Beam Angle Control Kit for Angle Sensitive Implantation

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***Abstract*—The unique dual axis tilt design of the gyro-super-disk (GSD) series end stations, as shown in figure 1, allow rapid adjustment of wafer tilt and twist angles and provide high throughput for multi-angle implantations. The treadmill of device scaling has been pushing for tighter process control in all sectors, including implant angle accuracy. Recently, there are rising demands for it to be tightened to < ±0.2°. The focus of this study is on high energy implantation with the beam angle normal (perpendicular) to the silicon wafer surface, corresponding to major axial crystal channeling. The obtained process results indicate high sensitivity in both device electrical performance and thermal-wave response to the angle variation even when it is within the original system specification of < ±0.5°. An implant beam angle control (BAC) kit was developed and tested to address the need of more accurate implant angle setup. The BAC kit includes a 2-dimentional beam angle measuring mask mounted on the implant disk, and an add-on software function to control the end station to the desired implant angle with an improved accuracy, which is determined from the beam angle measuring mask. Once the beam angle measurement is performed after beam setup, but prior to wafer implant, the true implant angle will be obtained by moving the end-station disk to position. In this study, the BAC kit has been demonstrated with achieved angle accuracy of < ±0.15° after the angle variation from the beam setup is measured and compensated**

Keywords—high-energy ion implanter, beam angle, channeling

I. INTRODUCTION

Implant angle is one of the key parameters for ion implantation process control, along with implant species, energy and dose. The unique dual axis tilt design of the gyro-super-disk (GSD) series end stations, as shown in figure 1, allows rapid adjustment of wafer tilt and twist angles and provides high throughput for multi-angle implantations. The angle accuracy of the GSD end stations is specified to < ±0.5°. This spec is the total angle accuracy of the GSD end station hardware alignment, excluding the real beam angle from the center of beam path at wafer plane. This spec has satisfied the implant angle accuracy requirement for the semiconductor manufacturing industry for more than a couple of decades. The treadmill of device scaling has been pushing for tighter process control, including implant angle accuracy. Recently, there are rising demands for it to be tightened to < ±0.2°. Although the new spec can be achieved by most of the new GSD tools during installation, it is known that such performance level is hard to maintain over time.

One of the reasons could be the GSD end station hardware may gradually go out of original alignment settings due to gravity, or other external forces. In addition, the beam line parts can wear and degrade. The ion implanter auto tuning needs to accommodate those changes, and thus may render the beam angle to deviate from the center after a considerable times of auto tuning attempts. For whatever the root cause it is, some manual tuning of the beam may be able to return the beam angle back to within spec. This aspect of the beam quality is especially important for angle sensitive implants. For these processes, the beam angle of the implant recipe need to be constantly monitored.

One of the methods, which has been commonly adopted by GSD platform users is to infer the beam angle by monitoring beam centroid on the disk faraday. Fig. 2 shows the implementation of beam height offset (BHO) limits on a 300mm GSD platform, which can 1) check BHO (y-centroid) from a 2-D beam profile before implant, and 2) hold implant if BHO is out of limits. If it did go out of process control spec, manually tuning of the beam would have to be involved, and it would inevitably impact the tool productivity. Besides, the centeredness of the beam centroid doesn't always translate to a fully aligned beam angle. In light of these issues, the solutions, which accruing to efficient real-time beam angle measurement, and in-situ beam angle correction were quickly developed for the GSD platform. The hardware and implant control system that provide these solutions are dubbed "beam angle control" (BAC) kit. Fig. 3 describes the hardware and function of the BAC kit on a GSD platform, where BAC angle detector mask is located on an inner shield of a 300mm GSD disk. The BAC kit delivers beam angle measurement and correction in α and β directions.

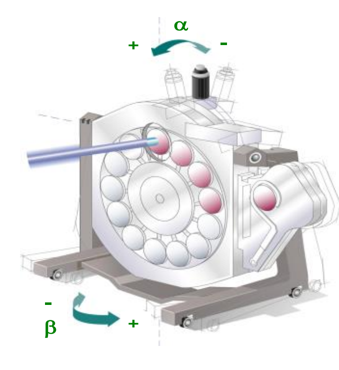

Fig. 1. The GSD end station, showing the orientation of the α and β tilts.

