Pad Angle Verification and Cone Angle Correction Method For Individual Rotatable Pads of a Batch Disk

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Individual rotatable pads of a batch disk are used in a batch type ion implanter for large implant angle application. Calibrating each pad’s angle to an ion beam is necessary if the implant angle accuracy needs to be controlled within ±0.2deg. Channeling effect on wafers implanted by low dose and high energy Boron beam can be detected by Boxer Cross metrology tool and can be used to calibrate 0 deg implant angle.

Similar method can be used to verify cone angle effect for a batch disk. Special designed pad surface has been applied to minimize cone angle effect. By implementing the special pad surface for cone angle correction, batch-type implanters will have uniform angular implant while avoiding beam angle manipulation for ribbon beam current uniformity control for serial type implanters.

1. Introduction

As the IC chips continue to shrink to sub-100nm scale, the requirements for semiconductor manufacturing equipments are increased to resolve concerns on micro device damage or performance reduction. For high current and low energy implanters, besides high beam current and high throughput, low energy contamination, and uniform dose control, accurate implant angle control becomes an increasingly important demand for shallow junction formation. Implant angle variation, especially tilt angle, could lead to implant depth profile variation [1]. As the poly gate width decreases, distance between source and drain extensions should be controlled accurately to avoid short channel effect. Some device test results showed that beam incident angle variation could lead to low performance of sub-100nm devices [2].

There are several factors to affect implant angle variation, including ion beam angle non-uniformity, ion beam alignment with processed wafers, and systematic cross wafer angle non-uniformity for a batch type implanter (usually called cone angle effect [3]). This paper only discusses the last two factors.

For a single wafer or serial type implanter, we can calibrate the wafer tilt angle vs. ion beam by observing different channeling effects at different implant angles near zero of low dose high energy implants [4, 5]. It usually needs more than 6 implants to obtain angle calibration accuracy near ±0.1°. For a conventional batch type implanter, we can only calibrate the wafer tilt angle of only one pad, and hope other remaining pads to have similar angle calibration, relying upon very tight mechanical tolerance on the disk and pad manufacture, which will be very difficult when the angle variation error is allowed to be <±0.2° for sub-100nm technology nodes. However, for the batch implanter with individually rotatable pads, we can calibrate each pad to as accurate as ±0.1°. Since a batch disk with flat pad surfaces has about ±1° cone angle variation across a wafer, we only need to do calibration implant once at a nominal tilt angle of 0°. The cone angle effect can help us to calculate the actual angle offset. The individual rotatable disk combines the merit of serial type implanter and conventional batch type implanter on angle calibration.

The cone angle effect on a batch type implanter with flat pad surfaces induces implant angle variation up to ±1.1° across a wafer no matter how accurate the pad angle is calibrated. The systematic angular error induces unavoidable shadowing effect and other concerns. By changing the flat pad surface to a conical surface, we can reduce the cone angle variation to 0° theoretically. Due to the difficulty of producing a perfect conical shape surface, we may use other shapes to simulate it, such as a cylindrical shape [6]. However, it is difficult to make the wafer bend to either conical shape or cylindrical shape under small centrifugal force at slow disk spin, which is required at sub-100nm technology node to avoid particular damage on poly lines and other micro structures. Using pads with wafer natural bending shape similar to the conical shape can minimize cone angle effect so that the cross wafer angle non-uniformity is reduced from ±1.1° to ±0.2°. It can also increase wafer-to-pad surface contact area for good wafer cooling [7].

2. Accurate tilt angle calibration

It is difficult to align ion beams to a batch disk with small error using mechanical alignment method, due to difficulties of measuring ion beam direction in vacuum with small error (<1°). We may use pin-hole array to measure beam divergent angle distribution over the whole beam area, by using a movable Faraday array, similar to the emittance measurement method. However, this method’s accuracy relies on the array accuracy that also needs to be calibrated.

