Architectural categories include single magnet and dual magnet designs. Two-dimensional wafer scanning with a spot beam and one-dimensional wafer scanning with a ribbon beam are both employed.

In a two-dimensional wafer scan implanter, a stationary spot beam is incident on a wafer that is scanned both vertically and horizontally. The beam line design is simple, but the end station hardware is complex. Other disadvantages include an inherent compromise between throughput and dose uniformity for low dose implants as well as issues with wafer temperature control for high power beams [2].

Systems utilizing one-dimensional wafer scan (such as the VIISta platform) rely on a uniform beam in the horizontal direction and a wafer scan in the

vertical direction to achieve uniform implants. The VIISta 810 medium-current implanter achieves horizontal beam uniformity by electrostatically scanning a spot beam while the VIISta HC high-current implanter uses a parallel ribbon beam. Advantages of this technique include mechanical simplicity without the throughput and thermal constraints of the two-dimensional scan system. The beam tuning approach required to produce a uniform beam is technically more challenging, however.

The dual magnet architecture of the VIISta platform has several advantages. First, the second magnet isolates the wafer from particles generated by beamline elements such as the mass resolving slit, resulting in two to five times lower particles on the wafer [3]. Second, the closed loop Varian Positioning System (VPS™) delivers accurate, repeatable and interlocked incident angle control over the full range of angles needed for high current applications. The result is precise wafer-to-wafer and lot-to-lot beam steering. Finally, in the case of decel operation on the high-current VIISta HC, the second magnet also isolates neutrals generated by beam impact at the mass resolving slit which has line of sight to the wafer on single magnet systems. A consequence of the dual magnet architecture is the added beam tuning effort to optimize the second magnet to achieve angle control across the wafer.

In this paper we discuss the approach to beam tuning in the single-wafer, one-dimensional wafer scan, two-magnet architecture of the VIISta 810 and VIISta HC. We present recent tuning algorithm improvements and production field data demonstrating state of the art tuning performance.

## IMPACT OF TUNE TIME ON IMPLANT PRODUCTIVITY

Semiconductor manufacturers demand the highest possible productivity from ion implantation equipment in order to decrease their costs of manufacturing. In many cases the implant equipment customer requests an increase in ion beam current for his recipe set in order to improve run rate and therefore productivity. In some cases, however, decreasing the time to tune the beam can have an equal or larger impact on productivity.

Tables I and II show the effective productivity as a function of implant run rate and tune time for implant lot sizes of 200 and 20 wafers, respectively. Lot size is defined as the average number of wafers implanted before a new recipe setup is required, while run rate is defined as the number of wafers implanted per hour after the beam is setup. Base run rates of 100 and 400 wafers per hour were chosen to highlight typical applications for high current and medium current implanters, respectively.

In Table I the lot size is 200 wafers, typical for a logic manufacturer focusing on relatively few types of products. From this table, it is clear that tune time has little effect on productivity for large lot sizes. For each case the effective productivity only changes by a few percent as the tune time is decreased from 5 min to 2 min.

In Table II the lot size is 20 wafers, typical for a semiconductor foundry which runs many different products for a wide array of customers. From this table, it is clear that tune time has a large effect on productivity for small lot sizes. In each case, a reduction of tune time by 1 minute has an effect equal to or greater than a 10% increase in implant run rate.

**TABLE 1.** Effective implant productivity (wafers per hour) as a function of implant run rate and tune time for a lot size of 200 wafers (typical for logic application).

Run rate (wph)	Tune time (min)			
	2	3	4	5
100	98	98	97	96
110	108	107	106	105
400	375	364	353	343
440	410	396	384	372

**TABLE 2.** Effective implant productivity (wafers per hour) as a function of implant run rate and tune time for a lot size of 20 wafers (typical for foundry application).

Run rate (wph)	Tune time (min)			
	2	3	4	5
100	86	80	75	71
110	93	86	80	75
400	240	200	171	150
440	254	210	178	155

## BEAM TUNING IMPROVEMENTS

In order to produce superior implant beam control the VIISa family of single wafer dual magnet implanters uses more beam line elements compared to traditional single-magnet ion implant systems. In addition to adjusting the mass analysis magnet to achieve the highest beam current, the VIISa family leverages the second (beam precision) magnet to produce a uniform and parallel beam. Since the VIISa single wafer implanters do not rely on complicated two-dimensional mechanical wafer scan to achieve implant uniformity, the beam itself is instead made uniform across the wafer diameter. The methods of achieving parallel, uniform beams on the medium- and high-current VIISa implanters are described elsewhere [4-7].

Advanced tuning algorithms have been developed to simultaneously achieve beam angle and uniformity performance, fast tune times and high tuning success rate.

Several improvements have been made to the VIISa HC hardware to produce a beam which is more easily tuned [7]. These improvements include a triply indexed analyzer magnet with neutralizing gas bleed, two quadrupole lenses and an indirectly heated cathode ion source.

In addition to these hardware upgrades, numerous improvements have been made to the VIISa HC tuning algorithms to improve the tune time and success rate. Certain components require software control over electro-mechanical systems (e.g. the extraction optics manipulator). Improvements were made to speed up the interface between the software and the electro-mechanical components. A unique feature of the VIISa HC is the ability to measure and correct the steering angle of the beam relative to the wafer. The typical time to make this measurement was reduced from 28 seconds to 8 seconds with no loss in measurement accuracy. Many of these

algorithm improvements have a favorable impact on both tune time and tuning success rate.

The common strategy in designing the beam tuning algorithm on the VIISa tools relies on developing an intelligent sequence that executes only those tuning steps required to achieve the desired beam current and beam uniformity. In this way, the highest success rate with the fastest tune time can be achieved [8].

