Productivity Improvements Utilizing OptiScan, Interlaced Beam Scanning, for Axcelis Purion XE Implanter

S. Satoh, R. Coolbaugh, C. Geary and J. Deluca
Axcelis Technologies
108 Cherry Hill Drive, Beverly, Massachusetts, USA
shu.satoh@axcelis.com

***Abstract*— The Axcelis Purion XE is a RF linac based single wafer, hybrid scan, high energy ion implanter. The Purion XE provides customers the highest mechanical throughput with best in class beam currents. It is also equipped with features to fully utilize its high beam current capability such as IntelliScan. IntelliScan maintains precise dose and uniformity even under conditions of extreme photoresist outgassing due to high beam power. To further enhance the Purion XE's industry leading productivity, OptiScan, a system for enhancing the beam utilization, has been developed.**

Keywords—Beam utilization; beam scan; dose control

I. Beam Utilization in Modern Implanters

Among many semiconductor manufacturing processes, ion implantation seems to be the only process which does not benefit from the round shape of the wafers. For many other processes, like annealing, etching, CVD, spin coating, CMP in device manufacturing and lapping and polishing in wafer fabrication, it must be a real blessing that wafers are round.

The difference comes from ion implantation's highly directional interaction with the wafer, which requires not only dose but the direction of the beam to be uniform across the wafer. Because of these requirements, ion implantation has employed some form of scanning mechanism from its infancy [1].

Purion XE, the Axcelis high energy single wafer ion implanter [2] on Axcelis' Purion platform, employs a hybrid scan system, the prevailing scanning system among the modern single wafer implanters. In the hybrid scan system, the ion beam is scanned in one direction at a high frequency and the wafer is moved in the orthogonal direction at a much slower velocity.

Although not essential to the hybrid scan system, the addition of one or two narrow faraday cups, usually called side cups, near the edges of scanned ion beam has given enormous advantages in the single wafer ion implantation and it is now considered as an indispensable feature of the hybrid scan system [3]. The constant monitoring of ion beam with the side cups enables the closed loop dose control system to adjust the wafer scan speed to maintain a superb dose uniformity even under fluctuating or drifting beam current. During beam glitches, short disappearance of ion beam stream are monitored and uniformity is maintained utilizing a function called glitch repainting. On Purion XE, there are two side cups on both sides of the scanned beam and they are called PR cups for its special function during photoresist outgassing and because they are strategically placed far upstream in the final pass of beam as shown in Fig. 1 [3].

The scan pattern of the hybrid scan is naturally a rectangle area because of its two independent scans along orthogonal directions. Combined with the circular shape of the wafer, the hybrid scan, even its primitive form without side cups, is destined to waste some of ion beam outside of the wafer, at least, 21 % (=1- π/4). By definition the beam utilization factor is the fraction of ion beam that lands on a wafer; the beam utilization in this ideal case is 79%. With a finite size beam, the requirement of over-scanning (i.e., full ion beam to go over the wafer edges before turning-around), would make the scan widths wider in either direction and make the beam utilization even poorer, for example, only 65% with 30mm round beam.

With the addition of two side cups on both sides of the scanned beam, scanned width has to be widened even further for fully exposure the ion beam to the two cups, typically

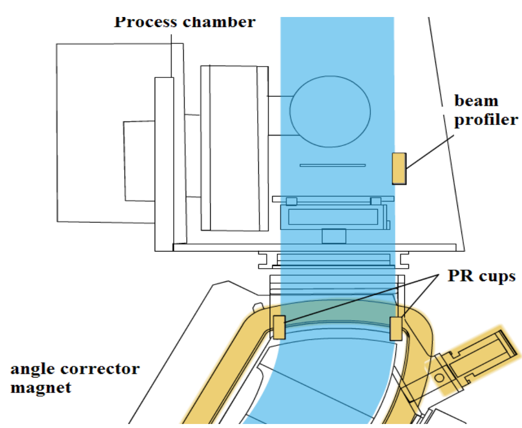

Fig. 1. Placement of PR cups, side cups on Purion XE

>400mm, and the beam utilization falls below 50% (i.e., >50% of ion beam does not contribute to the doping process at all). Not only does the low beam utilization adversely influence the productivity of implanter, but also affects the PM interval and the source life. This is the price we pay for those great benefits of the close loop dose control system with the side cups.