For a batch disk with individually rotatable pads, each pad can be calibrated to within ±0.1° accuracy by the following method. Due to cone angle effect for a 13-pad batch disk with 5° pedestal angle, there is ±1.1° tilt angle variation across a wafer during implant. We can use differential channeling effect to calibrate the relative angle between an ion beam and a wafer surface when the beam strikes on the wafer center. As shown in Figure 1a, the symmetric beam-to-disk alignment indicates that the ion beam is perpendicular to the pad surface when the beam strikes the wafer center at 0° tilt angle. It should correspond to the maximum channeling effect or deepest channeling profile comparing to other wafer positions. If the deepest profile is not at the wafer center, the 0° tilt angle is not well calibrated. We should adjust the tilt angle offset until the deepest profile is at the wafer center.

Channeling effect is usually more observable at high energy and low dose. We used 50keV B^+ beam at 5E13 atoms/sq dose for the calibration implant. The channeling effect on wafers can be observed on Therma-Wave and Boxer Cross maps, and on SIMS profiles. Figure 2a shows the BX10 patterns of the implanted wafers before tilt angle calibration. The channeling peak is not on the wafer center. The angle offset of 0.3° was very obvious when we plotted the BX10 signal against the equivalent pad tilt angle across the wafer in Figure 2b. After the angle offset was adjusted, the channeling peak indeed moved to the wafer center (Figure 3a) with angle offset <±0.1° (Figure 3b).

3. Curved pad surface for uniform cross-wafer tilt angle variation control

To eliminate the channeling effect on implant depth profile non-uniformity, we need to minimize cone angle effect for wafers on a batch disk. Figure 1b shows that a curved pad with curved angle about from -1° to +1° can have 0° tilt angle variation if the curved surface is a perfect conical shape. However, a silicon wafer is not flexible enough to bend to conical shape without a large centrifugal force. A pad with a curved surface similar to Si wafer natural bending shape can be used to support a wafer under sufficient centrifugal force with spin speed >200rpm. Medium spin speed should be sufficient to press a wafer onto the curved pad surface to provide sufficient contact area between the curved wafer and pad surface. Experimental data showed that an elastomer coated curved pad at 600rpm spin speed can cool a wafer below 80C at 1kW beam power.

To prove the concept of minimum tilt angle variation with curved pads for cone angle correction, we used a laser to aim on a wafer on a spinning disk. The reflection of the laser would a long curve if the wafer is flat, and a small point if the wafer is close to a conical shape. Figure 4 shows exactly what we expected except the reflection of the curved wafer was not a small point but a short curve since the curved wafer was not an ideal conical shape. However, the tilt angle variation was reduced from ±1.1° to ±0.2°, which meets most advanced device requirements.

To further confirm whether curved wafer gives better tilt angle uniformity, we should look at implant uniformity. Thermal Wave map of 70keV B+ at dose of 1E14 atoms/sq on a flat wafer showed clearly the channeling effect (Figure 5a). SIMS profiles confirmed the channeling effect with obvious profile separation between implant at wafer center and on the wafer edges (Figure 5b).

When we used the curved pad for cone angle correction to perform the same implant, we found no obvious channeling effect on either Therma-Wave map or SIMS profile (Figure 6). It indicates that the curved pads can minimize cone angle effect to improve cross-wafer implant angle uniformity.

4. Conclusions

Accurate implant angle control is required for ion implantation for advanced semiconductor micro device manufacturing. The cone angle effect can be used to calibrate the tilt angle of each pad against incident ion beam as accurate as ±0.1° for a batch process disk with individual rotatable pads. To minimize the cone angle effect and improve implant angle uniformity, we can use curved pads that have wafer natural bending shape similar to conical shape. Experimental data showed that the implant angle variation was reduced from ±1.1° to ±0.2° when we used the curved pads.

References:

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Figure Captions

Fig. 1. Tilt angle variations of wafers on flat and cone angle correction pads: ion beam angular alignment with a flat wafer and a curved wafer on a batch disk at different positions.

