Damage Engineering on Purion XE^{TM} High Energy Ion Implanter

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***Abstract*— Many IC and CIS manufacturers still rely heavily on batch high energy ion implanters such as the Axcelis HE3 and Paradigm XE systems. Angle control continues to become increasingly important with the scaling of devices and the increasing use of channeled implants to reduce the number of implant steps needed to produce a box-like dopant profile. The use of channeled implants limits the use of batch ion implanters for these applications due to the cone angle effect. The introduction of serial high energy ion implanters to replace the batch implanters has exposed subtle differences in damage characteristics related to the differences in tool architecture. Investigation into second order differences in the damage characteristics of the single wafer and batch implanters have resulted in the development of a new system for modifying the electrostatic scanning of the ion beam on the Purion XE with implications for improvement in damage reduction, low dose stability and utilization of the system's mechanical throughput limit.**

Keywords—ion beam scanning, implant damage, new hardware introduction

I. Introduction

The Purion XE is a high energy ion implanter that uses a Purion End Station capable of over 500 wafers per hour and an RF linac which has been evolved by Axcelis since the introduction of the NV1000 in 1986 [1]. The design of the Purion XE End Station includes a pair of faradays upstream of the wafer in the which are used for beam current monitoring during implant; the width of the scanned ion beam is optimized to fully illuminate these two faradays while providing the highest beam-on-wafer duty cycle; further increases of up to 16% in throughput have been reported from further optimization of the waveform for ion beam scanning [2].

Historically, the most common high energy tools-of-record in volume manufacturing have been Axcelis batch high energy implanters such as the HE3. Device scaling and the desire to utilize channeled implants to maximize productivity have initiated a transition toward serial high energy ion implanters such as the Purion XE which has achieved a total angle variation of 0.04° 1σ [3].

In-line matching to a tool-of-record is an important step when introducing a new implanter to a fab. During the installation of multiple Purion XE implanters at several high volume manufacturing sites several subtle differences to the batch implanter tools of record were notices including higher ThermaWave mean values on the Purion XE for matched Rs. One customer also observed higher ThermaWave variability on the serial high energy implanter than the batch implanter when the measurement was taken on a TP630xp using a Stationary Decay Compensation method. The higher variability was not observed when the measurement was taken using the Standard Decay Compensation method on the TP630xp or when using a TP680 with Spatial Averaging.

A controlled experiment to investigate this behavior has shown that the accumulated implant damage, as measured by ThermaWave, is sensitive not only to dose, energy, angle, beam current and temperature but also on the beam-on-wafer duty cycle derived from the implanter architecture. Axcelis has developed a system for modifying the electrostatic scan waveform to optimize the beam-on-wafer duty cycle for damage mitigation.

II. Observation of Implanter Archetecture Differences

Fig. 1 shows the in-line ThermaWave results from two production sites for a selection of high energy implant conditions. The general trend towards higher implant damage on the wafers implanted on the serial implanter than on the batch implanter is clear regardless of the selection of ThermaProbe tool.

HE Condition	Production ThermaWave Comparison Serial/Batch			
	Probe	***Tool***	***TW Mean***	***Location***
P+1200k	TP680	Serial	6736.7	Site#1
P+1200k	TP680	Batch	6456.0	Site#1
B+460k	TP680	Serial	12505.0	Site#1
B+460k	TP680	Batch	12305.0	Site#1
P+1000k	TP630xp	Serial	1234.9	Site#2
P+1000k	TP630xp	Batch	1225.4	Site#2

Fig. 1. Comparison of ThermaWave mean value for serial and batch implanters with matched dose measured on two ThermaProbe tools at two manufacuring sites.

An issue was reported from Site #2 that the ThermaWave mean and wafer-to-wafer repeatability were both higher on the serial tool than on the batch tool. A bare wafer comparison was performed on the two tools to characterize the differences between the systems. Fig. 2 shows a dramatically lower wafer-to-wafer repeatability for the serial implanter in the bare wafer test than was observed from the in-line monitor data.

Measurement Probe	**1 σ Repeatability Comparison**			
	Implanter	***Wafer Type***	***Decay Method***	***1σ Repeatability***
TP630xp	Batch	Production	Stationary	18.0 (1.5%)
TP630xp	Serial	Production	Stationary	30.2 (2.4%)
TP630xp	Serial	Bare	Standard	8.5 (0.6%)

Fig. 2. Wafer-to-wafer repeatability results on serial and batch implanters. Despite the introcuction of wafer-to-wafer variability in slice angle for this channeling sensitive condition the measurement repeatability is similar to the short to mid term gague repeatability reported by Kamenitsta et al. for ThermaWave measurements [4].

