# Angle Performance on Optima XE

Jonathan David and Shu Satoh

*Axcelis Technologies, Inc., 108 Cherry Hill Dr, Beverly, MA 01915 USA*

**Abstract.** Angle control on high energy implanters is important due to shrinking device dimensions, and sensitivity to channeling at high beam energies. On Optima XE, beam-to-wafer angles are controlled in both the horizontal and vertical directions. In the horizontal direction, the beam angle is measured through a series of narrow slits, and any angle adjustment is made by steering the beam with the corrector magnet. In the vertical direction, the beam angle is measured through a high aspect ratio mask, and any angle adjustment is made by slightly tilting the wafer platen during implant.

Using a sensitive channeling condition, we were able to quantify the angle repeatability of Optima XE. By quantifying the sheet resistance sensitivity to both horizontal and vertical angle variation, the total angle variation was calculated as 0.04° (1σ). Implants were run over a five week period, with all of the wafers selected from a single boule, in order to control for any crystal cut variation.

**Keywords:** Implant Angle Control
**PACS:** 85.40.Ry, 41.85.Qg

## INTRODUCTION

As device dimensions are shrinking, controlling beam-to-wafer angles is becoming more important. On high energy implanters there is an additional concern because of the high implant angle sensitivity of channeled implants. Previous work has shown the impact of beam angles on $V_t$ variation on 65nm and 45nm devices [1]. The Optima XE measures and corrects for beam angles in both the horizontal and vertical directions; this paper will describe how, using a sensitive channeling condition, the beam angle was calibrated to sheet resistance measurements, and the total angle repeatability was measured.

## HARDWARE

The Optima XE beamline and angle control system have been described in previous presentations [2, 3]. In summary, the Optima XE produces a horizontal, electrostatically scanned beam that is implanted into a mechanically scanned wafer in the vertical direction. Before reaching the wafer, the scanned beam passes through a corrector magnet which parallelizes the beam. Angles are measured in the horizontal direction by moving a profiler behind a seven slit mask, which measures each individual beam angle across the wafer, shown in Figure 1. The horizontal beam angle is then adjusted using the corrector magnet, ensuring that the beam is zeroed in the horizontal direction.

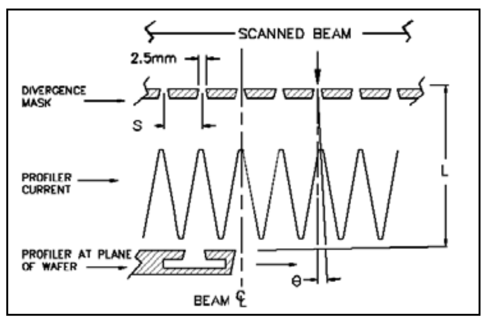


**FIGURE 1.** Schematic of the horizontal beam angle measurement using the seven slit mask and profiler.

The vertical angle is measured using the VBA (Vertical Beam Angle) Faraday shown in Figure 2. The VBA is a Faraday shadowed by a high aspect ratio mask which rotates vertically in front of the beam. This gives a precise measurement of the beam's vertical angle, which is then used to correct the mechanical tilt angle of the wafer during implant.

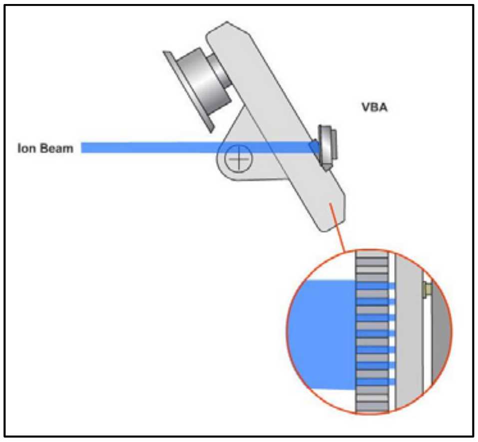


**FIGURE 2.** Diagram of the VBA measurement which uses a high aspect ratio mask in front of the Faraday.

# EXPERIMENT SETUP

Initially, Optima XE needed to be calibrated in both the horizontal and vertical directions. Using a P+ 500 keV, $5 \times 10^{13}$/cm2 implant, a known channeling sensitive condition [4, 5], V-curves were run about the <112> axial channel at tilt/twist angles of 35.26°/0°. In the vertical direction, adjusting the mechanical tilt angle produced the necessary variation. Horizontally, it was necessary to manually adjust the corrector magnet steering in order to intentionally create a horizontal angle offset. Figures 3 and 4 show the Rs results of both tests, validating the angle calibration.