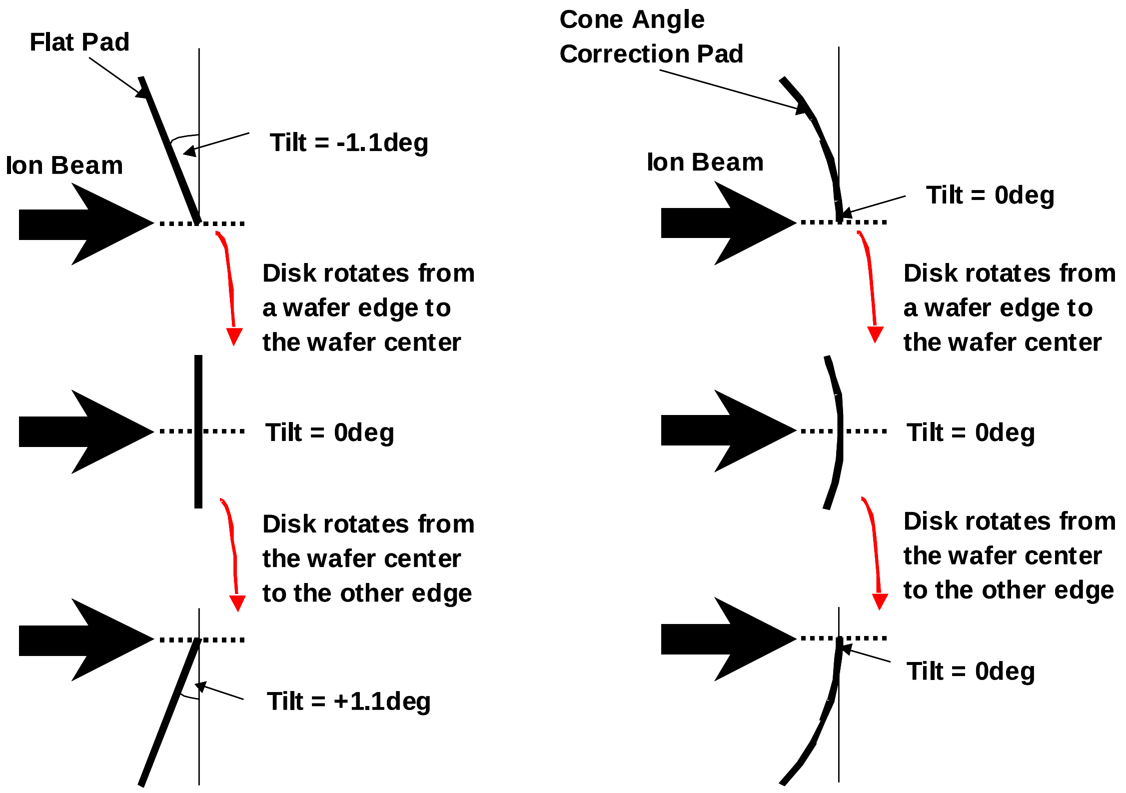
Fig. 2. a) BX10 scan image on a wafer implanted by 70keV Boron at 5E13 atoms/sq. along a line perpendicular to the disk scan direction at 0° tilt angle before angle calibration; b) BX10 signal vs equivalent pad tilt angle.

Fig. 3. a) BX10 scan image on a wafer implanted by 70keV Boron at 5E13 atoms/sq. along a line perpendicular to the disk scan direction at 0° tilt angle after angle calibration; b) BX10 signal vs equivalent pad tilt angle.

Fig. 4. Laser beam reflection traces from a wafer on a spinning disk indicate that the tilt angle variation can be corrected from ±1.1° to ±0.2° by pressing the wafer onto a curved correction pad surface.

Fig. 5. Channeling effects of Boron 70keV implant with dose 1E14 atoms/sq on a flat wafer, shown a) by Therma-Wave map, and b) by SIMS profile.