The root cause of the difference between the in line measurement and the bare silicon was found by a trivial inspection of the ThermaWave applications notes. The difference lies in the selection of decay compensation method. Standard Decay Compensation measures a TW_0 and $TW\infty$ value to best estimate the total damage relaxation that the wafer will experience; the Stationary Decay Compensation method measures only $TW\infty$ and uses an estimate for TW_0 [5].

The selection of decay compensation method cannot by itself explain the difference in measurement repeatability observed between the serial and batch systems because the same recipe is used on the TP630xp to measure wafers implanted on both systems. To explore the anomaly, a set of wafers was implanted on the batch implanter and another set was implanted on the serial implanter. Ten measurements of these wafers were completed using Stationary Decay Compensation and ten measurements were completed with Standard Decay compensation. To avoid any influence on the data from repeated measurement of the same spot, the theta offset of the measurement was incremented by 5° for each subsequent measurement. The order of the Standard and Stationary measurements on these wafers were randomized. Fig.3 shows that the serial implant was more repeatable with the Standard measurement than was the batch implant for the same TP630 conditions. When the same wafers were measured with Stationary Decay compensation, the measurement repeatability was more significantly degraded for the serial samples than the batch samples.

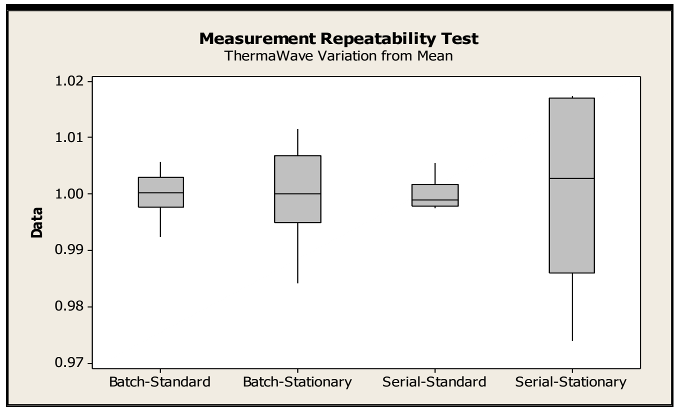

Fig. 3. Measurement repeatability is shown for the batch and serially implanted wafers, each measured multiple times with two different decay compensation methods. The critical observation from this data is the more dramatic increase in repeatability on the serial implanter than is observed on the batch implanter for nominally the same implant conditions.

The implant conditions that were matched for this test were the species, energy, implant angle, platen temperature and spot beam current. Furthermore the beamline up to and including the linear accelerator is near identical on the batch and serial implanters. The most significant architectural difference between the two systems is the beam-on-wafer duty cycle. Fig.4 shows how the duty cycle is defined by the batch implanter geometry.

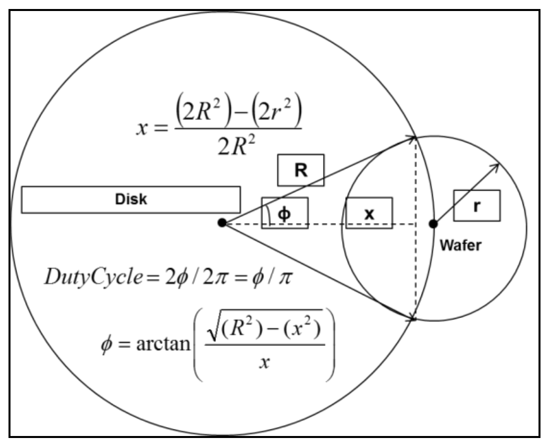

Fig. 4. Geometric definition of beam-on-wafer duty cycle at wafer center for batch implanter. For the Paradigm XE disk with a 300mm wafer the beam-on-wafer duty cycle at wafer center is ~7.3%.

The beam-on-wafer duty cycle of the Purion XE is defined by the width that the ion beam is scanned to fully illuminate two faraday cups which are used for the beam current measurement during implant. These cups are positioned in the Corrector Magnet, so that chamber pressure variation from Photoresist outgassing is negligible for most implant conditions [6] and to use the Corrector Magnet field for suppression. Fig. 5 shows the placement of these faradays.

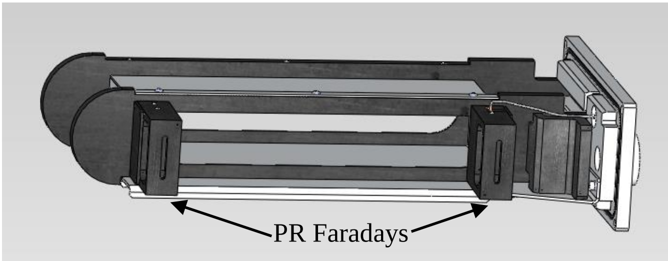

Fig. 5. Placement of the PR Faradays in the beam tunnel for the measurement of the beam current durring implant. The placement of these faradays in the Corrector Magnet allows a simple compact design due to the high magnetic field; this optimizes the width which the beam must be scanned to provide a high beam-on-wafer duty cycle and thus higher productivity.