II. OPTISCAN, BEAM UTILIZATION ENHANCEMENT SCHEME ON PURION XE

Compared to flashy marketing fanfares often given to meager increase of beam currents, improvements in beam utilization factor on the modern hybrid implanter have stayed out of the spot light. The main reason for the obscurity must be the technical difficulty, real or perceived, without compromising the ever-tightening requirements for the precision and stability of the close loop dose control system. For example, one system for the beam utilization enhancement uses a semicircular scan pattern [5] on an implanter with one side cup, in which a scan width on the side in which the cup resides is kept wide for full cup coverage to keep the dose control system completely unaffected, only the scan widths on the opposite side of the wafer were trimmed to loosely follow the semicircular wafer outline. Since Purion XE has two side cups on both ends of the beam scan, this approach could not be employed.

OptiScan on Purion XE is an attempt to answer the interesting puzzle presented by the hybrid scan with two side cups how to increase the beam utilization while keeping the closed-loop dose system with the side cups. To answer the puzzle, in OptiScan, a division of labor is introduced in beam scans, namely, wide scans for beam current monitoring on side cups and narrow scans purely for doping the wafer. The scan width for the narrow scan can now be set solely for uniform doping of a wafer without worrying about the side cups and are considerably smaller than the width of the wide scan. The two kinds of beam scans, narrow and wide, are interlaced with a fixed ratio. The pictures, Fig. 2, shows an example of the interlaced scans in OptiScan, two narrow scans for every wide scan in an exaggerated fashion.

The increase of beam utilization in the interlaced beam scan depends on the interlace ratio, the number of narrow scans per every wider scan, and scan width ratio, the width of narrow scan relative to that of wide scan. The higher the interlace ratio and lower the scan width ratio, the higher the beam utilization will be. If N is the interlace ratio and R is the scan width ratio the change in beam utilization relative to non-interlaced scan (all beam scans are wide scans) is represented as:

$$\text{Beam utilization improvement} = (1 + N) / (1 + NR) \qquad (1)$$

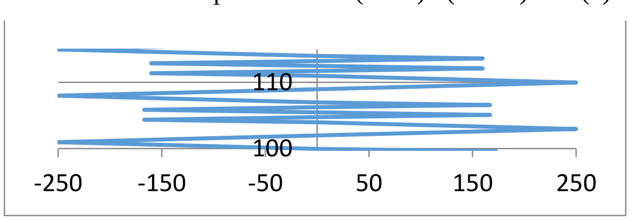

Fig. 2. Interlaced beam scans of OptiScan, exaggerated.

For N=3, three narrow scans per every wide scan, with 80% of scan width on narrow scans (R=0.8), the utilization goes up as much as by 17.6%. Naturally, this formula does predict the ultimate 1/R improvement for N= ∞ (i.e., if all the beam scans are narrow scans of 80% wide), where the improvement will be 25% for R=0.8.

III. MAINTAIN DOSIMETRY INTEGRITY.

One very important, although easily missed, detail exists on the interlaced scan scheme. To meet today's rigorous dose control requirements, the beam current monitored on the side cups has to be a very reliable and stable representation of actual beam current on the wafer. The ratio between the side cup current and a current on wafer is called "cup ratio" and every precaution is made to obtain a stable and reliable cup ratio calibration value and to maintain the value during the entire implantation duration.

The problem of the interlacing scan is the risk of producing an unstable cup ratio value because of the partial beam exposure to the side cups on narrow scans. Although narrow scan width is set solely for wafer coverage, some skirt part of ion beam is expected to illuminate the side cups. The side cup current on narrow scans will then not be zero as illustrated in Fig. 3. Due to the sharp slope, the skirt part of ion beam is expected to be highly vulnerable to various small changes and drift of machine conditions and too unreliable for precise dose control. That is the very reason why enough amount of "overscan" over a wafer's edge has been considered crucial in maintaining good uniformity and the reason why the beam scan width is so large on side cup based ion implanters: to ensure the whole ion beam, and not just a skirt part, is counted by the side cups by overscanning the beam well passed the side cups thus ensuring a reliable cup ratio.