Fig. 7. Channeling effects of Boron 70keV implant with dose 1E14 atoms/sq. on a curved wafer on a cone angle correction pad, shown a) by Therma-Wave, and b) by SIMS profile.


Flat Pad
Ion Beam
Tilt = -1.1deg
Disk rotates from a wafer edge to the wafer center
Tilt = 0deg
Disk rotates from the wafer center to the other edge
Tilt = +1.1deg
Cone Angle Correction Pad
Ion Beam
Tilt = 0deg
Disk rotates from a wafer edge to the wafer center
Tilt = 0deg
Disk rotates from the wafer center to the other edge
Tilt = 0deg

(a) (b)

Figure 1.

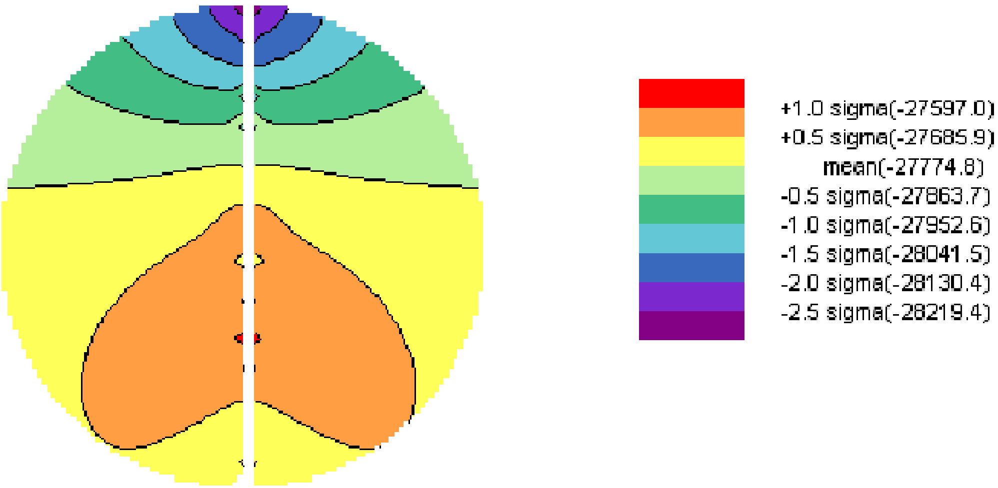


Figure 2 (a)