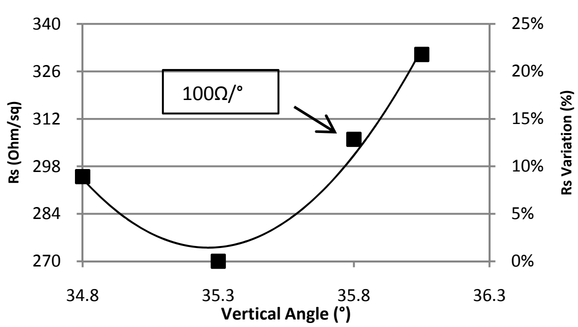


**FIGURE 3.** Average Rs as a function of vertical angle using P+ 500keV, $5 \times 10^{13}/cm^2$ near the <112> axial channel. The Rs sensitivity to angle is greatest at 35.8°.

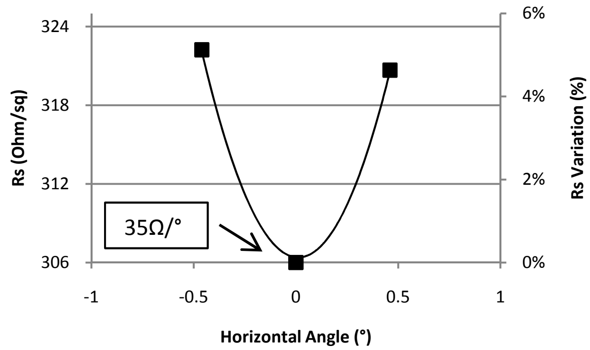


**FIGURE 4.** Average Rs as a function of horizontal angle using P+ 500keV $5 \times 10^{13}/cm^2$ near the <112> axial channel. At a tilt of 35.8°, the Rs sensitivity to horizontal angle is 35 ohm/sq per degree.

In addition to aligning the tool, the V-curves show the angle sensitivities for different tilt offsets. The most sensitive angle is at 35.8° where the Rs-to-angle sensitivity is 100 ohm/sq. per degree. Horizontally, the angle sensitivity is 35 ohm/sq per degree at that condition.

# RESULTS

Due to its increased sensitivity, the 35.8°/0° angle was chosen for the angle repeatability experiment on Optima XE. Twenty wafers were chosen from the same boule as those used for the calibration experiments in Figures 3 and 4 in order to maintain consistency. Wafers were implanted regularly over a period of five weeks using the P+ 500 keV, $5 \times 10^{13}/cm^2$ recipe at 1000 uA and at an angle of 35.8°/0°. Horizontal and vertical correction was enabled for each implant, and each wafer was annealed with the same 1150°C, 30 second, 0.4% $O_2$ recipe.

Figure 5 shows both the Rs measurement and equivalent angle measurement based on the calibration above, whereby all Rs variation is attributed to angle variation. Dashed lines above and below indicate a change of +/- 0.1°. In addition, implanter-measured horizontal and vertical beam angles were recorded for each implant. Table 1 summarizes the data in terms of average and 1σ standard deviation. Beam parallelism is defined as the range of individual horizontal beam angles as measured through the seven slit mask. Overall, attributing all Rs variation to angle variation, the 1σ total angle variation was 0.04° over the twenty data points.

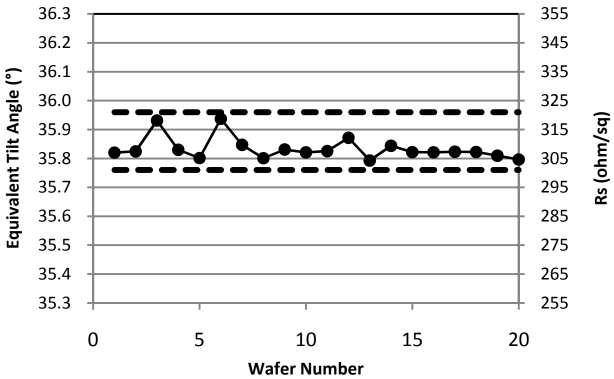


**FIGURE 5.** Sheet resistance and equivalent angle results of daily implants of P+ 500 keV 5x10$^{13}$/cm$^2$ at tilt/twist of 35.8°/0°. Upper and lower lines indicate a variation of +/-0.1°.