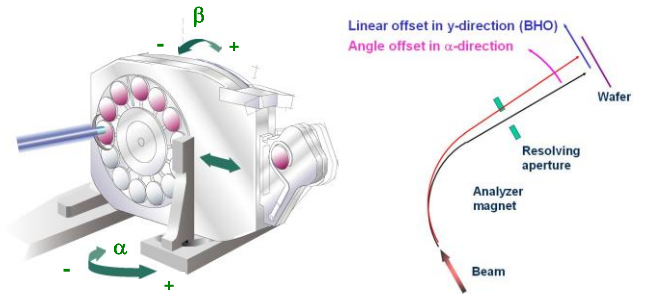

Fig. 2. A 300mm GSD disk chamber and the schematic showing the implementation of beam height offset (BHO) limits, which can 1) Check BHO (y-centroid) from a 2-D beam profile before implant, and 2) Hold if BHO is out of limits. Notice the double-sided arrow shown on the disk chamber wall. This arrow is the direction of disk movement, which represents the "slow scan" component of the 2-D mechanical scanning of the disk. Also that the orientation of a 300mm GSD disk is 90° different from the 200mm GSD disk, as shown in Fig. 1. The α tilt on a 300mm GSD disk is in the beam dispersive plane, within which the ion beam is being bent through the analyzer magnet. Due to the beam set up can change from implant to implant, the BHO component, or the α tilt angle accuracy is more of a concern than the β tilt angle accuracy for a 300mm GSD platform.

II. EXPERIMENTAL CONDITION

A. Hardware and Software Functions

The key component, beam angle detector mask of the BAC kit is shown in fig. 4 [1]. There are 132 holes in the mask, all of them have a 9.6:1 aspect ratio. As the gyro alpha and/or beta position travels over a range of angles provides the data to determine maximum beam transmission. To use the beam angle measurement and correction, the recipe parameter appears in the recipe editor screen can be set to "None", "Alpha", "Beta", "Both", "Alpha MO", "Beta MO", or "Both MO" with the action according to Table I. During the implant startup sequence, the gyro will scan from -5.5 to +5.5 degrees in the desired plane while collecting beam current data through the beam angle mask. This data is used to calculate the angle error and is applied to the desired angles before the implant starts. This mechanism is depicted in fig. 5.

TABLE I.

BAC in the Recipe	**BAC Function**
	Performed Action
None (default)	No angle measurement
Alpha	Alpha measurement and correction
Beta	Beta measurement and correction
Both	Alpha and Beta measurement and correction
Alpha MO	Alpha easurement only
Beta MO	Beta easurement only
Both MO	Alpha and Beta easurement only

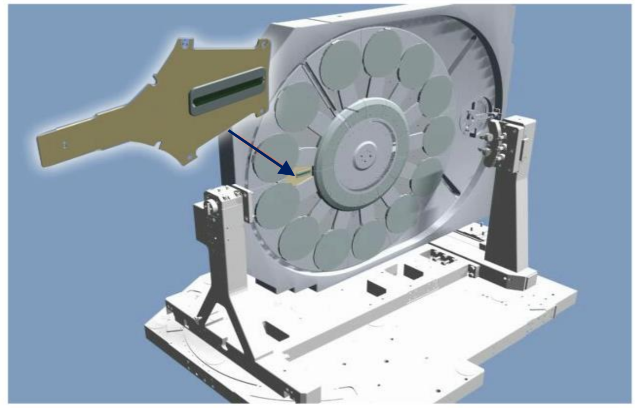

Fig. 3. BAC angle detector mask is located on an inner shield, as depicted in the inset on the upper left corner of this figure of a 300mm GSD disk. The BAC kit delivers beam angle measurement and correction in α and β directions.

The monitor and/or production wafers are placed on GSD pedestals of a high-speed rotated disk during implantation. To provide wafer clampless mounting on the disk and to improve thermal conductivity between the wafer and the disk during implantation the pedestals are tilted by the angle of p, which could be 5° or 1.5°, depending on the tool configuration, with respect to the disk plane. Because of the cone angle created by this inclination of the wafer pads from the plane of the disk, there is a variation of tilt and twist across the wafer as the disk spins and the beam sweeps across the wafer. This variation of tilt and twist might results in differential channeling across a wafer if the wafer is implanted at channeling conditions.

The definitions of wafer tilt and twist, across-wafer implant angles variation are considered in [2]. For the case of normal beam direction, $(\alpha, \beta) = (0, 0)$, differential channeling occurs. It should be noted that the point (5, 0) is sometimes referred to as the "origin" of the GSD end station, where the axis of disk rotation is parallel to the fixed ion beam and across-wafer angle variation is absent.