When the beam is scanned wide enough to fully illuminate the PR faradays approximately 70% of the scanned beam is implanted into the 300mm wafer when the wafer is centered vertically on the beam. Based on the geometry of the two tools, the serial ion implanter has roughly 9.6 times higher beam-on-wafer duty cycle than the batch implanter. Axcelis introduced a system to adjust the Purion XE duty cycle by modification to the scanned waveform [7]. This system was used to determine if the differences in duty cycle could explain the difference in Stationary Decay ThermaWave variation between the two platforms.

Fig. 6 shows a schematic of how the Purion XE uses a waveform generator to control two scan plates which spread the ion beam uniformly across the wafer and into the PR cups. In standard operation a modified 1000Hz triangular waveform is used to achieve a uniform flux profile in the plane of the wafer.

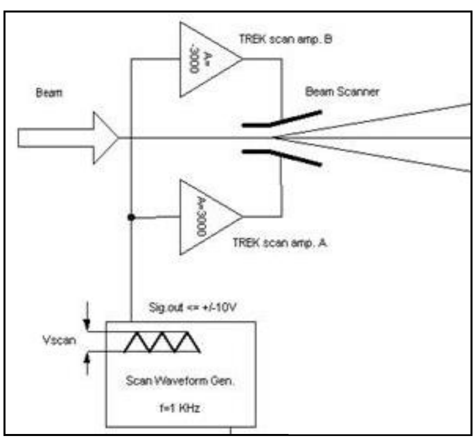

Fig. 6. A pair of TREK scan amps power the plates in a beam scanner which is used to spread the spot beam uniformly across the wafer. The Scan Waveform Generator controls the output of the scan amps. The duty cycle modification system adjusts the scan waveform to mimic the batch implanter duty cycle.

When the duty cycle modification system is employed to mimic the behavior of the batch implanter a hold is placed at the top and bottom of scan to simulate the time that the disk must rotate to bring the wafer back under the ion beam. The system allows for modification of the velocity of the ion beam across the wafer in the fast-scan direction and the length of the pause at the each end of the electrostatic scan. In this experiment only the pause at the end of scan was modified. Fig. 7 is an illustration of the scan waveform modification used in this experiment.

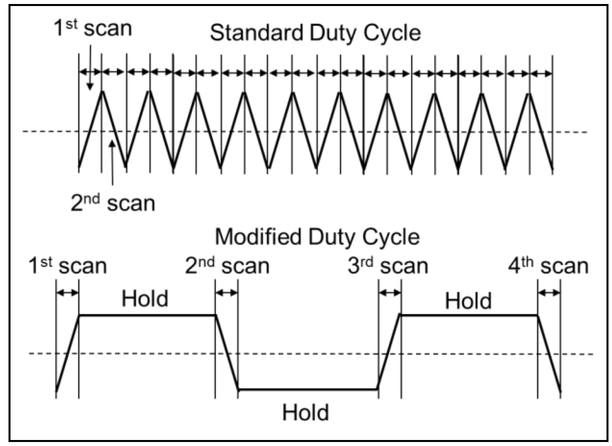

Fig. 7. Schematic illustrating the basic concept behind the modification of the standard scan waveform to the low duty cycle waveform. The system can also adjust the slope during each scan which represents the rate at which the beam centroid travels in the horizontal direction however this parameter was not adjusted in this experiment.

III. Experiment

The duty cycle on the Purion XE was reduced by 70% from the standard triangular waveform and the ThermaWave measurement repeatability test with stationary decay compensation was repeated to compare the batch implanter to the serial implanter with standard and reduced duty cycle. Fig. 8 shows the results of this experiment. A dramatic improvement in the measurement repeatability can be observed for the serial implanter when the duty cycle was reduced.

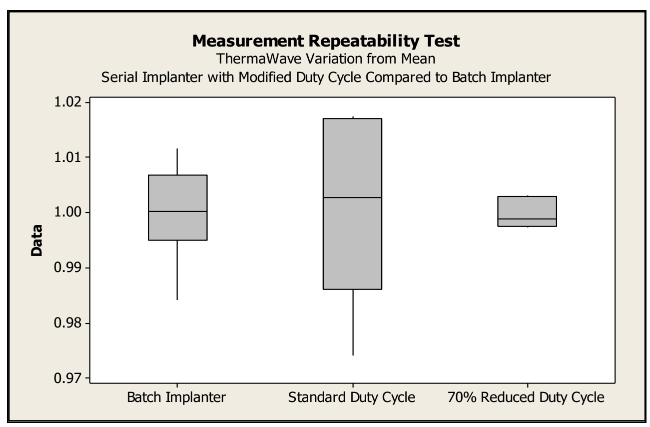

Fig. 8. With the 70% reduction in beam-on-wafer duty cycle at wafer center the measurement repeatability of the wafers implanted on the serial implanter is dramatically reduced.