To avoid this possible contamination to the cup ratio by the skirt of narrow scans, OptiScan employs a side cup current gating scheme synchronized with wide/narrow scans. Fig. 4 shows a typical OptiScan scan waveform for the 2:1 interlaced scans along with the synchronized gate signal (amplitude ratio are exaggerated for clarity). During the wide scan, the side cup current gate is opened and the side cup current is allowed to be transmitted to a current integrator for the dose control. During narrow scans, the gate is closed and the current path to the integrator is cutoff and the side cup is shorted to ground.

The gate signal is generated on the same scan waveform generator which generates the scan waveform, once the interlace ratio, N, and scan width ratio, R, are decided.

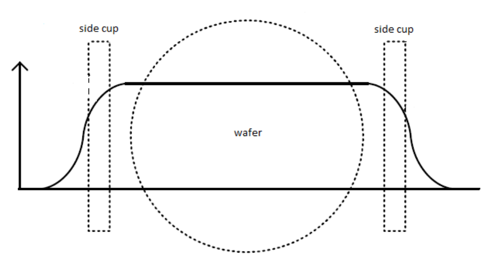

Fig. 3. Side cup current on narrow scans.

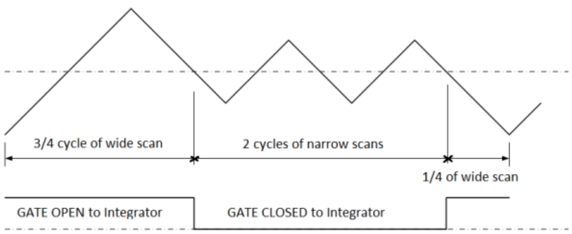

Fig. 4. OptiScan scan waveform with Gate signal.

RESULTS AND DISCUSSION

Improvement in beam utilization with OptiScan appears as an increase of scanned beam current density for a given unscanned beam current. Fig.5 shows the measured increases in the scanned beam current density at several scan width ratio (R in equation 1) under 2:1 interlace ratio (N=2). Scan width ratio=1 corresponds to a case when the narrow scan width = wide scan width and naturally there is no gain in the scanned beam current over non-interlaced scans. The scanned beam current increases as the narrow scan width is decreased (R<1) and beam utilization factor goes up. The solid line in the graph is the prediction by the equation (1) in the previous page. Since the scheme is based on purely geometrical manipulations, the good agreement is no surprise.

Translating the gain in the scanned beam current into the throughput numbers involves many other parameters, such as a fixed wafer exchange time, and only on an infinitely long implant a gain in beam current directly translates into a gain in throughput. In Fig. 6, an exemplary throughput gain with OptiScan using R=0.8 and N=2, are shown as a function of implant dose and beam current. The curves approach asymptotically to the predicted gain in beam current density on higher dose implants. Because the wafer exchange time is more or less fixed, the gain in the throughput is higher at a lower beam current for a given dose because of a longer beam time. Again, the values in the figure are strongly influenced by many other factors besides pure beam current and should be taken as exemplary.

The two parameters for the OptiScan, the interlace ratio N and the scan width ratio R, have practical limits. The limit on the scan width ratio R is rather straightforward, that is, the narrow scan width has to be at least wide enough for uniform coverage of the wafer. The limit on the interlace ratio N is more subtle. Since the interlacing reduced the effective scan frequency on the side cups by 1/N, not only the side cup current is reduced by 1/N, but the time interval between the beam exposures on the side cups is multiplied by N. The system of the glitch detection with the side cups has an inherent uncertainty window. The size of which is given by a wafer scan velocity divided by the beam scan frequency and the window increases with the interlace ratio of N.