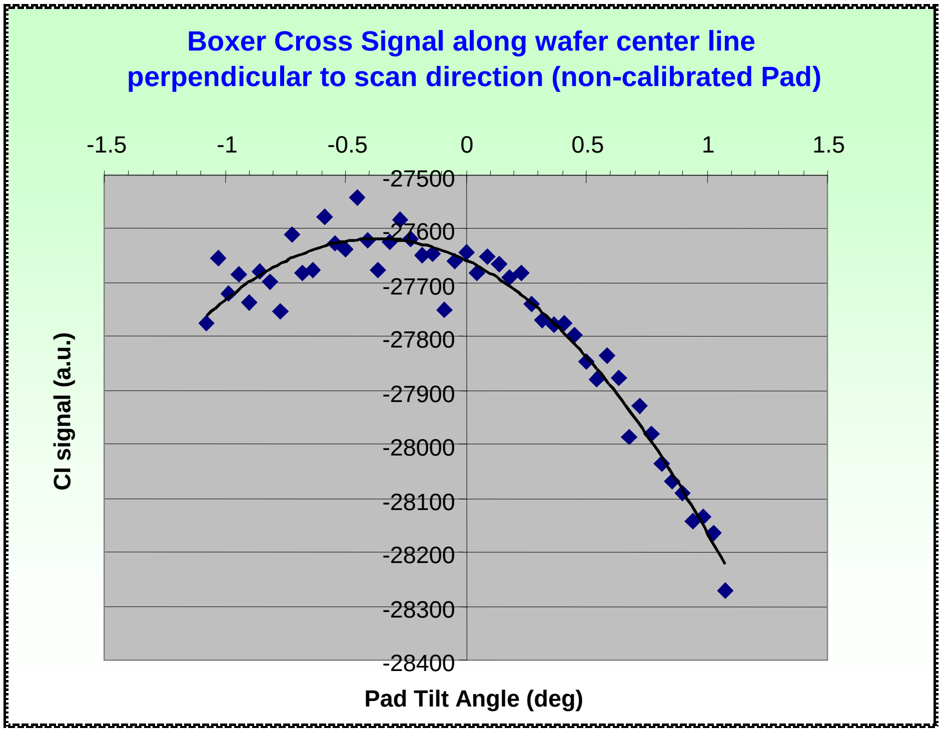


Figure 2 (b)

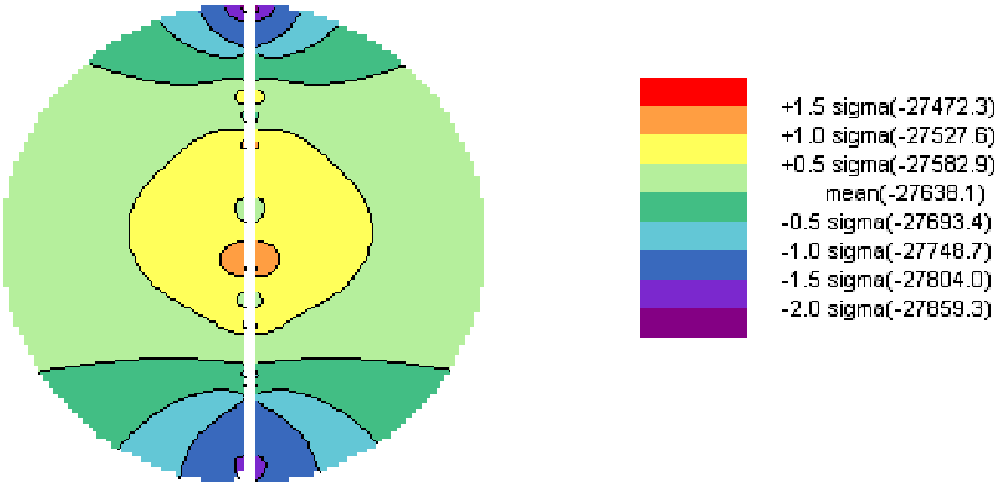


Figure 3 (a)