To understand the underlying mechanism behind the improvement in the measurement by the duty cycle reduction five wafers were implanted on the Purion XE with standard duty cycle and 5 wafers were implanted with the 70% reduction in duty cycle. For these 10 wafers, the ThermaWave value was monitored with the decay compensation feature completely disabled to measure only the raw ThemaWave signal as it decayed as a function of time between implant and measurement. Fig. 9 shows that the reduction in duty cycle reduces both the raw ThermaWave mean and the rate at which the ThermaWave mean decays.

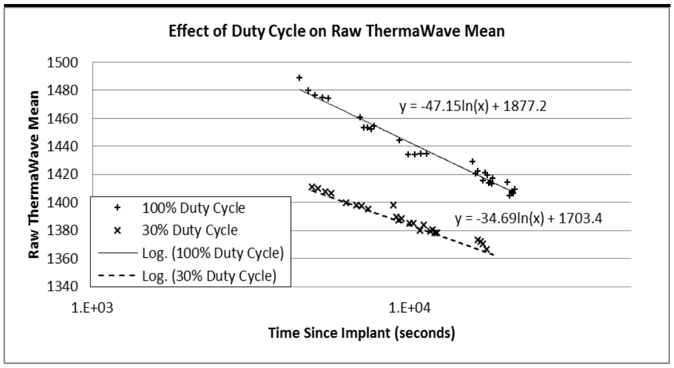

Fig. 9. Comparison of raw ThermaWave mean between wafers implanted with standard and 70% reduced duty cycles on Purion XE. An increase in both mean and rate of decay can be observed when using the higher duty cycle.

The lack of a TW_0 measurement when using stationary decay compensation may make the measurement more sensitive to differences in the rate of ThermaWave decay. In the case described above no Rs, SIMS or device parameter difference was observed between the batch or serial implanters so the implication of this experiment was a simple observation of the need for an adjustment of SPC target and limits. While the mechanism by which the level of implant damage prior to anneal is not yet well understood, CMOS Image Sensor manufacturers may be able to yield benefits in terms of dark current and or white pixel defects by more closely mimicking the damage characteristics of a batch system on their single wafer implanters [8]. Fig. 10 shows the superior within-wafer angle control on the Purion XE which cannot currently be matched on a batch implanter even with a 1.5° angle disk.

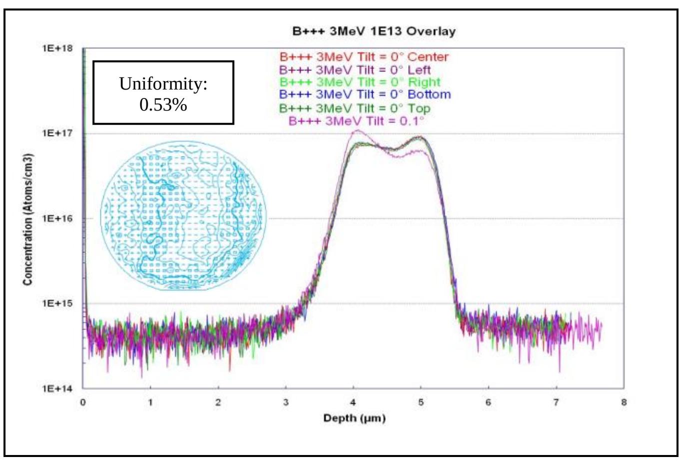

Fig. 10. An advantage of the use of a single wafer high energy implanter with reduced duty cycle over a batch high energy implanter is the complete elimination of the cone angle effect for superior within-wafer angle uniformity.

The duty cycle modification system offers the potential for benefits in the area of single wafer implant damage reduction without the added complexity or risk of thermal non-uniformity from the use of a high temperature platen. Due to the common platform design on the Purion Products the duty cycle modification capability which has been developed on the Purion XE can also be extended to the Purion M to cover the medium current application space.

IV. Conclusions

A new system for electrostatic modification of the beam on wafer duty cycle has been introduced on the Purion XE. This system can allow the Purion XE to match the damage characteristics of a batch implanter without the detrimental cone-angle effect. This system can be used to reduce implant damage without the hardware complexity of a high temperature platen.

The system can also enable more repeatable use of the Purion XE's >500 wafer per hour mechanical throughput limit. The beam-on-wafer duty cycle can be reduced if AutoTune prepares a beam with a current too high for the mechanical limit of the slow scan arm. By modifying the duty cycle to achieve this no additional time consuming beam tuning loops need to be invoked. In low dose operation this relaxes the stringent requirements for low extraction which could result in an unstable beam or implant holds.

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