**TABLE 1.** Data summary for angle repeatability implants

| | **Average Value** | **Standard Deviation (1σ)** |
|---|---|---|
| Horizontal Angle | -0.01° | 0.02° |
| Beam Parallelism | 0.08° | 0.02° |
| Vertical Angle | -0.07° | 0.03° |
| Total Angle Variation based on Rs | N/A | 0.04° |

In an attempt to decouple dose variation from angle variation, additional wafers were implanted intermittently during the angle repeatability test. Those wafers were implanted with the exact same beam condition as the angle repeatability implant, but at a tilt/twist angle of 5°/27°, a non-channeled condition. The sheet resistance results for those wafers are shown in Figure 6. For ease of comparison, upper and lower dashed lines indicated the same +/-0.1° variation as in Figure 5. Overall the repeatability over the eleven data points is 0.24% (1σ).

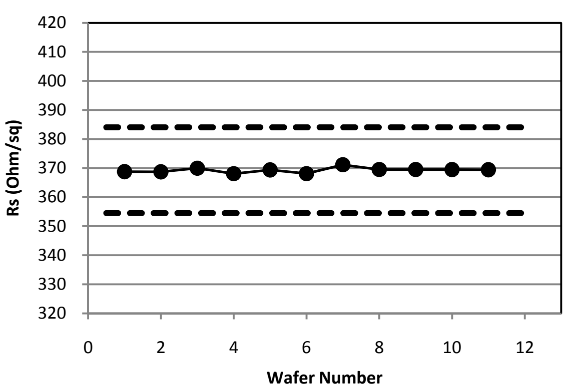


**FIGURE 6.** Sheet resistance of wafers implanted with P+ 500 keV 5x10$^{13}$/cm$^2$ at tilt/twist of 5°/27°. Upper and lower lines indicate an equivalent tilt variation of +/-0.1° as calculated in Figure 4.

By using the sum of squares equation, one could subtract out the dose variation from the overall variation shown in Figure 5. In this case, however, the dose variation is very small and ultimately only accounts for 0.007° out of the total 0.04° previously calculated. As such, the overall variation of the angle repeatability test can be wholly attributed to an angle variation of 0.04°.

# CONCLUSION

Optima XE has the capability to measure and correct for angle variation in the horizontal and vertical directions. Using the P+ 500 keV 5x10$^{13}$/cm$^2$ 35.8°/0° channeling sensitive implant, the tool alignment was calibrated and sheet resistance-to-angle sensitivity was measured. Repeating the implant over a five week period, the overall angle repeatability was calculated to be 0.04° (1σ). Implanting the same condition at a non-channeled angle, the Rs variation due to dose, was calculated as 0.24% (1σ) and determined to be insignificant relative to the angle variation at that condition.

# ACKNOWLEDGMENTS

The authors would like to thank Fred Silva for running the implants and all hardware support.

# REFERENCES

1. C. Krueger, R. D. Rathmell, D. E. Kamenitsa, and B. Krimbacher, Proc. of Intl. Conf. on Ion Implantation Tech., Monterey, California. 2008 pp. 257-260
2. S. Satoh, J. Ferrara, E. Bell, S. Patel, and M. Sieradzki, Proc. of Intl. Conf. on Ion Implantation Tech., Monterey, California. 2008 pp. 273-276
3. E. Bell, S. Satoh, Proc. of Intl. Conf. on Ion Implantation Tech., Monterey, California. 2008 pp. 380-383
4. R. D. Rathmell, J. David Proc. of Intl. Conf. on Ion Implantation Tech., Monterey, California. 2008 pp. 148-151
5. R. D. Rathmell, D. E. Kamenitsa, M. L. King, and A. M. Ray, IEEE Proc. of Intl. Conf. on Ion Implantation Tech., Kyoto, Japan, 1998, pp. 392-395