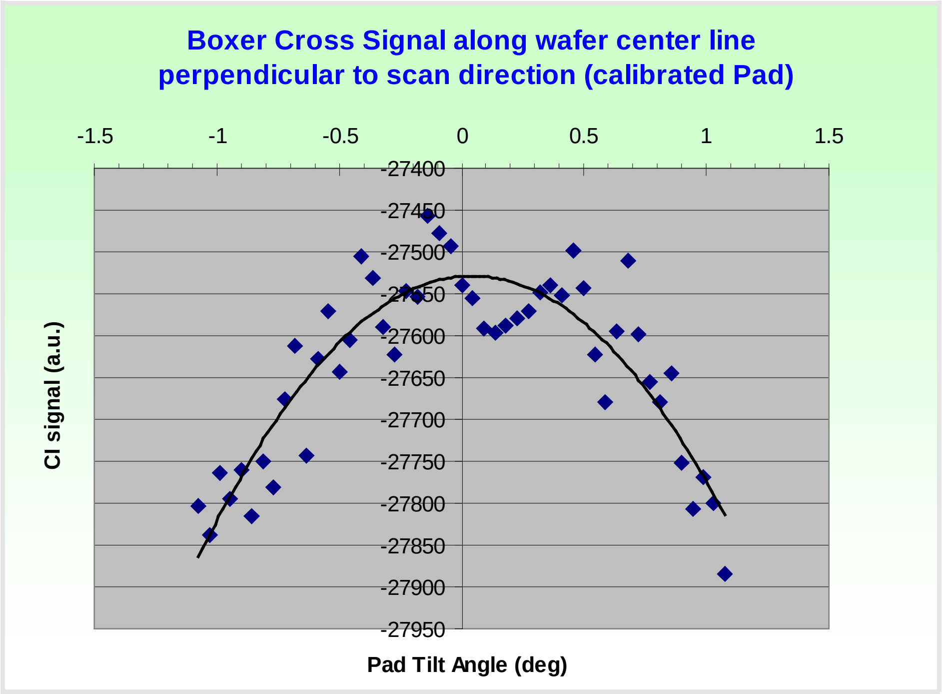


Figure 3 (b)

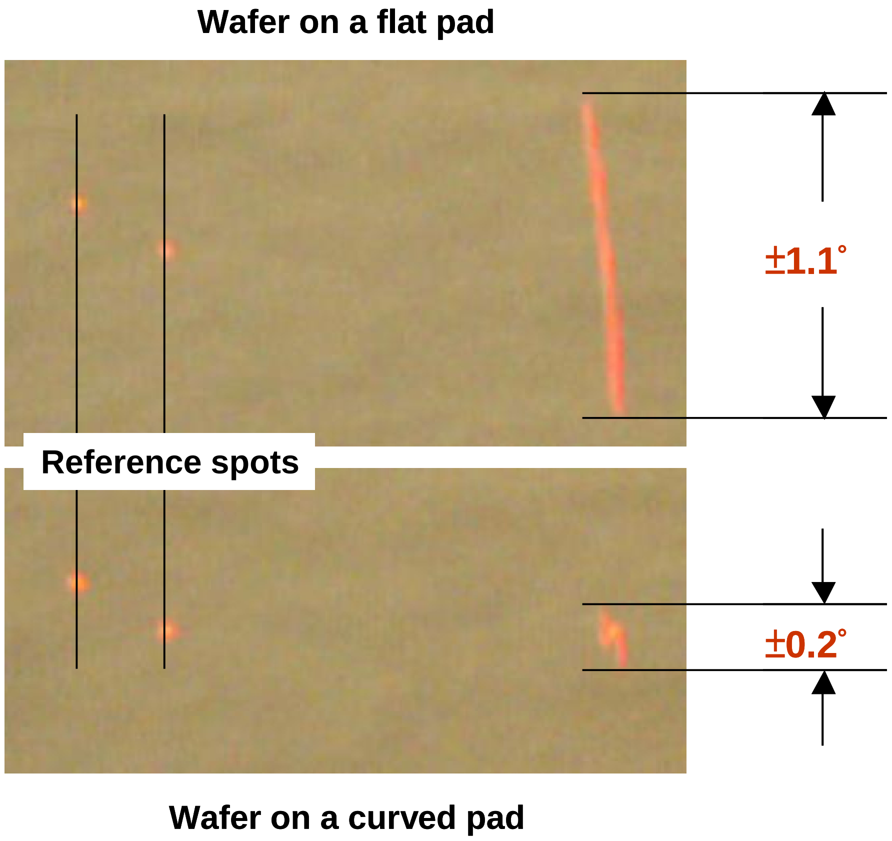
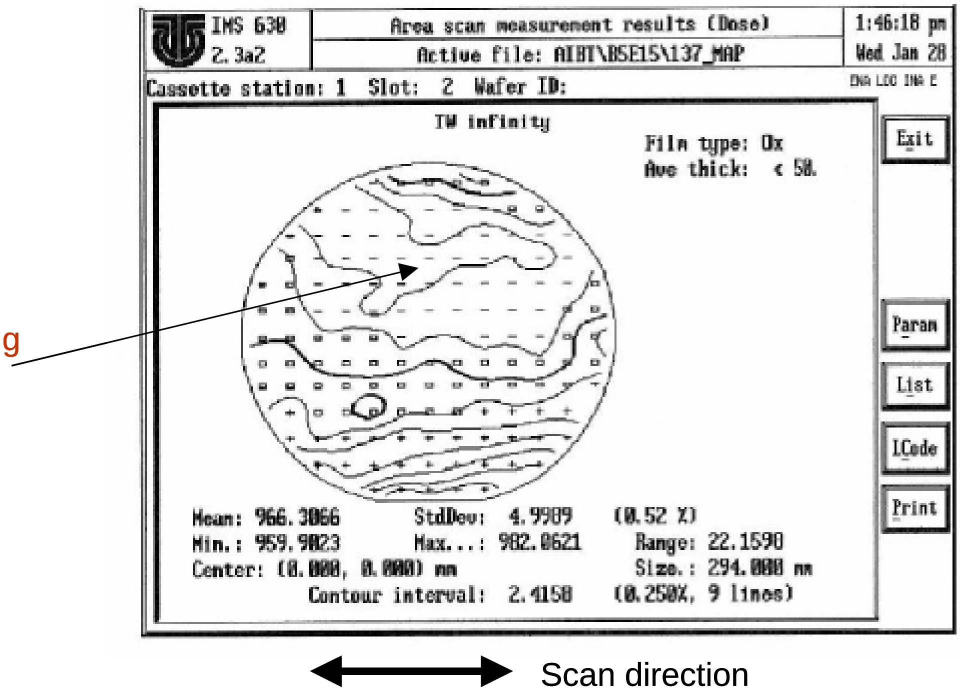