Fig. 7 shows two Rs vertical diameter scans from glitch repainted wafers, one without OptiScan and the other with OptiScan of N=3. These line scans demonstrate that glitch repainting worked well at N=3 with glitch repainting maintaining <0.3% Rs non-uniformity on both wafers. As the equation (1) suggests, the gain in the beam utilization saturates with larger interlace ratio N and there is not much reason to go above N=3.

OptiScan, a beam utilization improving scheme for Axcelis' Purion XE high energy implanter, has proven that the scanned beam current can be increased >15% simply by engineering a beam scanning scheme, without raising the total beam current. With the help of the synchronized side cup current gating scheme, dose integrity has been proven to be maintained with OptiScan.

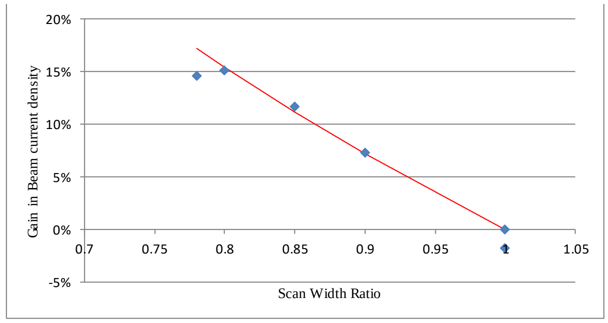

Fig. 5. Measured gain in scanned beam current density with OptiScan as a function of narrow scan width (R). Interlace ratio =2.

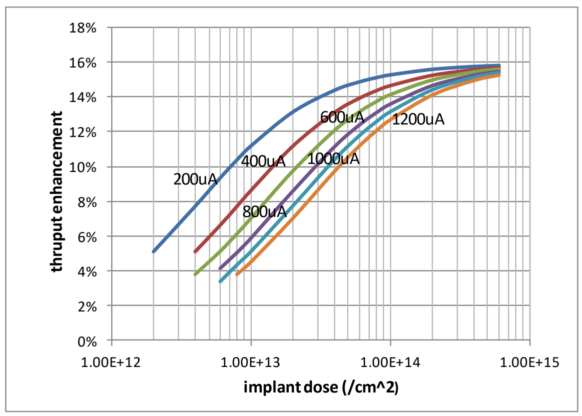

Fig. 6. An example throughput gain with OptiScan as a function of implant dose and beam current.

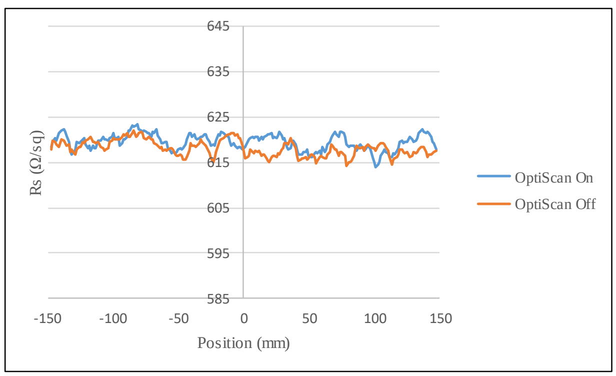

Fig.7. Vertical Rs line scans of glitch repainted wafers showing successful glitch repaintings with N=3 OptiScan.

REFERENCES

[1] For example, R. G. Wilson and G. R. Brewer, "Ion Beams, with applications to ion implantation" John Wiley & Sons, 1973

[2] S. Satoh, J. Ferrara, E. Bell, S. Patel and M. Sieradzki, Proc. 17th Int. Conf. in Ion Implantation Technology, AIP 1066, p. 273-276 (2008).

[3] D.W. Berrian, R.E.Kaim and J.W.Vanderpot, Proc. 7th Int. Conf. on Implantation Technology, Kyoto, Japan, 1988, Nucl. Instr. And Meth. B37/38 (1989) 518

[4] S. Satoh and J. David, Proc. 19th Int. Conf. in Ion Implantation Technology, AIP 1496, p.304 (2012)

[5] S. Ninomiya et al. Proc. 18th Int. Conf. in Ion Implantation Technology, AIP 1321, p.341 (2010)