During the initial transition from one recipe to another, the settings of gas feed type, gas flow rate, extraction voltage, analyzer magnet setting, etc. must be changed from those of the previous recipe to those of the new recipe. The software was improved to maximize the number of these transitions occurring in parallel with one another to reduce tune time. However, several built-in recovery routines have also been added to prevent failures and instabilities during arc strike as well as ramping of power supplies.

The time spent optimizing source and beam-line parameters is minimized. Parameters are tuned only if the target beam current has not already been met or if their optimization affects beam uniformity. Furthermore, if the current parameter optimization does not yield a significant beam current improvement, the tuning sequence will quickly skip ahead and focus on the next parameter.

Uniformity is achieved by electrostatic scanning on the medium current tool and by magnetic steering of beamlets on the high current tool. In both cases, the fine tuning of a large number of electrostatic waveform or magnetic elements is required (an electrostatic waveform with up to 100 elements for the medium current and up to 35 magnetic dipoles for the high current tool). The uniformity routine relies on learned recipe values as a starting point. Furthermore, an approach similar to downhill simplex is employed to optimize all the parameters in parallel and converge to a solution in the shortest amount of time [9].

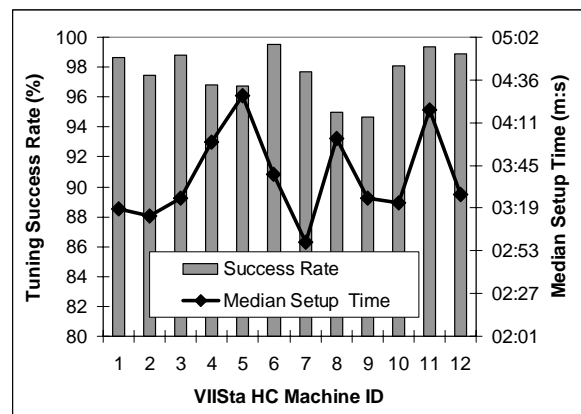
Finally, given the commonality of the Varian control system [10] and the significant overlap in hardware components between product-lines, improvements in accuracy and speed of controlling, measuring, and tuning common hardware can be propagated across all products. In particular, the lessons learned in tuning components such as the IHC source, the extraction manipulators, the analyzer and corrector magnets [11], are utilized wherever possible on both medium and high current. Furthermore, the common end station allows the benefits of faster and better beam metrology to be realized on all VIISa products.

## BEAM TUNING PERFORMANCE

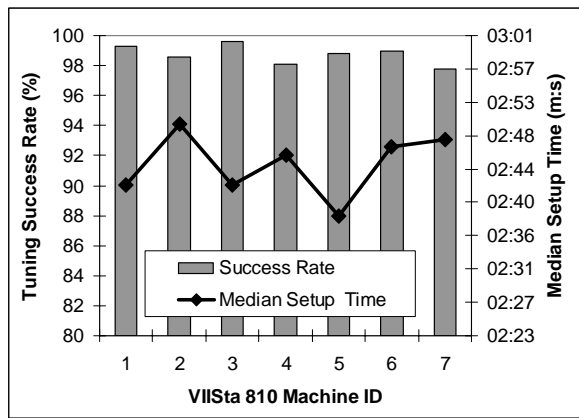
Figs. 1 and 2 show beam tuning performance for field installations of VIISa HC and VIISa 810HP. This data demonstrates excellent tuning performance for single-wafer, high-current and medium-current ion implanters. The data shown in Fig. 1 for the VIISa HC is a compilation of 5181 setups from 12 tools over a 30 day period at one customer site. The median tune time is 3:36 while the overall success rate is 98%. The data shown in Fig. 2 for the VIISa 810HP is a compilation of 19728 setups from 7 tools over a 30 day period at one customer site. The median tune time is 2:45 while the overall success rate is 99%.

The average number of setups per tool per month is 2818 for the VIISa 810HP and 431 for the VIISa HC. The VIISa 810HP averages more than six times the number of setups per machine than the VIISa HC. This large discrepancy is due to the fact that the medium-current tools are typically running low dose ( $<1e14$  atoms/cm<sup>2</sup>) implants at or near the mechanical throughput limit (500wph) while the high-current tools run mostly high dose implants ( $>1e14$  atoms/cm<sup>2</sup>) at lower average throughput. This difference leads to nearly 4 setups per hour on the medium-current tools and roughly 1 setup every 2 hours on the high-current tools.

While achieving the optimum tune time is important for high-current tools, it is absolutely essential for medium current tools. A savings of 1 minute of setup time over each of the 2181 medium current setups results in a savings of 47 hours (nearly 2 days) of productive implant time per machine per month.



**FIGURE 1.** VIISa HC beam setup performance. Tuning success rate (%) and median beam setup time is shown for a total of 5181 setups from 12 tools in production for a 30 day period. The number of setups per tool ranges from 240 to 631 which results in varied weighting of each tool's performance in the overall results. Overall success rate is 98% and median tune time for the entire population is 3:36.



**FIGURE 2.** VIISta 810HP beam setup performance. Tuning success rate (%) and median beam setup time is shown for a total of 19,728 setups from 7 tools in production for a 30 day period. The number of setups per tool ranges from 2255 to 3068 which results in varied weighting of each tool's performance in the overall results. Overall success rate is 99% and median tune time for the entire population is 2:45.

## CONCLUSIONS

Single wafer, dual magnet ion implantation systems with one dimensional wafer scan have demonstrated excellent performance for dose control, angle control, and prevention of device particle defects. Improvements in beam line hardware and tuning algorithms have resulted in excellent tuning performance. Field data from production implanters show 99% success rate and median tune time of 2 min. 45 sec. for the VIISta 810 and 98% success rate with a median tune time of 3 min. 36 sec. for the VIISta HC.

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