Wafer on a flat pad
±1.1°
Reference spots
±0.2°
Wafer on a curved pad

Figure 4

Channeling pattern



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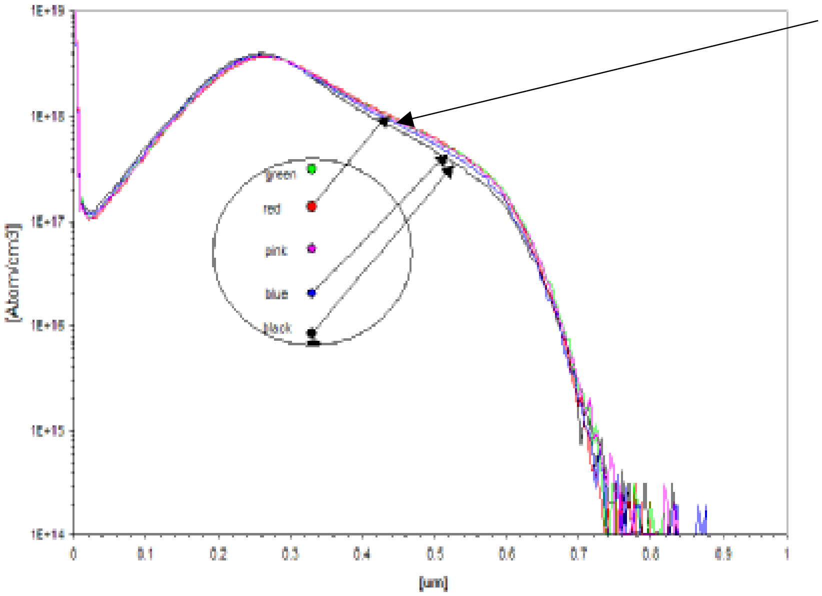
IMS 630          Area scan measurement results (Dose)        1:46:18 pm
2.3a2            Active file: AIBT\BSE15\137_MAP             Wed Jan 28
Cassette station: 1   Slot:   2   Wafer ID:                  ENA LOC INA E

                          TW infinity
                                                Film type: Ox
                                                Ave thick:  < 50.