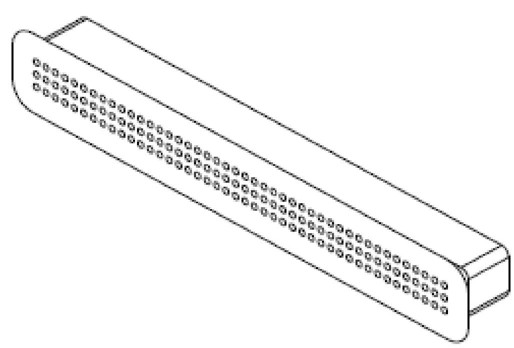

Fig. 4. Beam angle detector mask has 132 holes, which have a 9.6:1 aspect ratio. As the gyro alpha and/or beta position travels over a range of angles provides the data to determine maximum beam transmission.

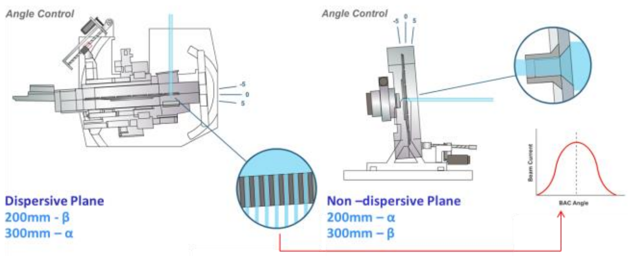

Fig. 5. During the implant start up sequence the gyro will scan from -5.5 to +5.5 degrees in the desired plane while collecting beam current data through the beam angle mask.

B. *Process Methodologies*

Channeling phenomena resulted from implants are most pronounced when the ion beam is normal (perpendicular) to the silicon wafer surface and/or at high energies. In the mundane silicon fabrication process flow, high-energy implantation is usually adopted for forming the device isolation areas. The precision in its dopant distribution rarely affects the device electrical properties due to its placement is deep in the substrate, whereas operational device currents usually flowing on the surface. In recent device technology trend, the shrinking geometry of the device rapidly reduces the headroom for process tolerance. This issue is compounded by the growing demands for zero degree implantation. Previously, channeling phenomena could be easily avoided by a tilt angle. With the angle setup nowadays gravitates toward zero degree tilt, channeling re-emergent to be a serious process variable now. To illustrate the problem, we use a typical high energy implantation of phosphorus at 1800keV, at a tilt angle of 0°. This condition is in the category of angle sensitive implantation. Fig. 6 shows the difference in implant SIMS profile of a merely 0.5° of angle deviation for a phosphorus 1800keV implant at 0° tilt. One of our customers, when in a device process qualification stage, the engineers found that some abnormal beam tuning resulted in high BHO values, which could lead to device parametric shift. It is believed that beam angle variation from beam tuning was the culprit. Thus, the implant angle accuracy needs to be controlled to < 0.2°.

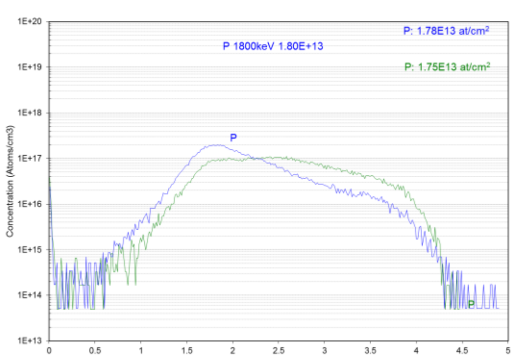

Fig. 6. SIMS dopant profiles of two implants with 0.5° implant angle difference.

TABLE II.

Parameter	Implant Condition	
	1	*2*
Recipe Angle	(0, 4)	(0, 4)
BAC Mode	MO (Off)	Both (On)
BAC Measured	(-0.29, 0.07)	(-0.32, 0.07)
BAC Corrected	(0, 4)	(-0.32, 4.07)
TW Min. Position	-50.7mm	-0.73mm
Converted Angle	-0.3°	-0.004°

After the BAC kit was introduced to the high energy implanter, a monitor implant recipe similar to that of the production implant was established to check the beam angle accuracy. The wafer implanted with tilt angle = 0°, or (α, β) = (0, 0), has the lowest peak concentration and deepest range in the dopant profile. The Therma-wave full wafer measurement of the implanted wafer should also get the lowest mean value. However, this value is dependent on wafer quality and measuring tool reliability, which can sometimes have variation of its own. Because the TW line-scan has a minimum, which can be an indicative of how far the implant angle in beta direction is from 0° for a 200mm GSD platform, it was used as another method to check the implant angle accuracy. It represents the absolute beam angle accuracy in beta direction. If the angle accuracy in alpha direction is in question, then another separate implant monitor recipe needs to be established.