Mean: 966.3066        StdDev:   4.9989    (0.52 %)
Min.: 959.9823        Max...: 982.0621      Range: 22.1590
Center: (0.000, 0.000) mm                   Size.: 294.000 mm
            Contour interval:   2.4150    (0.250%, 9 lines)
```

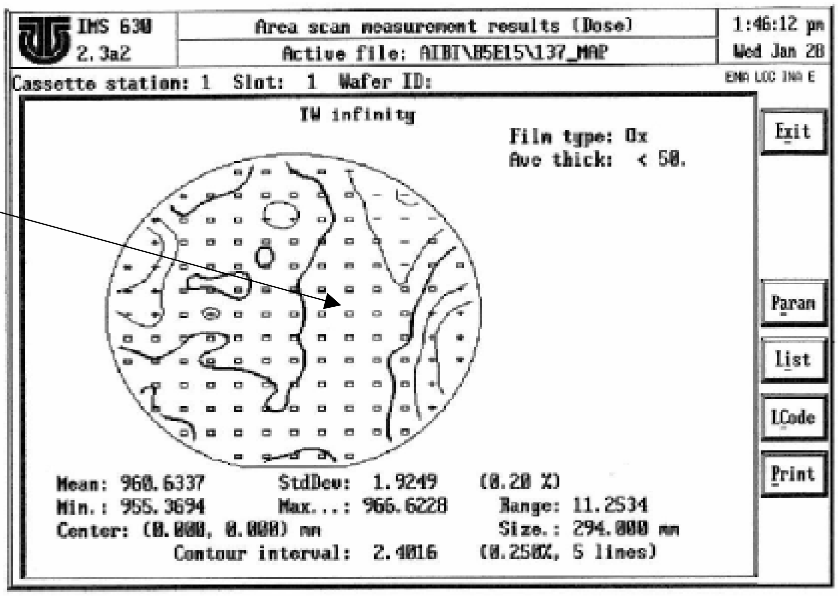
Scan direction

Figure 5 (a)



Deeper profile due to Channeling

Figure 5 (b)



IMS 630
2.3a2

Area scan measurement results (Dose)

Active file: AIBI\B5E15\137_MAP

1:46:12 pm
Wed Jan 28

Cassette station: 1 Slot: 1 Wafer ID:

Film type: Ox
Ave thick: < 50.

```
Mean: 960.6337        StdDev:  1.9249     (0.20 %)
Min.: 955.3694        Max...: 966.6228      Range: 11.2534
Center: (0.000, 0.000) mm                   Size.: 294.000 mm
          Contour interval:  2.4016     (0.250%, 5 lines)
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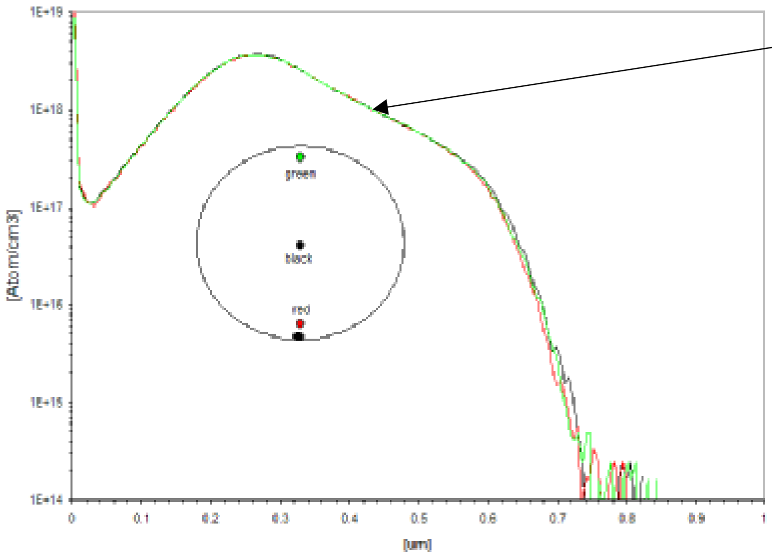
No channeling pattern

Disk scan direction

Figure 6(a)



Same depth profiles across a wafer

Figure 6 (b)