Since the beam dispersive plane on a 300mm GSD high-energy implanter is in alpha direction, the alpha angle is more likely to be affected by improper beam tuning. The feature of TW line-scan minimum for the (0, 4) tilt implant can be utilized for quantifying alpha angle accuracy. The TW line-scan minimum of this implant should be located in the wafer center too, if the beam alpha angle was perfectly aligned to 0°.

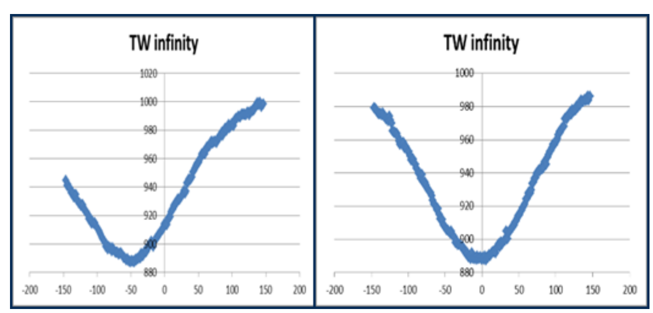

Fig. 7. The TW line-scan values across a wafer implanted from a 300mm GSD at (α, β) = (0,4). Wafer map 1 corresponds to -0.3° alpha angle offset before BAC correction, and wafer map 2 corresponds to 0° after BAC correction.

III. RESULTS AND DISCUSSION

The angle detector mask is the most important piece of the hardware in the BAC kit. The validness of its angle measurement is dependent on a proper installation and calibration. In order to verify the angle detector mask calibration, we implant good quality control wafers as an auxiliary measurement tool. If the BAC kit and control wafer analysis deliver consistent angle measurements, then we can rely on the BAC kit and trust its angle measurement during production.

Table II. shows the results of the BAC verification test using bare silicon monitor wafers. In the test, we mistuned the beam on a 300mm GSD high energy implanter with an alpha offset of -0.3 degrees (steering direction) and activated the BAC function for wafer implantation. The wafers were implanted at (α, β) = (0, 4) in order to pin point the alpha angle deviation. Figure 7 illustrates the effectiveness of the BAC function. TW plot 1 indicates a -0.3° offset in alpha angle before BAC correction. TW plot 2 corresponds to nearly 0° tilt after BAC correction. Since both BAC angle measurements and wafer TW line-scan minima coincide with each other, we can be sure of the BAC installation, and its function validness.

The issue of beam angle variation can exist on almost all versions of ion implanters. A tighter angle accuracy spec is not impossible to achieve, but it would increase the fab engineer workload with additional daily monitor implants and fine tuning the beams. With the advent of the BAC kit, the beam angle can be automatically measured and corrected for every implant on the GSD platform. It readily improves the implant process control performance without having to involve off-line implant monitoring of the beam angle accuracy. It also prevents the chance of miss operation if the beam angle is shifted out of control limits in between implant monitoring, when hundreds or even thousands of production wafers might have gone through the problematic implanter already. This BAC function, as most of the process control features on an implanter would inevitably increase wafer process time. Due to this function is recipe selectable, people can use it for the most angle sensitive implants or the implants which are known to be causing device parametric shift when their beam angle is off. Because the throughput impact on the tool can also be a factor for whether this function would be adopted or not, the beam angle scan length is also selectable. The gyro disk moving distance during angle measurement can be changed from the default values of ±5.5 to ±4.5 or ±3.5 degrees to improve wafer throughput. If BAC function is selected for both α and β tilt directions for an implant recipe, the impact to wafer throughput can be less than 5s for each wafer.

IV. CONCLUSION

In this study, the BAC function has been demonstrated with an angle accuracy of < ±0.15° after the beam angle variation in setup is measured and compensated. The BAC kit is expected to minimize the implant angle inaccuracy in the production environment, and reduce the effort to maintain beam angle manually. The experimental data from bare-silicon and device wafers proved that TW repeatability and device parameters uniformity can be tightly controlled by using the BAC function.

REFERENCES

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